ICRS 2022

Preliminary Book of Abstracts

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Plenary Talks

Plenary Talk
A-2222

Reimagining marine conservation

Ban, N.
University of Victoria, School of Environmental Studies, Victoria, Canada

nban[at]uvic.ca

Abstract

The conservation of coral reefs is paramount for their future as threats intensify. Indeed, improving local conditions to build reef resilience is one of the three pillars to improve reef health and resilience identified in the ICRS policy brief. While marine protected areas – especially no-take zones – are a crucial part of conservation efforts, the science is less clear how well other conservation efforts work. High on the international agenda, through the Convention on Biological Diversity, is the question of what constitutes “other effective area-based conservation measures” that might be equivalent to, but not recognized as, protected areas. Ecological and social monitoring of marine protected areas and these other conservation efforts (e.g., community-managed areas, tabu areas) is starting to shed light on their relative effectiveness – for achieving biodiversity and human wellbeing outcomes. I will present results from an analysis in which we used data from a coastal social-ecological monitoring program in six Indo-Pacific countries to analyze whether social, ecological, and economic objectives and specific management rules were associated with positive conservation outcomes across different area-based management tools (i.e., marine protected areas, potential other effective area-based conservation measures, and other types of area-based management tools). My presentation will also reflect on my experiences partnering with Indigenous peoples in conservation research in temperate marine environments, and the importance of taking human well-being and justice into account. Lessons from many diverse and long-standing conservation efforts globally provide inspiration for reimagining marine conservation approaches.

Plenary Talk
A-2237

How do corals adapt to rising temperatures?

Baums, I.
Penn State University, Biology, University Park, United States

baums[at]psu.edu

Abstract

Corals build the three-dimensional structure of one of the most diverse ecosystems of the planet. Yet, their ecological role is threatened by climate change because small changes in ocean temperature cause coral holobiont dysbiosis. Despite sharp population declines, large standing genetic and phenotypic variation remains in even the most threatened reef builders. We now know that standing genetic diversity fuels coral adaptation. Therefore, a prominent goal of coral conservation is to protect genetic diversity. It is nevertheless tempting to breed only those coral hosts that are, for example, temperature stress resistant to hasten the process of adaptation. Selective breeding and conservation of standing genetic diversity are thus management strategies with conflicting goals. Further complicating the matter are recent insights that coral adaptation may proceed using unusual pathways. Over any organism's lifetime, somatic genetic mutations accumulate. To limit damage from potentially deleterious somatic mutations, unitary animals generally do not pass them on to their offspring by segregating the germline from the soma early in development. It is commonly assumed that somatic mutations acquired during an animal's lifetime are evolutionarily irrelevant because they cannot cross this barrier between the soma and germline (known as Weismann's barrier), and thus cannot contribute to genetic variation of the next generation. Yet, somatic mutations can cross the Weismann barrier in some corals providing a path for adaptation. Advances in understanding coral adaptation underscore the need for broadly available, standardized methods to find stress resistant corals, to conserve genetic diversity, and to use these resources for restoration.

Plenary Talk
A-2223

Back-shifting the baseline of coral reefs

Cortés-Núñez, J.
Universidad de Costa Rica, Centro de Investigación en Ciencia del Mar y Limnología (CIMAR), San José, Costa Rica

jorge.cortes[at]ucr.ac.cr

Abstract

A high number of coral reefs world-wide are degrading, and we have known this for several decades. But we can reverse that trajectory by exploring, studying, sharing our knowledge, and protecting corals reefs at local, national and global scales. To do so, we first need to know why a reef is where it is, determine its present state, study its historical trajectory, and monitor it to understand its future trajectory. This knowledge must be shared at all levels, from local school children and users of the reefs, all the way to government officials and international agencies. And finally, actions at all levels must be applied to protect and conserve the coral reefs. During my more than 40 years as a coral reef scientist, I have seen degraded reefs recover, degrade and recover again. In some cases, simple government acts, such as the establishment of no-take marine protected areas, can have big impacts in promoting recovery. Unfortunately, in most cases larger initiatives such as multiple sectorial meetings, lobbing and public outreach must be implemented to attain the level of protection to promote recovery. Parallel to this, coral replanting is helping to recover coral reefs at local levels, and at the same time greatly raising awareness of their importance. If we combine actions to halt climate change with perseverance, good science and patience, these small but significant steps toward reef rewilding can backshift the baseline. Give seas a chance, and most people will be surprised with how rapidly coral reefs and the ocean recover.

Plenary Talk
A-2232

Ocean and coastal acidification – what are the issues for coral reefs?

Fabricius, K.
Australian Institute of Marine Science, Townsville, Australia

k.fabricius[at]aims.gov.au

Abstract
Surface ocean CO_2 is increasing rapidly with rising atmospheric CO_2, thus causing ocean acidification (OA). Here I will review the main OA issues for coral reefs. Today, the acidity of the surface seawater is 30% higher than during pre-industrial times. Inshore, acidification can be further accelerated by coastal processes including nutrient imports. Research over the last decade has identified the most insidious consequences of OA for coral reefs. We now understand better how OA directly affects the physiology of organisms, however physiological responses are not always predictive of resulting ecosystem changes due to a multitude of indirect ecological effects. Data from the Great Barrier Reef suggest that OA is already affecting coral reefs today. The near-term integrity of coral reefs under increasing OA depends on their specific biophysical properties, the ecological resilience of specific communities, and effective mitigation of local stressors including nutrient pollution. In most places surface OA would start to ease later this century, if the 1.5°C Target of the Paris Agreement were met and atmospheric CO_2 concentrations started declining under net-zero CO_2 emissions. Urgent global efforts are needed to halt and reverse atmospheric CO_2 increases, OA needs to be incorporated into coral reef management.

Plenary Talk
A-2220

Coral reefs under dynamic change

Graham, N.
Lancaster University, Lancaster Environment Centre, Lancaster, United Kingdom

nick.graham[at]lancaster.ac.uk

Abstract

Confronting the coral reef crisis requires multi-scale approaches to urgently limit global warming, to reduce local pressures on coral reefs, and to identify interventions that promote coral dominated reefs. However, even under the most optimistic of scenarios, coral reefs will continue to change dramatically. While some reefs have and will transition away from coral-dominated communities, others will change substantially in coral species composition. These dynamics also result in substantial reorganisation of reef fish communities. The science determining what these changes mean for coral reef ecology, management, and the people who depend on these ecosystems, is nascent. Ecologically, reefs are moving distribution, novel assemblages are emerging, and the species key to ecosystem functions are in flux. The outcomes of common coral reef management approaches are changing, and the ability to manage for multiple objectives is increasingly challenging. It is important to reflect on whether the scales of responses align with the changing scales of the pressures coral reefs are facing. The transformation of coral reefs has substantial ramifications for human health, including atoll habitability, food security, diseases, and wellbeing. In this talk I will discuss some of these implications of coral reef change, and highlight how much we need to learn.

Plenary Talk: Plenary talk
A-2248

Eyes wide open: Why exceptions and the unexpected matter

Knowlton, N.

National Museum of Natural History, Washington DC, United States

Knowltonn[at]gmail.com

Abstract

I arrived in Discovery Bay, Jamaica in the summer of 1974. Back then big fish were already scarce but corals covered the bottom as far as the eye could see. It was the heyday of sociobiology, and my PhD thesis was on the reproductive behavior of snapping shrimp. Most scientists today don’t know this, because I was soon distracted by a realization and an event. The realization was that the shrimp “species” I had been studying was actually multiple species, which led to my lifelong interest in biodiversity. The event was Hurricane Allen, which overnight swept away the reefs I had taken for granted.

Early efforts to monitor a recovery that was not to be shifted my focus from shrimp to corals, which also turned out to have cryptic species, and led to an early interest in alternate stable states. Cryptic coral species in turn led to explorations of their symbionts, coral spawning, and the coral family tree writ large. And through it all, a love for the remarkable biodiversity that is the hallmark of coral reef ecosystems never left me and inspired other projects, ranging from the calibration of molecular clocks to a global attempt to quantify reef diversity through a combination of DNA-based identifications and standardized sampling protocols.

Meanwhile, however, the prognosis for the future of coral reefs became evermore grim, and I spent decades on the lecture circuit giving “doom and gloom” talks. Eventually, however, working with students made me realize that a focus on problems without solutions can lead to apathy rather than action. The last decade has been spent searching for conservation successes, and in the process I’ve found that while things are indeed grim, they are not hopeless. A better future for reefs will depend on three pillars: addressing climate change, improving local conditions, and investing in reef restoration – they are all needed. I’ll provide some examples that give reason for cautious optimism, and close with some thoughts on lessons learned over my now 48-year career.

Plenary Talk
A-2240

Coral Probiotics: Premise, Promise, Updates

Peixoto, R.
KAUST: King Abdullah University of Science and Technology, Thuwal, Saudi Arabia

raquelpeixoto[at]micro.ufrj.br

Abstract

In the current context of global warming with an increasing intensity and duration of marine heatwaves, the use of BMCs (i.e., coral probiotics) has become a promising strategy to improve coral health and increase their ability to cope with heat stress - while carbon mitigation is implemented. The development of coral probiotics is aligned with one of the three key pillars proposed by the International Coral Reef Society to save coral reefs (i.e., active restoration and rehabilitation), as well as with other initiatives to prevent biodiversity loss (e.g., bees, amphibians, bats). Here, I will present some of our recent data indicating some BMC mechanisms involved in host protection, as well as challenges, a risk assessment framework, delivery systems and ideas to scale up the use of coral probiotics. I will also present our first attempts to implement the use of coral probiotics in the real world, as well as preliminary data on the development of probiotics for deep-sea corals.

Plenary Talk: Plenary talk
A-2246

Coral Reefs: Biodiversity Hotspots on the Brink *- Key findings from the 6th Assessment Cycle of the IPCC*

Pörtner, H.-O.
Alfred-Wegener-Institut, Bremerhaven, Germany

hans.poertner[at]awi.de

Abstract

Human-induced climate change is causing dangerous and widespread disruption in nature and is thereby affecting the lives and livelihoods of people around the globe. This is especially true for coral reefs and the millions of people that rely on them. Coral reefs are being hardest hit by the increasing frequency and intensity of extreme climate events such as marine heatwaves. Our ability to slow or stop coral reef degradation depends on the immediate implementation of mitigation and adaptation actions. This talk presents an overview of the climate impacts observed and projected and of actions that benefit the conservation of coral reefs as well as climate change mitigation. It also highlights the urgency of climate action and the need of a coordinated worldwide effort in conservation. Coral reefs are indicator marine systems for the impacts of climate change on ecosystems and human society. Reducing the losses and damages to coral reefs and their manifold ecosystem services requires nothing less than a radical transformation of human life as we know it.

Plenary Talk
A-2233

The evolution of the Great Barrier Reef in response to major environmental changes: is the past the key to the future?

Webster, J.
The University of Sydney, Sydney, Australia

jody.webster[at]sydney.edu.au

Abstract

The future of the Great Barrier Reef (GBR) is uncertain due to the cumulative impacts of global (e.g. ocean warming, acidification) and regional environmental changes (e.g. tropical cyclones, crown-of-thorns, and poor water quality). The study of the evolution of the GBR over the past 500-600,000 years can provide unique insights into how this iconic reef system responded to major environmental changes over a range of spatio-temporal scales. Over the past decade considerable progress has been made in the analysis of new and existing fossil coral reef cores, including those recovered from the edge of the continental shelf of the GBR, in water depths between 50 and 130 m by the International Ocean Discovery Program (IODP) Expedition 325 (Great Barrier Reef Environmental Changes). Together, these cores reveal exciting information about past sea level, climate and environmental changes but also crucial new insights into how the GBR responded to these perturbations. In this plenary, I will present a synthesis of all available geomorphic, sedimentologic, biologic, geochemical, dating and numerical stratigraphic modeling information. I will discuss the nature and timing of the reef initiation and demise events, while documenting the corresponding changes in reef communities, growth rates and paleoenvironmental conditions at key stages of the GBR's development. These cycles of reef death and recovery highlight the key environmental thresholds and mechanisms responsible for past ecosystem change. For example, I argue that the synergistic effects of sea level rise (i.e. also driving poorer water quality) have been crucial in ultimately causing reef drowning and demise over the past 30,000 years. Finally, I will highlight the exciting potential of the next major IODP reef drilling project - Expedition 389 (Hawaiian Drowned Reefs) off Hawai'i now scheduled for 2023.

Session 1A - Open Session: Reef environments and climate of the past

Conceptualized and chaired by: **Thomas Felis [1], Kristine DeLong [2], Amanda Godbold [3]**
[1] MARUM, University of Bremen (Bremen, Germany)
[2] Louisiana State University (Baton Rouge, LA, USA)
[3] University of Southern California (Los Angeles, LA, USA)

Oral
A-1708

Are there nutrient thresholds for cold water coral proliferation?

Anagnostou, E.[1], Corbera, G.[2], Lo Iacono, C.[2], Standish, C.[3], Foster, G.[3], Frank, M.[1]
[1]GEOMAR Helmholtz-Zentrum für Ozeanforschung Kiel, Paleoceanography, Kiel, Germany
[2]Institut de Ciències del Mar, Marine Geosciences, Barcelona, Spain
[3]University of Southampton, Southampton, United Kingdom

eanagnostou[at]geomar.de

Abstract

A key concern for cold water coral proliferation has been their resilience to ocean acidification (1). However, it has been shown that during glacial peak times, the Southern Ocean cold water corals were limited to a narrow depth band (2), even though pH conditions were likely not corrosive with the upper ocean of the Subantarctic Zone where these records are generated (3). An additional factor that could affect coral proliferation is nutrient loading. Here we are discussing nutrient reconstructions generated using the elemental ratio proxies in cold water corals (4) from coral mounds in the Mediterranean and compare them to other locations, which are showing distinctive patterns of growth and demise. These reconstructions are used to identify common nutrient thresholds for cold water coral proliferation, and how they compare to other environmental stressors.

(1)McCulloch et al., 2017, Nat. Comm. doi: 10.1038/ncomms15686; (2)Thiagarajan et al., 2013, Paleoceanography 28, 1-10; (3)Rae et al., 2018, Nature, 562, 569-573; (4)Anagnostou et al., 2011, GCA 75, 2529-2543

Oral
A-1347

Tridacna sclerochemistry at daily resolution from a controlled aquarium environment– records of habitat change, induced seasonality and growth effects

Fursman, M.[1, 2], Warter, V.[3], Janse, M.[4], Renema, W.[5, 6], Spötl, C.[7], Evans, D.[1, 2], Arndt, I.[1, 2], Müller, W.[1, 2]

[1]Goethe Univeristy Frankfurt, Earth Sciences, Frankfurt am Main, Germany
[2]Goethe Univeristy Frankfurt, Frankfurt Isotope and Element Research Center (FIERCE), Frankfurt am Main, Germany
[3]Royal Holloway University of London, Earth Sciences, London, United Kingdom
[4]Royal Burgers' Zoo, Arnhem, Netherlands, [5]Nationaal Natuurhistorisch Museum, Naturalis, Leiden, Netherlands
[6]University of Amsterdam, IBED, Amsterdam, Netherlands
[7]University of Innsbruck, Institute of Geology, Innsbruck, Austria,

fursmanm[at]tcd.ie

Abstract

The different species of the genus *Tridacna* represent valuable sclerochronological archives. Their longevity (>100 years) and rapid shell accretion (mm - cm/yr) mean that they can provide insights into past climatic and anthropogenic changes in reef environments. Previous studies have used isotopic and geochemical proxies in *Tridacna* shells to explore changes in factors such as temperature, productivity and/or light intensity. The rapid growth of *Tridacna* combined with spatially-resolved analytical methodologies facilitate retrieving such factors at seasonal to daily time-resolution and thus an assessment of the role of seasonal or shorter-term change in the geological past.
Relating geochemical proxies to environmental parameters usually requires laboratory culturing under controlled conditions, which is both time and resource intensive. Therefore, utilising existing facilities such as zoo aquaria is an alternative. Burgers' Zoo aquarium in Arnhem, the Netherlands, constructed a large live coral reef eco-display in 2000 that contains a living Indo-Pacific coral reef to demonstrate the biodiversity and typical characteristics of such a system. Seasonality was induced in the aquarium in 2009 by varying the temperature between the winter and summer periods. Water chemistry was periodically monitored during this time.
As a part of the exhibit, wild-collected *T. squamosa* were introduced. Upon natural death, the shells of one sample (TS2) provide a sclerochronological archive across an ~11 year lifespan that allows isotopic and geochemical proxies to be linked to environmental data. This includes the natural seasonal environment in Vietnam (prior to collection) and both non-seasonal and artificially seasonal environments within the aquarium.
In this study, we utilize a multi-proxy approach to assess the impact of natural vs artificial environments and seasonality on TS2 sclerochemistry at up to daily time-resolution, with both micro-milled stable isotope ($\delta^{13}C$ and $\delta^{13}C$) and laser ablation ICPMS (e.g. Mg/Ca, Sr/Ca, Pb/Ca etc.) data. Moreover, we can compare these chemical records of TS2 to corresponding seawater compositions. Finally, daily growth bands allow growth rates to be established, using counting along the growth axis using different imaging techniques. We note strongly non-uniform shell growth, especially for the final 4 years. Corresponding sclerochemistry data at high time-resolution and their relationship to environmental parameters will be presented.

Poster
A-2079

Thermal stress variability of the coral reef systems in Jaffna, Sri Lanka during the El- Nino years: 1998, 2010 and 2016

Ashani, A.[1], Harishchandra, A.[2], Pradeep Kumara, T.[3, 4]
[1]Marine Environment Protection Authority, Colombo 05, Sri Lanka
[2]School of Marine Sciences, University of Maine, Orono, United States
[3]University of Ruhuna, Department of Oceanography and Marine Geology, Matara, Sri Lanka
[4]Marine Environment Protection Authority, Colombo, Sri Lanka

ashaarul1904[at]gmail.com

Abstract

The live coral cover in the Northern Sri Lankan coastal belt remains the highest amongst the coral reefs in the North-eastern, Southern and Western parts of the country, despite the damage caused by many factors, including El-Nino. This study shows the Sea Surface Temperature (SST variability) between 1987 - 2018 and the heat stress recorded in Jaffna (JF) coral reefs during the El-Nino years 1998, 2010, and 2016. The insights of warming SSTs offer the recurrent and future trajectories of corals in JF. Reprocessed daily SST data were downloaded (0.05×0.05 degrees) from the Marine Copernicus server at six coral reef sites along the northern coast of JF, namely, Point Pedro (PPD), Thondaimanaaru (THD), Valithoondal (VTD), and the island reef sites of Punkudutivu (PKD), Kayts (KYT), and Delft (DFT). Calculated Degree Heating Month (DHM) showed that the DFT and PKD reefs had undergone higher thermal stress during 1998, 2010, and 2016 (0.7833 0.8545, 1.3522 °C-month and 0.7449, 0.7809, 0.5583 °C-month respectively). KYT reefs experienced heat stress only during 1998 (0.9258 °C-month), and PPD reefs experienced elevated heat stress during 1998 and 2010 (0.6008 and 0.976 °C-month respectively) El-Nino events. Except for those reef systems, THD experienced thermal stress during 1998 (0.5199 °C-month), but other reefs have undergone lesser thermal stress than 0.5 °C-month. The highest thermal stress is recorded during July or August month of each year, the summer months of Sri Lanka. DHM index indicates that reefs in the DFT region exceed the threshold DHM for coral bleaching (1 °C-month) during the 2016 El-Nino event (1.3522 °C-month), suggesting that DFT reefs could have bleached. However, an underwater visual survey conducted in 2018 showed that most of the coral reefs around the island sites of JF died and covered with excessive turf and fleshy algae. These coral deaths were not well documented but could be an effect of elevated thermal stress during the El-Nino periods. Though the coral reefs in JF have undergone the impacts of the last three El-Nino events at different magnitudes, approximately 50% of live coral cover exists in most of the Northern coast reefs. It could be inferred that these coral species are thermal tolerant or are developing adaptive mechanisms to tolerate thermal stresses or exposed to upwelling or ocean current-based cooling. Further studies are needed to identify the factors for the survival of corals in JF.

Poster
A-1165

Dynamic growth patterns of giant clams in turbid-reef environments

Mills, K.[1], Sosdian, S.[1], Muir, D.[1], John, E.[1], Santodomingo, N.[2], Johnson, K.[2], Waheed, Z.[3], Syed Hussein, M. A.[3]
[1]Cardiff University, School of Earth and Environmental Sciences, Cardiff, United Kingdom
[2]Natural History Museum, London, United Kingdom
[3]Universiti Malasia Sabah, Borneo Marine Research Institute, Kota Kinabalu, Malaysia,

millsk3[at]cardiff.ac.uk

Abstract

The Coral Triangle comprises the most biodiverse marine ecosystems on the planet. Yet, this high diversity is increasingly threatened by unprecedented environmental change and large-scale bleaching. Turbid reefs occupy 30% of reefs in the Coral Triangle and could act as potential ecological refugia in the face of thermal stress. However, they are relatively understudied with limited information on reef function, particularly how key reef builders respond aside from corals. Giant clams are one of the most important reef calcifiers with ecological, economic, and cultural significance. Here, we investigate how the mixotrophic *Tridacna squamosa* grows across a mosaic of turbid reefs in Darvel Bay (Sabah, Malaysia). We apply a sclerochronological approach to fourteen modern shells combining petrography and scanning electron microscopy (SEM) to develop growth chronologies at daily resolutions. We find that combining methods gives the best results due to differences between visual identification of growth increments in some sections. Preliminary comparisons show although growth rates are similar between clear and turbid sites, seasonal structure is different (i.e., lacking in turbid- but not in clear-water reefs). Annual and seasonal growth in turbid reefs (i.e., proximal to river mouth) is likely controlled by different environmental variables (i.e., Kd490 and chlorophyll-a) compared to that of clearer waters (i.e., SST, cloud cover and rainfall). These findings suggest that the heterotrophic nature of *T. squamosa* might impact its growth among reef sites and modified biomineralization responses capture the dynamics of diverse reef environments. Further work looking at daily variations in growth will help us understand the synergy of drivers (e.g., tidal and light) influencing growth on multiple time scales.

Virtual
Oral
A-1439

Geochemical responses of Scleractinian Corals to Nutrient Enrichment and Depletion

Standish, C.[1], Chalk, T.[1, 2], Saeed, M.[1], Lei, F.[3], D'Angelo, C.[1], Wiedenmann, J.[1], Foster, G.[1]

[1]University of Southampton, School of Ocean & Earth Science, Southampton, United Kingdom
[2]CEREGE – Centre Européen de Recherche et d'Enseignement des Géosciences de l'Environnement,Aix-en-Provence, France
[3]Nanjing University, School of Geographic & Oceanographic Sciences, Nanjing, China

c.d.standish[at]soton.ac.uk

Abstract

A number of natural and anthropogenic drivers can alter the nutrient budget available to coral holobionts, including changes in upwelling and water mixing, river runoff, sewage discharge, and nearby fertiliser use. Whilst some studies have revealed either an absence of negative effects, or even positive reactions, to increased nutrient concentrations, such enrichment can also have a detrimental effect on coral physiology such as reducing calcification rates and skeletal density. Furthermore, nutrient deprivation can impair the functioning of the coral-algae symbiosis.
In addition, scleractinian corals are important archives of environmental information, with the trace element concentration and isotopic composition of their aragonite skeletons providing proxies for the water in which they mineralised and/or as tracers of the carbonate system of their calcifying fluid. Trace elements are incorporated into the calcium carbonate crystal lattice that form their skeletons via a variety of processes, however it is currently unclear how these processes are impacted by the available nutrient budget.
Here we will present results of a study that investigated the trace element ratio (Li/Ca, B/Ca, Mg/Ca, Sr/Ca, Ba/Ca) and $\delta^{11}B$ composition of skeletal carbonate of *Acropora polystoma* and *Porites lichen*, cultured under four treatments of enriched and/or depleted nitrate and phosphate concentrations, and measured by laser ablation inductively-coupled-plasma mass spectrometry. We will explore the effects of nutrient enrichment and deprivation on these geochemical proxies that underpin much of the utility of coral skeleton geochemistry in palaeoceanography. Our results indicate that when these proxies are being applied, consideration must be paid to nutrient budgets within a given study region, and particular care is needed when samples derive from regions where nutrient budgets have been heavily disturbed by anthropogenic activity.

Session 1B - Lessons from the past: how do coral reefs respond to paleo-environmental and oceanographic changes over different spatio-temporal scales?

Conceptualized by: **Daniel Harris**[1], **Jody Webster**[2], **Stephanie Duce**[3], **Ana Vila-Concejo**[2]
[1] The University of Queensland (Brisbane, Australia)
[2] The University of Sydney (Sydney, Australia)
[3] James Cook University (Townsville, Australia)

Chaired by: **Jody Webster**[2], **Ana Vila-Concejo**[2]

Oral
A-1119

‘My, how you've grown!’ - quantifying environmentally driven growth rate changes in fossil giant clams using daily-resolved geochemistry

Arndt, I.[1, 2], Coenen, D.[1, 2], Fursman, M.[1, 2], Evans, D.[1, 2], Renema, W.[3], Müller, W.[1, 2]
[1]Goethe University Frankfurt, Institute of Geosciences, Frankfurt, Germany
[2]Frankfurt Isotope and Element Research Center (FIERCE), Goethe University Frankfurt, Frankfurt, Germany
[3]Naturalis Biodiversity Center, Department of Geology, Leiden, Netherlands

iris.arndt[at]stud.uni-frankfurt.de

Abstract

Bivalves are important high resolution environmental archives in coral reefs. The (sub)tropical giant clams *Tridacna* can build large (>1 m) dense aragonitic shells. These feature seasonal to daily growth bands recording life spans of up to 100 years. Ontogenetic ages of modern and fossil *Tridacna* can be estimated by counting macroscopically well visible seasonal bands. This approach is, however, susceptible to uncertainties. Some specimens show annual bands, others display two bands per year and some show less periodic banding patterns overall. Additionally, growth bands can occur with different intensities, expressed in either shell colour or geochemical signals. Yearly $\delta^{18}O$ cycles within a shell can be used as basis for internal age models. However, in tropical areas the annual water temperature variability can be low and seasonal precipitation events may influence the $\delta^{18}O$ values of coastal seawater, limiting the applicability of this method. Counting daily bands provides a more robust and detailed internal age model. Daily bands occur at few micrometre to tens of micrometre spacing within *Tridacna* shells. Unfortunately, they are not always visible throughout the entire shell with light microscopy, and fluorescence microscopy does not enhance the daily band visibility in fossil specimens. Manually counting daily bands also becomes less practical when investigating organisms that can live up to a century. Following Warter and Müller (2017), we utilize (ultra-) high-resolution laser-ablation inductively coupled plasma mass spectrometry (LA-ICPMS) to retrieve daily geochemical cycles even in areas where daily bands are not microscopically visible for our large late Miocene specimen. As such, high-resolution LA-ICPMS not only allows for sub-daily resolved elemental ratio analysis but also provides a relatively quick method to quantify the growth rates of fossil giant clams across large shell sections (100s of mm). After evaluating daily growth rates, using wavelet transform, a highly resolved internal age model can be built, which facilitates the monitoring of growth rate variability throughout the lifespan of the organism. We compare growth rate variability to geochemical data to assess the links between measured geochemical signals, environmental parameters and the clam’s growth rate.

Warter, V., Müller, W., 2017. Palaeogeography, Palaeoclimatology, Palaeoecology 465, 362–375.

Oral
A-2190

Calcification rates of reef corals from the Neogene and Quaternary (23 to 0 Ma) - why were they so low?

Brachert, T.[1], Corrège, T.[2], Reuter, M.[1], Wrozyna, C.[1], Londeix, L.[2], Perrin, C.[3], Spreter, P.[1]
[1]Universität Leipzig, Institut für Geophysik und Geologie, Leipzig, Germany
[2]Université de Bordeaux, UMR 'EPOC' CNRS 5805, Pessac cedex, France
[3]Muséum national d'Histoire naturelle, Département Homme et Environnement, Tautavel, France

brachert[at]uni-leipzig.de

Abstract

Current global environmental change endangers symbiotic corals and shallow-water coral reefs in a wide range of ways. Among these, anthropogenic CO2 emissions are perhaps the most severe. In addition to ocean warming and sea-level rise, rising pCO2 causes warming and ocean acidification, which aggravates the biomineralization process of reef corals. Nevertheless, coral reefs were more widespread-than-present during geological periods with high pCO2, hot climates and high sea level because the oceanic carbonate system maintained high saturation with calcium carbonate due to various weathering feedbacks. For the warmest episode of the last 23 Ma, the Middle Miocene Climate Optimum (17 - 15 Ma), proxy data show a long-term atmospheric pCO2 peak associated with seawater pH and aragonite saturation (AS) below known current thresholds for the growth of coral reefs. For testing the pH proxy data, long-term records of coral calcification are mandatory. Here we present the first comprehensive dataset of fossil coral calcification records. The corals investigated are from 16 time-slices that cover the period of time from 22.2 to 1.2 Ma ago. Various screening procedures (microscopy, SEM, XRD, X-radiography) were used to ensure that the corals under study are in a pristine state of preservation that makes them suited for meaningful radio-densitometry and stable isotope proxy analyses. Compared to the Recent, the calcification data show that the process of biomineralization responded in a fully compatible way to environmental stresses (e.g. turbid water, freshwater discharge, upwelling etc.), but calcification performance at typical reef sites (i.e. clear-water settings) remained below that of modern symbiotic corals (= hypo-calcification). Because the carbon stable isotope values are fully compatible with those of modern symbiotic corals, we infer the light-enhanced calcification system of scleractinian corals was fully established by the beginning of the Neogene and lower-than-present calcification performance to be the likely result of globally low AS. If so, the present-day's AS appears to be more the exception than the norm and not suited for interpreting past and predicting future calcification trends.

Oral
A-1585

Pacing of Red Sea deep water formation events during the last centuries from a coral oxygen isotope record

Felis, T.[1], Mudelsee, M.[2]
[1]MARUM - Center for Marine Environmental Sciences, University of Bremen, Bremen, Germany, [2]Climate Risk Analysis, Heckenbeck, Bad Gandersheim, Germany, (tfelis[at]marum.de)

Abstract

The Red Sea is a deep marine basin that hosts some of the most productive and diverse shallow-water coral reefs. This desert-surrounded basin is often considered as a small-scale version of the global ocean. The reefs of the northern Red Sea are considered as refugia from global warming and ocean acidification. Moreover, the northern Red Sea is a rare place on Earth in which deep water forms and where corals grow. Deep vertical water mass mixing events triggered by open-ocean deep convections in the northern Red Sea during anomalously cold and dry winters can have severe impacts on coral reefs of the area. Improved knowledge of their pacing is essential for future management strategies of these unique coral reef ecosystems. Hydrographic observations and ocean-atmosphere modelling indicate Red Sea deep water was episodically renewed by wintertime open-ocean deep convections in the northern Red Sea during 1982-2001, suggesting a deep water renewal time on the order of a decade. However, the long-term pacing of Red Sea deep water renewals is largely uncertain, due to a lack of hydrographic observations. Importantly, the oxygen isotope signal in massive coral skeletons can serve as proxy for surface water density and deep water formation. By using an annually resolved coral oxygen isotope record of winter surface water conditions in the northern Red Sea we show that the observed late twentieth century deep water renewals were probably unusual in the context of the preceding ~100 years. Our results suggest an absence of major deep water formation events until the 1883 Krakatau volcanic eruption. More frequent major events are detected during the late Little Ice Age (~1750-1850), and particularly during the early nineteenth century characterized by large tropical volcanic eruptions. From our long-term perspective we conclude that Red Sea deep water renewal time is on the order of a decade up to a century, and depends on the mean climatic conditions as well as on the large-scale interannual climate forcing. This should be considered in future management strategies of the unique coral reef ecosystems of the northern Red Sea. This study highlights the value of annually resolved reconstructions of large-scale oceanographic processes derived from proxy records incorporated into skeletons of centuries-old massive corals during growth, in order to place observed recent and projected future coral reef ecosystem changes into a longer-term context of the last centuries.

Oral
A-1116

The Belize barrier and atoll reefs revisited: new data on Holocene reef accretion and the impact of sea level, subsidence, and climate

Gischler, E.[1], Hudson, H.[2], Pisera, A.[3], Stocchi, P.[4], Eisenhauer, A.[5]
[1]Goethe University, Institute of Geosciences, Frankfurt am Main, Germany
[2]ReefTech Inc., Miami Florida, United States
[3]Institute of Paleobiology, Warzawa, Poland, [4]Nioz, Texel, Netherlands
[5]Geomar, Kiel, Germany

gischler[at]em.uni-frankfurt.de

Abstract

The Belize barrier and atoll reefs represent the largest tropical reef system in the Atlantic. A revisit of 22 existing drill cores with individual lengths of >20 m from this major reef system in combination with new U-series age data from corals (n=77) and previous age data (n=57) provide a detailed insight into reef accretion patterns and possible controlling environmental factors over the past ca. 10 kyrs. The most common corals encountered include the branched *Acropora palmata* and the massive *Orbicella* group. Gaps in *Acropora* occurrence exist during 6-5.5, 4.2-3.7, and 2.5-2 kyr BP and fall together with *Diadema* sea urchin mass-mortality events. In the basal Holocene sections, the brain coral *Pseudodiploria strigosa* and the staghorn coral *Acropora cervicornis* show elevated abundances. Other common corals encountered in the cores include *Porites* sp., *Siderastrea* sp., *Agaricia* sp., and the hydrocoral *Millepora* sp. Vertical reef accretion rate (n=64), calculated between age data points, averages 3.26 m/kyr (std.-dev. 4.53). Interestingly, branched and massive coral facies accrete at more or less the same accretion rates (2.72 and 3.16 m/kyr, respectively), thereby challenging previous models of Holocene reef accretion including keep-up, catch-up, and give-up reef anatomies. Average reef accretion rate is at the lower minimum of projections of 21st century sea-level rise that range from 3-10 m/kyr. Holocene sea-level rise appears to be the most important environmental factor as it provides ample accommodation space. Accretion rate and sea-level rise show a statistically significant correlation ($r=0.446$, $p<0.0002$). Subsidence provides accommodation as well, however, at rates one to two orders of magnitude lower as compared to sea-level rise. As in other regions, Holocene reef accretion rate declines during the Holocene ($r=0.408$, $p<0.0008$). With regard to the Holocene temperature conundrum, reef accretion rate shows a statistically significant negative correlation ($r=-0.319$, $p<0.010$) with SST-anomaly data characterized by a constant, asymptotic rise; there is no correlation with SST-anomaly data exhibiting a thermal maximum in the early-mid Holocene and a subsequent SST-fall.

Oral
A-1184

Patch-reef development within rubble beds found in the Upper Triassic Dachstein platform of the Northern Calcareous Alps in Austria

Godbold, A.[1], Hohmann, N.[2], Jarochowska, E.[3], Wolfgang, K.[4], Bottjer, D. J.[1]
[1]University of Southern California, Department of Earth Sciences, Los Angeles, United States
[2]University of Warsaw, Faculty of Biology, Biological and Chemical Research Centre, Institute of Evolutionary Biology, Warsaw, Poland
[3]Utrecht University, Department of Earth Sciences, Utrecht, Netherlands
[4]Friedrich-Alexander University Erlangen-Nuremberg, Department of Geography and Geosciences, Erlangen, Germany

agodbold[at]usc.edu

Abstract

The structural complexity of coral reefs play an important role in supporting biodiversity. Natural and anthropogenic stressors continue to exacerbate reef erosion leading to the development of rubble beds which have lasting effects on reef communities. Recent studies have shown that while rubble beds have low surface complexity, they can provide a dynamic ecological framework that supports a diverse community. Additionally, consolidated rubble can promote reef recovery, which has led to a growing interest in the stabilization of rubble beds as a coral restoration method. However, our understanding of the natural processes involved in coral recovery within rubble beds is limited. This study aims to investigate the community membership and reef development within ancient rubble frameworks found within the Upper Triassic (ca. 210 Ma) Dachstein platform of the Northern Calcareous Alps in Austria. Our quantitative assessment shows that 67.4% of collected samples were composed of reef rubble and 29% were composed of in-situ reef patches. The abundance of reef rubble suggests that physical disturbances acted as a major control on the taxonomic composition and reef development. Based on modern ecological studies, reef recovery in this storm driven environment would require the stabilization and lithification of rubble followed by the colonization of important frame-building organisms. Our study shows that organisms known for their ability to bind and stabilize sediments (i.e., sponges, microbes, and macroalgae) are prominent within the study localities through time. Additionally, the abundance of borings within the matrix points to early lithification. A linear regression shows that there is a strong positive correlation (R^2=0.65, p-value<0.001) between sponge abundances and coral abundances through time suggesting that sponges could play a role in creating substrate favorable to coral settlement in rubble beds. Despite the evidence of rubble consolidation and the colonization of frame-building organisms, coral reefs were not able to build large complex structures and instead were restricted to highly diverse but structurally simplistic reef patches (<2 meters in length). This could be due to the frequency of physical disturbances. This study highlights the ecological importance of sponges within rubble beds and how frequently recurring storms can hinder the development of structurally complex reefs, which are otherwise common along the Dachstein platform.

Oral
A-1300

How did Mid-Late Holocene reefs respond to slow-rate, low-amplitude sea-level changes?

Hallmann, N.[1], Camoin, G.[1], Eisenhauer, A.[2], Samankassou, E.[3], Vella, C.[1], Botella, A.[4], Milne, G. A.[4], Fleury, J.[1], Fietzke, J.[2], Goepfert, T.[5]
[1]Aix-Marseille Université, CNRS, IRD, INRAE, Coll France, CEREGE, Aix-en-Provence, France
[2]GEOMAR Helmholtz-Zentrum für Ozeanforschung Kiel, Kiel, Germany
[3]University of Geneva, Department of Earth Sciences, Geneva, Switzerland
[4]University of Ottawa, Department of Earth and Environmental Sciences, Ottawa, Canada
[5]Arizona State University, School of Earth & Space Exploration, Tempe, Arizona, United States,

hallmann[at]cerege.fr

Abstract

The mid-late Holocene is characterized by slow-rate, low-amplitude and high-frequency sea-level changes. It provides the opportunity to document the response of coral reefs and coastal systems to changing accommodation space in relation to low-amplitude (about 1 m) relative sea-level changes. This could help to better assess how these systems might respond to projected sea-level rise by the year 2100.
This study provides a high-resolution reconstruction of the reef growth history in French Polynesia and their response to sea-level fluctuations and associated environmental changes over the past 6,000 years. After the stabilisation of sea level at its present position, the new development of reef systems was initiated by the creation of accommodation space due to a glacio-eustatic sea-level rise from 6.0 to 4.1 kyr BP, and controlled by the antecedent topography of the islands. A single short-lived sea-level highstand of less than one metre between 4.1 and 3.4 kyr BP is documented. The amplitude of the highstand is less than one metre, within the range of the predicted sea level at the end of the current century. The reported RSL changes are characterized by slow rates ranging from a few tens of millimetres per year up to 2.5 mm/yr and by significant sea-level stability (stillstands) lasting more than a century and up to 250 years.
Regionally, continuous reef development has been maintained throughout the last 6,000 years and is typified by the widespread development of microatoll fields and reef flat units. Microatolls are coral colonies with living outer margins and flat dead upper surfaces that have grown laterally for decades or centuries as their vertical growth has been constrained by exposure at lowest tides. Therefore, they are excellent low-tide recorders. The persistence of reef assemblages displaying similar overall composition and diversity throughout the period and the continued development of coral microatolls suggest optimal environmental conditions. The detailed reconstruction of reef development over the last 6,000 years provides valuable information regarding coral reef dynamics and coastal processes during periods of higher sea level and wave energy regimes.

Oral
A-1070

Fringing reef development at Mahahual, southeast Yucatan: testing the hurricane control hypothesis

Islas-Domínguez, E.[1], Blanchon, P.[2], Medina-Valmaseda, A. E.[1]
[1]Universidad Nacional Autónoma de México, Posgrado en Ciencias del Mar y Limnología, Mexico City, Mexico
[2]Universidad Nacional Autónoma de México, Reef Systems Unit (Puerto Morelos), Instituto de Ciencias del Mar y Limnología, Cancun, Mexico

egidsm[at]gmail.com

Abstract

Models of Caribbean reefs development have traditionally been based on the vertical accretion of coralgal framework in response to Holocene sea level rise. Drill cores from a fringing reef at Galeta Point in Panama, for example, showed that the reef-crest coral Acropora palmata had accreted 15 m over the last 7 ka and was capped by an extensive reef flat as sea-level rise slowed. A variation of this was later found in cores from a fringing reef on St. Croix, which showed that mid-shelf sediment accumulation had facilitated the initiation of an A. palmata reef, which then built to sea level. More recently however, a different model of development has been proposed after cores from a fringing reef off Punta Maroma in the northeast Yucatan recovered a layer of A. palmata rubble that had retrograded over the back-reef in the last 6 ka in response to hurricane impact. This paucity of framework in the Yucatan where hurricanes are frequent, combined with the predominance of framework in Panama where hurricanes are rare, implies that the degree of hurricane incidence controls reef development. To test this hypothesis, we investigate reef development at Mahahual in the southeast Yucatan which is sheltered from hurricane impact by Chinchorro Bank. Based on a preliminary analysis of bathymetric and core transects we show that reef geomorphology and internal structure is significantly different to the hurricane-impacted reef at Punta Maroma. The geomorphic differences at Mahahual consist of the development of an intertidal reef flat and an extensive but low gradient spur and groove zone which contrast with the steeper crest-type reef at Punta Maroma. In addition Cores show differences in the reef deposit, which consists of numerous large in-place head corals surrounded by rubble. These preliminary results are consistent with hurricane control on reef geomorphology and development through time.

Oral
A-1770

Negligible effect of temperature changes on cold-water coral development over the last 20.000 years

Portilho-Ramos, R., Titschack, J., Wienberg, C., Hebbeln, D.
MARUM – Center for Marine Environmental Sciences, University of Bremen, Bremen, Germany., Bremen, Germany

rcpramos[at]marum.de

Abstract

As “ecosystem engineers” framework-forming scleractinian cold-water corals (CWC) build reefs that are unique biodiversity hotspots in the deep sea. The ocean warming of 3–4.4ºC predicted by the end of this century are expected to have a severe impact on CWC ecosystems with considerable negative economic consequences. Understanding how CWC ecosystems might respond to this ocean warming in the future is of pivotal importance to enable knowledge-guided management decisions and mitigation policies to protect these ecosystems and their services for society. Assessing the fate of CWC under ongoing and future climatic changes is difficult, mostly because of a complete lack of field observations documenting the crossing of environmental thresholds (“tipping point”) which trigger local extinction events. Furthermore, the complexity of physiological processes, species-specific tolerances and their time-dependence to multi-stressor exposition have been leading to contradictory results in manipulative experiments. In this context, a paleoceanographic approach offers the unique opportunity to align events of demise and recurrence of CWC ecosystems recorded in sediment cores to the variability of paleoenvironmental parameters such as temperature. Here, we reconstruct the temperature of intermediate water (200–900m water depth) for the last 20.000 years by using benthic foraminifera Mg/Ca ratio from 6 sediment cores collected in the North Atlantic and the Mediterranean Sea. This interval of time comprises the last major global warming (3–5ºC) event associated with the transition from the last glacial period to the present interglacial. Astonishing, our results show that, contrary to expectations regarding the current ocean warming, temperature exerts no influence on the coral development cycle (at least not within their temperature threshold between 5–15ºC). No significant changes and/or trends in temperature over the studied period were associated with either the demise or the recurrence of CWC, indicating that temperature had no direct controlling effect on the proliferation of CWC. Instead, our results show that CWC were far more sensitive to food supply, especially by lateral advection triggered by enhanced bottom water hydrodynamics. Thus, modeling projections on the ecological response of CWC to future climatic changes should consider especially the role of (lateral) food supply as a major stressor having the potential to push CWCacross significant tipping points.

Oral
A-1310

Holocene sand apron development in the Southern Great Barrier Reef

Vila-Concejo, A.[1], Hamylton, S.[2], Webster, J.[1], Duce, S.[3], Fellowes, T.[1]
[1]The University of Sydney, Geocoastal Research Group, School of Geosciences, Sydney, Australia
[2]University of Wollongong, School of Earth, Atmospheric and Life Sciences, Wollongong, Australia
[3]James Cook University, College of Science and Engineering, Townsville, Australia

ana.vilaconcejo[at]sydney.edu.au

Abstract

Sand aprons are found on the leeward side of many coral reefs. They are distinctive landforms that offer important insight into sedimentary dynamics for reef platform development. Here we link temporal and spatial scales of 21 sand aprons in the Southern Great Barrier Reef, evaluating present day morphodynamic processes to understand their Holocene formation and evolution based on relative sea level changes, the depth of the Pleistocene base and contemporary morphodynamics. Our results show that lagoon infilling through sand apron progradation is a function of reef size and a self-limiting process that does not depend on the type of reef, or whether it is an exposed or a protected reef. Our results pose interesting questions about carbonate productivity with estimates based on lagoon infilling being remarkably similar to those inferred from habitat classification.

Oral
A-1816

The response of coral reef development to climate conditions on Holocene uplifted terraces in Kikai Island, Japan

Yamazaki, A.[1, 2], Kobayashi, W.[3], Garas, K.[4], Watanabe, T.[5, 6]
[1]Kyushu University, Faculty of Science, Fukuoka, Japan
[2]KIKAI Institute for Coral Reef Sciences, Kikai-town, Kagoshima, Japan
[3]Hokkaido University, School of Science, Sapporo, Japan
[4]Hokkaido University, Graduate School of Science, Sapporo, Japan
[5]Hokkaido University, Faculty of Science, Sapporo, Japan
[6]KIKAI Institute for Coral Reef Sciences, Sapporo, Japan

zaki[at]kikaireefs.org

Abstract

The decline of coral reefs has been a concern due to recent climate change and sea-level rise. However, the relationship between climate conditions and coral reef development is still unknown. In this study, we reconstructed the composition of coral communities, coral carbonate production, and climate condition (sea surface temperature and salinity) from Holocene uplifted terraces in Kikai Island, Japan, and discussed the relationship between reef growth and climate change during mid to late Holocene.
Kikai Island is located at the central Ryukyus, the boundary of subtropical and temperate areas, and borders between the East China Sea and the Pacific Ocean. The coast of Kikai Island is composed of four terraces (Terrace Ⅰ - Ⅳ) developed from 8.1 ka to 1.4 ka. The topographic profiles and coral genus composition along five transects crossed over from Terrace Ⅱ to Ⅳ (Ⅱ; 6.3-4.1 ka, Ⅲ; ~3.1ka, Ⅳ; ~1.4 ka) around the island. Coral carbonate production (CCP) in each terrace was calculated from each coral genus's coverage, skeletal density, and growth rate. Seasonal variation of SST and salinity were reconstructed by oxygen isotopes and strontium/calcium ratios in fossil *Porites* corals skeletons from each terrace.
The group of coral genera was classified by its tropical and temperate adapted type in modern Japanese areas. The coverage of tropical adapted corals, including *Acropora sp.,* was small on terrace Ⅲ at the east coast and *vice versa* at the west coast. The temperate adapted corals were increased with decreasing the tropical adapted corals, especially on terrace Ⅲ. CCP values were generally correlated with the cover of *Acropora sp.* The seasonal variation of reconstructed SST and salinity through Holocene suggested the strength of the East Asian monsoon.
These results revealed the relationship between climate and coral reef developments in Kikai Island. Terrace Ⅱ was highly developed under a warm (Holocene climatic optimum) climate and strong solid summer monsoon conditions. On terrace Ⅲ at the east coast, cooling weather decreased the abundance of tropical adapted corals and CCP. However, coral diversity was increased with a lot of temperate adapted corals. On terrace Ⅲ at the west coast, strong winter monsoon (northwest wind) developed coral reef. On terrace Ⅳ, the cover of *Acropora sp.* and CCP was recovered with the transition to the modern, warm climate. Reef corals changed their diversity and have kept the reef growth through the Holocene in Kikai Island.

Poster
A-1195

Initiation of the Holocene Great Barrier Reef: a numerical modelling study of coral regeneration dependency on tidal dynamics

Lee, K.[1], Webster, J.[2], Salles, T.[2], Hill, J.[3]
[1]University of York, Environment and Geography, York, United Kingdom
[2]University of Sydney, Sydney, Australia
[3]University of York, York, United Kingdom

kl909[at]york.ac.uk

Abstract

Great Barrier Reef (GBR) coral regeneration is made effective by the “sticky water phenomenon” (SWP), the process by which eddies collect larvae from mass spawning events together on the surface in vast slicks, which float and travel for up to 48 hours before sinking. GBR tidal patterns, and therefore eddies, are influenced by both sea level and reef density. As sea level has increased by 75 metres over the last 15,000 years, tidal dynamics will have significantly changed and the SWP may therefore be a recent development. If the SWP is reliant on sea level, future sea level rise may cause the extinction of this phenomenon. Here, we investigate the connection between Holocene reef regeneration and past tidal dynamics to understand the importance of the SWP.

We use a finite element model with varying spatial resolution to build four numerical models of modern and past tides on the GBR. We simulate the tides at 10 ka, 12.5 ka and 15 ka, which represent 20 m, 45 m and 75 m of sea-level drop respectively. We identified potential locations of palaeo-reef settlement and then ran a Lagrangian particle tracking model, using modelled tidal velocities, to simulate the movement of larvae for 48 hours following the Spring full moon in November/December from the determined reef locations.

Results showed reef density only enabled the SWP to exist from ~10 ka, coinciding with the initiation of the current Holocene reef. Prior to 10 ka, tidal currents showed a high degree of oscillating flow, meaning larvae could be deposited further from the parent reef, possibly on unsuitable sites. From 10 ka, the tidal currents became more complex, with a number of eddies forming on and around potential reef sites. This meant that although larvae travelled a greater distance, they remained near the parent reef to settle. There was then a clear increase of coral reef growth following SWP initiation, suggesting a dependency. The models of past GBR tides show that there is a connection between sea level and reef connectivity based on tidal dynamics. The initiation of SWP is related to the palaeo-tidal conditions but also to the palaeo-bathymetry, which affects the palaeo-tides. Our results suggest that GBR coral regeneration is reliant on the SWP, which, in turn, is reliant on sea level and bathymetry. Understanding the connection between these processes now and in the past is necessary for predicting future impacts.

Poster
A-1114

Environmental controls on the survival of Scott Reefs, NWS, Australia since the Miocene: Insights from 3D seismic data

Williams, C.[1], Webster, J.[1], Paumard, V.[2], Salles, T.[1]
[1]University of Sydney, Sydney, Australia
[2]University of Western Australia, Perth, Australia

carra.williams[at]sydney.edu.au

Abstract

The initiation, development and survival of carbonate platforms and coral reefs is complex, and governed by multiple environmental forcing conditions, including; sea level, tectonics and oceanographic factors.
The North West Shelf (NWS) of Australia endured dramatic climatic and oceanographic changes throughout the Miocene, Pliocene and Quaternary periods, most remarkably: (1) the Mid Miocene Climatic Optimum (MMCO), which saw the onset of isolated carbonate build-ups and carbonate platform development, (2) a rise in sea level amplitude and decreasing frequency during the Mid Pleistocene Transition (MPT) between ca.0.8-0.6Ma and the associated change in regional climate from wet to dry, and (3) glacial-interglacial variability throughout the Pleistocene until present day.
North and South Scott Reefs are isolated carbonate reefs separated by an inter-reef channel on the NWS that evolved from a carbonate platform - part of the largest barrier reef system in the Neogene, to isolated carbonate build-ups (ICB's) and atolls in the Pliocene, and finally to the reefal build-ups that survive to present day. However, the timings of coral reef turn on and off are insufficiently understood with respect to global climatic changes in this region.
Availability of 3D seismic data provides a unique opportunity to investigate the evolution of these reefs using seismic stratigraphy (SS) and seismic geomorphology. SS reveals that despite rapid accommodation rate changes as a result of global (e.g., climate, eustasy) and regional (e.g., tectonics) forcing parameters, the unique oceanographic setting, antecedent topography and rapid vertical reef accretion played a key role in their survival. It is likely that the Indonesian throughflow current was a critical component in controlling the local climate by transporting warm waters from the Indo-Pacific warm pool to the Indian Ocean extending down to the NWS. The Leeuwin current, tides, swells and wind regimes similarly exert a major influence on the NWS climate, whilst the inter-reef channel likely bypassed terrigenous sediment influx away from the reefs basinward via canyons, avoiding periods of inundation during wet climates in the Pliocene.
The 3D seismic data has allowed us to reconstruct the evolution of subsurface reef geomorphology in unprecedented detail to better understand the major environmental controls on carbonate platform and coral reef initiation, development and survival over the last 17 million years to present day.

Virtual
Oral
A-2150

Shifting coral cover and carbonate production trajectories of massive corals from the northeastern-Pacific.

Tortolero-Langarica, J. A.[1, 2], Rodríguez-Troncoso, A. P.[3], Cupul-Magaña, A. L.[3], Carricart-Ganivet, J. P.[4], Morales-de-Anda, D. E.[3], Caselle, J.[5]
[1]ICMyl, Universidad Nacional Autónoma de México, Laboratorio de Esclerocronologia de corales arrecifales, Puerto Morelos, Quintana Roo, Mexico
[2]Tecnologico Nacional de Mexico /IT Bahía de Banderas, Bahía de Banderas, Mexico
[3]universidad de Guadalajara, Laboratorio de ecologia marina, Puerto Vallarta, Jalisco, Mexico
[4]Universidad Nacional autonoma de Mexico, Laboratorio de Esclerocronologia de corales arrecifales, Puerto Morelos, Quintana Roo, Mexico
[5]Marine Science Institute, University of California, Santa Barbara, California, United States

adolfo.tl[at]bahia.tecnm.mx

Abstract

Scleractinian corals build and maintain tridimensional calcium carbonate ($CaCO_3$) framework and contribute to ecological coral-reefs functionality. However, coral reef accretion capacity has been affected by natural and anthropogenic stressors, menacing their good and services provisions. This study evaluated the long-term trajectories of coral parameters as live coral cover, sclerochronological characteristics (annual extension, skeletal density and calcification), and carbonate production rate of the massive coral *Pavona clavus* from the eastern Pacific, Islas Marias Archipelago. Results (mean ± SD) showed annual calcification rate of 1.14 ± 0.32 g cm^{-2} yr^{-1}, and carbonate production ranged between 0.39-1.72 kg $CaCO_3$ m^{-2} yr^{-1}. Live cover of *P. clavus* and constructional attributes decrease ~30-60 % (over ten-years period) with a similar negative trend (-3.8 % yr^{-1}) that branched and other massive corals. Sclerochronological data shows that coral growth decline was associated with intense negative (La Niña, 2010-2011) and positive (El Niño, 2014-2015) ENSO events, yet *P. clavus* exhibited a rapid recovery (two-times) after anomalies periods. The carbonate production differs significantly between reef zones (shallow vs depth), highlighting the high production values of depth-water reef sites. The findings of study reveal that massive corals play a key functional role in coral reef ecosystems in the eastern tropical Pacific, due their capacity to sustain live coral coverage and calcification rates, which significantly contributes to the long-term reef carbonate production, and in turn enhance coral reef biodiversity and ecological functionality.

Virtual
Oral
A-2205

Climate change and the geological integrity of coral reefs

Toth, L.
U.S. Geological Survey, St. Petersburg Coastal and Marine Science Center, St. Petersburg, United States

ltoth[at]usgs.gov

Abstract

Contemporary degradation of coral-reef ecosystems has reached a tipping point beyond which further declines threaten both the ecological function of reef ecosystems and the geological process of reef accretion. Understanding how climate and other anthropogenic disturbances will influence reef-building in the future is critical to ensuring the continued construction and maintenance of reef framework and the valuable ecosystem services that geological structure supports; however, accurately forecasting the long-term process of reef accretion is generally not possible with short-term ecological studies. Geological records, particularly those from sensitive, marginal reef environments such as the subtropical reef system of south Florida, are key to projecting how the processes of reef-framework construction and destruction will change in the future. During the early Holocene, rapidly accreting reefs occurred throughout the region, with the reef tract extending nearly 500 km along Florida's southeastern shorelines. Reef development in south Florida reached its peak during the mid-Holocene climatic optimum but declined dramatically as the climate cooled during the late Holocene. By 6000 years ago, the reef tract had contracted to the lowest latitudes of south Florida. By 3000 years ago, reef-building was negligible throughout the region, marking the threshold for the geological shutdown of Florida's reefs. Despite these major changes in the rates of reef accretion, the species composition of Florida's reefs remained stable over the last 8,000 years, suggesting that reef accretion may be among the most sensitive processes to environmental change. The shutdown of reef-building by 3000 years ago confined Florida's reefs to an unstable equilibrium, in which a veneer of living coral was the only barrier to catastrophic reef erosion. Modern climate change and other anthropogenic disturbances have now pushed many reefs into a novel state characterized by the unprecedented loss of reef-building corals and relative increases in non-reef-building taxa, effectively removing that protective barrier and permitting rapid reef-framework erosion. The ecological and geological impacts of climate change on construction and destruction of Florida's coral reefs highlight the perilous state of contemporary coral reefs.

Session 1C - Look forward to the past: What role does historical data play in the future of coral reefs?

Conceptualized by: **Aaron O'Dea**[1], **Erin Dillon**[2], **Loren McClenachan**[3], **John Pandolfi**[4]
[1] Smithsonian Tropical Research Institute (Bocas del Toro, Panama)
[2] University of California Santa Barbara (Santa Barbara, CA, USA)
[3] Colby College (Waterville, ME, USA)
[4] University of Queensland (Brisbane, Australia)

Chaired by: **Aaron O'Dea**[1], **Erin Dillon**[2], **Angelina Ivkic**[3]
[1] Smithsonian Tropical Research Institute (Bocas del Toro, Panama)
[2] University of California Santa Barbara (Santa Barbara, CA, USA)
[3] University of Vienna (Vienna, Austria)

Oral
A-1696

Reconstructing long-term change in Caribbean coral communities to inform management and conservation

Cramer, K.[1], Donovan, M.[2], Jackson, J.[3], Greenstein, B.[4], Korpanty, C.[5], Cook, G.[6], McClenachan, L.[7], Pandolfi, J.[8]
[1]Arizona State University, Center for Biodiversity Outcomes, Tempe, United States
[2]Arizona State University, Tempe, United States
[3]American Museum of Natural History, New York, United States
[4]Roger Williams University, Bristol, United States
[5]MARUM Center for Marine Environmental Sciences, Bremen, Germany
[6]New England College, Henniker, United States
[7]University of Victoria, Victoria, Canada
[8]The University of Queensland, St Lucia, Australia

katie.cramer[at]gmail.com

Abstract

The mass die-off of Caribbean corals has transformed the structure and functioning of this region's reefs since systematic monitoring began in the 1970s. Although attributed to a combination of local and global human stressors, the lack of long-term data on Caribbean reef coral communities has prevented a clear understanding of the causes and consequences of coral declines. We integrated paleoecological, historical, and modern survey data to track the occurrence of major coral species and life-history groups throughout the Caribbean from the prehuman period to the present. The regional loss of competitive *Acropora* corals beginning in the 1950s and 1960s from local human disturbances resulted in increases in the occurrence of formerly subdominant stress-tolerant and weedy scleractinian corals and the competitive hydrozoan *Millepora* beginning in the 1970s and 1980s. However, increases in disturbance-adapted corals slowed or reversed beginning in the 1980s and 1990s as coral bleaching and disease intensified. These patterns reveal the long history of increasingly stressful environmental conditions on Caribbean reefs that began with widespread local human disturbances and have recently culminated in the combined effects of local and global change. Although these and other historical datasets provide the long-term perspective necessary for effective reef management and conservation, these data are rarely incorporated into management frameworks. Potential pathways for integrating these data into decision-making will be discussed.

Oral
A-1971

Improving historical reconstructions with modern analogs: using stable isotopes to track nutrient assimilation into the coral skeleton

Cybulski, J.[1, 2], Conti-Jerpe, I.[3], Corley, A.[2], Duprey, N.[4], McIlroy, S.[2], Yasuhara, M.[2], Thibodeau, B.[5], Baker, D.[2]
[1]The Smithsonian Tropical Research Institute, Panama City, Panama
[2]The University of Hong Kong, School of Biological Sciences, Hong Kong, Hong Kong SAR China
[3]University of California, Berkeley, Berkeley, California, United States
[4]The Max Planck Institute for Chemistry, Mainz, Germany
[5]The Chinese University of Hong Kong, School of Life Sciences, Hong Kong, Hong Kong SAR China

cybulski.j[at]gmail.com

Abstract

The skeletal organic matrix (SOM) of scleractinian corals is significant for both biogeochemical and paleoecological research because it records environmental parameters *in situ* that can be preserved over geologic timescales. The nitrogen bound inside the SOM reflects the nutrient sources of the coral-algal holobiont at the time of carbonate nucleation. Methods for extraction and isotopic analysis of the SOM exist; however, little is still known about which nutrients are preferentially assimilated by corals. This limitation undermines the accurate interpretation of skeletal-bound isotopic records. We address this gap by answering two main questions: 1) What food source is preferentially incorporated into the SOM, and therefore preserved during coral calcification; and 2) How does nutrient preference alter historical reconstructions of past marine environments? We conducted a feeding experiment where *Porites* sp. and *Acropora* sp. were simultaneously exposed to 3 different forms of nutrients: 1) inorganic nutrients (nitrate and bicarbonate) accessible by the algal symbionts, 2) organic nutrients (urea and glucose) accessible to the entire holobiont, and 3) phytoplankton (*Isochrysis galbana*) and zooplankton (*Artemia salina*) for coral heterotrophic feeding. In each treatment, one nutrient source was enriched in nitrogen ($\delta^{15}N$) and carbon ($\delta^{13}C$), allowing us to trace it from ingestion through assimilation to SOM incorporation. Our results show both species are mixotrophic, assimilating all nutrients except phytoplankton. Furthermore, assimilated nutrients by the holobiont were subsequently incorporated into the SOM during calcification in similar relative abundances. We used these results to interpret a dataset of $\delta^{15}N$ values from *Acropora sp.* sub-fossils collected around Hong Kong extending back 5000 years, creating the first “ground-truthed” historical nutrient baseline. This skeleton-bound record confirms that a previously documented spike in $\delta^{15}N$ values during the 1990’s was unique over the Holocene, and likely indicates regional eutrophication resulting in wide-spread coral mortality. This work adds clarity to baseline data obtained from paleo-nutrient archives; data needed as we attempt to understand the deleterious ecological consequences of human-dominated nutrient cycles.

Oral
A-2025

How does productivity shape pre-exploitation shark baselines and resilience on coral reefs over millennia? A preliminary exploration

Dillon, E.[1, 2], McCauley, D.[1], O'Dea, A.[2]
[1]University of California, Santa Barbara, Dept. Ecology, Evolution, and Marine Biology, Santa Barbara, CA, United States
[2]Smithsonian Tropical Research Institute, Panama City, Panama

erinmdillon[at]ucsb.edu

Abstract

Shark populations worldwide have declined steeply over the last half century, but the patterns of change vary across space. Long-term records of shark abundance are limited, so it is challenging to quantify sharks' natural spatiotemporal variability and the extent to which they have shifted from pre-exploitation baselines in regions with different environmental conditions. Here, we use fossil shark scales (dermal denticles) to reconstruct shark communities during the mid-Holocene (~4-7ka) and today on both coasts of the Isthmus of Panama. The Tropical Eastern Pacific is a highly productive, dynamic system driven by seasonal upwelling with a long history of shark exploitation that continues today. The Caribbean coast, on the other hand, is oligotrophic and environmentally stable, with much lower rates of harvesting. We find that denticle accumulation rates, a proxy for shark abundance, are an order of magnitude greater on reefs in Pacific Panama (Gulf of Panama) than those in Caribbean Panama (Bocas del Toro). Comparing patterns over time, denticle accumulation rates declined by 71% since the mid-Holocene on reefs in Caribbean Panama, with selective losses observed in pelagic sharks. In sharp contrast, modern denticle accumulation rates in Pacific Panama are comparable to their range of variability during the mid-Holocene, and the functional composition of denticle assemblages remained similar through time—suggesting that the shark community in the Gulf of Panama has persisted despite intensive fishing activity. We postulate that the region's high productivity might underlie its high shark abundance and apparent resilience, although we remain unsure whether they are manifested through life history traits (e.g., increased fecundity, reproductive turnover, and growth rates) and/or resource availability (e.g., higher rate of energy input or pelagic subsidies). Our preliminary findings, although geographically restricted, provide insight into the drivers of variability in reef shark baselines and recovery potential in the face of ongoing overfishing.

Oral
A-1189

Sticking it out when the going gets tough: in-situ Red Sea coral reef refugia maintained a coral reef fish species during the Last Glacial Maximum

Emms, M.[1], Maisano Delser, P.[1], Robitzch, V.[2], Alpermann, T.[3], Kiflawi, M.[4, 5], Manica, A.[1]
[1]Universty of Cambridge, Department of Zoology, Cambridge, United Kingdom
[2]Universidad Austral de Chile, Valdivia, Chile
[3]Senckenberg Research Institute and Nature Museum, Frankfurt, Germany
[4]Ben Gurion University, Department of Life Sciences, Beer Sheva, Israel
[5]The Interuniversity Institute for Marine Sciences, Eilat, Israel

memms24[at]gmail.com

Abstract

Given the ongoing rise in sea surface temperatures threatening coral reefs around the world, the unique environment of the Red Sea has become an important source of knowledge on how species or populations may respond to environmental change. Many Red Sea reef fish species persisted during periods of coral reef habitat loss, for example during the Last Glacial Maximum (LGM), likely in refugia. These refugia represent a natural example of a successful conservation design for coral reef fish populations threatened by environmentally-induced habitat loss. We studied the most likely location of such refugia, either inside or outside the Red Sea basin, and how many there were – a single refugium vs multiple refugia. Widespread reef fish species' populations in the Indian Ocean make it difficult to assess the likelihood of a Red Sea population refugium located outside the Red Sea basin, as they risk dilution of the Red Sea signal. *Dascyllus marginatus* represents a model species which allows us to study the location of Red Sea refugia during the LGM given its restricted range in the Indian Ocean lessening the genetic impact on any temporary external Red Sea refugia. Restriction site-associated DNA sequencing (RADseq) data was obtained and combined with an Approximate Bayesian Computation framework via a machine learning tool, providing more information and power for comparing demographic models and estimating population parameters than methods based on mitochondrial DNA. This study reveals that *Dascyllus marginatus* experienced a mild genetic bottleneck in the Red Sea with an effective population size estimate of ~77 % of pre-LGM estimates, from which the population was able to recover. This is comparable to the demographic history experienced by two previously studied, wider-ranging, congeneric species, *Dascyllus abudafur* and *Dascyllus trimaculatus.* The extensiveness of external populations does not appear to affect population response to, or recovery from, environmentally-induced habitat loss. By considering several demographic models varying in the location of coral reef refugia, we show that such refugia were unlikely to have been in the neighbouring Gulf of Aden but rather inside the Red Sea during the LGM, most likely only in the North. Our results provide evidence that in-situ refugia (possibly even a single one) are capable of maintaining a population during periods of habitat loss, that is capable of recovery given the return of more favourable conditions.

Oral
A-1213

Lessons from Egyptian Eemian reefs

Ivkic, A.[1], Klaus, R.[2], Kroh, A.[3], Mansour, A. M.[4], Reinicke, G. B.[5], Riegl, B.[6], Zuschin, M.[1]
[1]University of Vienna, Vienna, Austria
[2]Senckenberg Research Insitute, Frankfurt am Main, Germany
[3]Natural History Museum Vienna, Vienna, Austria
[4]South Valley University, Qena, Egypt
[5]Deutsches Meeresmuseum, Stralsund, Germany
[6]Nova Southeastern University, Fort Lauderdale, United States

angelina.ivkic[at]univie.ac.at

Abstract

A wide variety of simultaneously occurring stressors result in rapid changes in modern coral reefs and make it difficult to disentangle their individual effects. Elevated oceanic temperatures and reduced pH that lowers carbonate availability are caused by the same driver, increased CO_2 concentrations, and impact practically all coral systems. The effects of other man-made impacts like overfishing and nutrient input cannot be disentangled as drivers easily either, and laboratory experiments often cannot take potential adaptation mechanisms of corals into account.
Past periods with similar conditions as projected for the future can be used to resolve some of those difficulties. One such period is the Eemian (MIS5e) in the last interglacial (125 kya), with higher oceanic temperatures, but lower reconstructed CO_2 concentrations and therefore presumably higher pH. With only one of the recent stressors acting on MIS5e reefs, community and population structure of these corals may help to differentiate the effect of ocean warming vs. other human-induced stressors on modern reef corals. Therefore, this period can be considered a natural experiment for long-term adaptations to higher temperatures.
Since the Egyptian Red Sea coast was subject to limited coastal uplift since the Eemian, its MIS5e coral reefs are well preserved and accessible. These fossil reefs were studied by line intercept transects (LITs) and compared to similarly obtained data from modern reefs.
Modern Red Sea coral reefs show a compositional change along a depth gradient. Topography and coral composition indicate that species composition is similar between modern and Eemian reefs but that mainly shallow reef habitats of different degrees of hydrodynamic exposure are preserved in the fossil record. Accordingly, we only used shallow modern sites for comparison with the fossil data. Results on abundance and composition of the fossil coral communities will be presented and serve as a baseline to evaluate the effects of higher oceanic temperatures without the impact of a lower pH, a shortage of carbonate ion availability and the absence of human stressors such as overfishing or pollution. Therefore, coral species that were more abundant during the Eemian than today, may have the potential to survive better under future, rising temperatures. Furthermore, differences between the fossil and modern composition may also aid in understanding how degraded modern Egyptian Red Sea reefs already are.

Oral
A-1751

Museum collections as historical records of reef coral calcification, growth, and bioerosion

Johnson, K.[1], Summerfield, R.[1], Santodomingo, N.[1], Bertini, L.[1], Hendy, E.[2], Bayley, D.[3]
[1]Natural History Museum, London, United Kingdom
[2]University of Bristol, Bristol, United Kingdom
[3]University College London, London, United Kingdom

k.johnson[at]nhm.ac.uk

Abstract

Reef building is important for delivering the ecosystem functions of coral reefs, and reef carbonate budgets are increasingly providing important information on reef health for ecosystem management.The critical data underlying reef carbonate budgets are estimates of carbonate production and subsequent removal from the system, and there is abundant evidence that rates of calcification anderosion are changing in response to accelerating anthropogenic change on reefs on local to global scales. Museum collections around the world contain hundreds of thousands of reef coral specimens collected from throughout the tropics during the past 250 years. Traditionally these collections have been used for taxonomic or biodiversity studies, but they also contain useful ecological information.Technologies such as X-ray computed tomography coupled with advances in computer vision and artificial intelligence now provide non-destructive methods to extract large volumes of growth, calcification, and bioerosion data from museum specimens. Usually studies of coral growth are done using cores extracted from long-lived colonies which host records spanning decades to centuries. In contrast, museum collections typically contain smaller colonies or fragments extracted from larger colonies, but working on small colonies provides different information than traditional studies based on cores. For example, small colonies might be more sensitive to environmental change and the large number of specimens available can allow broader geographic, environmental, and taxonomic scope. As an example, we show how analysis of large historical collections from the Chagos Archipelago show variation in calcification and bioerosion rates across taxa, habitat and depth and between colonies that lived in the 19th, 20th, and 21st centuries. The same approach was applied to well-preserved fossil material to document reef function in the past including during past warm intervals such as the Miocene and Pliocene that represent "natural experiments" with potential to help predict how reef function will respond to ongoing warming. Study of Miocene and Pliocene fossils from the Coral Triangle region of SE Asia suggests that reef function was maintained in the region during this warm interval. These preliminary examples demonstrate how collections can help unlock the history of coral growth, bioerosion and reef health during the past centuries and in deep time.

Oral
A-1949

Nitrogen isotopes reveal modern Caribbean reefs have less complex trophic pathways than their mid-Holocene counterparts

Lueders-Dumont, J., O'Dea, A.
Smithsonian Tropical Research Institute, Panama, Panama

odeaa[at]si.edu

Abstract

Coral reefs are famed for their complex energetic pathways, which have been predicted to be strongly influenced by human impacts such as eutrophication, overfishing, and climate change. Yet we have no direct evidence of how trophic complexity has changed since the onset of human impacts. Here, we use the nitrogen isotopic composition (δ15N) of the organic constituents of fossil corals and otoliths to provide the first direct reconstructions of trophic pathways on fossil coral reefs and compare them to their modern counterparts. We focus on Caribbean coral reef systems in Panama and the Dominican Republic where large, exceptionally preserved mid-Holocene (7 ka) reefs are exposed. δ15N from corals provide a measure of the autotrophic baseline (δ15Nbase) while δ15N from otoliths (δ15Noto) provide a geochemical estimate for trophic level of fishes. In the Dominican Republic, δ15Nbase from corals decreased from the mid-Holocene to today, consistent with expectations from previously established changes in the nitrogen cycle over this time period (in particular, the basin-wide increases in biological nitrogen fixation that have occurred since the last glacial period), demonstrating that our samples captured pre-human to modern end-members. In Panama, there was no significant change in the mean δ15Nbase, suggesting that the basin-scale averages have been offset by the effects of increased δ15N from well-documented eutrophication in the region. Estimated trophic levels of Haemulidae and Apogonidae fishes from δ15Noto values decreased in the DR, even when fish size and isotopic baseline conditions were accounted for, suggesting a reduction in trophic length in these ecosystems today. Mean δ15Noto in most groups of fishes in Panama remained similar over time, implying that trophic lengths are roughly similar on average. However, we observed a dramatic reduction in intra-taxon δ15Noto variability in modern fishes compared to the mid-Holocene; a pattern that was also seen in the Dominican Republic. These findings suggest that energy flow pathways in modern reefs have become homogenised. The causes and consequences of this observation are discussed.

Oral
A-1811

Major shifts in taxonomic composition but not gross ecological function in Caribbean coral reef fish communities since the mid-Holocene

O'Dea, A., De Gracia, B., Lueders-Dumont, J., Lin, C.-H.
Smithsonian Tropical Research Institute, Panama, Panama

odeaa[at]si.edu

Abstract

Caribbean coral communities are distinct from their mid-Holocene baselines and documenting that change with fossils offers a powerful way to set conservation guidelines and understand mechanisms of change in ecosystems with and without humans. In contrast, we know much less about how reef fish communities have changed over the same time period. In this study we describe the discovery of more than 5000 fossil reef fish otoliths in mid-Holocene (~7ka) reefs in Bocas del Toro, Panama and the Dominican Republic and discuss their utility to reconstruct baseline conditions of reef fish communities. We were able to identify the majority of the fossil otoliths to family using a specially-built reference collection housed at the Smithsonian Tropical Research Institute in Panama. Surveys of modern reef fishes found otoliths reflected the abundances of living fishes on the same reefs (live-dead comparison). Both fossil and modern otolith assemblages were dominated by small, cryptobenthic (e.g. Gobiidae and Apogonidae) and epipelagic (e.g. Engraulidae) fishes with high reproductive turnover. Analysis of the taxonomic composition of the otolith assemblages showed that modern reef fish communities are entirely distinct from their mid-Holocene counterparts, but when otoliths were assigned gross functional guilds, modern and pre-human reefs were found to be indistinguishable. This result could imply that while community membership has changed over time, basic functional roles may have persisted into the Anthropocene. However, assuming uniform diets likely overlooked important details, particularly as many reef fishes can readily switch diets. Direct evidence of reef fish function on coral reefs past and present is therefore required.

Oral
A-1874

Caribbean reef building coral populations from multiple species have rebounded in the last 80,000 year

Prada, C.
University of Rhode Island, Kingston, United States

prada[at]uri.edu

Abstract

As a result of human induced climate change corals worldwide are suffering from a combination of increasing storm damage, rising temperatures, and ocean acidification. To develop effective strategies to preserve coral reef biodiversity it is necessary to understand how corals will react to these threats under various climate change scenarios. Much of the current coral research focuses on short-term responses to a few stress factors in a laboratory or in the field. However, to understand how climate change and all of its threats affect coral populations in a complex multidimensional natural environment, it is essential to complement these studies by looking at historical changes in coral abundance in response to past environmental perturbations. Here we present a comprehensive picture of climate effects on coral demography over the past half a million year by integrating, genomics-based inference of historical population sizes in major Caribbean reef building corals. The last 500Kyrs contain a period of drastic changes in the ocean's climate with major variations in temperature, carbon dioxide, sea level and biological communities. We analyzed genome-wide data from *Acropora palmata, A. cervicornis, Agaricia fragilis, Diploria labyrinthiformis, Porites porites* and *Orbicella faveolata*. Model fitting of the site frequency spectrum is consistent with multiple changes in population size (multi-epoch model) for most species analyzed. With a few exceptions, after changes in climatic conditions, populations of corals have initially declined in population size and then increased in size (recovered) in the last 80Kyrs. The two *Acropora* species despite massive declines in coral cover in recent years still hold large amounts of genetic variation and undetectable recent (< 10 Kyrs) bottleneck effects. Populations of modern corals are capable of rebounding from greatly reduced population sizes under suitable conditions. Our work suggest that modern populations have rich standing genetic variation that may facilitate adaptation to climate change if optimal coral climatic conditions are restored.

Oral
A-2028

How central Indian Ocean coral communities have responded to cold and warm water stress events since the late 19th C

Summerfield, R.[1], **Hendy, E.**[2], Johnson, K.[1], Bayley, D.[3]
[1]Natural History Museum London, London, United Kingdom
[2]University of Bristol, School of Earth Sciences, Bristol, United Kingdom
[3]University College London, London, United Kingdom

e.hendy[at]bristol.ac.uk

Abstract

Reports of mass coral bleaching have increased in frequency and severity since the early 1980s, strongly suggesting that rising heat stress has passed a threshold of thermal environmental conditions for tropical coral reefs. An important caveat in this causal relationship, however, is that there has been a coincident increase globally in monitoring and reporting efforts on coral reefs. In this study we explore temporal shifts in the stress expressed by a coral community by identifying the frequency and distribution of potential stress markers (skeletal growth anomalies, partial mortality and mortality events) evident in X-ray computed tomography scans of museum-archived populations of coral specimens. The 136 coral colonies and fragments were collected during 7 scientific expeditions from 1885 to 2017 to the Chagos Archipelago, central Indian Ocean, and grew during three distinct time periods; 1879-1904, 1947-1977, and 1992-2016. Over the years sampled the maximum monthly sea surface temperature (SST) anomalies experienced by the Chagos coral reefs ranged from -0.76°C (1904) to +1.32°C (2016) relative to the mean maximum monthly SST for 1951-78. The specimens comprise 11 genera, and were collected from a range of depths (>1 to <65 m), reef positions (lagoon, back reef, reef flat and reef front) and localities across the Chagos Archipelago. This sample set allows us to assess coral population response as recorded by skeletal features in typically young colonies (3 to >24 years) through time, and across a variety of different habitats, environmental conditions and hydrodynamic regimes, from restricted lagoons to open back reef or exposed upwelling-influenced reef fronts. It is critical that we are able to tease apart the pattern of reef-wide responses occurring during warm and cold water stress events, and the significant shift in response for the recent population. Tropical Indian Ocean SSTs have warmed faster during the period 1950-2010 than the tropical Atlantic or Pacific, in part due to a decrease in upwelling-related cooling over the Seychelles-Chagos Thermocline Ridge. We observe partial mortality in the sample population for all years of reported coral bleaching at Chagos as well as finding evidence for previously unreported stress events, and identify differences in population response resulting from remote forcing related to the El Niño Southern Oscillation.

Poster
A-1735

Changes in Coral Triangle Habitats Mask a Neogene Carbonate Decline

Harrison, G. W.[1], Johnson, K.[2], Renema, W.[1]
[1]Naturalis Biodiversity Center, Marine Biodiversity, Leiden, Netherlands
[2]Natural History Museum, London, United Kingdom

william.harrison[at]naturalis.nl

Abstract

Climate change is among the main causes of coral reef decline in the modern world.
However, the proximal causes of modern coral reef decline vary by region, including ocean acidification, bleaching from temperature, increased runoff from climate shifts combining with land use changes, and more direct human impacts. The Pliocene Climate Optimum presents a parallel to near-future environmental conditions since the climate was 4C warmer than it is today and carbon dioxide levels were around 400 µatm, making both temperature and carbon dioxide analogous to the modern day and near future. Therefore, changes in the extent and composition of coral reefs and other carbonate platforms from the Miocene through the Pleistocene serve as a proxy for how modern coral reefs might respond to climate change and how they might recover therefrom. While literature on coral reefs and other carbonate facies in the coral triangle has been published for individual sites, this is the first study to integrate all of it into one analysis on how the number of coral reefs decreased from the Miocene through the Pliocene with a partial recovery in the Pleistocene.

Virtual
Poster
A-1196

Long-term changes in algal symbiont communities (Family Symbiodiniaceae) on Caribbean coral reefs

Williamson, O.[1], **Hardy, K.**[1], Cunning, R.[2], Baker, A.[1]
[1]University of Miami, Miami, United States
[2]Shedd Aquarium, Chicago, United States,

katherinemhardy[at]gmail.com

Abstract

As coral reefs experience a range of chronic and acute stressors, selective pressures and recovery from disturbance may facilitate large-scale, regional shifts in coral-algal partnerships. In fact, repeated disturbances may have already altered the distribution of Symbiodiniaceae on reefs over recent decades, although data to evaluate such changes are currently lacking. Here, we exploit a unique collection of archived samples from throughout the Caribbean collected 20-25 years ago, representing some of the earliest surveys of Symbiodiniaceae diversity undertaken anywhere in the world. We returned to these locations in 2020-2021 to collect contemporary samples from the same species, locations, depths, and times of year to test the hypothesis that Symbiodiniaceae communities on coral reefs throughout the region may have changed over recent decades. We then related the magnitude of change with the thermal environment and disturbance history of these reefs to explain site-related differences in these patterns. Preliminary results from Florida indicate that there has been a significant increase in the abundance of thermotolerant *Durusdinium trenchii* in some coral species and locations, and across depths. We hypothesize that recent acute disturbances, such as bleaching episodes and disease outbreaks, together with chronic environmental changes such as warming baseline temperatures and increasing nutrient loads, may have altered competitive hierarchies and driven shifts in the relative dominance of different symbiont types (particularly *D. trenchii*) within coral hosts. Although this approach is not comprehensive in space (we can only test sites where we have historical samples) or time (we are only comparing two time points separated by ~20 years, and cannot document changes that occurred on shorter time scales), it nevertheless represents the best available approach to assessing whether long-term changes in Symbiodiniaceae communities are occurring on reefs. Because different symbiont types endow the coral holobiont with different phenotypic traits (growth rates, thermal tolerance, etc.), large-scale shifts in favor of a particular taxon may have important ecological consequences for coral health and reef resilience. Consequently, understanding the trajectory of these symbiont metacommunity changes is critical for assessing recent changes and predicting the future of Caribbean reefs.

Session 1D - Using coral reefs as paleo sea level recorders: how can we improve paleo-archives using modern ecological data?

Conceptualized by: **Andrea Dutton**[1], **Alessio Rovere** [2]
[1] University of Florida (Gainsville, Fl, USA)
[2] MARUM, University of Bremen (Bremen, Germany)

Oral
A-1553

Emergent coral reef terraces in west Luzon, Philippines as paleo sea-level indicators since the Plio-Pleistocene

Maxwell, K.[1, 2], Westphal, H.[2, 3], Rovere, A.[4, 5], Guinto, M.[6], Garas, K.[7]
[1]Leibniz Centre for Tropical Marine Research (ZMT), Bremen, Germany
[2]University of Bremen, Department of Geosciences, Bremen, Germany
[3]King Abdullah University of Science and Technology (KAUST), Thuwal, Saudi Arabia
[4]Università Ca' Foscari, Department of Environmental Sciences, Informatics and Statistics, Venice, Italy
[5]MARUM - Center for Marine Environmental Sciences, University of Bremen, Bremen, Germany
[6]University of the Philippines - Los Baños, Institute of Renewable Natural Resources, College of Forestry and Natural Resources,, Laguna, Philippines
[7]Department of Environment and Natural Resources–Mines and Geosciences Bureau (DENR-MGB), Quezon City, Philippines

kathrine.maxwell[at]leibniz-zmt.de

Abstract

Following our previous work using the framework of the World Atlas of Last Interglacial Shorelines (WALIS), in which we produced a standardized database of Last Interglacial (LIG) sea-level indicators in Southeast Asia, we revisited a site in west Luzon, Philippines where inferred LIG coral reef terraces were previously reported. Based on previous literature, raised coral reef terraces of Late Pleistocene to Holocene in age are observed along the western coast of Pangasinan, west Luzon Island. The highest terrace, with elevations ranging from 100-155 meters above mean sea level (m amsl), was inferred to correspond to the Marine Isotope Stage 5e (MIS 5e, LIG) about 125 ka. Rising to about 14 meters above mean sea level (m amsl) along the coast of western Pangasinan are previously dated Holocene coral reef terraces. In this paper, we present new geomorphic and stratigraphic data on the fossil coral reef terraces in Pangasinan, west Luzon which adds to the limited LIG sea-level indicators in the region. We conducted Real-Time Kinematic Global Navigation Satellite System (RTK-GNSS) surveys along select areas in western Pangasinan to provide precise elevations and geographic locations to these fossil sea-level indicators. Samples for geochronological analyses (e.g., fossil corals, shells) were collected whenever they are available. The geology of the low-lying areas of western Pangasinan is characterized by sequences of calcareous sandstone-mudstone with minor pebbly conglomerate and tuffaceous sandstone units belonging to the Sta. Cruz Formation, with tentative age designation of Late Miocene to Early Pliocene. Unconformably overlying the Sta. Cruz Formation is the Plio-Pleistocene Bolinao Limestone, the youngest formational unit in the area. While additional data is needed to shed more light on the RSL changes in the region, our work proves to be more challenging due to the difficulties of finding pristine dateable materials for radiometric dating and the difficulties of doing field surveys during a global pandemic. Nonetheless, we hope that data from this research will help us further understand the different drivers of past sea-level changes in SE Asia providing necessary geologic baseline data for projections of sea-level change in the future.

Session 1E - What can corals and marine calcifiers tell us about anthropogenic effects and trajectory of coral reef ecosystems under global change?

Conceptualized by: **Henry C. Wu**[1], **Delphine Dissard**[2], **Jens Zinke**[3], **Nathalie F. Goodkin**[4,5]
[1] Leibniz Centre for Tropical Marine Research (Bremen, Germany)
[2] IRD-Sorbonne Universités (Paris, France)
[3] University of Leicester (Leicester, United Kingdom)
[4] Nanyang Technological University (Singapore)
[5] American Museum of Natural History (New York, NY, USA)

Chaired by: **Henry C. Wu**[1], **Jens Zinke**[3]

Oral
A-2043

High Resolution Coral skeleton N isotope records from the eastern tropical North Pacific over the last 80 years

Duprey, N. N.[1], Foreman, A. D.[1], Martínez-García, A.[1], Sanchez, S. C.[2], Charles, C. D.[3], Carriquiry, J. D.[4], Vonhof, H.[1], Sigman, D. M.[5], Haug, G. H.[1]
[1]Max Planck Institute for Chemistry, Climate Geochemistry, Mainz, Germany
[2]University of Colorado Boulder, Oceans and Climate Lab, Boulder, United States
[3]Scripps Institution of Oceanography (La Jolla), Geosciences Research Division, San Diego, United States
[4]Universidad Autonoma de Baja California (Ensenada), Instituto de Investigaciones Oceanologicas, Ensenada, Mexico
[5]Princeton University, Department of Geosciences, Princeton, United States

n.duprey[at]mpic.de

Abstract

Large water bodies, located at intermediate-depth, and presenting a low dissolved O2 concentration (<2mg/l), are known as oxygen-deficient zones (ODZs). The lack of oxygen is exerting a strong constraint on marine organisms, selecting toward low oxygen tolerant species. Such a shift in the ecosystem may lead to the collapse of economically important fisheries. Thus, the dynamics of the ODZs are of great importance and have been a focus of study. Dissolved oxygen concentration is very
sensitive to air-sea fluxes and ocean circulation, such that climate change may alter (e.g., expand, contract, or shift) the ODZs. Ocean warming will decrease the O2 dissolved in surface waters that ventilate the depths of the ODZ, which by itself will work to expand the ODZs. Warming is predicted to enhance tropical water stratification, with effects on both productivity and ventilation rate, leading to uncertainty in the expected response of the ODZs. The lack of instrumental data covering past climate
oscillations restricts one of our major tools for predicting the evolution of these features in the coming decades.
In low oxygen concentration environments, nitrate is used by denitrifying bacteria instead of oxygen for respiration. In the process, bacteria select preferentially the light N isotope (14N), leaving the heavy isotope (15N) behind causing nitrate δ15N to raise. Since primary producers use nitrate for growth, any change in the source δ15N is propagated through the food web. Consequently, stable nitrogen isotopes ratio of marine organisms provides information about the intensity of denitrification and thus on the dynamics of the ODZs. Here, we report data intended to reconstruct the dynamics of the eastern tropical Pacific's northern ODZ over the last 80 years using high resolution coral skeleton δ 15N records. In particular, the records allow us to characterize the link between the footprint of this ODZ and the decadal climate variability modes of the tropical Pacific and its response to the upwelling dynamics.

Oral
A-2068

Nitrogen isotope constraints on southwestern Indian Ocean variability in the late 20th century

Foreman, A. D.[1], Zinke, J.[2], Duprey, N. N.[1], Guillaume, M. M. M.[3], Bruggemann, J. H.[4], Charles, C.[5], Martínez-Garcia, A.[1], Haug, G.[1]
[1]Max Planck Institute for Chemistry, Mainz, Germany
[2]University of Leicester, Leicester, United Kingdom
[3]Muséum National d'Histoire Naturelle-SU-UCN-UA-CNRS-IRD, Paris, France,
[4]Université de La Réunion-CNRS-IRD, Saint-Denis, France
[5]University of California San Diego, San Diego, United States

alan.foreman[at]mpic.de

Abstract

Tropical variability in the Indian Ocean impacts both regional and global climate via atmospheric teleconnections. The ocean-atmosphere dynamics in the tropics are extremely sensitive to perturbations associated with natural and anthropogenic climate change, and respond to these changes on multiple (seasonal, interannual, and multi-decadal) time scales. Despite their importance in informing our understanding of past and future climate, historical records of Indian Ocean variability are sparse. One particularly under-sampled region is the Mozambique Channel, which supplies warm surface waters to upper arm of Atlantic Meridional Overturning Circulation (Beal et al., 2011), and which can therefore impact both local and global climate (Zinke et al., 2019).

Here we present seasonally-resolved coral proxy data from a massive Porites coral drilled at Europa Island, in the southern Mozambique Channel. This collection of data, which spans the years between 1970-2013, combines proxies potentially sensitive to changes in nutrients (e.g. δ15N, Ba/Ca) with those sensitive to changes in temperature and salinity (e.g. δ18O, Sr/Ca, Li/Mg), as well as other proxies whose interpretations are not as straightforward (e.g. δ13C, B/Ca). Collectively this multi-proxy approach provides a holistic picture of the evolution of oceanic conditions in the southern Mozambique Channel over a time period associated with increased anthropogenic climate change. We supplement these observations further by comparing them with seasonal δ15N measurements over the same time period measured on a massive Porites coral core collected at St. Joseph Atoll, in the Seychelles Archipelago. Taken together, these records allow us to better characterize the variability of the southwestern Indian Ocean during a period in which observational data for the region is scarce, and in doing so better understand the regional impacts of anthropogenic climate change.

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Oral
A-1757

There Is More To Boron Isotopes Than pH: Controls On Boron Isotopes In A Cold-Water Coral And The Cost Of Resilience To Ocean Acidification

Gagnon, A.[1], Gothmann, A.[2], Branson, O.[3], Rae, J.[4], Stewart, J.[5]
[1]University of Washington, School of Oceanography, Seattle, WA, United States
[2]St. Olaf College, Physics and Environmental Studies, Northfield, MN, United States
[3]Cambridge University, Cambridge, United Kingdom
[4]University of St. Andrews, St. Andrews, United Kingdom
[5]University of Bristol, Bristol, United Kingdom

gagnon[at]uw.edu

Abstract

Coral skeletal growth is sensitive to environmental change and can be adversely impacted by an acidifying ocean. However, physiological processes can also buffer biomineralization from external conditions, providing apparent resilience to acidification in some species. These same physiological processes affect skeletal composition and can impact paleoenvironmental proxies. Understanding the mechanisms of coral calcification is thus crucial for predicting the vulnerability of different corals to ocean acidification and for accurately interpreting coral-based climate records. Here, using boron isotope ($\delta_{11}B$) measurements on cultured cold-water corals, we explain fundamental features of coral calcification and its sensitivity to environmental change. Boron isotopes are one of the most widely used proxies for past seawater pH, and we observe the expected sensitivity between $\delta^{11}B$ and pH. Surprisingly, we also discover that coral $\delta^{11}B$ is independently sensitive to seawater dissolved inorganic carbon (DIC). We can explain this new DIC effect if we introduce boric acid diffusion across cell membranes as a new flux within a geochemical model of biomineralization. This model independently predicts the sensitivity of the $\delta^{11}B$-pH proxy, without being trained to these data, even though calcifying fluid pH (pH_{CF}) is constant. Boric acid diffusion can resolve why $\delta^{11}B$ is a useful proxy across a range of calcifiers, including foraminifera, even when calcifying fluid pH differs from seawater. Our modeling shows that $\delta^{11}B$ cannot be interpreted unequivocally as a direct tracer of pH_{CF}. Constant pH_{CF} implies similar calcification rates as seawater pH decreases, which can explain the resilience of some corals to ocean acidification. However, we show that this resilience has a hidden energetic cost such that calcification becomes less efficient in an acidifying ocean.

Oral
A-1583

High resolution environmental and ecological information recorded in the skeletons of the Mediterranean coral Cladocora caespitosa

Kersting, D. K.[1], Brachert, T.[2], Hathorne, E.[3], Linares, C.[1], Pretus, J. L.[1], Reuning, L.[4], Spreter, P.[2], Zinke, J.[5]
[1]Departament de Biologia Evolutiva, Ecologia i Ciències Ambientals, Institut de Recerca de la Biodiversitat (IRBIO), Universitat de Barcelona, Barcelona, Spain
[2]Institut für Geophysik und Geologie, Universität Leipzig, Leipzig, Germany
[3]GEOMAR, Helmholtz Centre for Ocean Research Kiel, Kiel, Germany
[4]Institute of Geosciences, Kiel University, Kiel, Germany
[5]School of Geography, Geology and the Environment, University of Leicester, Leicester, United Kingdom

diegokersting[at]gmail.com

Abstract

The Mediterranean Sea is one of the world regions most affected by anthropogenic climate change. Developing climate archives in this sea is essential to reconstruct past environmental and ecological conditions, especially during the last decades which are characterized by a sharp increase in summer heat waves and widespread ecological impacts. We used high resolution geochemical analyses of skeletons of the temperate scleractinian *Cladocora caespitosa*, the only reef-builder coral in the Mediterranean Sea, together with the longest *in situ* temperature and coral mortality data series available in this region (Columbretes Islands, NW Mediterranean Sea), to reconstruct environmental and ecological conditions. We also assessed the reproducibility of the recorded information by testing for intra- and intercolony differences in trace elements (e.g., B/Ca, Mg/Ca, Sr/Ca, Ba/Ca, U/Ca) and stable isotopes ($\delta^{18}O$, $\delta^{13}C$) by analyzing 3 corallites from the same colony and 3 corallites each from a different colony covering a time span of 10 to 20 years. Laser ablation and a new developed milling method produced a potentially daily and weekly-fortnightly sampling resolutions in trace elements and stable isotopes, respectively. Geochemical information was calibrated against 10 years of high-resolution seawater temperature data, recorded hourly exactly at the site and depth (15 m) where the coral colonies were sampled. The obtained results show how information on environmental and ecological variables (e.g., temperature, seasonal photosynthesis peaks, environmental stress), together with climatic anomalies, are accurately recorded in the coral skeletons, however, with differences among corallites. Additionally, well preserved fossil *C. caespitosa* samples (Holocene, Balearic Islands, NW Mediterranean Sea) were analyzed applying the same methodology and the results compared to the modern samples. Altogether, the obtained results support the use of this coral as a climate and ecological archive for the Mediterranean Sea and provide new insights into the reproducibility of geochemical proxies.

Oral
A-1774

A Century of Change in the California Current: Quantifying the Impact of Anthropogenic Climate Change on Ocean Acidification

Stoll, M. M.[1], Deutsch, C.[2], Gothmann, A.[3], Jurikova, H.[4], Rae, J.[4], Gagnon, A.[1]
[1]University of Washington, School of Oceanography, Seattle, WA, United States
[2]Princeton University, Department of Geosciences, Princeton, NJ, United States
[3]St. Olaf College, Environmental Studies and Physics Department, Northfield, MN, United States
[4]University of St. Andrews, School of Earth and Environmental Sciences, St. Andrews, Scotland, United Kingdom

mmstoll[at]uw.edu

Abstract

The California Current System (CCS) is an eastern boundary current off the west coast of North America that is characterized by intense upwelling of low-pH and high-pCO_2 waters. This shoaling of the pycnocline towards the coast provides a pathway for nutrient transport from the deep ocean and fuels one of the most economically vital and biologically productive ecosystems in the world. As a result of these low-pH upwelled waters, the CCS represents the leading edge of ocean acidification (OA) impacts while also providing a window into future ocean conditions and processes. Predicting the extent and pace of acidification in eastern boundary current upwelling systems is complicated because anthropogenic contributions to acidification are intertwined with natural sources of acidity and variability. Indeed, a central and contested question is whether acidification in coastal upwelling regions like the CCS will follow the pace of increasing atmospheric CO_2, or if dynamical climate effects will act to either accelerate or attenuate acidification. Here, we apply boron isotope and B/Ca paleo-carbonate system proxies to cold-water corals collected since the 1890s along the west coast of the North America. We establish a historic baseline for acidification in the CCS and the Salish Sea, an associated coastal estuary. Combining these geochemical records with a regional ocean model (ROMS) of the California Current, we show that the CCS and Salish Sea have experienced accelerated acidification and increased CO_2 accumulation over the industrial era relative to the atmosphere. The CCS has acidified faster than expected over the last 130 years. We use our validated ROMS model to show that this acceleration is projected to continue into the future. Our record of accelerated acidification is important for accurately predicting the impacts of OA in eastern boundary currents and is also an indicator for climate-driven shifts in the processes that govern these productive ecosystems.

Oral
A-1795

Tracking the anthropogenic influence on surface temperatures and pH in the Southwest Pacific since the Industrial Revolution

Todorovic, S.[1, 2], Wu, H.[1], Linsley, B.[3], Kuhnert, H.[4], Benthien, A.[5], Richter, K.-U.[5], Bijma, J.[5], Raitzsch, M.[4], Dissard, D.[6]
[1]Leibniz Centre for Tropical Marine Research (ZMT), Bremen, Germany
[2]Faculty of Geosciences, University of Bremen, Bremen, Germany
[3]Lamont-Doherty Earth Observatory of Columbia University, New York, United States
[4]MARUM – Center for Marine Environmental Sciences, University of Bremen, Bremen, Germany
[5]Alfred Wegener Institute – Helmholz Centre for Polar and Marine Research (AWI), Bremerhaven, Germany
[6]IRD-Sorbonne Universités, UPMC, Univ Paris 06-CNRS-MNHN, LOCEAN, Paris, France

sara.todorovic[at]leibniz-zmt.de

Abstract

The modern rate of increase in atmospheric CO_2 driven by fossil fuel combustion and land-use change since the Industrial Revolution is warming our surface oceans. The absorption of this excess CO_2 by the oceans decreases seawater pH in a process known as ocean acidification (OA), which represents a threat to marine ecosystems with adverse impacts on coral health. In this study, we present multi-proxy (e.g. Sr/Ca, $\delta^{18}O$, $\delta^{13}C$, $\delta^{11}B$, B/Ca) reconstructions of sea surface temperature (SST), surface seawater carbonate chemistry and pH of the Southwest Pacific back to preindustrial times. This region of the Pacific is interesting for tracking the development of OA because of the well-constrained interannual to interdecadal SST and SSS variability from existing coral-based reconstructions in this region. Massive *Porites* sp. corals from Rotuma, Tuvalu, and Tonga will be analyzed to extend the currently available SST reconstructions and expand the spatio-temporal coverage beyond the instrumental records. New monthly-resolved SST records and annually-resolved records of $\delta^{11}B$ will provide larger analyses exploring the influence of interannual and decadal-interdecadal climatic fluctuations on CO_2 absorption and pH variation. We aim to quantify the anthropogenic impact on SST, pH and the ocean carbonate system to achieve a better understanding of the status in the South Pacific under open ocean conditions.

Oral
A-1246

Reconstructing the impacts of past thermal stress events in the temperate coral Cladocora caespitosa along an environmental gradient.

Vergotti, M.[1], D'Olivo, J. P.[1], Linares, C.[2], Brachet, T.[3], Spreter, P.[3], Pretus, J. L.[2], Kersting, D.[2]
[1]Freie Universität Berlin, Institut für Geologische Wissenschaften, Fachrichtung Paläontologie, Berlin, Germany
[2]Universitat de Barcelona, Institut de Recerca de la Biodiversitat (IRBIO), Department of Evolutionary Biology, Ecology and Environmental Sciences, Faculty of Biology, Barcelona, Spain
[3]Universität Leipzig, Institut für Geophysik und Geologie, Leipzig, Germany

m.vergotti[at]fu-berlin.de

Abstract

The temperate coral *Cladocora caespitosa* plays an important and unique ecological role as the only zooxanthellated reef-builder in the Mediterranean Sea. During the last two decades, *Cladocora* populations have been severely impacted by mass mortality events associated to marine heat waves. However, little is known about the frequency and severity of these events prior to recent monitoring efforts, started in the 2000s. Here we use sclerochronology to reconstruct the histories of past stress events and their effects on growth in *Cladocora caespitosa* from three locations in the NW Mediterranean subjected to different environmental regimes. We used over 400 modern corallites samples from the Columbretes Islands, Montgrí and Cap de Creus (Spain). Twenty-six fossil samples (Holocene) from the Balearic Islands were also analysed to provide a long-term perspective of current changes to the modern samples. We used the information from the annual density bands revealed by x-ray images to calculate annual and seasonal rates of skeletal growth, density, and calcification. For modern samples, coral growth variables were compared to in situ seawater temperatures from each site to find the relation between temperature and growth. In addition, we assessed the coral records for signs of past rejuvenescence to reconstruct stress events over the past 30 years. The growth parameters and stress frequency of the modern corals was compared to those from the relatively warm period between ~4500 and 5500 yr BP. Our results underline the potential of using sclerochronology in *Cladocora caespitosa* as archives of past environmental and ecological changes, particularly to provide a long-term perspective of thermal stress on the growth of corals.

Oral
A-1813

Reconstruction of anthropogenic CO_2 uptake in the NW Pacific over the last 100 years

Watanabe, T.[1], Yamazaki, A.[2], CREES member
[1]Hokkaido University, Sapporo, Japan
[2]Kyushu University, Faculty of Science, Fukuoka, Japan

nabe[at]sci.hokudai.ac.jp

Abstract

The ocean surface is the largest sink source for anthropogenic carbon dioxide (CO_2), which has increased with industrial global warming, however, the sensitivity and mechanism of it's atmospheric and oceanic balance have not well been documented due to the lack of long-term observation. Coral cores from massive corals could provide long-term histories of marine environments in their skeletons with annual bands. Here, we present a new century-scale dataset of carbon isotopic records in corals and sclerosponges from mid-latitude areas of north western Pacific regions including Japan, Taiwan, and Hawaii. Although the exact mechanism and factor controlling on coral $\delta^{13}C$ are complicated and still unknown, our carbon isotope records show the decreasing trend over last 100 years (Suess effect) with rapid and strongly oscillation, suggesting significant anthropogenic CO_2 uptake in the NW Pacific corals. Our coral records include the highest increases in dissolved anthropogenic CO_2 levels among those reported for other oceans, including the Atlantic, Indian, Caribbean, and tropical Pacific oceans. This rapid CO_2 uptake was accompanied by strong decadal oscillations, implying that regional and global climatic and oceanic conditions relating to Asian monsoon and Kuroshio transportation patterns may drastically affect the future atmospheric CO_2. may drastically affect the future atmospheric CO_2.

Poster
A-1976

Geochemical perspectives to thermal stress acclimatisation in corals

D'Olivo, J. P.[1], Bogdaniuk, E.[2], Sadekov, A.[3, 4], DeCarlo, T.[5], Scott, P.[6], McCulloch, M.[4, 6]
[1]Freie Universität Berlin, Institut für Geologische Wissenschaften, Berlin, Germany
[2]University of Western Australia, Crawley, Australia, [3]University of Western Australia, Centre for Microscopy, Characterisation & Analysis, Crawley, Australia
[4]ARC Centre of Excellence for Coral Reef Studies, Crawley, Australia
[5]Hawai'i Pacific University, Department of Natural Science, Honolulu, United States
[6]University of Western Australia, Oceans Graduate School, Crawley, Australia,

juan.dolivo[at]fu-berlin.de

Abstract

The bleaching events of 2015-2017 had devastating effects in coral reefs around the world. However, there is evidence that the repeated exposure to stress resulted in an increased thermal tolerance in some corals from New Caledonia, the northern Great Barrier Reef and Coral Sea (DeCarlo *et al*., 2019). Here we use high-resolution geochemical and growth information stored in the skeleton of some of these massive Porites corals to provide a novel perspective into the changes in calcification at the calcifying fluid level associated with these recent thermal stress events. Findings from this work are expected to not only improve the application of geochemical proxies as indicators of past bleaching events but also importantly contribute to our still limited understanding of the potential of corals to acclimatise and/or recover from thermal stress.

DeCarlo, Thomas M., et al. "Acclimatization of massive reef-building corals to consecutive heatwaves." Proceedings of the Royal Society B 286.1898 (2019): 20190235.

Poster
A-1897

Relationship between sclerochronological characteristics and dissepiments in Orbicella faveolata in a light gradient

Gutierrez Estrada, G.[1], Iglesias Prieto, R.[2], Carricart Ganivet, J. P.[3], Tortolero-Langarica, J. A.[3]
[1]UNIVERSIDAD NACIONAL AUTONOMA DE MEXICO, Posgrado en Ciencias del Mar y Limnología, Puerto Morelos, Mexico
[2]Pennsylvania State University, Department of Biology, University Park, United States
[3]Universidad Nacional Autónoma de México, Instituto de Ciencias del Mar y Limnología, Puerto Morelos, Mexico

gabrielagutes[at]gmail.com

Abstract

Coral calcification is directly influenced by light due to a symbiotic relationship between corals and photosynthetic algae in the Symbiodinaceae Family. Along depth gradients, light availability elicits changes in coral morphology and sclerochronological characteristics including skeletal density (DEN), extension rates (ER) and calcification rates (CR). Exotecal dissepiments (ED) are responsible for the formation of density bands in the massive reef-building species *Orbicella faveolata.* However, the response of these skeletal structures to depth gradients are not well defined. Here, we characterized changes in the sclerochronological characteristics of *O. faveolata* along a light gradient. Using optical densitometry techniques, changes in the number, distance and width of ED were detected. We found: (1) As light availability decreases, DEN increases caused by thickening of ED. (2) ER and the number of ED formed in a growth year diminishes expone84ntially with depth. (3) ER is positively correlated with the number of ED. (4) CR increases from 5 to 9 m depth and subsequently decreases exponentially from 9 to 38 m. Our findings demostrate that the number and characteristics of ED are affected by light availability and are related to coral growth parameters. This has an important implications in the use of coral skeletons as environmental proxies.

Poster
A-1021

Ocean acidification in the industrial era: Boron isotope-pH proxy records from Pacific microatolls

Knebel, O.[1], Kench, P.[2], Foster, G.[3], Carvajal, C.[4], de la Vega, E.[3], Sayani, H.[5], Cobb, K. M.[5]
[1]Goethe-University, Department of Geosciences, Frankfurt am Main, Germany
[2]Simon Fraser University, Department of Earth Sciences, Burnaby, Canada
[3]University of Southampton, School of Ocean and Earth Science, Southampton, United Kingdom
[4]University of Auckland, School of Environment, Auckland, New Zealand
[5]Georgia Institute of Technology, School of Earth and Atmospheric Sciences, Atlanta, United States

okne620[at]aucklanduni.ac.nz

Abstract

Ocean acidification has caused a reduction of pH_{sw} (seawater pH) altering the ability of many organisms to calcify. As instrumental records of pH_{sw} only exist for the past three decades, geochemical proxies such as the $\delta^{11}B$ (boron isotope ratio) of tropical corals have been utilized. However, physiological modification of a coral's internal pH_{cf} (calcifying fluid pH) complicates the application of this proxy. Corals of the genera *Porites* growing on intertidal reef flats often form microatolls when their vertical growth is limited by minimum water level at spring tide. The enhanced preservation potential and accessibility makes them promising paleoclimate recorders. However, due to low water levels, seawater chemistry on intertidal reef flats is more dynamic than in other reef environments or in the open ocean.
In this study, multi-decadal $\delta^{11}B$ coral records covering the industrial era (mid-19th – 21st centuries) from sites with largely differing seawater pH are compared. Study locations were Kiritimati Island (Republic of Kiribati; pH ≈ 8), Arno Atoll (Republic of Marshall Islands; pH ≈ 8.08), and Rarotonga (Cook Islands; pH ≈ 8.15). Comparison between the $\delta^{11}B$ of these colonies allowed an assessment of pH_{cf} upregulation under naturally differing pH_{sw} conditions and anthropogenic ocean acidification. Furthermore, this study is one of the first to explore the potential of microatoll $\delta^{11}B$ for pH reconstructions.
Results showed that $\delta^{11}B$-pH records exhibited no significant decline in pH_{cf} towards the present and that pH_{cf} upregulation between sites did not linearly follow the difference in ambient pH_{sw}.

Poster
A-1236

Increased soil erosion in Borneo recorded by coral Ba/Ca ratios

Naciri, W.[1], Krawczyk, H.[1], Rankenburg, K.[2], Browne, N.[3], Nagarajan, R.[4], McDonald, B.[2], Evans, N.[2], McIlwain, J.[3], Zinke, J.[1]
[1]University of Leicester, School of Geography, Geology and the Environment, Leicester, United Kingdom
[2]Curtin University, John de Laeter Centre, Perth, Australia
[3]Curtin University, Molecular and Life Sciences, Perth, Australia
[4]Curtin University, Department of Applied Geology, Miri, Malaysia

wn36[at]leicester.ac.uk

Abstract

Industrial-scale deforestation in Malaysian Borneo has impacted both terrestrials and marine ecosystems since the 1970s (Gaveau et al., 2016). Biodiversity loss as well as land erosion are only two of the many consequences forest clearance has had for the last 50 years. Deforestation has created erosion hotspots and models estimated it to be responsible for the loss of 28 t h^{-1} $year^{-1}$ of soil in 2017 in Malaysian Borneo (Vijith et al., 2017). However, this model heavily relies on the accuracy of the satellite and topographic data as well as soil maps. Additionally, it is very limited in time by the availability of observational data.
In this study we circumvent the issue of data scarcity and use the skeletal barium to calcium ratio (Ba/Ca) in massive *Porites* corals off the coast of Miri in Malaysian Borneo as a proxy for river discharge and land erosion. This non-quantitative record allows us to uncover past variations and thus compare soil loss from the beginning of industrial-scale deforestation to the present.
Results show a 1.72 fold increase in Ba/Ca values between pre-1991 and post-1991 periods. As this significant increase is not reflected in freshwater discharge or salinity values, it is indicative of a steady rise in land erosion and soil loss through time. This increase exposes the non-linear behaviour of industrial scale deforestation as demand in palm oil rises.
This showcases the need of new deforestation regulations to limit the human impact on both terrestrial and marine ecosystems. This study highlights the need to access proxy records that go further back in time before industrial-scale deforestation to establish a baseline value of land erosion. This baseline can then be used to assess the current and possible future trends and how both are influenced by deforestation and land use.

Poster
A-1902

Can environmental changes be linked to coral calcification in Fijian inshore reefs?

Samperiz, A.[1], Sosdian, S.[1], Hendy, E.[2], Johnson, K. G.[3], John, E. H.[1], Jupiter, S. D.[4]
[1]Cardiff University, School of Earth and Environmental Sciences, Cardiff, United Kingdom
[2]University of Bristol, School of Earth Sciences, Bristol, United Kingdom
[3]Natural History Museum, Department of Earth Sciences, London, United Kingdom
[4]Wildlife Conservation Society, Melanesia Program, Suva, Fiji

samperizvizcainoa[at]cardiff.ac.uk

Abstract

The Fiji archipelago includes approximately 35% of the coral reef area in the southwestern Pacific. These reefs are at risk from both global (e.g. seawater warming, ocean acidification and increased tropical cyclone activity) and local stressors (e.g. overfishing, poor water quality in terms of elevated levels of sediments, nutrients, and pollutants). Here we explore records from massive reef-building corals in Fiji and how they are impacted by different environmental conditions and events. Ten coral cores from massive *Porites* colonies were collected across four inshore reefs in Viti Levu (Fiji) in 2017. We used computed tomography (CT) to produce annual linear extension, density and calcification rates and assessed site-specific variability and drivers of coral growth over the 1998-2016 period. Average linear extension rates at each location ranges from 5 mm/yr up to 17 mm/yr, and inversely correlates with local seawater turbidity (GLM, R^2= 0.71, $p <$ 0.001). Further, all locations showcase a significant decrease in growth during the 2013-16 period relative to the previous years (ANOVA, p <0.01) aligning with a significant increase of thermal stress across all sites during the same period. Our data shows how both seawater quality and thermal stress are key in controlling coral growth rates in Fiji. As global sea temperature is expected to keep increasing in the upcoming decades, managing coastal seawater quality presents itself like an important strategy to prevent corals in Fiji to cease growing. However, in a framework where enhanced ENSO phases, stronger tropical storms and strengthened Pacific trade winds have been predicted by the end of the 21st century, whether the extent of the local management to mitigation can overcome the climate change-driven conditions remains uncertain.

1E - What can corals and marine calcifiers tell us about anthropogenic effects and trajectory of coral reef ecosystems under global change?

Virtual
Oral
A-1718

Coral Growth on the Great Barrier Reef over the Holocene

Arzey, A.[1], McGregor, H.[1], Lough, J.[2], Webster, J.[3], Clark, T.[1], Fischer, M.[4], Frank, G.[2], Hunter, J.[1], Opdyke, B.[5], Mallela, J.[5]
[1]University of Wollongong, School of Earth, Atmospheric and Life Sciences, Wollongong, Australia
[2]Australian Institute of Marine Science, Townsville, Australia
[3]University of Sydney, Camperdown, Australia
[4]Australian Nuclear Science and Technology Organistaion, Lucas Heights, Australia
[5]Australian National University, Canberra, Australia

aka548[at]uowmail.edu.au

Abstract

Our understanding of coral growth and the resilience of the Great Barrier Reef (GBR) is based on relatively recent studies where the reef was already influenced by anthropogenic-induced environmental stresses. Previous studies have assessed the growth characteristics of modern massive Porites spp.using gamma densitometry to calculate annual average density, annual linear extension rate, and annual calcification rate. This provides baseline data to characterise average growth characteristics of modern Porites spp., and the relationship of these characteristics with environmental factors such as sea surface temperature. However, these methods have not previously been applied to fossil coral pieces.
Our study used the gamma densitometry techniques to quantify the growth of massive Porites spp. coral from the GBR over the Holocene. We measured the density of 158 fossil coral pieces, with ages spanning from ~200 years before present (yBP) to 8300 yBP, from 16 mid-shelf and outer-shelf reefs. Each piece was assessed for diagenetic alteration and a total of 778 years of annual data was obtained to characterise discrete periods of coral growth to compare with the previously established modern Porites spp. growth characteristics. This study represents the most comprehensive dataset of fossil coral growth characteristics from the GBR.
Results indicate that average annual density was greater for Holocene Porites spp. corals than their modern counterparts. However, Holocene corals also exhibited lower average annual extension rates and subsequently lower average annual calcification rates. This indicates slower growing Holocene corals.
While there are multiple possible explanations for the changes in coral growth characteristics, since the changes are widespread, both spatially and temporally, the results suggest changes in sea surface temperatures may be the leading cause.

Virtual
Oral
A-1515

Geochemical insights into the temperature dependency of coral calcification rates

Foster, G.[1], Standish, C.[2], Chalk, T.[3, 4], Fowell, S.[5], Bates, N.[1, 6]
[1]University of Southampton, School of Ocean and Earth Science, Southampton, United Kingdom
[2]Univesity of Southampton, School of Ocean and Earth Sciences, Southampton, United Kingdom
[3]Univesity of Southampton, School of Ocean and Earth Science, Southampton, United Kingdom
[4]CEREGE, Centre européen de recherche et d'enseignement des géosciences de l'environnement, Aix en Provence, France
[5]National Oceanography Centre, Southampton, United Kingdom
[6]Bermuda Institute of Ocean Science, St George's, Bermuda

gavin.foster[at]noc.soton.ac.uk

Abstract

Tropical coral reefs are the ocean's most biodiverse ecosystem, home to over a million species and providing billions of dollars of ecosystem services each year worldwide. All these ecosystem services are dependent upon the 3D framework of the reef that is constructed by hermatypic scleractinian corals. Ocean warming is having wide range of negative impacts on marine organisms and ecosystems, and reef-building corals are no exception. In particular, elevated temperatures are known to disrupt the symbiosis that exists within many hermatypic corals between the coral animal and its dinoflagellate symbionts, leading to expulsion of the symbionts in a process known as bleaching. The loss of symbionts in this way is associated with a dramatic modification of the organism's energy balance leading to a decrease in calcification, retarding ecosystem function, and ultimately leading to coral mortality. In contrast, many studies have found that calcification and temperature are positively correlated well below that required for bleaching, although the mechanistic reasons for this is uncertain.
Here we combine the boron-systematics of *Porites astreoides* from Bermuda with a numerical model of the chemical composition of the calcifying fluid. We use this combined approach to isolate the processes behind the temperature dependency of coral calcification in this region, allowing us to draw unique conclusions regarding the processes responsible for the temperature dependency of calcification in this reef building species.

Virtual
Oral
A-1587

Surface ocean pH over the last ~300 years: A synthesis and re-evaluation of coral-based reconstructions

Guo, W.
Woods Hole Oceanographic Institution, Department of Geology and Geophysics, Woods Hole, United States

wfguo[at]whoi.edu

Abstract

Ocean acidification poses a serious threat to the health of coral reef and many other marine ecosystems. However, instrumental records of seawater pH are sparse and at most only span the last few decades. The boron isotope composition of long-lived coral skeleton ($\delta^{11}B_{coral}$) provides one of the few opportunities to extend our records of past seawater pH beyond the instrumental records. But accurate interpretation of $\delta^{11}B_{coral}$ in terms of seawater pH (pH_{sw}) is not straightforward, as growing evidence suggests that many factors other than pH_{sw} can also influence $\delta^{11}B_{coral}$. This questions the common practice of $\delta^{11}B_{coral}$-pH_{sw} reconstructions which has so far been largely based on the empirical correlations between $\delta^{11}B_{coral}$ and pH_{sw} observed in some laboratory culture experiments.
Here I systematically quantify the effects of various non-pH_{sw} factors, including seawater temperature, dissolved inorganic carbon concentration, and coral physiological regulation, on $\delta^{11}B_{coral}$ and thus the reconstructed pH_{sw}. Taking into account these factors, I re-evaluate the constraints on ocean pH evolution over the last ~300 years from published $\delta^{11}B_{coral}$ records.

Virtual
Oral
A-1646

Variability in coral recruitment, succession, and net reef accretion on settlement tiles on Palmyra Atoll, Central Pacific over time

Romero, S.[1], Clements, S.[2], Khen, A.[3], Sandin, S.[2], Smith, J.[2]
[1]University of California San Diego, SIO, San Diego, United States
[2]University of California San Diego, La Jolla, United States
[3]University of California San Diego, SIO, La Jolla, United States

slromero[at]ucsd.edu

Abstract

Coral ecosystems are experiencing disturbance events and thermal bleaching more frequently due to climate change. The need for new and successful coral recruitment, favorable succession, and increasing calcification potential (net reef accretion) is becoming increasingly important. With coral recruitment there is greater capacity for the community to adapt to changing conditions, favorable succession could provide coral larvae with ideal substrates for settlement, and suitable seawater conditions could increase net reef accretion. The impacts of climate change and ocean acidication have been widely studied in relation to these processes in experimental settings; however, much less is known about natural rates of recruitment and succession on reefs. The studies which do include in situ methods are short-term or are only seasonal. Here we aim to understand how climate change and ocean acidication are affecting these processes by using a long-term monitoring dataset (2009-2020) on a remote atoll, Palmyra Atoll. The time period includes disturbances events such as El Niño in 2014-2016 and mass bleaching events that have affected Palmyra. My findings on coral recruitment, benthic community development (sucession), and net reef accretion will be valuable to compare to other human-impacted reefs. It provides a baseline of what a “healthy” reef looks like and how it responds over time through multiple disturbance events. This will provide information to reefs which will inevitably be impacted by disturbance events to come.

1E - What can corals and marine calcifiers tell us about anthropogenic effects and trajectory of coral reef ecosystems under global change?

Virtual
Oral
A-1372

First long term (~30 years) coral acclimatization to ocean acidification recorded in geochemical signatures: A case study of New Caledonia

Tanvet, C.[1, 2], Dissard, D.[1], Guillermic, M.[3], Sutton, J.[2], Thouzeau, G.[2], Butscher, J.[1], Dubosc, J.[4], Rodolfo-Metalpa, R.[1]
[1]French Research Institute for Sustainable Development (IRD), Nouméa, New Caledonia
[2]European Institute for Marine Studies, UMR LEMAR, Plouzané, France
[3]University of California, Los Angeles, Earth, Planetary and Space Sciences, Los Angeles, United States
[4]Aquarium des Lagons Nouvelle-Calédonie, Nouméa, New Caledonia

clement.tanvet[at]ird.fr

Abstract

Calcifying organisms such as corals currently living on the thresholds of their optimal environment, and adapted to extreme conditions have become useful models to predict the future of coral reefs facing ocean acidification (OA) and holistically climate change. In New Caledonia we discovered a large semi-enclosed lagoon surrounded by mangroves (Bouraké) where the three main parameters most ecologically relevant for the oceans in the context of climate change varied towards extreme future predictions: lower pH (<7.7) and oxygen (-20 to 30%), and warmer temperatures (+ 0.5 to 3°C). However, a rich and abundant coral reef thrives in this unique natural site. In March 2020, we have sampled two 30-cm long *Porites* sp. cores, one in Bouraké and one in an adjacent reference reef exhibiting environmental conditions close to actual open ocean values.
We performed geochemical analyses through the *Porites* sp. cores and reported 30 years of annually resolved $\delta^{18}O$, $\delta^{13}C$, $\delta^{11}B$ and B/Ca results. Here, we present evidence of striking trends of pH decline in the past 30 years in our reference reef while it remained stable at around 7.7 pH units in Bouraké. Our study allowed us to compare an uninterrupted OA with a pH-decreasing trend in the South Pacific over the last three decades to a naturally long-term acidified environment on multi-generational coral reefs evolution. In parallel, to assess the physiological traits of *Porites* sp. and help geochemical calibrations, we maintained under culture small fragments of *Porites* sp from 1) Bouraké, potentially adapted to extreme conditions, and 2) from the reference reef where pH was near global ocean value. Fragments were maintained in aquaria during 100-day to four different pH_T conditions, three at constant value: 8.05±0.05 (Present-day); 7.7±0.07 (Future); 7.4±0.08 (Extreme); and one at variable pH: 7.4-8.0, which mimic the diurnal pH variation at Bouraké.
Physiological results from culture experiments showed an increased growth of Bouraké samples regardless of the pH treatment, while no differences regarding other physiological traits could be observed. This indicates a strong and specific calcification for the Bouraké population potentially acquired through many generations in an extreme environment. The comparison of our geochemical proxies in our 100-day monitored *Porites* sp. and in the sampled cores showed significant differences between the two populations and gave us some clue on coral responses to anthropogenic effects.

Oral
A-1685

Coral Mn/Ca: A Window into Pacific Trade-wind Behavior

Chapman, A.[1], Thompson, D.[1], Carilli, J.[2], Sayani, H.[3], Marchitto, T.[4], Cobb, K.[5]
[1]University of Arizona, Geosciences, Tucson, Arizona, United States
[2]Scripps Institution of Oceanography, San Diego, California, United States
[3]Florida State University, Tallahassee, Florida, United States
[4]University of Colorado Boulder, INSTAAR, Boulder, Colorado, United States
[5]Georgia Institute of Technology, School of Earth and Atmospheric Sciences, Atlanta, Georgia, United States

alicechapman[at]email.arizona.edu

Abstract

As drivers of atmospheric and ocean circulation in the tropical Pacific, trade winds are a key contributor to the Pacific Ocean's climate state and can modulate the rate of climate change on interannual and decadal timescales. Despite their importance, wind records of sufficient length are not available in this region to analyze trade-wind behavior on these timescales. Equatorial Pacific corals may live for many centuries and extend this limited record of historical wind observations. The ratio of manganese-to-calcium (Mn/Ca) in the skeleton of reef-building corals at the equatorial Pacific islands of Tarawa, Kiritimati, and Butaritari has been linked to local trade-wind behavior, with spikes of Mn/Ca occurring during or following westerly wind activity (i.e., trade-wind reversals) prior to and during El Niño events. However, the magnitude of the coral Mn/Ca signal at each island is variable, and can vary between sites within the same island. To better understand the underlying cause of these differences, previous work analyzed the sediment, porewater, and seawater Mn reservoirs at Kiritimati, revealing the role of the island's physical (i.e., lagoon depth, channel characteristics, fetch distance) and geochemical (i.e., Mn reduction and accumulation in sediment porewater) processes in the coral Mn/Ca proxy mechanism. This work emphasized that the combination of lagoon depth and westerly wind event (WWE) strength and frequency has a controlling effect on the lagoon water Mn incorporated by nearby corals, and thus provides constraints on how to calibrate each site's coral Mn/Ca records. Here we present new coral Mn/Ca records from Abaiang atoll (Republic of Kiribati) and an extended record from Butaritari, while comparing them against pre-existing Mn/Ca records at Tarawa, Kiritimati, and Butaritari. After site-specific calibrations that take into consideration differences in lagoon morphology and depth, we produce a composite trans-Pacific coral Mn/Ca-based wind reconstruction that includes the 1997-1998 El Niño event. This composite record provides new insights into the spatial and temporal footprint of WWEs, as well as the potential for extending this wind reconstruction back in time.

1E - What can corals and marine calcifiers tell us about anthropogenic effects and trajectory of coral reef ecosystems under global change?

Oral
A-1894

New coral proxy records from northern Australia reflect diverse impacts of Pacific SST on regional hydroclimate and ocean circulation

Cole, J.[1], Dyez, K.[1], Patterson, E.[2], Lough, J.[3], Schrag, D.[4]
[1]University of Michigan-Ann Arbor, Earth and Environmental Sciences, Ann Arbor, United States
[2]University of California - Irvine, Earth System Science, Irvine, United States
[3]Australian Institute of Marine Sciences, Townsville, Australia
[4]Harvard University, Earth and Planetary Sciences, Cambridge, United States

colejul[at]umich.edu

Abstract

Across northern Australia, the sparse instrumental record of environmental variability limits understanding of the natural and anthropogenic factors operating on coral reefs. Here we use coral cores from three regions (the Timor Strait, the Gulf of Papua, and the northern Great Barrier Reef) to provide a first look at the past ~250 years across these diverse locations. At Nightcliff Reef, offshore Darwin in the Timor Strait, we find that coral $d^{18}O$ reflects changes in seawater $d^{18}O$ associated with the Indonesian Throughflow (ITF), an important conduit for heat and salt from the Pacific into the Indian Ocean. The Timor Strait is the largest single outflow region of the ITF. We compare our record with others from the Indonesian gateway, and find (in agreement with oceanographic data) that this outflow is the most strongly coupled with Pacific variability, both the El Niño-Southern Oscillation (ENSO) and especially the Interdecadal Pacific Oscillation (IPO). Further east, at Bramble Cay (Gulf of Papua), we find strong coral $d^{18}O$ variability is associated with hydroclimatic fluctuations also orchestrated by ENSO and the IPO, but here the $d^{18}O$ signal responds to regional freshwater balance. Finally, at Jeannie River (Far North Queensland), we use a multiproxy record from stable carbon and oxygen isotopes, Ba/Ca, and luminescence to generate a robust, quantitative reconstruction of regional rainfall. We find that rainfall variability has increased distinctly over the 20th century, as expected in a warming world, and we document a lagged relationship with southwest Pacific SST that may have predictive utility. We use the emerging physical understanding of tropical Pacific decadal variability to explore how these new records, taken together, add to the picture of pre-instrumental variability and address how recent decades compare to the past 200+ years.

Session 1G - Can large-scale ocean and climate reconstructions from corals improve our understanding of past, present, and future extremes?

Conceptualized by: **Kristine DeLong** [1], **Diane Thompson**[2], **Thomas Felis**[3], **Hali Kilbourne**[4]
[1] Louisiana State University (Baton Rouge, LA, USA)
[2] University of Arizona (Tucson, AZ, USA)
[3] MARUM, University of Bremen (Bremen, Germany)
[4] University of Maryland (College Park, MD, USA)

Chaired by: **Kristine DeLong** [1], **Diane Thompson**[2], **Thomas Felis**[3]

1G - Can large-scale ocean and climate reconstructions from corals improve our understanding of past, present, and future extremes?

Oral
A-2196

Towards Understanding Past Climate of the Inter-America Sea Using a Network of Siderastrea Siderea corals

DeLong, K.[1], Ouellette, G.[1], Martin, E.[2], Goodkin, N.[3], Wagner, A.[4], Manfrino, C.[5], Taylor, F.[6], Shen, C.-C.[7]
[1]Louisiana State University, Geography and Anthropology, Baton Rouge, United States
[2]University of Oklahoma, Norman, United States
[3]American Museum of Natural History, New York, United States
[4]California State University, Sacramento, Sacramento, United States
[5]Central Caribbean Research Insitute, Little Cayman Island, Cayman Islands
[6]University of Texas at Austin, Austin, United States, [7]National Taiwan University, Taipei, Taiwan

kdelong[at]lsu.edu

Abstract

Sea surface temperature (SST) in the Intra-Americas Sea (IAS), which includes the Caribbean Sea and Gulf of Mexico (GOM), plays a vital role in the weather and climate of the Americas. Within the IAS, SST undergoes variability on seasonal to multidecadal timescales yet historical and instrumental records are limited in their temporal and spatial coverage thus hindering our understanding of how SST impacts coral reefs. Despite advancements in global climate models (GCMs), coupled atmosphere-ocean GCMs reveal the IAS has a cold bias (~2ºC) in mean SST calling into question future climate predictions for SST thresholds such as coral bleaching and tropical cyclone formation. We are building a network of SST reconstructions using the massive coral Siderastrea siderea for the past ~250 years, Holocene, and Last Interglacial (LIG), which will provide additional temporal targets for diagnosing GCMs and the IAS cold bias. Numerous calibration and replication studies for this coral species from GOM to Brazil are yielding consistent transfer equations allowing us to assess absolute SST for past intervals as well as seasonal to decadal variability. We have completed coral Sr/Ca-SST
reconstructions for the 20th century revealing the GOM (Flower Garden Banks and Dry Tortugas) has the greatest seasonality and consistent variability between the north and southeast GOM whereas corals from Haiti and Little Cayman have less seasonality and distinct interannual variability compared with the GOM corals. A 75-yearlong LIG (128 ka) coral SST reconstruction from Hispaniola in the northern Caribbean reveals mean SST similar to today with greater seasonal, interannual, and decadal variability whereas the Community Climate System Model version 3 (CCSM3) 125 ka simulation suggest ~2ºC colder mean SST and suppressed interannual and decadal variability yet CCSM3 does have the same seasonal range as the coral. A mid-Holocene coral (5.5 ka) from Little Cayman Island (LIC) in the central Caribbean has greater seasonality with suppressed interannual variability whereas other storm-washed corals from this island suggest cooler intervals in the Holocene with less seasonality. These boulder-size storm-washed corals were transported inland several meters (~20-200 m) over sand dunes suggesting storm surge from major hurricanes impacted LIC during the Holocene where summer temperatures exceeded 28.25ºC, the SST threshold for a major hurricane to develop and be sustained in the Atlantic Ocean.

Oral
A-2215

The warming of the tropical Indian Ocean during the twentieth century: causes and consequences

Pfeiffer, M.[1], Leupold, M.[2], Reuning, L.[1], Watanabe, T. K.[1]
[1]Institute of Geosciences, Kiel, Germany
[2]RWTH Aachen University, Aachen, Germany

miriam.pfeiffer[at]ifg.uni-kiel.de

Abstract

The tropical Indian Ocean is currently warming faster than any other ocean basin, and is thought to contribute to the global mean temperature rise. However, the mechanisms behind the Indian Ocean warming are not fully understood. Proposed drivers include the rise in greenhouse gases, an asymmetric El Niño Southern Oscillation (ENSO) teleconnection and a weakening of the Asian Monsoon. The warming has affected the climate and ecosystems of the Indian Ocean in various ways. For example, coral cores from the central Indian Ocean(Chagos Archipelago) show that El Nino related warming pushes mean sea surface temperatures (SSTs) in the tropical Indian Ocean above 28.5°C post-1975, causing a much stronger rainfall response. In addition, the Chagos corals suggest that the warming causes increased thermal stress and hampers coral growth post-2003. ENSO is the dominant mode of interannual climate variability in the tropical Indian Ocean and El Niño events lead to a basin-wide warming in boreal winter. El Niño weakens upwelling in the Arabian Sea and along the Seychelles-Chagos thermocline ridge, an important region of open ocean upwelling south of the equator. It has been proposed that an asymmetric ENSO teleconnection, where El Niño causes warming, while La Niña does not cause significant cooling, together with a shift to more frequent El Niño events contribute to the warming of the Indian Ocean during the 20th century. The ENSO teleconnection is documented in coral Sr/Ca temperature reconstructions from the Seychelles- Chagos thermocline ridge. The corals show that the relationship between ENSO and Indian Ocean SSTs is stationary during the 20th century. In fact, the impact of ENSO on Indian Ocean SSTs appears to be stable from the Little Ice Age to the present day. However, the corals do not support the notion of an asymmetric ENSO teleconnection, as La Nina events appear to cause strong cooling via enhanced open ocean upwelling, with a magnitude comparable to the warming seen during El Nino events. This suggests that the long-term warming of the tropical Indian Ocean is not driven by ENSO, and other processes, such as the weakening of the monsoon circulations and greenhouse warming, must be investigated to better understand the current and future temperature rise.

Oral
A-1321

Coral records support upwelling in the Arabian Sea is weakening during the current warming era

Watanabe, T. K.[1, 2, 3], Watanabe, T.[2, 3], Pfeiffer, M.[1], Hu, H.-M.[4], Shen, C.-C.[4], Yamazaki, A.[2, 3, 5]
[1]Christian-Albrechts Universität zu Kiel, Kiel, Germany
[2]KIKAI Institute for Coral Reef Sciences, Kikai Town, Japan
[3]Hokkaido University, Sapporo, Japan
[4]National Taiwan University, Taipei, Taiwan, [5]Kyusyu University, Fukuoka, Japan,

takaaki.watanabe[at]ifg.uni-kiel.de

Abstract

Upwelling pumps cold and eutrophic water from the deep sea to photic zones, a key process for coastal environments in various fields (climate, ecosystems and socioeconomics). Summer upwelling in the Arabian Sea (Arabian upwelling) strongly influences to south Asian livelihoods. Although the upwelling histories were reconstructed with sediment cores, satellite-data and simulations, there is no agreement on whether recent global warming intensifies the Arabian upwelling. Here, we infer the intensity of the Arabian upwelling through the past millennium with coral proxy records.
We collected one modern and four fossil corals from Masirah island, Arabian Sea. The ages of fossil corals determined by U-Th techniques were from 1162 to 1965, *i.e.* they include the medieval climate anomaly and the little ice age (LIA). The seawater oxygen isotopic composition ($\delta^{18}O_{sw}$) was estimated from paired Sr/Ca and coral oxygen isotopes in the modern and fossil corals at biweekly resolution. Results show that the Arabian upwelling in summer brings low $\delta^{18}O_{sw}$ from deep sea to the surface. Data also reveal that significantly higher $\delta^{18}O_{sw}$ in the present, compared to the LIA. This suggests weaker Arabian Sea upwelling in the present compared to the LIA. One of highlights is that the Arabian upwelling intensity generally correlates with the northern hemispheric temperature throughout the last millennium.

1G - Can large-scale ocean and climate reconstructions from corals improve our understanding of past, present, and future extremes?

Oral
A-1171

The West Pacific Gradient as novel index for ENSO variability and Walker Circulation strength over the past Millennium

Zinke, J.[1], Browning, S.[2], Hoell, A.[3], Goodwin, I.[4]
[1]University of Leicester, School of Geography, Geology and the Environment, Leicester, United Kingdom
[2]Risk Frontiers, Sydney, Australia
[3]NOAA, Boulder, United States, [4]ClimaLab, Sydney, Australia

jz262[at]leicester.ac.uk

Abstract

Small changes in Pacific temperature gradients connected with the El Niño Southern Oscillation (ENSO) influence the Walker Circulation and are related to global climate anomalies. Therefore, it is of paramount importance to develop robust indices of their past behavior. Here, we reconstruct the difference in sea surface temperature between the west and central Pacific during ENSO, coined the West Pacific Gradient (WPG), based on the Last Millennium Paleo Hydrodynamics Data Assimilation.
We show that the WPG tracks ENSO variability and strongly co-varies with the zonal gradient in Pacific sea surface temperature. We demonstrate that the WPG strength is related to significant atmospheric circulation and precipitation anomalies during historical El Niño and La Niña events by magnifying or weakening droughts and pluvials across the Indo-Pacific. We show that an extreme negative WPG coupled to a strong zonal Pacific temperature gradient is associated with enhanced megadroughts in North America between 1400 CE and the late sixteenth century. The twentieth century stands out in showing the most extreme swings between positive and negative WPG conditions over the past
Millennium. We conclude that the WPG is a robust index together with ENSO indices to reveal past changes in Pacific zonal sea surface temperature gradient variability.

1G - Can large-scale ocean and climate reconstructions from corals improve our understanding of past, present, and future extremes?

Poster
A-1661

20th Century Warmth Unprecedented on Northeastern Caribbean Coral Reefs Since 1000 CE: A Synthesis of Coral-Geochemistry Based Paleoclimate Records

Kilbourne, K. H.[1], Hughes, H. P.[2], Maupin, C. R.[3], Nyberg, J.[4], Nalesnik, A.[5], Pearson, S.[6], Quinn, T. M.[7], Shen, C.-C.[8], Sun, H.[9], Winter, A.[10], Xu, Y.-Y.[11, 12]
[1]University of Maryland Center for Environmental Science, Chesapeake Biological Laboratory, Solomons, United States
[2]University of North Carolina, Earth Marine and Environmental Science, Chapel Hill, United States
[3]Texas A&M University, Department of Geography, College Station, United States
[4]Geological Survey of Sweden, Uppsala, Sweden
[5]University of Deleware, Earth Science, Newark, United States
[6]University of Connecticut, Department of Molecular and Cell Biology, Storrs, United States
[7]University of Texas Institute for Geophysics, Jackson School of Geosciences, Austin, United States
[8]National Taiwan University, Department of Geosciences, Taipei, Taiwan
[9]Chinese Academy of Sciences, State Key Laboratory of Environmental Geochemistry, Guiyang, China
[10]Indiana State University, Earth and Environmental Systems Department, Terre Haute, United States
[11]University of Miami, Miami, Cooperative Institute of Marine and Atmospheric Studies, Miami, United States
[12]National Oceanic and Atmospheric Administration, Atlantic Oceanographic and Meteorological Laboratory, Miami, United States

kilbourn[at]umces.edu

Abstract

Warming conditions in the tropical oceans have clearly had an effect on the health of reef-building corals, based on the instrumental record of sea surface temperature (SST). However, the instrumental record of SST is short compared with coral generation times and hence the coral adaptation time-scale. Over the last 20 years, we have produced several coral-based paleoclimate records from Puerto Rico and the Virgin Islands that represent substantial periods of nearly every century since 1000C.E. Temperature and salinity estimates made from the skeletal Sr/Ca and oxygen isotopic data provide a longer-term context for coral adaptation temperatures. The data come from more than 8 colonies of two species, *Orbicella faveolata* and *Pseudodiploria strigosa*. Some of the corals temporally overlap, providing a check on the results from any single specimen. Quantifying the mean geochemistry of coral colonies growing at the same time and comparing those means between different times illustrates that significant differences can be found. This indicates that the temporal variability in climate is large enough to be resolved despite the uncertainty of mean climate conditions from any single coral specimen due to inter-colony geochemical variability.
The data indicate that conditions in Puerto Rico and the Virgin Islands before the 20th Century were consistently cooler for at least the last 1000 years. We characterize the frequencies of interannual- to multidecadal-scale variability present in each record and discuss the potential for diagenetic, environmental, and climatic causes. Fundamentally, the data indicate that corals in this region are likely adapted to substantially cooler conditions than they have experienced in the last 100 years. Thus, corals may be under chronic thermal stress today, with extreme marine warming events adding to the problem.

Poster
A-1132

High-resolution record of coral Sr/Ca and $\delta^{18}O$ from Browse Island, NW Australia

Krawczyk, H.[1], Zinke, J.[1], Lough, J.[2], Garbe-Schönberg, D.[3], Hambach, B.[4], Cantin, N.[2], Wilson, P.[4], Boom, A.[1]
[1]University of Leicester, School of Geography, Geology and the Environment, Leicester, United Kingdom
[2]Australian Institute of Marine Science, Townsville, Australia
[3]Christian-Albrechts-Universität zu Kiel, Geosciences, Kiel, Germany
[4]University of Southampton, National Oceanography Centre, Southampton, United Kingdom

hak19[at]leicester.ac.uk

Abstract

Geochemical proxy records from stony corals provide a useful, high resolution archive of past climatic conditions. In the tropical oceans, which are critical sources of heat and moisture for the global climate system, these records are particularly crucial since instrumental data are often short and spatially scarce.
Here, we present a coral-based hydroclimate reconstruction of the past 200 years from the Indonesian Throughflow (ITF) outflow region into the south-eastern Indian Ocean along the North West Shelf of Australia, a key region for Indo-Pacific climate connectivity. Our objective was to assess the role of tropical Pacific forcing on Indo-Pacific sea surface temperature (SST) and salinity exchange through the El Niño-Southern Oscillation (ENSO) in concert with Indian Ocean Dipole (IOD) events. Paired Sr/Ca and $\delta^{18}O$ analyses from modern *Porites* sp. corals from Browse Island enabled the reconstruction of both SSTs and the oxygen isotopic composition of the seawater ($\delta^{18}O_{sw}$). We have carried out a replication study of cores from two coral colonies from different locations around the island, covering the satellite based instrumental data period back to 1982. Through the calibration and comparison with instrumental and modelled data, we demonstrate that reliable climate records can be generated from the Browse Island coral cores, indicating the expansion of the Indo-Pacific warm pool into the Indian Ocean, as well as correlation of the coral proxies with large scale interannual variability. Our long core coral record shows good agreement with the instrumental data until approx. the 1950s. Prior to that, we have identified decades where instrumental observations diverge from the coral-based reconstructions. These periods include the World War II period, known for biases in ship-of-opportunity SST records. A preliminary comparison to an ITF transport time series revealed excellent agreement. While the imprint of the IOD seems to be rather reflected in sea surface temperature anomalies in the region, the influence of ENSO is recorded in hydrological anomalies because of changes in ocean advection, e.g. Indonesian Throughflow dynamics, and/or precipitation.
Our long, highly resolved proxy record presented here will enhance our understanding of climatic and oceanographic processes in a globally important ocean gateway, far beyond the current observational capacities.

Poster
A-1035

Unlocking Western Tropical Indian Ocean temperature and hydroclimate back to the Little Ice Age, reconstructed from coral geochemistry

Zhang, M.
University of Leicester, Leicester, United Kingdom

mz224[at]le.ac.uk

Abstract

Indian Ocean sea surface temperatures (SST) have a profound influence on precipitation over the tropics and Indian Monsoon regions. Sea surface salinity (SSS) reflects the near surface evaporation-precipitation (E-P) balance and its seasonal and interannual variabilities were found to be majorly impacted by monsoonal precipitations and the Indian Ocean Dipole (IOD) (Vinayachandran and Nanjundiah, 2009; Grunseich et al., 2011). Furthermore, teleconnections between Indian Ocean Monsoon system and El Niño–Southern Oscillation (ENSO) have been reported in many studies (e.g.: Cai et al., 2011; Achuthavarier et al., 2012). Further global warming is thought to increase the probabilities of extreme weather conditions, which can exert great economic and social impacts. Advanced knowledge of past SST and hydroclimate variability over the Indian Ocean is therefore crucial for characterizing natural climate variabilities and recognizing anthropogenic impacts, which can help yield more reliable predictions for future climate.

Coral cores are of vital importance to reconstructions for site-specific variability in SST, SSS, ocean advection and the hydrological balance, providing insights into past climate change in the tropical oceans (Grove et al., 2013). Here we present first data for multi-site temperature and hydroclimate reconstructions based on coral geochemistry from north and northeast Madagascar with bimonthly to monthly temporal resolution, dating back to early 20th century. Coral record of skeleton oxygen stable isotope (d^{18}O) is coupled with Sr/Ca (U/Ca) ratios to reconstruct past variations in seawater d^{18}O (hydrology) by subtracting the thermal component of d^{18}O based on the Sr/Ca (U/Ca) - SST estimates (Zinke et al., 2008). We aim to assess natural changes in the teleconnectivity of the western Indian Ocean for both SST and SSS with the tropical eastern Indian Ocean and the Pacific. Evolution of land-ocean climate teleconnections will be assessed by comparing our data to terrestrial climate archives and instrumental climate data from Sub-Saharan Africa and Madagascar.

Session 2A - Open Session: Species and their populations

Conceptualized by: **Götz B. Reinicke [1], Gert Wörheide [2]**
[1] German Oceanographic Museum (Stralsund, Germany)
[2] LMU München (München, Germany)

Chaired by: **Götz B. Reinicke [1], Gert Wörheide [2], Íris Sampaio [3]**
[1] German Oceanographic Museum (Stralsund, Germany)
[2] LMU München (München, Germany)
[3] Tel Aviv University (Tel Aviv, Israel)

Oral
A-1057

Refining the Ecological Role of Stingrays in Coral Reef Ecosystems

Barbosa Martins, A.[1], Heupel, M.[2], Chin, A.[3], Simpfendorfer, C.[3]
[1]Dalhousie University, Biology, Halifax, Canada
[2]Integrated Marine Observing System, Hobart, Australia
[3]James Cook University, Townsville, Australia

a.martins[at]dal.ca

Abstract

The world's coral reefs are facing rapid and substantial declines in abundance, diversity, and habitat structure. Global climate change, declining water quality and rising demand for reef fish are some of the main threats, resulting in the degradation of coral reef systems and depletion of reef-associated marine life. Stingrays inhabiting coral reef areas are particularly vulnerable to these anthropogenic pressures due to their life history characteristics (e.g. slow growth, late sexual maturity, low fecundity, and high longevity). Unfortunately, the ability to better understand population declines and effectively manage stingrays is hindered by the absence of knowledge on essential aspects of their biology and ecology. This study aimed to understand the roles juvenile stingrays play in coral reef habitats and determine the importance of coral reef habitats to stingray populations in a communal nursery area located in the central region of the Great Barrier Reef. We combined two biotelemetry approaches (acoustic and towed-float GPS telemetry) with stable isotope analysis to determine movement patterns, habitat use and relative trophic relationships of two stingray species commonly found in coral reef habitats: the cowtail stingrays *Pastinachus ater* and the mangrove whiprays *Urogymnus granulatus*. Juvenile stingrays mostly used sand flat areas, with the reef crest identified as secondary refuge during the lowest tides. Sand flats provided access to food resources and soft bottom for burying. Juvenile stingray movements were strongly influenced by tidal cycles and rate of movements were significantly different between day and night. Individuals moved faster and chose more direct paths during the outgoing and incoming tide and were more active during daytime. Stable isotope analysis showed strong evidence of niche partitioning between mangrove whiprays and cowtail stingrays indicating differences in feeding strategy. Nearshore pelagic and benthic prey items (e.g. crabs, annelid worms and small baitfishes) contributed most to juvenile stingray diets, while mangrove or offshore prey and carbon sources appeared to have less significant input. Results of telemetry and stable isotope analysis confirmed juvenile stingrays play important roles as mesopredators and energetic links within communal nursery areas associated with coral reefs.

Oral
A-1089

Dynamics of changes in echinoderms population of the Gulf of Aqaba – population collapse of the sea urchin Diadema setosum

Eviatar, G.[1, 2], Bronstein, O.[1]
[1]Tel-Aviv University, Zoology, Tel Aviv, Israel, [2]The Interuniversity Institute for Marine Sciences, Eilat, Israel

galeviatar[at]gmail.com

Abstract

The phylum Echinodermata is ecologically fundamental to maintaining a functional and stable ecosystem. Sea urchins, which are predominantly grazers, regulate algae accumulation on coral reefs, clearing space for scleractinian corals to grow. Sharp changes in sea urchin populations are the main driver of ecosystem phase shifts in coral reefs. The best-known example of such sea urchin-driven phase shift is the dramatic and destructive alternation of Caribbean coral reefs in the early 80's – from reef-building corals dominance to algae fields – due to the population collapse of the local sea urchin *Diadema antillarum.* In the present study, we assessed the echinoderm community in the Gulf of Aqaba (GOA), Red Sea, using field surveys conducted for over a decade between 2007-2021. The latest data point to a dramatic decline in the population size of *Diadema setosum*, the most dominant echinoid species in the GOA. Extreme southern storms in the years 2009, 2010, and 2020 led to sharp declines in sea urchin population size in shallow waters, albeit with a varying effect on different species. Broadly, our data points to an overall consistent decline of echinoid population size for most species in the GOA. Today, the abundance of 75% of key echinoderm species is at its lowest level since recording began. These results point to an alarming and ongoing decline of the main regulators of the seasonal algae blooms in the GOA and place the coral community of the GOA in clear and immediate danger.

Oral
A-1924

Axes of the n-dimensional hypervolume: spatial, temporal and trophic partitioning in a guild of zooplanktivorous fish in Moorea, French Polynesia

French, B.[1], Schiettekatte, N.[2], Minich, J.[3], Zgliczynski, B.[1], Siu, G.[4], Sandin, S.[1], Planes, S.[4, 5]
[1]UC San Diego, Scripps Institution of Oceanography, La Jolla, United States
[2]University of Hawaii Manoa, Hawaii Institute of Marine Biology, Kaneohe, United States
[3]Salk Institute for Biological Studies, La Jolla, United States
[4]Centre de Recherches Insulaires et Observatoire de l'Environnement (CRIOBE), Laboratoire d'Excellence, Papetoai, Moorea, French Polynesia
[5]Universite de Perpignan, Centre de Biologie et d'Ecologie Tropicale et Méditerranéenne, Perpignan, France

bfrench[at]ucsd.edu

Abstract

In a dynamic world, the biodiversity of today is not the biodiversity of yesterday, which is unlikely to be the biodiversity of tomorrow. Understanding processes that promote and maintain diversity over time is particularly important for reservoirs of biological diversity, such as coral reefs, threatened by rapid environmental and anthropogenic change. Here, we use coexistence theory to identify the processes involved in the maintenance of species diversity in zooplanktivorous coral reef fish in Moorea, French Polynesia. In particular, we look for evidence of niche differentiation that increases the strength of intraspecific competition relative to that of interspecific competition, thus facilitating coexistence. As a trophic group, zooplanktivores often dominate coral reef fish assemblages in terms of abundance. In Moorea, French Polynesia, 42-79% of the total fish community consists of planktivores. Accordingly, we describe several axes of the niche for co-occurring species in a guild of related zooplanktivorous fish over time. Through the use of stereovideo monitoring, we analyzed diel patterns of intraspecific and interspecific space use superimposed on a protected site with extensive long-term (>50 years) monitoring efforts of fish and benthic assemblages, allowing us to determine nearest-neighbor distances for individuals. Metagenomic sequencing of gut contents for several species was conducted to assess detailed patterns of diet through identification of prey items and the gut microbiome. Finally, we used an annual time series of fish abundance along a cross-shelf transect at Tiahura consistent with the location of stereovideo monitoring to analyze temporal patterns of species abundance. Analyses revealed significant habitat-partitioning and differential fluctuations in abundance, indicating niche partitioning that is stable over time. The two most morphologically similar species, *Pycnochromis margaritifer* and *Pycnochromis iomelas*, exhibit differing population sizes through time. More frequent observations of *P. margaritifer* at shallower depths, including the fringing and barrier reefs, further indicate likely spatial partitioning. Taken together, these findings highlight cryptic diversity in coral reef fishes and provide insight into the mechanisms sustaining diversity in species-rich coral reefs.

Oral
A-1241

Spatial variability of Red Sea coral reef fishes: perspectives from taxonomical and ecological trait approaches

Gil Ramos, G. L.
King Abdullah University of Science and Technology, Biological, Environmental Science and Engineering (BESE), Thuwal, Saudi Arabia

gloria.gilramos[at]kaust.edu.sa

Abstract

The Red Sea is known to be a unique environment on the planet due to its environmental gradients in temperature and salinity. Likewise, this basin is known to host a diverse fish community. However, patterns of variability in fish communities are still poorly understood. This study aims to contribute to a better understanding of how fish communities vary along multiple spatial scales (10-100' of kilometers) along the coastline of the Saudi Arabian Red Sea and to provide a baseline for future comparisons, fundamental to assess responses to climate change and other disturbances. Nearshore coral reefs along the Saudi Arabian Red Sea coast were surveyed from 2017 to 2019. The reefs ranged from 28° N to 18 °N and were grouped according to their geographical position within three regions: north (24-28.5°N), central (20.4-22.3°N), and south (18.5-21.2°N). The quantification of spatial patterns was conducted based on both taxonomic and trait-based approaches. Considering the dependence of fish communities on the benthic habitat, the relationship between different attributes of the fish assemblages and of the coral community was also investigated. A consistent pattern of separation between assemblages of the northern and central region from the ones in the south was observed. The analysis showed that transect and reef scales contributed to the greatest variation in fish communities, suggesting higher levels of variability within small spatial scales. Several parameters of the fish community were positively correlated to coral cover, particularly in the northern region. This study can be helpful to design management strategies as it provides a current baseline from both taxonomic and trait perspectives for Red Sea reefs that can be used to evaluate future changes due to natural and human-based disturbances.

Oral
A-1483

Trophic niche partitioning in the evolution of giant clams

Guibert, I.[1], Conti-Jerpe, I.[2], Pons, L.[1], Tayaban, K.[3], Lyn, S. S.[3], Cabaitan, P.[3], Conaco, C.[3], Baker, D.[1]
[1]The University of Hong Kong, Swire Institute of Marine Science, Hong Kong, Hong Kong SAR China
[2]University of California Berkeley, Museum of Vertebrate Zoology and Department of Integrative Biology, Berkeley, United States
[3]University of the Philippines, Marine Science Institute, Quezon, Philippines

guibert.isis[at]orange.fr

Abstract

Competition for limited resources is a major driver of niche partitioning. The evolution of phenotypic characters that exploit novel resources reduces competition, underpins speciation, and facilitates sympatry and biodiversity. However, additional layers of ecological complexity – aka symbiosis - can obscure the phylogenetic signal of niche partitioning. Giant clams are a charismatic albeit understudied taxon widely distributed across the Indo-Pacific. Using a unique common garden experiment, we applied Stable Isotope Bayesian Ellipses in R (SIBER) analysis to stable isotope values from six giant clam species and their associated algal symbionts from the Tabunan lagoon (Philippines). We showed that giant clams' trophic niches vary along an autotrophy-heterotrophy gradient with one species standing out as a heterotroph (*Tridacna squamosa*) and one shifted towards autotrophy (*Tridacna gigas*) by building a novel metric - the Host Evaluation: Reliance on Symbionts (HERS) index - that integrates several SIBER measurements. We found significant phylogenetic signals for the contribution of symbiont nutrition to their clam hosts, the relative abundance of some symbiont phylotypes, and the geographic distribution of each clam species, highlighting the role of selection in clam trophic partitioning. These interesting results support niche partitioning as a driver of giant clam evolution and lend insights into their conservation status.

Oral
A-1247

Estimated extinction risk of Atlantic Reef-Building Corals: An Update

Gutierrez, L.[1], Polidoro, B.[2, 3], Obura, D.[3, 4], Cabada-Blanco, F.[5, 6], Pettersson, E.[3], Kemppinen, K.[1], Linardich, C.[7, 8]
[1]Arizona State University, School of Life Sciences, Tempe, AZ, United States
[2]Arizona State University, School of Mathematical and Natural Sciences, Glendale, AZ, United States
[3]IUCN SSC Coral Specialist Group, Gland, Switzerland
[4]Coastal Oceans Research and Development in the Indian Ocean (CORDIO), Mombasa, Kenya
[5]Zoological Society of London, London, United Kingdom
[6]University of Portsmouth, Portsmouth, United Kingdom
[7]Old Dominion University, Biological Sciences, Norfolk, VA, United States
[8]IUCN SSC Marine Biodiversity Unit, Norfolk, VA, United States

beth.polidoro[at]asu.edu

Abstract

In 2008, one-third of the world's zooxanthellate reef-building corals were at elevated risk of extinction based on the Categories and Criteria of the IUCN Red List of Threatened Species. Over the past 10 years, many reef areas across the globe have continued to degrade due to climate change, disease, and other pervasive anthropogenic threats. Recently, more than 20 species experts and members of the IUCN Coral Species Specialist Group have worked to update and reassess the level of extinction risk for all 84 Atlantic coral species using IUCN Red List methodology. For this reassessment, two analytical approaches were applied to estimate species-level population trends, one based on GCRMN modeled live coral cover loss over time, and the second using the IPCC projected onset of annual severe bleaching (ASB) across each species' distribution. In both approaches, the degree of population reduction for each species was informed by nine ecological or biological traits related to the increased or decreased vulnerability of each species to specific threats. Preliminary results indicate that 52% (44 species) of Atlantic coral species are now in elevated extinction risk categories, with 31% (26 species) listed as Critically Endangered. However, a back-casting exercise showed that if current GCRMN coral cover loss trend data were available during the 2008 assessment process, more of the species would have qualified for higher extinction risk categories. Under the business-as usual emissions scenario, spatial analyses estimated that the average year of ASB onset is 2030 for Western Atlantic coral species, assuming no level of species adaptation to warming SST, and 2059 when assuming a capacity for 1°C of adaptation. This result is consistent with the conclusions of the 2020 UNEP report in relation to projected ASB onset in the Wider Caribbean region. The conservation status of Atlantic corals remains dire. Future assessments would benefit from species-level population monitoring and additional research on the adaptability of species to climate change and other impacts.

Oral
A-2186

The role of cleaner fish in parasite transmission

Narvaez, P.[1], Vaughan, D.[1], Morais, R.[1], Yong, R.[2], Grutter, A.[2], Hutson, K.[3]
[1]James Cook University, Townsville 4811, QLD, ARC Centre of Excellence for Coral Reef Studies, Townsville 4811, QLD, Australia
[2]University of Queensland, Brisbane, Australia
[3]Cawthron Institute, Nelson, New Zealand

pauline.narvaez[at]my.jcu.edu.au

Abstract

In marine systems, cleaner fish are key to ecosystem functioning. Cleaners remove parasites from other fish (the clients), an interaction that provides food for the cleaners. Cleaners have been applied in temperate aquaculture to reduce ectoparasite infection. This has further revealed that cleaner fishes are susceptible to parasitic diseases, and can also act as vectors. Despite a large body of work on cleaning interactions on coral reefs, the potential role of tropical cleaner fishes in disease transmission between clients in the wild remains unclear. This study aimed to understand if the cleaner fish Labroides dimidiatus: a) naturally carries parasites in the wild; b) is susceptible to generalist ectoparasites under laboratory condition and c) can potentially transmit parasites to other fishes through cleaning interactions. To answer these questions, we combined comprehensive parasite surveys of wild L. dimidiatus from the Great Barrier Reef and a series of detailed laboratory experiments. In the experiments, we exposed L. dimidiatus and a control species (Lates calcarifer) to the infective stage of three ectoparasites: gnathiid isopod (Gnathia aureamaculosa), monogenean flatworm (Neobenedenia girellae) and ciliate protozoan (Cryptocaryon irritans), quantifying parasite prevalence and infection rates. Then, we tested if adult (non-infective stage) monogenean flatworms could live and reproduce on L. dimidiatus. Results indicated that wild L. dimidiatus carry a series of ectoparasites and endoparasites represented by eight parasite groups, and the abundance of most parasite groups was comparable to other labrids from the same region. Under controlled conditions, L. dimidiatus are significantly less susceptible than control fish to the ciliate ectoparasite C. irritans, are susceptible to gnathiid G. aureamaculosa and are not susceptible to N. girellae. However, manual transfer of adult N. girellae from a donor fish (L. calcarifer) has shown that N. girellae can survive for at least 48h on L. dimidiatus and can also release viable eggs. Our findings provide the first evidence that cleaner fish are not clean from parasitic infection in the wild. Although L. dimidiatus showed resistance to some generalist ectoparasites that affect other fishes, these individuals were still able to carry other viable ectoparasites. These results clearly highlight the potential role of L. dimidiatus as a vector of parasites while interacting with other fish in the wild.

Oral
A-1860

Population collapse of the long-spined sea urchins Diadema and Echinothrix in the coral reef lagoon of Moorea, French Polynesia

Nugues, M.[1, 2], Pozas-Schacre, C.[1], Siu, G.[3], Salvat, B.[1], Dubé, C.[3, 4, 5], Chancerelle, Y.[3]
[1]CRIOBE-EPHE-PSL, Perpignan, France
[2]Laboratoire d'Excellence CORAIL, Perpignan, France
[3]CRIOBE-EPHE-PSL, Moorea, French Polynesia
[4]Institute of Integrative Biology and Systems, Québec, Canada
[5]California Academy of Sciences, San Franscisco, United States

maggy.nugues[at]univ-perp.fr

Abstract

Although sea urchins are important species that influence the health and dynamics of reef ecosystems, we still have limited information on their population dynamic, their response to global and local environmental changes, and their contribution to reef functioning. We analysed two long-term data sets on sea urchin abundance in Moorea, French Polynesia. Densities across 13 sites in the backreef habitat declined from 4.6 and 0.5 individuals per 10 m2 in 2005 for Diadema and Echinothrix, respectively, to 0.005 and 0.015 individuals in 2018. Older data from one site indicate that the decline may have already started five decades ago. These declines were not associated with major changes in algal and herbivorous fish abundance. Although the cause(s) of these population collapses are unknown, mass die-off were reported in Moorea and the rest of French Polynesia. In Moorea, the 2013 die-off occurred during the austral summer and was preceded by high rainfall, indicating a potential link with elevated seawater temperature and water quality. Symptoms of the disease were similar to those described in the 1983/1984 Caribbean mass mortality. We suggest that the long-spined urchins of Moorea experience the same fate as those in the Caribbean, but that their decline is less abrupt and does not have the same cascading effects on the reef community due to a higher reef resilience.

Oral
A-1405

Trophic niche partitioning of small coral reef mesopredators (Family: Pseudochromidae) in the Red Sea.

Palacios-Narvaez, S.[1], Coker, D. J.[1], Tietbohl, M. D.[1], Justo, M. S.[1], Nunes-Peinemann, V.[1], Aylagas, E.[1, 2], Berumen, M. L.[1]
[1]King Abdullah University for Science and Technology, Red Sea Research Center, Division of Biological and Environmental Science and Engineering, Thuwal, Saudi Arabia
[2]The Red Sea Development Company, Department of Environmental Sustainability, Riyadh, Saudi Arabia

stephania.palaciosnarvaez[at]kaust.edu.sa

Abstract

Understanding the factors and mechanisms that contribute to the maintenance of tropical biodiversity and how diversity is partitioned along natural and anthropogenic gradients within ecosystems is important to predict the persistence of species and the ecological functions they provide. Dottypacks, members of Pseduochromidae, are a diverse group of mesopredators that feed on cryptic macro-invertebrates and newly recruited fishes. This diet behavior may modify the composition and abundance of cryptobenthic fauna within coral reef ecosystems. Understanding how diverse mesopredators partition their diet and the functional role of their consumed prey within reefs can assist in understanding the ecological role of these predators in coral reef trophodynamics and provide necessary information to predict the effect of their changes to their abundance and diversity on the reef ecosystem. We used a combination of i) visual stomach content analysis, ii) stomach DNA metabarcoding, and iii) muscle isotope analysis (bulk $\delta^{15}N$, $\delta^{13}C$) to assess dietary niche breadth, degree of dietary specialization, trophic level, and the spatial variation in diet composition of three common species and two distinct color morphs of Pseudochroimids in the Red Sea. These techniques show different levels of resource partitioning between species, with limited variation within color morphs of the same species. Resource partitioning seems to be driven by differences in the specific dietary targets of each species and by subtle differences between the ecology of these species. With these findings, we highlight unique variability and species-specific differences in the trophic ecology and the importance of these species in the Red Sea. This study highlights the importance of combining several approaches (short-term: visual and DNA metabarcoding approaches; and long-term: isotope analysis) to analyze the feeding habits of coral reef fish and demonstrates the role multiple analysis techniques play in more completely determining trophic niche partitioning among species in complex reef systems.

Oral
A-1570

Sponge dwelling fauna: a model to assess species diversity in living islands at multi-spatial scales

Pérez-Botello, A. M.[1], Guerra-Castro, E. J.[2], Hernandez-Diaz, Q.[3], Muciño-Reyes, M. d. R.[1], Paz-Rios, C. E.[4], Cervantes-Campero, G.[5], Simões, N.[3, 6, 7]
[1]Universidad Nacional Autónoma de México, UMDI-Sisal, Facultad de Ciencias. Posgrado de Ciencias Biológicas., Sisal, Mexico
[2]Universidad Nacional Autónoma de México, Departamento de Sistemas y Procesos Naturales, Escuela Nacional de Estudios Superiores - Unidad Mérida, Merida, Mexico
[3]Universidad Nacional Autónoma de México, Unidad Multidisciplinaria de Docencia e Investigación - Sisal, Yucatán, Facultad de Ciencias, Sisal, Mexico
[4]Instituto de Ecología, Pesquerias y Oceanografia del Golfo de México, Campeche, Mexico
[5]Investigador Independiente, Ciudad de México, Mexico
[6]Harte Research Institute for Gulf of Mexico Studies, Texas A&M University, International Chair for Coastal and Marine Studies in Mexico, Texas, United States
[7]Laboratorio Nacional de Resilencia Costera (LANRESC, CONACYT), Sisal, Mexico

antarmijail[at]comunidad.unam.mx

Abstract

The sponge's aggregations could provide reef three-dimensionality complexity, refuge and, food to several coral reef species. In particular, the sponges of the Desmospongiae class are a refuge and food source for a wide range of sponge-dwelling fauna. Only for the North-Western Tropical Atlantic coral reefs are 91 species of sponges hosting at least 300 species. This guest diversity generates the idea that reef sponges could behave like small living islands. On the other hand, the co-dependence between biodiversity and the spatial scale drives us to question, how sponge guest diversity changes on different spatial scales? The main objective of this work was to analyze the changes in the guest's symbiont diversity in three spatial scales: (i) sponge scale, (ii) local scale, and (iii) regional scale. To answer our question, we select both a sponge with a wide diversity of dwelling-fauna and extensive distribution, and a region with several reefs covers a latitudinal and longitudinal gradient. The selected sponge was *Callyspongia aculeata.* The selected area was seven reefs of the Campeche Bank in the Gulf of Mexico. SPONGE SCALE: we correlate the individual sponge guest diversity with the sponge structural complexity. LOCAL SCALE: we measure the association between the sample point (*i.e.,* sponge density and sponge deep) and the guest community changes. REGIONAL SCALE: we compare the sponge dwelling-fauna in each sample reef. Finally, a PERMANOVA test was performed to calculate the significance and variation percentage of every spatial scale. The highest percentage of variation is explained by regional processes, followed by local factors, and lastly, by the sponge complexity. The correlation between complexity and species richness is positive; an increase in complexity means an increase in species richness. In conclusion, the three scales of variation provide a significant explanation of the sponge dwelling-community changes. The potential to host species is directly related to the sponge heterogeneity. This process could be mediated by colonization-dispersion cycles and refuge competition. At the same time, the reef processes will be determining which dwelling-species will be found in a particular reef.

Oral
A-1508

The Indo-Pacific soft corals: discovering biodiversity of Paralemnalia Kükenthal, 1913

Sampaio, Í.[1], S. McFadden, C.[2], M. Quattrini, A.[3], Benayahu, Y.[1]
[1]Tel Aviv University, School of Zoology, George S. Wise Faculty of Life Sciences, Tel Aviv, Israel
[2]Harvey Mudd College, Department of Biology, Claremont, United States
[3]National Museum of Natural History, Smithsonian Institution, Department of Invertebrate Zoology, Washington, United States

irisfs[at]gmail.com

Abstract

Paralemnalia Kükenthal, 1913 was established following the historic Pola expedition (1895-1898) to the cradle of octocoral research, the Red Sea. At present, there are six valid species within this genus. Since the discovery of *Paralemnalia flabella* (Quoy & Gaimard, 1833) in Papua New Guinea during the Voyage de L'Astrolabe, other species have been found at various Indo-Pacific coral reefs. *Paralemnalia* colonies consist of a three-dimensional cluster of digitiform branches, arising from a common encrusting base. These species are foundation inhabitants in shallow coral reefs and in mesophotic coral ecosystems of the Indo-Pacific, distributed from the Red Sea to Madagascar and from Mozambique to Australia. Some species are also source of natural products with antimicrobial properties.
The six species hypotheses were tested by integrating morphology with genetics and zoogeography. Type specimens deposited in natural history museums were re-examined and used as references for species identification. The genus *Paralemnalia* was revised by taking advantage of the octocoral collection of Steinhardt Museum of Natural History, whose octocoral collections encompass a variety of Indo-Pacific reefs sampled over the last ~50 years. Morphology of the colonies and their polyps was described along with their sclerites, calcitic elements found in soft coral tissues. Sclerites were imaged for the first time with scanning electron microscopy (SEM). Additionally, DNA barcoding and sequence capture of ultraconserved elements and exon loci were integrated with the morphological and biogeographical data, and used for species delimitation. New species are described along with the re-description of old type material. So far, results suggest that there are more than six species of *Paralemnalia* in the Indo-Pacific. This work will lay the foundations for future research in discovery of biodiversity hotspots, changes of distribution ranges, evolution and conservation of *Paralemnalia* soft corals.

Oral
A-1918

Evaluating global species-to-genus ratios of algae reveals biodiversity patterns mimicking corals and reef fishes

Tomasetti, R.[1], Bracken-Grissom, H.[2, 3, 4]
[1]Florida International University, Biological Sciences, CRUSTOMICS Lab, Miami, United States
[2]Florida International University, Institute of Environment and Biological Sciences, North Miami, United States
[3]Florida International University - Biscayne Bay Campus, Coastlines and Oceans Division, North Miami, United States
[4]Florida International University - Biscayne Bay Campus, CRUSTOMICS Lab, North Miami, United States

roetti[at]fiu.edu

Abstract

Using traditional biodiversity metrics of taxonomic diversity, marine benthic algae have been shown to have different biogeographical patterns compared to corals and reef fishes. However, evaluating the species-to-genus ratios (S/G) of algae on a global dataset reveals a unimodal peak in this diversity metric centered in the Philippines, like patterns seen with corals and reef fish. Tropical locations contain more algal species per genus than temperate or subtropical localities. Similarity analyses suggest that relatively few algal genera invaded the tropics from cooler waters, but that these genera speciated rapidly, increasing S/G. When examining individual algal families with higher tropical speciation, their global biodiversity patterns according to typical species richness metrics approximate those seen with corals, reef fish, and algal S/G.

Global distribution patterns of marine benthic algae were analyzed according to latitudinal/longitudinal gradients, temperature, spatial scales, and taxonomic gradients. Algal diversity was measured with three metrics: species richness, generic richness, and S/G. Global presence/absence records of marine algae from scientific papers, online resources, and gray literature were compiled into a database of 292,160 unique species-locality records occurring after geographic and taxonomic filters. Records were grouped into 155 unique localities in three temperature regions (temperate, subtropical, tropical) based on NOAA/NCEP sea surface temperature data. The Tripartite Similarity Index was used to measure similarity between localities, with minimum distances between all pairwise combinations calculated using Dijkstra's algorithm for shortest-path problems along a modeled connectivity network.

Algal biogeography is complex, with Florideophyceae, Phaeophyceae, and Ulvophyceae responding differently to temperature gradients and each oceanic basin having statistically distinct taxonomic compositions. A rebuttal is provided to the notion that S/G patterns are a mathematical artifact of undersampling or increasing geographical area. In algae, a tight relationship exists between species and genera of different algal groups and temperature regions, with most linear regressions being significantly different from each other. This result contrasts with previous terrestrial studies showing that tree population S/G did not vary significantly with geography or habitat.

Oral
A-1551

Caribbean coral species distributions and traditional coral species names hide an abundance of unrecognized cryptic species and morphospecies

Vermeij, M.
University of Amsterdam, IBED, Amsterdam, Netherlands

carmabilog[at]gmail.com

Abstract

Traditionally, the Caribbean basin has been considered to be a small, uniform sea in which approximately 70 reef building coral species occur. Species distributions were believed to span the entire basin for most taxa, resulting in the assumptions that the Caribbean is an area of “high uniformity” and that newly discovered species must occur throughout the region, too. Recent datasets from several islands, spanning 50% of the latitudes within the Caribbean, provide three lines of evidence that challenge such commonly held beliefs. First, several commonly used Caribbean coral species names are used to refer to groups of coral morphospecies that are coarsely similar, but clearly different between islands and latitudes. Second, the labelling of clearly different (morpho)species using identical names has resulted in large-scale species distributions that do not reflect the distinct differences in the ranges, and co-occurrences of the (morpho)species therein. Further, biogeographic analyses traditionally do not capture these differences in distributions because they rely on a binary presence/absence system, ignoring the relative abundance of species, i.e., clues to a species’ local ecological and evolutionary dynamics. Third, in addition to the mistaken clumping of morphospecies under single names, species identifications based on morphology further underestimate the “true” number of Caribbean coral species due to the large amount of cryptic species. In both individual, traditional species (e.g., *Leptoseris cucullata*) or accepted coral species complexes (e.g., *Madracis*), more than half of the traditionally accepted coral taxa contain at least one or more cryptic species. This occurs even in species whose morphological identification appears straightforward (e.g., *Diploria labyrinthiformis*). Morphospecies and cryptic species combined, the resulting larger number of Caribbean coral species implies that each is more threatened than previously thought. Smaller population sizes make corals more susceptible to Allee effects and complicate the assessment and identification of stable population sizes. Using examples for each of the 3 categories mentioned above, I argue that (1) there are more coral species in the Caribbean than scientists recognize and (2) there is more structure to their geographical distributions than currently assumed. This has consequences for studies of coral reef ecology as well as the management of these fragile ecosystems.

Oral
A-1170

Coral reef predator assemblages of the Gulf of Aqaba and northern Red Sea

Williams, C.[1], Garzon, F.[2], Cochran, J.[1], Tanabe, L.[1], Hawkes, L.[2], McIvor, A.[3], Eweida, A.[4], Marshall, P.[5], Berumen, M.[1]
[1]King Abdullah University of Science and Technology, Red Sea Research Center, Thuwal, Saudi Arabia
[2]University of Exeter, Exeter, United Kingdom
[3]Marine and Environmental Sciences Centre, Funchal, Portugal
[4]NEOM, Marine and Environmental Division, Riyadh, Saudi Arabia
[5]NEOM, Nature Reserve Sector, Riyadh, Saudi Arabia

collin.williams[at]kaust.edu.sa

Abstract

Coral reef ecosystems of the Gulf of Aqaba and northern Red Sea are divided by a narrow, shallow passage, the Straits of Tiran, and exhibit distinct environmental characteristics (e.g., temperature, salinity, and geomorphology). Spatial patterns of diversity and abundance between these two basins remain largely unrefined for many biological assemblages. Baited remote underwater video systems (BRUVS) were used characterize predatory fish assemblages (Elasmobranchii and several taxa within Osteichthyes) along ~300km of coral reefs spanning the eastern Gulf of Aqaba and main basin of the Red Sea (Saudi Arabia). Across 111 BRUVS deployments, 55 predatory coral reef fish species were recorded, including evidence of range extensions for 2 species into the Gulf of Aqaba where they have never been documented before. Marked differences in the composition, species richness, abundance, and structuring of predatory fish assemblages were observed between the Gulf of Aqaba and northern Red Sea, with abundance and species richness generally found to be greater in the northern Red Sea. Environmental factors (e.g., sea surface temperature, habitat type, and distance to mainland) accounted for less than 10% of variation in assemblage structure between the Gulf of Aqaba and northern Red Sea at the resolution examined here. While further investigation is required to determine the mechanisms underlying assemblage differentiation, our findings suggest that coral reef fish assemblages between the Gulf of Aqaba and northern Red Sea are more distinct than previously thought, and that incorporating abundance estimates can reveal deffirences otherwise hidden by comparisons of species diversity alone. The region surveyed in this study is expected to serve as a refugia for coral reef ecosystems in projected climate scenarios, and is also encompassed by NEOM, a newly established development project tasked with managing natural areas. Beyond a descriptive ecological context, our results provide foundational information that is intended to guide innovative management strategies for these unique and valuable coral reef ecosystems.

Oral
A-1402

Population outbreak of the invasive echinoid Diadema setosum (Leske, 1778) in the Mediterranean Sea

Zirler, R.[1, 2], Leck, L.[1, 2], Feldstein-Farkash, T.[1, 2], Bronstein, O.[1, 2]
[1]Tel Aviv University, Zoology, Tel Aviv, Israel
[2]The Steinhardt Museum of Natural History, Tel Aviv, Israel

rotemzirler[at]tauex.tau.ac.il

Abstract

The Eastern Mediterranean Sea is a unique habitat. Its relative isolation and distinct characteristics create an exceptional ecosystem recognized as a marine biodiversity hot spot, where one-fifth of its species are endemic. Yet, local biodiversity is under constant threat, mainly due to massive marine invasions of Indo-Pacific origin. The opening of the Suez Canal created a new route by which marine species migrate from the Red Sea to the Mediterranean, in a process termed *Lessepsian Migration*. To date, more than 800 non-indigenous species have been reported in the Eastern Mediterranean, justifying its reputation as one of the most severely affected habitats in the world in terms of marine invasions.
The echinoid *Diadema setosum*, one of the most ubiquitous sea urchin species in the Red Sea and Indo-Pacific, was first documented in the Levantine basin in 2006. As it primarily feeds by algae grazing on hard substrates, *Diadema* species are often recognized as environmental engineers, capable of altering the structure and composition of entire benthic communities.
Here we follow the invasion dynamics of *D. setosum* in the Eastern Mediterranean Sea from its initial appearance to its recent accelerated population growth, implying a population outbreak. We combined sampling with extensive survey data complemented by citizen-science reports, to depict the invasion's current status and scope. We used molecular data from samples collected along the Israeli Mediterranean to identify the genetic makeup of the invaders and determine their origin. Moreover, we examined possible similarities in the reproductive cycles between the alien Mediterranean population to the native Red Sea one using histological analysis.
Our results show an alarming exponential population growth of *D. setosum* throughout the Eastern Mediterranean since 2019. Our molecular analysis illustrates the presence of a single genetic clade in the Mediterranean, matching the one found in the Arabian Peninsula, reinforcing the notion of Red Sea origin. We also provide evidence of *D. setosum* reproductive development within its new environment. Our data show a well-established population with a balanced size distribution, from juveniles to mature individuals of remarkable large size.
In contrast to other alien species in the region, the ecological footprint of *D. setosum* poses a clear and immediate threat to the entire Levantine Basin, calling for rapid and coordinated action at both national and regional scale.

Poster
A-1263

Temporal damselfish occupation patterns of corals: suburb rentals, retention, and recolonization

Chase, T.[1], Hein, M.[2], Hoogenboom, M.[3]
[1]Villanova University, Geography and the Environment, Villanova, United States
[2]Marine Ecosystem Restoration (MER) Research and Consulting, Coral Reef Restoration, Monaco, Monaco
[3]James Cook University, College of Science and Engineering, Townsville, Australia

tory.chase[at]villanova.edu

Abstract

Marine mutualisms between branching scleractinian corals and aggregating damselfishes on corals reefs are well-known for positive feedback loops that enhance coral processes and resilience at local scales. However, patterns of fish occupation of a coral colony over time are poorly understood. *In situ* short- (17 days) and long-term (355 days) assessments of the occupation of *Pocillopora damicornis* coral colonies by adult damselfish *Dascyllus aruanus* were conducted within a reef lagoon on the southern Great Barrier Reef. Results revealed low levels of change in occupancy (13-15%) over both short and long-term, with net coral occupancy status (number of occupied and vacant corals) and biomass retention per site remaining high (>90%) after one year. Upon experimentally removing fish from host colonies during short-term occupancy quantification, recolonization of previously occupied colonies occurred rapidly (< 3 days) with corals regaining ≥ 50% of their original *D. aruanus* numbers within 14 days. This is one of the few studies monitoring obligate coral-dwelling damselfishes occupancy patterns over multiple timeframes, providing novel insight into the association variability, duration, and function at the coral colony and population levels. Rapid recolonization and overall stability of coral occupancy leading to robust mutualistic interactions will be discussed in terms of the potential role of these obligate damselfishes in maintaining coral resilience and potential applications for the design of coral reef restoration efforts.

Poster
A-1822

Spatial-temporal movement patterns of Lane snappers (Lutjanus synagris) in Brewers Bay, St. Thomas, US Virgin Islands

Duffing Romero, M. D.[1], Mattley, J. K.[2], Ault, J. S.[3], Luo, J.[3], Pittman, S. J.[4], **Nemeth, R. S.**[1, 5]
[1]University of the Virgin Islands, Center for Marine and Environmental Studies, St Thomas, U.S. Virgin Islands
[2]University of Windsor, Great Lakes Institute for Environmental Research, Windsor, Canada
[3]University of Miami, Rosentiel School of Marine and Atmospheric Science, Miami, United States
[4]University of Plymouth, Marine Institute, Plymouth, United Kingdom
[5]University of the Virgin Islands, St. Thomas, U.S. Virgin Islands

rnemeth[at]uvi.edu

Abstract

Lane snapper (*L. synagris*) is a widespread reef-associated fish species of commercial importance in the Caribbean and Gulf of Mexico region. Lane snapper inhabits coral reefs, mangroves and other structurally complex diurnal shelters but partake in diel migrations to forage in adjacent seagrass beds and sand habitats. Acoustic telemetry was used to investigate the diurnal and seasonal movement patterns and activity space of lane snapper in Brewers Bay, St. Thomas, US Virgin Islands. Fifteen adult lane snappers were passively tracked from July 2015 to December 2017 to identify their space use during diel, crepuscular and seasonal periods. Eleven lane snappers were detected daily with greater than 90% residency time and high site fidelity to four distinct areas of the bay throughout the year. Mean home range area was 0.034 km^2 and range [0.002 km^2 to 0.13 km^2]. Lane snappers with home ranges encompassing shallow sand and seagrass seascapes exhibited spatially distinct day and night activity spaces, while lane snappers with home ranges encompassing coral reefs exhibited spatially overlapping day and night activity spaces. Daytime home range size was significantly greater than nighttime (*post hoc* $p<0.05$) with higher rate of movement during the day than night and peaks during crepuscular periods. Home ranges and rate of movement were greatest in the spring and summer months (March-September). During the passing of two major hurricanes (Irma and Maria) in September of 2017, two lane snappers significantly changed their behavior and habitat utilization by moving away from their home ranges to deeper waters within Brewers Bay. This study provides a better insight of distinct habitat use and movement patterns of a commercially important reef fish species.

Poster
A-1219

Mating Success of the Six-bar wrasse (Thalassoma hardwicke, Labridae) Utilizing Two Mating Strategies

Ebeling-Whited, K.
University of Guam EPSCoR, Mangilao, Guam, Guam

kebelingwhit2012[at]my.fit.edu

Abstract

Reef fish spawning aggregations are a critical aspect of population resilience and fisheries sustainability for many fish species. Various species of wrasse and parrotfish (Labridae) will spawn within an aggregation, but the dynamics of these aggregations vary. The purpose of this study was to investigate paired and group spawning behavior in the wrasse *Thalassoma hardwicke* on a daily resident spawning aggregation at Finger Reef, Apra Harbor, Guam. In-field observations were used to answer following questions about the spawning behavior of *T. hardwicke*: 1) which spawning method is most successful?, 2) does the abundance of *T. hardwicke* affect the spawning success or spawning method used?, 3) is the spawning success or method influenced by lunar phases, seasons, or tidal states?, 4) does egg predator abundance affect the spawning success or spawning method?, and 5) are egg predation events influenced by egg predator abundance, and is there a relationship between predation and spawning method? Within the aggregation, terminal phase (TP) males pair spawn with initial phase (IP) females while (IP) males and females spawn in groups. Group spawning was the more successful spawning strategy within this aggregation. The abundance of *T. hardwicke* did not affect spawning success or spawning strategy. Spawning success and strategy were not influenced by seasons or tides, and lunar phase did not affect spawning success. Pair spawns, however, occurred more often during the full moon, and group spawns occurred more often during the new moon. Egg predator abundance at Finger Reef did not affect spawning success or influence spawning method. Egg predation was higher in group spawns compared to pair spawns. Finally, some correlation was found between egg predator abundance and egg predation, however, egg predator abundance was not a good predictor of egg predation. These observations increased our knowledge of labrid spawning behavior and will provide a model to evaluate spawning behavior at other spawning aggregation sites.

Poster
A-1360

Acanthopagrus oconnorae, a new species of seabream (Sparidae) from the Red Sea

Pombo-Ayora, L.[1], **Nunes Peinemann, V.**[1], Williams, C. T.[1], He, S.[1], Lin, Y.[2], Iwatsuki, Y.[3], Bradley, D. D. C.[1], Berumen, M. L.[1]
[1]King Abdullah University of Science and Technology, Thuwal, Saudi Arabia
[2]King Fahd University of Petroleum and Minerals, Center for Environment & Water, Dahran, Saudi Arabia
[3]University of Miyazaki, Marine Biology and Environmental Sciences, Miyazaki, Japan

viktor.nunespeinemann[at]kaust.edu.sa

Abstract

A new species of sparid fish, *Acanthopagrus oconnorae*, is described on the basis of 11 specimens collected in the shallow (0-1 m depth) mangrove-adjacent sandflats of Thuwal, Saudi Arabia. The new species is distinguished from its congeners by the following combination of characters: second anal-fin spine 12.8-16.6% of SL; 3½ scale rows between fifth dorsal-fin spine and lateral line; suborbital width 5.7-6.7% of SL; eyes positioned at anterior edge of head, often forming a weakly convex break in an otherwise gently curved head profile, when viewed laterally; caudal fin light yellow with black posterior margin (approximately half of fin); anal fin dusky grey with posterior one-fifth of the fin light yellow; black streaks on inter-radial membranes of anal fin absent. The most similar species to *Acanthopagrus oconnorae* is *Acanthopagrus vagus*, which differs in having a w-shaped anterior edge of the scaled predorsal area, a more acute snout, and black streaks on the inter-radial membranes of the anal fin. The phylogenetic placement and species delimitation of *A. oconnorae* is discussed on the basis of COI, CytB, and 16S sequences. It is hypothesized that ecology and behavior explain how this species avoided detection despite likely occurrence in coastal areas of the Red Sea with historically high fishing pressures.

Poster
A-1447

Embryonic and larval development of the Red Sea clownfish, Amphiprion bicinctus

S. Justo, M.[1], Majoris, J.[1, 2], Berumen, M.[1]
[1]King Abdullah University of Science and Technology, Red Sea Research Center, Thuwal, Saudi Arabia
[2]The University of Texas / Marine Science Institute, Texas, United States

micaelasofia.dossantosjusto[at]kaust.edu.sa

Abstract

Coral reef fishes typically have a bipartite life cycle: including a relatively sedentary reef-associated phase, characterized by juveniles and adults, and a pelagic larval phase, characterized by altricial larvae that disperse away from their parents. The study of the larval phase has been an essential prerequisite to understand how the persistence, connectivity, and gene flow operates between populations. Clownfish, nowadays known as “Nemo”, are an important family of coral reef fishes that can be reared in aquaria. Over the past years, clownfish have been the subject of considerable scientific research, not only because of their value in the ornamental fish trade but also because they are considered model species thanks to characteristics such as: easiness to maintain in the laboratory, regular spawning, and short embryonic and larval development. In the Red Sea, there is only one endemic species of clownfish called *Amphiprion bicinctus* (Rüppel, 1830), and despite its value, knowledge about early development is still a significant gap in the literature, when compared with other *Amphiprion* species. Here, we describe several morphometric traits during embryonic and larval development of *A. bicinctus*. Establishing a detailed characterization of the development of the Red Sea clownfish will help us to establish foundational information about its ontogeny and standardize sampling for future studies exploring the early life history of this iconic species.

Poster
A-1701

Newly described nesting sites the green sea turtle (Chelonia mydas) and hawksbill sea turtle (Eretmochelys imbricata) in the central Red Sea

Scott, K.[1], Tanabe, L.[1], Miller, J.[2], Berumen, M.[1]
[1]King Abdullah University of Science and Technology, Thuwal, Saudi Arabia
[2]Biological Consultants, Missoula, United States

kirsty.scott[at]kaust.edu.sa

Abstract

Sea turtles are important marine ecosystems, they facilitate nutrient transport between habitats and balance food webs by regulating populations of their prey to maintain healthy coral reefs and sea grass beds. There is relatively little published information about sea turtle nesting distribution and seasonality in the Saudi Arabian Red Sea. Upcoming large-scale developments occurring along the Saudi Arabian Red Sea coast will affect sea turtle nesting beaches with potential impacts on the survival of local populations. In 2019, two coastal beaches and three near-shore islands were surveyed for turtle nesting in the central Red Sea. We recorded all emergences, examined beach morphology, and collected sand samples to determine grain size, moisture content and colour. Sea turtle nesting was found at all surveyed sites, though emergence counts were often low. The limited occurrence of nesting at several previously undocumented sites suggests that nesting activity may be widespread, but sparsely distributed, in the central Red Sea region. In addition, nesting at novel sites appeared to favour the seaward side of islands, a pattern that was not observed in previously documented areas. The substrate of most surveyed sites was composed of calcium carbonate, with Ras Baridi as the only exceptional site, composed of dark quartz-rich sediment. This study highlights several important sea turtle rookeries while also demonstrating that low levels of nesting occur throughout the region, although inter-annual nesting patterns still need to be determined. Future developments should be steered away from key nesting areas and the seaward bias in marginal rookeries should be taken into account where possible.

Poster
A-1658

Photographic identification of hawksbill (Eretmochelys imbricata) and green turtles (Chelonia mydas) in the central Red Sea, Saudi Arabia

Tanabe, L., Scott, K., Berumen, M.
King Abdullah University of Science and Technology, Red Sea Research Center, Thuwal, Saudi Arabia

lyndsey.tanabe[at]kaust.edu.sa

Abstract

The Red Sea is an understudied marine ecosystem, especially in regards to sea turtle ecology, distribution, and movement patterns. Photographic identification (photo-ID) is an inexpensive and non-invasive tool that can help fill some of these knowledge gaps. Photo-ID relies on permanent identifiable fixed features, for sea turtles it uses the shape, size, and arrangement of their facial scales. Obtaining a baseline knowledge of sea turtles in Saudi Arabian waters is crucial due to upcoming giga-projects planned in the northern Red Sea. The largest development will be NEOM, a $500 billion investment planned to cover 26,500 km2 of land, including the Red Sea coastline. Thus, there will be increased anthropogenic threats during the upcoming decades. Photo ID can help elucidate information on site fidelity, presence of resident and transient turtles, and population demographics. Methods of unique identification included using I3S software in conjunction with manual identification. Data on turtle sightings, depth, location, time, and behavior was recorded bi-weekly for one year from Rabigh in the central Red Sea. This site exhibited a high number of critically endangered hawksbill turtles using this reef as a foraging habitat. Data from this photo ID study can provide basic biological, ecological and population demographic information that is essential to species conservation and management.

Poster
A-2091

Coral-associated fauna on a Caribbean coral reef over a pollution gradient

van der Schoot, R. J., Hoeksema, B. W.
Naturalis Biodiversity Center, Marine Evolution & Ecology, Leiden, Netherlands

roel.vanderschoot[at]naturalis.nl

Abstract

Coral-associated invertebrates form an important group of organisms on Caribbean coral reefs. The nature of their symbiotic relation is often not fully understood and depending on their density, they could potentially be harmful for their hosts. Four groups of coral-associated invertebrates were investigated on the Caribbean coral reefs along the leeward side of Curaçao. Coral barnacles (Cryptochiridae), boring mussels (Lithophaginae), gall crabs (Cryptochiridae), and Christmas tree worms (*Spirobranchus* spp.) were recorded with their host corals by means of a photo survey over a depth gradient and across sites with high and low sewage output. The results show a decrease in the number of barnacles and Christmas tree worms per host over depth, which could be related to host-species availability. Sites with high sewage output show a higher abundance of barnacles and Christmas tree worms per host than sites with low sewage output. This indicates that sewage could be favourable for these filter feeding organisms but when they tend to overgrow their hosts they could become a threat to the growth of their hosts.

Virtual
Oral
A-2096

Taxonomic and functional diversity of zooxanthellate corals and hydrocorals in Southwestern Atlantic reefs

Bleuel, J.[1], Waechter, L.[2], Ortigara Longo, G.[1], Bender, M.[2]
[1]Federal University of Rio Grande do Norte, Department of Oceanography and Limnology, Natal, Brazil
[2]Federal University of Santa Maria, Department of Ecology and Evolution, Santa Maria, Brazil

jessica.bleuel.700[at]ufrn.edu.br

Abstract

The Southwestern Atlantic harbors a relatively species poor but highly endemic coral assemblage due to historical processes and local environmental conditions considered marginal for most coral species. As a result, coral cover in this region is usually low or moderate but as foundation species corals still have a disproportionate contribution to ecosystem function and stability. We combined taxonomic and functional approaches to describe diversity patterns, variation in species and functional composition (diversity partitioning) of the 20 zooxanthellate corals and hydrocorals in the Southwestern Atlantic (1°N-27°S). We used nine functional traits comprising reproduction, dispersion, morphology and symbiotic associations to evaluate the functional space and to calculate functional metrics (e.g. originality, evenness). We found eight sub-regions within this Southwestern Atlantic area, based on the taxonomic composition, which coincides with ecoregions previously defined based on a robust combination of environmental and biogeographical processes. The most diverse area, both in taxonomic and functional diversity, is located in the Abrolhos bank (17°S-19°S) related to the wider shallow continental shelf in this area prompting species diversification through historical sea-level changes. This pattern also translates into low taxonomic and functional beta diversity due to increased nestedness among regions caused by dispersion barriers (distance or river outflow) and the paucity of suitable habitat (low temperature and salinity). The Southernmost region (23°-27°S) has relatively high functional originality and comprises only three species that share similar traits: hermaphrodites, brooders, great depth tolerance and wide corallite. Because this region was pointed out as a critical area for corals in the future facing tropicalization, tropical corals that share similar traits may be more likely to succeed if this area becomes more suitable. Despite the relatively low coral cover and species diversity, the Brazilian province has at least eight heterogeneous coral assemblages that are mostly a subset of the Abrolhos region, functionally homogeneous with moderate redundancy among groups. By understanding the spatial patterns of taxonomic and functional diversity of Southwestern Atlantic corals, we can identify critical areas for conservation and indicate functional traits that may help corals to thrive in future tropicalization scenarios.

Virtual
Oral
A-1973

Interactions affecting community structure of fishes and macroinvertebrates on the branching coral Pocillopora grandis

Brush, E., Hixon, M.
University of Hawaii at Manoa, School of Life Sciences, Honolulu, United States

ebrush[at]hawaii.edu

Abstract

As coral reefs face an unprecedented suite of stressors that threaten to reduce biodiversity and drastically alter ecosystem function, it has become more important than ever to understand what factors affect and alter community structure. The south shore of O‘ahu, Hawai‘i, is largely characterized by spur-and-groove coral reefs dominated by pocilloporid corals, including *Pocillopora grandis*, the large and highly branching morphology of which attracts many reef fish and macroinvertebrate species. Some of the most common fish species found within these colonies include a mesopredator of fish recruits and macroinvertebrates (the Arc-eye Hawkfish, *Paracirrhites arcatus*) and an aggressive interference competitor (the Blue-eye Damselfish, *Plectroglyphidodon johnstonianus*). On twelve 100m^2 square reef plots, each centered on a 35-70cm diameter *P. grandis* colony, I conducted a controlled press removal of both the mesopredator and the interference competitor on half of the plots to determine the combined direct effects of these strong interactors on resident fishes and macroinvertebrates, and indirect effects on host colony growth. All non-focal fish were initially removed from each *P. grandis*. In the absence of Arc-eye Hawkfish and Blue-eye Damselfish, there was a resulting increase in resident fish abundance and species richness, as well as macroinvertebrate abundance compared to controls. There was also evidence of increased recruitment of trapeziid guard crabs, which aid the host coral by defending against invertebrate corallivores such as the crown-of-thorns seastar. These changes to community structure could, in turn, affect the host colony. Previous studies have found that greater resident fish biomass, particularly of planktivores, can significantly increase coral growth via fertilization by excreta. Preliminary results, however, suggest that there was no difference in host colony growth rates when Arc-eye Hawkfish and Blue-eye Damselfish were absent. Understanding such direct effects of predation and competition on community structure and potential indirect effects on coral demographic rates may provide insight on future changes in coral reefs as the oceans continue to warm and acidify.

Virtual
Oral
A-2161

Microhabitat type and abundance drive intrapopulation heterogeneity in the population dynamics of two sympatric Caribbean cleaner gobies

Germain, J., **Vallès, H.**
The University of the West Indies at Cave Hill, Department of Biological and Chemical Sciences, Cave Hill, Barbados

henri.valles[at]cavehill.uwi.edu

Abstract

In the Caribbean, the cleaner gobies Elacatinus evelynae (E_eve) and Elacatinus prochilos (E_pro) can be found inhabiting two different microhabitats at the same location: live massive corals and barrel sponges (Xetospongia muta). In Barbados, E_eve mainly inhabits corals, where it is generally found living in mating pairs, whereas E_pro mainly inhabits sponges, where it is generally found in large social groups. Based on these differences in microhabitat use between gobies, we expected that the preferred microhabitat (i.e. coral for E_eve; sponge for E_pro) would become quickly saturated following pulses in goby recruitment, resulting in higher rates of negative number-dependence and more stable goby abundance over time. Conversely, we expected the non-preferred microhabitat (i.e. sponge for E_eve; coral for E_pro) to show less stable goby abundance over time. We monitored the abundance of both gobies on 130 sponges (total surface area: 75m2) and 284 corals (32m2) at the same location in Barbados at 4-d intervals over a full year (90 consecutive surveys). Total goby abundance over time varied approximately 5-fold and 7-fold for E_eve and E_pro, respectively. For both species, corals exhibited more stable goby abundance and higher rates of number-dependence in abundance over time than sponges, as expected for E_eve but not for E_pro. However, this implied that the two gobies differed in the fraction of the population that was subject to strong number-dependence: 3/5 for E_eve versus only 1/10 for E_pro. Moreover, assessing the size-structure of the coral- and sponge-dwelling populations showed that the largest gobies were mainly found on corals for E_eve versus sponges for E_pro, supporting quantitative and qualitative differences between gobies in number-dependent effects. Overall, only data for E_eve supported the existence of a buffer effect driven by limited availability of the preferred microhabitat for mating pairs (corals), with floaters temporally occupying the non-preferred microhabitat (sponges). For E_pro, the preferred microhabitat (sponge) did not appear to be limiting because of both high local availability (twice that of corals) and E_pro's ability to live in large social groups on sponges. Our study reveals substantial and complex intrapopulation variability in population dynamics - and sheds light onto mechanisms potentially contributing to population regulation and co-existence - in two reef fish microhabitat specialists

Virtual
Oral
A-1612

Spatial partitioning in coral-reef fishes that do not compete

Jones, R., Hixon, M.
The University of Hawaii at Manoa, School of Life Sciences, Honolulu, United States

rnjones[at]hawaii.edu

Abstract

Coral reefs on exposed coastlines around O‘ahu, Hawai‘i are largely dominated by cauliflower coral (*Pocillopora* spp.), whose highly complex branching structure provides habitat for a variety of fishes and invertebrates. Two fish species that commonly inhabit these colonies are the Galactic Scorpionfish (*Sebastapistes galactacma*) and the Speckled Scorpionfish (*S. coniorta*). These species typically have overlapping depth ranges: Galactic Scorpionfish deeper and Speckled Scorpionfish shallower. In the zone of overlap (reefs 4-9 m deep), these fishes inhabit coral colonies in close proximity to one another, occasionally co-occupying the same colony. Because these two species appear to be ecologically similar, interspecific competition could be limiting their abundances in areas where both are present. To test this hypothesis, I conducted reciprocal removal experiments of both species at two spatial scales. Between May and October of 2019, I maintained reciprocal press removals of each species within clusters of coral colonies and followed the abundances of each in the presence and absence of their putative competitor within each cluster. In the summer of 2020, I ran a second reciprocal removal of each species among coral colonies where both species were present within the same colony. If competition is limiting one or both species' abundances at either spatial scale, then removal of the potential competitor should result in an increase in the abundance of the remaining species. At the cluster scale, the expected pattern was not observed, and the remaining species' abundances were nearly unchanged following the removal of their congener. At the scale of a single colony, both species showed a slight increase in abundance immediately following the removal of the other species, though abundance returned to pre-removal levels after a couple of months. These outcomes indicate that competition is not presently an important interaction between these species despite their ecological similarity. One potential explanation for these patterns could be a partitioning of food resources between these species, which is currently being investigated. Alternatively, severe recruitment limitation in Hawai‘i may lessen competition between these species to levels that allow coexistence.

Virtual
Oral
A-1357

Reproductive morphology and biometry of the non-zooxanthellate papillose cup coral Paracyathus pulchellus (Scleractinia: Caryophylliidae)

Marchini, C.[1,2], Fossati, V.[1], Cerpelloni, M.[1], Caroselli, E.[1,2], Falini, G.[3], Dubinsky, Z.[4], Goffredo, S.[1,2]
[1]University of Bologna, Department of Biological, Geological and Environmental Sciences, Bologna, Italy
[2]The Inter-Institute Center for Research on Marine Biodiversity, Resources and Biotechnologies, Fano Marine Center, Fano, Italy
[3]University of Bologna, Department of Chemistry "Giacomo Ciamician", Bologna, Italy
[4]Bar-Ilan University, The Mina and Everard Goodman Faculty of Life Sciences, Ramat Gan, Israel

chiara.marchini2[at]unibo.it

Abstract

Basic information on the reproductive biology of many scleractinian corals species is limited or entirely lacking, particularly from temperate zones, though it is essential for a better understanding of their ecology. This study describes the morphological aspects of gametogenesis and biometric parameters of the papillose cup coral *Paracyathus pulchellus* collected at Palinuro (Italy, Southern Tyrrhenian Sea), filling a knowledge gap about the reproductive biology and growth of a widespread Mediterranean and Northern Atlantic coral, which is currently labelled as Data Deficient by IUCN. Samples of *P. pulchellus* were collected by SCUBA diving between 5- and 10-meters depth during 18 monthly collections from June 2010 to December 2011. Polyps have been analyzed through histological techniques. All 57 polyps displayed either oocytes or spermaries, indicating that *P. pulchellus* was gonochoric. Gametogenesis began with undifferentiated germ cells arose in the gastrodermis that migrated towards the mesoglea of the mesentery where they completed the development. During spermatogenesis, spermary diameter increased from 25 to 83 µm. Oocyte diameter ranged from 9 to 146 µm and during oogenesis the nucleus/cytoplasm ratio decreased due to the accumulation of yolk. The nucleus migrated to the periphery of the oocyte adhering closely to the cell membrane. No embryo was observed in the coelenteric cavity of the polyps, suggesting a broadcast spawning reproductive mode with a possible planktotrophic larval development due to the small-sized mature oocytes. The analysis of the main biometric parameters (polyp width, height, dry skeletal mass, volume, surface/volume ratio and bulk skeletal density) showed a negative correlation between size and skeletal density, and no sexual dimorphism.

Virtual
Oral
A-2174

Environmental DNA metabarcoding as fish biodiversity baseline data: pilot study from Banggai Island, Banggai MPA, Indonesia

Moore, A. M.[1], Tassaka, A. C. M.[2], Yasir, I.[2], Ndobe, S.[3], Umar, W.[2], Jompa, J.[2]
[1]Universitas Hasanuddin, Graduate School, Makassar, Indonesia
[2]Universitas Hasanuddin, Faculty of Marine Science and Fisheries, Makassar, Indonesia
[3]Universitas Tadulako, Faculty of Animal Husbandry and Fisheries, Palu, Indonesia

abigail[at]pasca.unhas.ac.id

Abstract
The Banggai Archipelago in eastern Indonesia is home to the endangered endemic Banggai cardinalfish *Pterapogon kauderni*, popular in the marine aquarium trade. Legally established in 2018, the Banggai Marine Protected Area (MPA) covers most of the endemic range of this species. There is a need for comprehensive and up-to-date biodiversity data for this MPA; however taxonomic expertise and funding are limited. Furthermore, many taxa are cryptic or nocturnal and likely to be missed using visual census methods. This study applied molecular biology methods to evaluate fish biodiversity at four sites around Banggai Island, three in *P. kauderni* habitat. Environmental DNA (eDNA) seawater samples were collected in October 2018 (3 replicates per site). The eDNA was extracted at Bionesia in Bali. Metabarcoding (standard MiFish 12S Teleost primers) and sequence library preparation were conducted at the Barber Lab, University of California Los Angeles (UCLA). High-throughput sequencing was performed on a Nextseq and generated sequences were processed using the Anacapa Toolkit to identify taxa. Sequences were analysed by site and aggregated into amplicon sequence variants (ASVs) using the 100% and 60% Bayesian confidence score files generated. Across all sites 41 orders, 97 families, 250 genera and 307 species were identified from 487 ASVs (192-224 ASVs/site) at 100% confidence; 41 orders, 112 families, 308 genera and 498 species from 635 ASVs (227-295 ASVs/site) at 60% confidence. Species present varied but alpha and beta diversity did not differ significantly between sites. Comparison with the 661 species Gerald Allen identified from 19 sites in the Banggai Archipelago in 1998 (120-213 species/site) shows that eDNA can identify taxa missed by visual surveys, and vice-versa. Furthermore, many fish ASVs/sequences were not assigned to species, genus or higher taxonomic levels. The findings also highlight a need for further collection of specimens for traditional taxonomy accompanied by barcoding in eastern Indonesia, in particular the Banggai Archipelago.

Virtual
Oral
A-2097

The most endangered parrotfish of the Atlantic Ocean: what is known and future perspectives

Roos, N., Longo, G.
Marine Ecology Laboratory, UFRN, Natal, Brazil

nataliaroos[at]gmail.com

Abstract

Parrotfishes play important roles in reefs environments, such as grazing, bioerosion and sediment transportation, but are among the main targets in reef-associated fisheries. The greenbeak parrotfish, *Scarus trispinosus*, is the largest parrotfish of the southwestern Atlantic, endemic to Brazil, and targeted by reef-associated subsistence, commercial and recreational fisheries throughout the coast. After a sharp population decline of ~50% over the last 30 years, *S. trispinosus* is now one of the most endangered parrotfishes in the world. The paucity of basic information on its biology have hampered the implementation of appropriate management policies, until recent. We assembled data on abundance, biomass, size class distribution, habitat preferences and demography of *S. trispinosus* along the Brazilian coast, to discuss how current Marine Protected Areas (MPAs) and newly implemented management strategies could aid this species recovery and protection. Despite occurring from latitude 0° to 27°S, *S. trispinosus* is more abundant in the northeast and is mostly associated to calcareous substrates and reefs with high structural complexity. Shallower inshore reefs act as nurseries, while larger individuals often occupy deeper offshore reefs, such ontogenetic habitat shift occurs around the timing of maturation. Estimated size and age of first maturity (39.2 cm; 4.2 years) also indicate that *S. trispinosus* is relatively long-lived and has a later sexual maturity compared to other parrotfishes in the Caribbean and the Pacific, highlighting its vulnerability. Most fishing is on immature individuals at the inshore reefs, affecting the reproductive capacity of the populations. Brazilian MPAs protect some critical areas including nursery grounds, but the species' continuous decline suggests that MPAs alone are not enough if there is no fisheries management. These data combined suggest that the most appropriate management strategy would likely be a fishing moratorium, but the social impacts and lack of political context hampers its implementation. Alternatively, the Brazilian Government released the National Recovery Plan for Endangered Species that restricts fishing to multiple use MPAs, following proper monitoring and regulatory measurements, and prohibits fishing this species elsewhere in the country. If this novel management strategy is well implemented and successfully protects such a vulnerable species, it could be used as a model to manage parrotfish elsewhere.

Virtual
Oral
A-2146

Abundance and size of a photosynthetic sea slug in different coral reefs of the Mexican Atlantic coast

Vital, X.[1, 2], Simões, N.[2, 3, 4], Cruz, S.[5], Mascaró, M.[2]
[1]National Autonomous University of Mexico (UNAM), Posgrado en Ciencias Biológicas, Ciudad de México, Mexico
[2]National Autonomous University of Mexico (UNAM), UMDI-Sisal, Facultad de Ciencias, Sisal, Yucatán, Mexico
[3]Laboratorios Nacionales, CONACYT, Laboratorio Nacional de Resiliencia Costera, Sisal, Yucatán, Mexico
[4]Harte Research Institute for Gulf of Mexico Studies, Texas A and M University, International Chair for Coastal and Marine Studies, Corpus Christi, Texas, United States
[5]University of Aveiro, ECOMARE, CESAM, Department of Biology, Aveiro, Portugal

vital[at]ciencias.unam.mx

Abstract

Light determines the presence of a wide variety of marine species, including photosynthetic animals. *Elysia crispata* is a sea slug that can retain chloroplasts from the algae they feed on (i.e. kleptoplasts) and maintain them functional for several months to provide energetic products through photosynthesis. Its characteristically large size makes *E. crispata* an ideal model to study the ecology of photosynthetic animals. Light conditions could determine the abundance and size of this species because they constrain the obtaining of photosynthetic resources. Whilst research efforts have mainly focused on the relation between light and *Elysia´s* physiology and behavior, studies on its natural distribution are scarce. The aim of the present study was to describe and compare changes in size and abundance of three populations of *Elysia crispata* in the southern Gulf of Mexico (Verde and Arcas) and the Caribbean (Puerto Morelos) as a function of depth and time of day. We hypothesized that differences in abundance would be related to locality, time of the day and depth, and differences in size would be related to locality and time of the day. Using snorkeling and SCUBA diving, all individuals of *E. crispata* in each of ~8 quadrat (25 m^2) within each of ~8 transect (40 m) at each locality were counted and measured with a Vernier caliper (±0.1 mm). A total of 682 organisms of *E. crispata* was recorded in all three reefs at different times-of-day (sunrise, morning, zenith, evening, night) at depths ranging from 0 to 13 m. Zero Inflated Negative Binomial (ZINB) regressions adjusted to abundance data showed that *E. crispata* in reefs at Arcas and Verde is expected to be more abundant (> 50) in shallow depths (< 3 m) at any time of the day except sunrise, whereas a low abundance (< 1 organism) is predicted in Puerto Morelos at all depths considered. Sea slug size was found to be related to locality and time-of-day, with sea slugs from Arcas and Verde having similar size, and both larger than those in Puerto Morelos. Differences between populations from the GOM and Caribbean are discussed in terms of the dependency of both the quantity and quality of light on depth, turbidity and the sun’s angle at certain times of the day. Novel field information on the population biology of these photosynthetic animals allows for *Elysia’s* light preferences to be further explored.

Virtual
Poster
A-2116

An Assessment of Acropora palmata populations across Jamaica's north coast.

Maddix, G.-M.[1], Webber, M.[2]
[1]The University of the West Indies Mona Campus, Department of Life Sciences, Kingston 7, Jamaica
[2]The University of the West Indies Mona Campus, Centre for Marine Sciences, Kingston, Jamaica

ginamarie.maddix02[at]uwimona.edu.jm

Abstract

The Elkhorn Acropora palmata, a branching coral usually identified by its growth morphology and prevalence on the reef crest, was described in the 1950's as a dominant component of Jamaica's north coast reefs. More recently, A. palmata has been classified as critically endangered across its range and extensive stands of this distinctive species were reported to be rare on Jamaican reefs. Despite this, the actual distribution of this species across Jamaican reefs remains poorly studied. The purpose of this study is therefore to document the abundance and distribution of the north coast A. palmata populations to determine where they still occur, their health and any morphological and potential genetic variability within the population. Twenty-two sites across five different parishes were sampled via phototransects using snorkel and dive surveys. A total of 437 individual corals were found with the largest abundances recorded at Rio Bueno in Trelawny and just outside Discovery Bay, St. Ann. Only 32% of the corals counted were located in the traditional reef crest habitat zone, while 54% were located on the reef flat. The health status of the population varied spatially with Oracabessa in St. Mary having the greatest proportion of unhealthy (diseased, pale, mortality percentage) corals and Monkey Island, Portland having the greatest proportion of healthy corals. The reef crest supported a greater proportion of healthy individuals than any other zones. Three different growth morphologies were observed (especially across four of the sites); the traditional flat palmate form, an encrusting growth form and a thick elongated branching variety. The research will create a new baseline of A. palmata distribution, the environmental conditions in which they exist and ultimately facilitate conservation of this important species.

Keyword: Acropora palmata, coral survey, growth morphologies, reef health

Session 2B - How can we use phylogenetic tools to better understand biodiversity, evolutionary patterns, and processes?

Conceptualized by: **James Reimer**[1], **Danwei Huang**[2], **Francesca Benzoni**[3]
[1] University of the Ryukyus (Nishihara, Japan)
[2] National University of Singapore (Singapore)
[3] University of Milano-Bicocca (Milan, Italy)

Chaired by: **Danwei Huang**[1], **Gert Wörheide**[2]
[1] National University of Singapore (Singapore)
[2] LMU München (München, Germany)

Oral
A-1395

Implication of range overlap along the pacific tropical-temperate transition zone - genomic lessons from the genus Tripneustes

Bronstein, O.[1], Kroh, A.[2], Byrne, M.[3]
[1]Tel Aviv University, School of Zoology, Tel Aviv, Israel
[2]Natural History Museum Vienna, Vienna, Austria
[3]University of Sydney, Sydney, Australia

bronstein[at]tauex.tau.ac.il

Abstract

Sea urchins are among the most abundant and ecologically important marine invertebrates. Recognised as potent ecosystem engineers and highly valued for their gonads, wild populations of the genus Tripneustes are commercially exploited for fisheries and aquaculture and as bio-control agents. Recently, a new species, Tripneustes kermadecensis, was described from the southern Pacific Ocean, off the remote Kermadec Islands, near the tropical/sub-tropical transition zone. Here, we explore speciation and the range of Tripneustes species combining morphological and genetic tools. Integrating fossil records with novel genomic evidence we elucidate the potential mechanisms that have long masked species boundaries in this genus. We report, for the first time, the presence of a second Tripneustes species, T. kermadecensis, from Australia and show that this species is in fact highly abundant throughout most of the sub-tropical eastern Pacific, where it occurs in association with coral and temperate reefs. As commercial exploitation and stock-release programs of Tripneustes are rapidly expanding, and as global warming causes tropicalization of eastern Australia, driving the southern expansion of its congener T. gratilla, we call for re- evaluation of the conservation vulnerability of T. kermadecensis along the Australian continent and action by the aquaculture industry to genetically confirm the species identity of stocks in their facilities.

Session 2B - How can we use phylogenetic tools to better understand biodiversity, evolutionary patterns, and processes?

Oral
A-1223

Barcoding and phylogenetic analyses of reef-building Porites corals in Micronesia

Combosch, D.[1], Rios, K.[2], Fernandez, J.[1], Rios, D.[1], Primov, K.[1], Burdick, D.[1]
[1]University of Guam, Marine Laboratory, Mangilao, Guam
[2]University of Guam, College of Natural and Applied Sciences, Mangilao, Guam

comboschd[at]triton.uog.edu

Abstract

Coral reefs are the most diverse ecosystem on the planet based on the abundance and diversity of phyla and other higher taxa. However, it is still very difficult to assess the abundance of lower taxa, particularly at the species level. This is of particular significance since proper species identification is the basis for any type of study, quantification or description of nature. Morphologic species identification is complicated by inconspicuous cryptic species and phenotypic plasticity can blur species boundaries. This is most prominently true for the foundational taxa of coral reefs as well, reef-building scleractinian corals. One potential remedy are genetic markers than can be used to unequivocally identify cryptic species and assess species boundaries.
Here, we present one such approach for a particularly important and challenging group of reef-building corals. *Porites* corals are the main reef-builders of many coral reef in the Indo-Pacific due to their general abundance and the massive growth forms of some *Porites* species. The current number of *Porites* species is controversial, and several common species can only be distinguished based on detailed microstructure analyses by taxonomic experts. We therefore test a genetic barcoding approach to identify the most suitable genetic marker to facilitate species differentiation and provide unambiguous identification - for example for the *Porites* collection in the UOG Biorepository. In addition, we compare our results with genome-wide RAD-Seq data to assess the resolution and validity of mtDNA derived species delimitations. This is useful and timely information for ongoing experimental, ecological and physiological research at the UOG Marine Lab and elsewhere. We combine this barcode developing work with a first phylogenetic analyses of Guam's *Porites* species, which we will develop further in the near future.

Oral
A-1136

Biogeography, connectivity and evolution of the Atlantic oceanic islands

Cord, I.[1], Floeter, S. R.[2]
[1]Universidade Federal de Santa Catarina, ECZ, Florianopolis, Brazil
[2]Universidade Federal de Santa Catarina, ECZ, Florianópolis, Brazil

sergiofloeter[at]gmail.com

Abstract

Oceanic islands are “natural laboratories” for biogeographic and evolutionary studies, as they are highly isolated, small and with recent geological histories. Using the most complete and updated database of geographic distribution of reef fish, we have studied the faunal similarities among eleven tropical and warm temperate oceanic islands (or archipelagos) in the Atlantic and their relationships with the Western and Eastern coastlines of the Atlantic. We also compiled phylogenetic and phylogeographic studies to identify genetic connectivity at ecological and evolutionary timescales. The Brazilian oceanic islands are biogeographically (greater sharing of species) and evolutionarily (phylogenetic relationships) more related to the coast of Brazil. The islands of the Gulf of Guinea and Cabo Verde have multiple connections with the African coast, the Western Atlantic, as well as with the Indian Ocean. The islands of Ascension and St Helena located in the Mid-Atlantic Ridge almost equidistantly between the coasts of South America and Africa, have greater biogeographical connectivity between the two islands as well as with the Western Atlantic. However, when investigating the evolutionary hypotheses through a chronologically and taxonomically broad phylogenetic approach, we observed a strong link between the species endemic to these two islands and the Eastern Atlantic revealing that most of the endemics are historically connected to this region of the Atlantic. Interestingly, some endemics are older than the age of the island where they live, which demonstrates the historical-evolutionary complexity of these islands, including the potential importance of seamounts in the region. The ecological and evolutionary connectivity is key to the understanding of community assembly of isolated islands over time.

Oral
A-1157

Fine-mapping of colour pattern variation in the Caribbean hamlets provides insights into the genomic bases of phenotypic diversification

Coulmance, F.[1], Akkaynak, D.[2], Le Poul, Y.[3], McMillan, W. O.[4], **Puebla, O.**[1]
[1]Leibniz Centre for Tropical Marine Research (ZMT), Bremen, Germany
[2]Inter University Institute for Marine Science (IUI), Eilat, Israel
[3]Ludwig-Maximilians-Universität München, Munich, Germany
[4]Smithsonian Tropical Research Institute (STRI), Panama, Panama,

oscar.puebla[at]leibniz-zmt.de

Abstract

Coral reef fishes live in a highly visual environment and display a stunning diversity of colour patterns that play a fundamental role in their ecology and evolution. Nevertheless, colour pattern is a complex trait in reef fishes - a collection of traits actually - that is difficult to analyse objectively and quantitatively. Here, we address this challenge with a fully automated, standardized and quantitative approach to the analysis of colour pattern variation that we apply to the hamlets (*Hypoplectrus* spp, Serranidae), a group of reef fishes from the wider Caribbean that is characterized by a spectacular diversity of colour patterns. Furthermore, we complement colour pattern analysis with whole-genome analysis of 113 samples from 13 species and 4 locations. This approach allows to i. analyse colour pattern variation objectively and quantitatively, ii. identify sharp peaks of genotype-phenotype (G x P) association along the genome, and iii. visualize the phenotypic effects of the Single Nucleotide Polymorphism (SNP) markers that are most strongly associated with colour pattern variation. The results indicate that the modular combination of a small number of large-effect loci that are each associated with different components of colour pattern variation (bars, marks, colour, ...) underlie phenotypic diversification in this group of reef fishes.

Oral
A-1523

Combining DNA metabarcoding and co-occurrence network analysis to unravel bacterial-metazoan diversity and interactions in Red Sea coral reefs

Daraghmeh, N.[1], Marasco, R.[1], Aylagas, E.[1, 2], Pearman, J.[3], Villalobos, R.[1], Solà, J.[4], Wild, C.[5], Daffonchio, D.[1], Carvalho, S.[1]
[1]Red Sea Research Center, Biological and Environmental Sciences and Engineering Division, King Abdullah University of Science and Technology, Thuwal, Saudi Arabia
[2]The Red Sea Development Company, Riyadh, Saudi Arabia
[3]Coastal and Freshwater, Cawthron Institute, Nelson, New Zealand
[4]Biosciences Department, College of Science, Swansea University, Swansea, United Kingdom
[5]Marine Ecology Department, Faculty of Biology and Chemistry, University of Bremen, Bremen, Germany

naurasd[at]gmail.com

Abstract

In the past decades, coral reef ecology has largely focused on the community dynamics of conspicuous, macrobiotic components. Despite playing key structural and functional roles within coral reef ecosystems, knowledge of the reef cryptobiome (i.e., small organisms inhabiting cryptic spaces of the reef framework) and associated microbes remains limited. This lack of understanding prevents us from predicting future responses of these ecologically significant biota to global climate change and local anthropogenic impacts. Here, we addressed this issue by investigating the diversity, structure and networking patterns of coral reef-associated bacterial and metazoan communities across a latitudinal environmental gradient in the Red Sea. Two sets of 33 Autonomous Reef Monitoring Structures (ARMS, 66 units in total) were deployed in 11 reefs along the Saudi Arabian Red Sea coastline spanning 11° of latitude. Each set of ARMS remained submerged at depths between 8 and 12 m for approximately 2 years. Bacterial and metazoan communities colonizing ARMS were assessed by DNA metabarcoding of 16S ribosomal RNA and mitochondrial cytochrome c oxidase subunit I genes, respectively, with subsequent high-throughput amplicon sequencing. We then applied a novel approach, combining diversity and co-occurrence network analysis to unravel spatiotemporal patterns in diversity (i.e., alpha and beta diversity) and bacterial-metazoan taxa networking across Red Sea regions. Our presentation will summarize how the distinct environmental conditions found along the latitudinal gradient drive biodiversity, co-occurrence network complexity and connectivity, presence of putative keystone taxa, and computed taxa interactions (i.e., co-occurrence and mutual exclusion). The combined investigation of prokaryotic (bacteria) and eukaryotic (metazoans) organisms colonizing ARMS can help deepen the understanding of coral reef community dynamics. We propose this framework as a unique analytical tool that goes beyond commonly performed biodiversity assessments in coral reefs by adding the dimension of the potential interactions in understudied reef biota.

Oral
A-1994

Widespread introgressive hybridization in the Caribbean coral genus Madracis

Frade, P.[1], Goodbody-Gringley, G.[2], Latijnhouwers, K.[3], Hoey, J.[4], Arrigoni, R.[5], Benzoni, F.[5], Muir, P.[6], Bongaerts, P.[4]
[1]Natural History Museum Vienna, Vienna, Austria
[2]Central Caribbean Marine Institute, Little Cayman, Cayman Islands
[3]CARMABI Foundation, Willemstad, Curaçao
[4]California Academy of Sciences, San Francisco, United States
[5]King Abdullah University of Science and Technology, Red Sea Research Center, Thuwal, Saudi Arabia
[6]Museum of Tropical Queensland, Townsville, Australia

pedro.frade[at]nhm-wien.ac.at

Abstract

Species boundaries in scleractinian corals remain highly elusive due to conflicting patterns between morphological and molecular phylogenies, often caused by morphological plasticity, the occurrence of cryptic species, or transient phases of evolution such as incomplete lineage sorting (speciation) and introgressive hybridization (fusion). Here, we use reduced representation genome sequencing (nextRAD) to infer phylogenetic relationships among a group of closely related species in the Caribbean coral genus *Madracis,* combined with a detailed micro-morphometric characterization and compilation of their life history traits (reproduction, distribution, associated symbiont lineages) to generate a detailed elucidation of the evolutionary ecology of this Caribbean coral genus. Concatenation-based phylogenetic analyses and coalescent-based trees (based on 268,839 loci across 78 *Madracis* samples) generate unprecedented resolution of species relationships in the genus, with five out of six recognized morphospecies becoming reciprocally monophyletic, a result contrasting with little resolution in mitochondrial phylogenies used as comparison. Furthermore, the genome-wide approach contributed to resolve geographical variation (between Bermuda and Curacao) and to unveil undescribed diversity linked to depth-divergence in the genus. The non-monophyletic morphospecies, *M. pharensis*, was represented across clades in the tree. Signatures of admixture and tests of introgressive hybridization showed that with the exception of a well-defined lineage in deep water, most *M. pharensis* specimens are actually introgressed individuals. This variable and highly divergent genetic background shows that the *M. pharensis* phenotype does not correspond to an isolated species entity but it rather results from widespread hybridization in the genus. Given the abundance of this phenotype on the reef, its broad depth distribution and wide morphological plasticity are supportive of a highly adapted lineage. Overall, we argue the possibility that hybridization and pervasive gene flow are not necessarily transient (recent/ongoing) phases of evolution, but might be advantageous under certain conditions and therefore selected for to remain in the gene pool, thus establishing what can be interpreted as a *Madracis* syngameon. Pervasive gene flow among closely related species may be an assurance of adaptability and gene persistence in the reef, in particular with respect to climate change pressures.

Oral
A-1069

Coral cryptic lineages segregate across a depth cline on the Caribbean

Gómez-Corrales, M.[1], Medina, M.[2], Prada, C.[1]
[1]University of Rhode Island, Biological Sciences, Kingston, United States
[2]The Pennsylvania State University, Department of Biology, State College, United States

matias_gomez[at]uri.edu

Abstract

Cryptic diversity often harbors different physiological variation that allows cryptic species, morphologically similar yet genetically distinct groups, to occupy heterogeneous habitats and respond distinctly to environmental variation. Therefore, the discovery of cryptic species and their distribution are key to understanding ecosystem functioning and implementing successful conservation strategies. Genomic data facilitates the detection of such species, a task not always achievable with traditional molecular markers, or morphology, alone. The mountainous star coral, *Orbicella faveolata*, is a major Caribbean reef builder listed as threatened due to increasing water temperatures and habitat losses. We explored *O. faveolata* genome-wide, morphological, and environmental (temperature, light, and DO_2) variation across a depth cline (5-20 m) at Media Luna Reef, Puerto Rico. Based on over 20,000 single nucleotide polymorphisms and polyp density from 103 individuals, we uncovered two genetically ($F_{ST} = 0.18$) and morphologically (W = 616.5, $p < 0.01$) divergent lineages that inhabit opposite depths of the cline, with a mixed zone around 11-14 meters. A historical demographic reconstruction of these genetic lineages yielded a scenario of recent divergence (~200 Kyr) coincident with sea-level changes, after which both shallow and deep lineages experienced population expansions with two-way asymmetric migration events. Further, reciprocal transplants of shallow and deep micro-fragments (n = 1,600) presented differential survivorships. Shallow colonies transplanted to the deep had a survivorship below 40 %, whereas those placed back to their natal habitat had a survivorship of 66 %. In contrast, deep colonies performed similarly well in shallow and deep habitats (~75 % survivorship). Our results indicate that these two *O. faveolata* cryptic lineages occupy distinct habitats, where the shallow colonies are specialized to shallow environmental conditions, while deeper corals exhibit more habitat flexibility. Misidentifying the ecological and physiological ranges of individual species by overlooking cryptic coral diversity may result in unsuccessful conservation and restoration efforts.

Oral
A-1749

Does a coral community fit in two liter water? An environmental DNA metabarcoding approach for the reefs of Koh Phangan, Thailand.

Gösser, F., Mittelbach, P., Tollrian, R., Schweinsberg, M.
Ruhr University Bochum, Department of Animal Ecology, Evolution and Biodiversity, Bochum, Germany

fabian.goesser[at]rub.de

Abstract

Information on diversity indices and abundance of individual species is critical for proper assessment of ecosystem health, especially for endangered species such as hermatypic corals. However, the application of environmental DNA (eDNA) to monitor coral biodiversity is just beginning to come into focus for marine biologists. To determine the relationship between coral abundance and eDNA reads, a metabarcoding approach was used for filtered and extracted water samples. A region of the COI gene was amplified and sequenced and compared to the relative abundance of corals from visual surveys at three different reef sites on Koh Phangan, Thailand. To determine possible diurnal variation, eDNA samples collected during the day and night were compared. As a technical extension, a comparison was made between two different methods of library preparation (commercial kit vs. custom fusion primers). A Koh Phangan-specific coral barcode library was also created.
Combining eDNA metabarcoding and visual data, 28 different genera of scleractinian corals from 14 families were found. Overlap between the visual surveys and the eDNA data was found for 17 genera. In addition, a correlation was found between the abundance of eDNA reads and visually determined percent coral cover, suggesting a predictive relationship between eDNA reads and coral cover. Although diurnal variation was not expected for sessile organisms, the results showed differences between day and night samples. This is likely related to the activity phases of corals and indicates the need to coordinate sampling with the activity phases of the target organisms.
The use of uniquely labeled fusion primers, which are inexpensive if used frequently, produced similar results to a commercially available library preparation kit. Using a custom reference database of 89 sequences from coral tissue samples of 23 different coral genera produced better results than querying against the NCBI GenBank, highlighting the importance of locally optimized databases.
We consider these results important for establishing eDNA as a complementary tool to visual surveys to track changes in coral diversity and cover due to climate change and other disturbances.

Session 2B - How can we use phylogenetic tools to better understand biodiversity, evolutionary patterns, and processes?

Oral
A-1663

World List of Scleractinia (WoRMS): the role of phylogeny reconstructions

Hoeksema, B.[1, 2], Cairns, S.[3]
[1]Naturalis Biodiversity Center, Leiden, Netherlands
[2]University of Groningen, Groningen Institute for Evolutionary Life Sciences, Groningen, Netherlands, [3]Smithsonian Institution, Department of Invertebrate Zoology, National Museum of Natural History,, Washington, D.C, United States

bert.hoeksema[at]naturalis.nl

Abstract

The World List of Scleractinia, as part of the World Register of Marine Species (WoRMS), is a database of scleractinian species names. It contains approximately 1680 valid names and over 4200 synonyms of extant species. The ratio of valid species with zooxanthellae vs. those without them is 48/52. The largest family is Caryophylliidae with 305 azooxanthellate species, whereas Acroporidae is second with 270 zooxanthellate species. As a result of phylogeny reconstructions applied to taxonomic revisions, many species were moved to another genus or even to another family during the last three decades. These revisions were first based on morphological cladistics and in the last decade mostly on molecular analyses. Despite the recognition of cryptic taxa, the discovery rate of new taxa has not clearly increased and has even slowed down, except for azooxanthellate species. Maybe the number of unknown scleractinians is getting low. Some of them were synonymized and became rediscovered with old names available for reinstatement. Also, the timespan in which phylogenetic tools have been applied is still short and many scleractinian families and genera are still in need of taxonomic revisions. Since most phylogenetic analyses involved shallow-water scleractinians, there is still a high potential for the discovery of deep-sea species.

Oral
A-1610

Molecular operational taxonomic units reveal biogeographic distributions and regional endemicity in zooxanthellate soft corals

McFadden, C. S.[1], Lane, A.[1], Erickson, K.[1], Benayahu, Y.[2]
[1]Harvey Mudd College, Biology, Claremont, CA, United States
[2]University of Tel Aviv, School of Zoology, George S. Wise Faculty of Life Sciences, Tel Aviv, Israel

mcfadden[at]g.hmc.edu

Abstract

Octocorallia is a species-rich sub-class of anthozoan cnidarians that includes many of the most prominent, ecologically dominant, and structurally important sessile macro-organisms found in all oceans, including shallow tropical reef and deep sea environments. Gaps in our knowledge of the taxonomy of the group and the inadequacy of many early taxonomic descriptions, along with poorly understood, environmentally plastic morphological traits, make species-level identification challenging—sometimes even impossible—for most of the >3000 described taxa of octocorals. As a result, names cannot be assigned reliably to many species belonging to even the most common genera of octocorals found on Indo-Pacific reefs, a situation that hinders understanding of fundamental aspects of their biology, including species diversity, biogeography, depth distributions, and community interactions. These problems are exemplified within the widespread and ecologically dominant zooxanthellate soft coral families Alcyoniidae and Xeniidae, the primary spatial competitors of scleractinian corals on many reefs. We used multilocus molecular barcodes to assign alcyoniids and xeniids to molecular operational taxonomic units (MOTUs) as proxies of species, and surveyed their biodiversity at locations spanning the Indo-Pacific. Among Xeniidae, few MOTUs were shared among sites, suggesting high levels of regional endemicity by species with narrow geographic ranges. Among Alcyoniidae, geographic ranges of MOTUs were greater and endemicity less pronounced, although many MOTUs were nonetheless restricted to either the western Indian or western Pacific Oceans. These different biogeographic patterns among families may reflect differences in their dispersal potential. To date, most alcyoniids are known to be broadcast spawners while most xeniids brood larvae; the former mode of reproduction is suggested to lead to higher dispersal capabilities. In both families, however, geographic ranges are more restricted than expected based on the present literature, suggesting the occurrence of unrecognized cryptic species complexes, and emphasizing the need for major revisionary taxonomic studies to synthesize the molecular findings. A thorough re-examination of historical museum collections, including sequencing of type material, is necessary to revise our understanding of past and present species distributions on Indo-Pacific coral reefs.

Oral
A-1867

Genomic evidence for punctuated equilibrium as the mode of coral symbiont evolution

Parkinson, J.[1], Hume, B.[2], Baumgarten, S.[3], Avila-Magana, V.[4], Medina, M.[5], Voolstra, C.[2], LaJeunesse, T.[5]
[1]University of South Florida, Integrative Biology, Tampa, United States
[2]University of Konstanz, Konstanz, Germany
[3]Institut Pasteur, Paris, France
[4]University of Colorado Boulder, Boulder, United States
[5]Pennsylvania State University, State College, United States

jeverettparkinson[at]gmail.com

Abstract

Genomic evidence for gradualism as the mode of coral symbiont evolution

Since the time of the dinosaurs, mutualisms between corals and dinoflagellate micro-algae (family Symbiodiniaceae) have sustained coral reef ecosystems through major episodes of climate change. As present-day ocean waters warm, reef persistence will depend on the ability of the micro-algal partner to evolve rapidly. To date, analyses of molecular evolution among Symbiodiniaceae have exclusively compared species from different genera separated by ~80-120 million years. These efforts have revealed highly divergent genes and genomes between genera, but offer little insight into how genetic changes explain ecophysiological differences between closely-related, congeneric species. Here, we sought to understand how natural selection influences molecular evolution during processes of ecological specialization and ultimately speciation among symbionts that diverged <5 million years ago. We analyzed ~7,000 *bona fide* protein-coding orthologs shared among six species spanning two divergent lineages within the genus *Breviolum*. We found that the total number of genes under positive selection correlated linearly with the molecular divergence between species pairs, consistent with a gradual tempo of evolution, and that there was little overlap with previously identified differentially expressed genes among the same species. By comparing mutualistic and putatively free-living species, we identified several biochemical pathways subject to selection based on symbiosis ecology, such as those associated with transcriptional regulation, the cell wall, and responses to environmental cues. Results remain preliminary as key challenges limit our capacity to interpret aspects of Symbiodiniaceae molecular data in a comparative framework owing mostly to the lack of high-quality genomes from multiple species within each genus. Nevertheless, our investigation provides novel insights into gradual genetic changes underpinning speciation among Symbiodiniaceae with implications for understanding evolutionary processes in other micro-eukaryotes.

Session 2B - How can we use phylogenetic tools to better understand biodiversity, evolutionary patterns, and processes?

Oral
A-1863

Phylogenomics of stony corals via target enrichment

Quek, R.[1], Jain, S.[1], Arrigoni, R.[2], Benzoni, F.[3], Carvajal, J.[4], Kitahara, M. V.[5], Richards, Z.[6], Rouse, G.[7], Vaga, C.[5], Wilson, N.[8], Huang, D.[1]
[1]National University of Singapore, Singapore, Singapore
[2]European Commission, Joint Research Centre (JRC), Ispra, Italy,
[3]King Abdullah University of Science and Technology, RSRC, Thuwal, Saudi Arabia
[4]Western Australia Museum, Perth, Australia
[5]Universidade Federal de São Paulo, Sao Paulo, Brazil
[6]Curtin University, Perth, Australia
[7]Scripps Institution of Oceanography, La Jolla, United States
[8]Western Australia Museum, Perth, Australia, Perth, Australia

randolphquek[at]nus.edu.sg

Abstract

Forming some of the most diverse marine ecosystems in the world, stony corals are of great ecological and economic importance. However, the phylogeny of Scleractinia remains uncertain despite centuries of research, largely due to uneven taxon sampling and a paucity of consistent markers across clades. Today, phylogenomics is increasingly used for clarifying phylogenetic relationships across the tree of life, and target enrichment of loci based on hybrid-capture ranks high in popularity due to their cost-effectiveness and accessibility. In this study, over a hundred coral species were sequenced by enriching and analyzing 449 phylogenetically informative loci across 865 exon regions following stringent filtering parameters, reconstructing one of the largest scleractinian phylogenomic trees to date. Furthermore, we estimated the origin and diversification of coral clades using available fossils for time calibration and conducted preliminary trait evolution analyses. The method outlined here is based on a consistent set of loci that facilitates the pooling of data across studies, building the fundamentals for a robust and comprehensive scleractinian phylogeny for future applications.

Oral
A-2001

Population structure and genetic connectivity of the excavating sponge Cliona delitrix in a small Caribbean island

Trew, H.[1], Segura-Garcia, I.[2], Chaves-Fonnegra, A.[2], Valles, H.[1]
[1]The University of the West Indies, Cave Hill Campus, Bridgetown, Barbados
[2]Florida Atlantic University, Harbor Branch Oceanographic Institute, Fort Pierce, United States

hvtrew[at]gmail.com

Abstract

Excavating sponges are among the most important bioeroders on Caribbean reefs and are of increasing concern as reefs continue to degrade. This regional decline is due to a variety of stressors which leave corals vulnerable to colonization and overgrowth by *C. delitrix*. The larvae of this sponge have never been observed, which has limited our understanding of its population dynamics, including mechanisms and capacity for dispersal. In this study we have sought to shed light on the genetic connectivity of populations of *C. delitrix* in Barbados, a small (400 km^2) Caribbean island, at multiple spatial scales: within sites (at distances of tens of meters); among sites (across 13 sites around Barbados, 2 to 40 kilometers apart); and among Atlantic geographic locations (Barbados, Florida and Belize; 1,000s of kms apart). The genetic relationships of 346 sponges have been analysed using 2b-RAD genotyping. The 2b-RAD method is a type of single nucleotide polymorphism (SNP) genotyping that uses restriction site-associated DNA (RAD) tag sequencing with restriction enzymes and next-generation sequencing methods. A biophysical ocean model of larval dispersal will be developed to help explain the spatial patterns of connectivity revealed. Finally, these connectivity data will be compared to sponge demographic data (size-structure, abundance and growth) from 1019 *C. delitrix* outcrops derived from *in situ* benthic surveys at seven of the sampled sites, which have so far revealed high variability in demographic rates among sites over a 26-month period. Our work seeks to (1) shed light onto the spatial scale and processes underlying *C. delitrix* population connectivity in small Caribbean islands, and (2) assess links between sponge population connectivity and coral reef bioerosion, an ecological process that underpins the long-term persistence of coral reefs. This is also the first use of 2b-RAD genotyping to characterize any sponge population structure in the Caribbean Sea.

Oral
A-1943

High partner fidelity in coral-dinoflagellate mutualisms maintained for millions of years across the Indo-Pacific

Turnham, K.[1], Wham, D.[2], Sampayo, E.[3], LaJeunesse, T.[2]
[1]Pennsylvania State University, State College, United States
[2]Penn State University, University Park, United States
[3]The University of Queensland, St Lucia, QLD, Australia

ket7[at]psu.edu

Abstract

Species recognition is essential for assessing ecological and evolutionary processes. Moreover, species as a fundamental unit in biology define ecological niches and provide the basis of biodiversity estimates. The majority of reef corals on the planet depend on dinoflagellate symbionts in the genus *Cladocopium* (formerly *Symbiodinium* Clade C). This dominant group contains hundreds of genetically differentiated lineages that have distinct geographic distributions and exhibit diverse physiological and ecological attributes. However, there is virtually no taxonomy for this microalgal assemblage. We endeavored to describe symbiont species occurring in the common branching coral genus *Pocillopora* across the Indo-Pacific Ocean using genetic, morphological and ecological evidence. One species, *C. latusorum*, occurred predominantly in *P. grandis/meandrina* (=*P. eydouxi*) from the western Indian Ocean to the eastern Pacific Ocean. A second species, *C. pacificum* n. sp., was widespread in the Pacific in colonies of *P. verrucosa*. Both symbiont species form mutualisms with Pocillopora that brood their young. Molecular clock estimates place the age of these species at ~ 2 my, and provides evidence for placement of the most recent common ancestor of all *Cladocopium* to the early or mid Miocene. These findings highlight the large geographical breadth of certain symbionts and their coral hosts, the importance of host specialization on species diversification, and the ability of particular host-symbiont pairings to adapt to a broad range of environmental conditions. Lastly, the distinction of these two closely related species exemplifies the diversity within this vast genus and the hundreds of *Cladocopium* species awaiting formal descriptions.

Session 2B - How can we use phylogenetic tools to better understand biodiversity, evolutionary patterns, and processes?

Oral
A-1441

Diversity of the stony coral family Agariciidae from the Saudi Arabian Red Sea

Vimercati, S.[1], Terraneo, T. I.[1], Arrigoni, R.[2], Abdulla Eweida, A.[3], Rodrigue, M.[4], Benzoni, F.[1]
[1]King Abdullah University of Science and Technology, Red Sea Research Center, Thuwal, Saudi Arabia
[2]Stazione Zoologica Anton Dohrn Napoli, Department of Biology and Evolution of Marine Organisms (BEOM), Naples, Italy
[3]NEOM, Riyadh, Saudi Arabia
[4]OceanX, New York, United States

silvia.vimercati[at]kaust.edu.sa

Abstract

The family Agariciidae is an ecologically important component of shallow and mesophotic coral reefs and includes a deep water azooxanthellate representative. However, this morphologically diverse and species rich family remains poorly studied, and very limited information is currently available on its genetic diversity and species boundaries. The Red Sea is a semi-enclosed basin connected to the Indian Ocean that has long been recognized as a region of high marine biodiversity and endemism, with 17 scleractinian coral families found and 6.4% of coral species endemic. There, 4 Agariciidae genera, Leptoseris, Pavona, Gardineroseris, and Dactylotrochus, and 26 nominal species have been recorded. While the occurrence of agariciids at mesophotic depths is well documented in the Gulf of Aqaba, almost no information is available for the rest of the Red Sea. Recently, twenty agariciid nominal species from the shallow Red Sea were included in the first genetic assessment of the family diversity in the basin showing genus level polyphyly and unresolved species boundaries. Here, we assess the northern Red Sea and Gulf of Aqaba Agariciidae genetic diversity including material collected between 1 and 510 m. The skeletal macromorphology of the examined material was used to identify the specimens based on taxonomic descriptions and type material. A highly variable mitochondrial marker (IGR), used in previous studies of the family, was used to obtain a phylogenetic tree. Overall, 27 morphospecies were encountered in the Red Sea, 5 of which do not correspond to any described material. Although most examined morphospecies corresponded to monophyletic clades, others resulted polyphyletic, with Red Sea specimens retrieved in distinct clades from those including material from the species Indo-Pacific type localities. Moreover, other morphologically different species were recovered in the same clade based on the used marker. This study represents the first molecular phylogeny including mesophotic and deep Agariciidae from the Red Sea and provides the first assessment of the depth distribution of the morpho-molecularly defined lineages in the basin. Our results showed the occurrence of a highly diversified Red Sea Agariciidae fauna, with several new species level lineages, some of which likely endemic. However, they also highlighted the need for a more in depth investigation of the family diversity and phylogenetic relationships, ideally through a genomic approach.

Oral
A-1657

Towards resolving the crown-of-thorns sea star (Acanthaster 'planci') species complex, and a new species from the Red Sea

Wörheide, G.
Ludwig-Maximilians-Universität München, GeoBio-Center, München, Germany

woerheide[at]lmu.de

Abstract

The crown-of-thorns sea star (COTS) *Acanthaster 'planci'* is a coral predator distributed throughout the Indo-Pacific, well known for its so-called 'mass-outbreaks', where thousands of suddenly appearing individuals can devastate coral reefs quickly. Despite the scientific focus on the biology and outbreaks of COTS, the taxonomy of this species has been problematic. For a long time, *Acanthaster 'planci'* has been thought to be a single widely-distributed species. However, DNA barcoding data showed in 2008 that this 'species' consists of four deeply divergent clades with largely non-overlapping geographical distribution, representing at least four distinct species. One clade/species was restricted to the Red Sea, the second one to the Northern Indian Ocean, the third one to the Southern Indian Ocean (both were found to overlap in the Gulf of Oman), and the forth one encompassed specimens from the whole Pacific, and overlapped with the Northern Indian Ocean clade in the area north of Jakarta (Indonesia). More recently, previously available species names were *ad hoc* assigned to three of the clades based on the geographic location of the respective species type locality, except the one from the Red Sea for which no name was available. Here, the current state of affairs is briefly reviewed and names assigned for each of the clades, in an effort to aid future studies of this coral predator with a more stable taxonomy and nomenclature. Furthermore, a new COTS species from the Red Sea is introduced and named.

Poster
A-1541

Species delimitation in the zooxanthellate soft coral genus Rhytisma guided by phylogenomics

Abadiano, A. J.[1], Quattrini, A. M.[2], Durkin, K.[3], Ekins, M.[4], Benayahu, Y.[5], McFadden, C. S.[3]
[1]University of the Philippines, Marine Science Institute, Quezon, Philippines
[2]National Museum of Natural History, Smithsonian Institute, Invertebrate Zoology, Washington, DC, United States
[3]Harvey Mudd College, Biology, Claremont, CA, United States
[4]Queensland Museum, South Brisbane BC, Queensland, Australia
[5]University of Tel Aviv, School of Zoology, George S. Wise Faculty of Life Sciences, Tel Aviv, Israel

mcfadden[at]g.hmc.edu

Abstract

Zooxanthellate soft corals are a conspicuous and ecologically important component of Indo-Pacific marine communities, where mixed-species assemblages often dominate primary space on shallow-water coral reefs. Despite their ubiquity, the taxonomy of these familiar genera remains poorly known with many species undescribed or unidentifiable. The genus *Rhytisma* was established by Alderslade, 2000 to accommodate four species of encrusting, zooxanthellate soft corals previously assigned to *Alcyonium* Linnaeus, 1758. *Rhytisma fulvum* (Forskål, 1775) is a commonly encountered denizen of shallow to mesophotic coral reefs throughout the Red Sea. The other three nominal species of *Rhytisma* are poorly known, having been documented only rarely since their original descriptions (type localities Zanzibar, Madagascar and the Great Barrier Reef). Uncertainty regarding the diagnostic morphological characters used to distinguish *Rhytisma* species has instead led to specimens collected from throughout the Indian and Pacific oceans being attributed to *R. fulvum*. Here, we used a target-enrichment approach to sequence an average of 1500 ultraconserved elements (UCE) and exon loci in addition to sequencing two standard barcode loci (*mtMutS*, *28S rDNA*) from *Rhytisma* collected from locations throughout the Indo-Pacific. Phylogenetic and phylogenomic analyses reveal at least seven molecular operational taxonomic units (MOTUs) suggested to represent different species. Results of scanning electron microscopy support these MOTUs as distinct morphospecies distinguished mainly by unique forms, sizes and arrangements of the sclerites found in the polyps. In addition, each MOTU occupies a limited geographic range, suggesting high regional endemism in this genus known to reproduce by surface-brooding. The concordance between molecular, morphological and biogeographical evidence for species boundaries allows us to validate the existing nominal species of *Rhytisma* as well as describe new ones.

Poster
A-1861

Island biodiversity and phylogeny on coral reef communities in the wake of ecological risks associated with port development in a developing country

Belford, S.
University of Tennessee Southern, Biology, Pulaski, United States

sbelford[at]martinmethodist.edu

Abstract

Caribbean coral reef communities continue to follow the global trend of facing demise or adaption due to current ecological crises. Each year, higher temperatures are recorded, together with coral mortality, and increased anthropogenic stressors, which aggressively counteract coral growth and distribution. Development and pollution threaten Caribbean reefs. Annual biodiversity monitoring from 2005-2022 using line and point, video, and quadrat techniques maintain data collection for benthic coverage on reef communities at sites located along the northeastern coast of Trinidad. Genetic techniques analyzed species diversity, which looked at intricate relationships of local species in comparison to other Caribbean islands. For approximately 15 years, research conducted at these sites, have improved local knowledge of a mixture of undefined patch reefs and fringing reef. Over 257 species have been identified thus far, with average cnidarian coverage between 30-45% at sites. Important invertebrate species, such as the rock-boring sea urchin (*Echinometra lucunter*) showed high population densities and sizes in low wave energy, compared to high wave energy environments. Phylogenetic analyses revealed zoantharian, sea urchin, and *Symbiodinium* species diversity in this region, with color morphotypes of zoantharians and sea urchins showing specific genetic identities. *Symbiodinium* species diversity highlighting species, such as *Symbiodinium microadriaticum* within the colonial zoanthid: *Palythoa caribaeorum*. Current records for cnidarian species phylogeny continue to show that this region is a unique, however a current push to develop a local port in the area threatens a complete halt on research, and a 100% loss of benthic reef communities at an invaluable site. This ecological crisis may only be averted with data presentation, publication, and change in attitudes towards marine environments.

Poster
A-1305

Taxonomy of the genus Cladiella (Octocorallia) with an emphasis on the Red Sea species

Lazar, E.[1], McFadden, C. S.[2], Huchon, D.[1], Benayahu, Y.[1]
[1]Tel Aviv University, Tel Aviv, Israel, [2]Harvey Mudd College, Claremont, California, United States

einavlazar4[at]gmail.com

Abstract

Soft corals of the genus *Cladiella* Gray, 1869 are common on the Indo-Pacific coral reefs, as well as in the Red Sea. At present, 63 morphospecies of the genus are listed in WoRMS, reflecting the extensive biogeographical distribution of this genus on many reefs. Among them, 24 species were originally described from the Red Sea, including the oldest known species of the genus: *C. brachyclados* (Ehrenberg, 1834), *C. pachyclados* (Klunzinger, 1877), and *C. sphaerophora* (Ehrenberg, 1834). The only existing taxonomic revision of the genus is by Tixier-Durivault, published in 1948, who earlier described 19 species new to this genus from the Red Sea. The goal of the current study is to re-examine using both light and scanning electron microscopy (SEM) the *Cladiella* type-material from the Red Sea in order to validate the morphological features present in each species. The diagnostic morphological features of the types used by us include colony morphology as well as shape and size-range of their sclerites, obtained from different parts of the colonies. The sclerites of all examined species include dumbbells, and most species also have polyp sclerites featuring a figure-eight morphology. SEM examination provided for the first time the detailed sclerite microstructure and dimensions for the historic Red Sea type-material. In some cases, the findings correspond to the descriptions appearing in Tixier-Durivault's revision, such as for *C. hicksoni* (Tixier-Durivualt, 1944) and *C. sphaerophora*, but for others they are contradictory when sclerites morphology was examined (e.g., *C. pachyclados* and *C. brachyclados*). Interestingly, the current findings for *C. pachyclados* correspond to Klunzinger's original description but Ehrenberg's description of *C. brachyclados* is incomplete and therefore a comparison to the current findings cannot be made. To conclude, the examination of *Cladiella* type material and its re-description, along with the collection of relevant fresh material from the type localities, is the first step to link each morphospecies to a molecular taxonomic operational unit (MOTUs). Such a study is critical in order to delineate species boundaries and to recognize biodiversity patterns across different biogeographic regions.

Session 2B - How can we use phylogenetic tools to better understand biodiversity, evolutionary patterns, and processes?

Virtual
Oral
A-2206

When does taxonomy matter?

Baird, A. H.[1], Bridge, T. C. L.[1, 2], Cowman, P. F.[1, 2], Miller, D. J.[1, 3]
[1]ARC Centre of Excellence for Coral Reef Studies, James Cook University, Townsville, Australia
[2]Biodiversity and Geosciences Program, Museum of Tropical Queensland, Townsville, Australia
[3]Molecular & Cell Biology, College of Public Health, Medical & Vet Sciences, James Cook University, Townsville, Australia

andrew.baird[at]jcu.edu.au

Abstract

Molecular approaches have revolutionised our understanding of the systematics and evolution of most branches on the tree of life, including corals. Over the last twenty-five years molecular research has revealed that few of the 18 families and 100+ genera recognised by Veron (2000) were monophyletic. New techniques and vision promise a more robust and consistent species level taxonomy, but it will take time and there is always likely to be some uncertainty. It is therefore important to establish when taxonomy matters and when it does not. To illustrate problems with the current species level taxonomic framework we reassess the identity of 30+ recently sequenced genomes using multiple lines of evidence, including an *Acropora* phylogeny based on targeted capture of ultraconserved elements and exonic loci and comparisons with the type material, to demonstrate that most of these genomes have been incorrectly identified. This is not necessarily a problem, depending on the research question, however, we present a number of examples from the literature to highlight times when a robust taxonomy is essential. We next present a brief history of coral taxonomy to illustrate how the concepts of phenotypic and geographical variation in morphology led researchers in the 1980s to vastly underestimate species richness in the order. We conclude by outlining a framework towards a robust and consistent species level taxonomy for the hermatypic Scleractinia.

Virtual
Oral
A-1617

The Mediterranean grouper Serranus cabrilla (L. 1758) resurrected as ancient resident of coral reefs in the northern Red Sea

Bos, A.
The American University in Cairo, Biology, New Cairo, Egypt

arbos[at]aucegypt.edu

Abstract

Since the opening of the Suez Canal in 1869, a plethora of Red Sea fishes have entered the Mediterranean Sea (Lessepsian migration). The Comber *Serranus cabrilla* is considered to have moved in the opposite direction as anti-Lessepsian migrant and has an established population in the northern Red Sea. Mitochondrial (COI) and nuclear DNA from 49 individuals from Red Sea (Gulf of Suez) and Mediterranean populations (Cyprus, Egypt and Lebanon), as well as GenBank sequences from other Mediterranean and Atlantic populations were analyzed to study phylogenetic relationships. COI sequencing resulted in a phylogenetic tree that isolated the Red Sea population from all Mediterranean and Atlantic populations. Furthermore, sequence divergence within the Red Sea population was significantly lower than in Atlantic and Mediterranean populations. Moreover, none of the Mediterranean haplotypes were present in the Red Sea. SNPs and MIG-seq analyses of nuclear DNA confirmed that the Red Sea population is genetically different from the Mediterranean populations. A rough estimate of divergence time suggested that Mediterranean and Red Sea populations separated 194,055 y ago, at the latest. *Serranus cabrilla* must therefore have existed in the Red Sea prior to the opening of the Suez Canal and can no longer be considered an anti-Lessepsian migrant.

Session 2B - How can we use phylogenetic tools to better understand biodiversity, evolutionary patterns, and processes?

Virtual
Oral
A-1497

Skeleton morphometric analysis of reef-building corals for taxonomic identification and genotype prediction

Mitushasi, G.[1], Kitano, Y.[2], Hume, B. C. C.[3], Armstrong, E.[4], Porro, B.[5], Boissin, E.[6], Poulain, J.[4], Carradec, Q.[4], Paz-García, D. A.[7], Zaccola, D.[8], Röttinger, E.[8], Moulin, C.[9], Bourdin, G.[10], Iwankow, G.[6], Romac, S.[11], Consortium, T. P.[9], Planes, S.[6], Allemand, D.[8], Voolstra, C. R.[3], Forcioli, D.[5]
[1]Shimoda Marine Research Center, University of Tsukuba, Shimoda, Japan
[2]National Institute of Environmental Science, Tsukuba, Japan
[3]University of Konstanz, Department of Biology, Konstanz, Germany
[4]Genoscope, Institut François Jacob, CEA, CNRS, Univ Evry, Université Paris-Saclay, Génomique Métabolique, Evry, France
[5]Université Côte d'Azur, IRCAN CNRS UMR7284/INSERM U1081, Nice, France
[6]CRIOBE, Laboratoire d'Excellence CORAIL, Université de Perpignan, Perpignan, France
[7]Centro de Investigaciónes Biológicas del Noroeste, La Paz, Mexico
[8]Centre Scientifique de Monaco,, Monaco, Monaco
[9]Fondation Tara Océan, Base Tara, Paris, France
[10]University of Maine, School of Marine Sciences, Maine, United States
[11]Sorbonne Université, CNRS, Station Biologique de Roscoff, Roscoff, France

guinther[at]shimoda.tsukuba.ac.jp

Abstract

High morphological variation is found throughout reef-building coral species. This can be attributed to phenotypic plasticity, hybridization, phenotypic polymorphism, geographic distribution, environmental factors leading to coral misidentification. Recent studies have demonstrated the relevance of combining landmark skeleton morphometry and genetic analysis to identify coral species and the populations within. Accurate and reproducible methods for taxonomical analysis are required to understand the distribution of coral populations. The Tara Pacific expedition collected more than 3000 coral samples from 32 different islands across two transects spanning the Pacific Ocean (east to west, south to north). Three species were chosen based on their relative abundance and presence across the Pacific: *Pocillopora meandrina, Porites lobata* and *Millepora platyphylla*. However, these species present great variation in their morphologies both at the colony and corallite levels. In this study, we present the use of colony morphology, skeleton morphometry landmark analysis and genomewide SNPs-based genotyping for the taxonomical identification of the coral samples collected during the Tara Pacific Expedition. Additionally, we tried predicting genetic lineages for the three genera using colony morphology and genotype through unsupervised and supervised random forests. We found that only a limited number of genetic lineages could be predicted based on colony morphology with low error rates. Furthermore, we discuss environmental factors such as temperature and wave intensity as determinants of colony morphology variation. This study shows the potential and limitations of *in situ* photographs for the identification of genetic lineages in reef-building corals.

Session 2B - How can we use phylogenetic tools to better understand biodiversity, evolutionary patterns, and processes?

Virtual
Oral
A-1764

New insights from genomic data in the revision of Pocillopora species

Oury, N.[1], Noël, C.[2], Mona, S.[3], Aurelle, D.[4], Magalon, H.[1]
[1]Université de La Réunion, UMR Entropie, Saint Denis, Réunion
[2]Ifremer, Service de Bioinformatique (SeBiMER), Plouzané, France
[3]École Pratique des Hautes Études, ISYEB, Paris, France, [4]Aix-Marseille Université, MIO, Marseille, France

nicolasoury[at]hotmail.fr

Abstract

The recent development of sequencing technologies now enables the cost-effective capture of a large number of loci from hundreds of individuals in a single sequencing run. These methods appear as promising approaches to resolve complex phylogenies. This is particularly true in cnidarians, for which insufficient data due to the small number of currently available markers, associated with hybridization, introgression and morphological incongruences, leads to incomplete lineage sorting in gene trees. In this study, we focused on the coral genus *Pocillopora*, widely distributed in the tropical belt of the Indo-Pacific, playing key roles in reef ecosystems. We used sequence capture of ultraconserved elements (UCEs) and exon loci to call single-nucleotide polymorphisms (SNPs) from hundreds of *Pocillopora* colonies, sampled in the western Indian Ocean, the tropical southwestern Pacific and southeast Polynesia, representing a huge variety of morphotypes. Phylogenetic inferences, clustering approaches and species delimitation methods were used to resolve *Pocillopora* phylogeny and define genetic species that were confronted to traditional genetic markers (ORF, PocHistone and 13 microsatellites). Following an integrative approach, species genetic limits were also confronted to evidences based on morphology (corallite micromorphology), biogeography and symbiosis (ITS2 metabarcoding of Symbiodiniaceae communities). The different genetic approaches allowed us to delimit up to 21 species, but not all were distinct morphologically nor associated with distinct Symbiodiniaceae communities. Nevertheless, other species were supported by all approaches, either confirming their currently recognised species status, or supporting the presence of cryptic species that need to be formally described. All together, our results support (1) the obsolence of macromorphology but the relevance of micromorphology to define *Pocillopora* species, (2) the need to identify molecularly species prior to experiments as morphology can blur species identification on the field, (3) the relevance of the ORF (coupled with other markers in some cases) as a diagnostic marker of the species, and (4) the need for a taxonomical revision in the *Pocillopora* genus. These results give new insights into the puzzle of defining *Pocillopora* species limits and will, ultimately, allow a better understanding and conservation of the species from this scleractinian genus.

Virtual
Oral
A-2137

Unravelling at the Edges: Using RADSeq to study population structure, adaption, and speciation at coral range edges.

Pearton, D.[1], Gilmore, J.[1], Gouws, G.[2], Schleyer, M.[1]
[1]South African Association for Marine Biological Research, Oceanographic Research Institute, Durban, South Africa
[2]South Africa Institute for Aquatic Biodiversity, Grahamstown, South Africa

dpearton[at]ori.org.za

Abstract

Corals are well known for exhibiting remarkable genetic and morphological diversity and this is amplified at the extremes of their ranges. Given their exposure to large environmental fluctuation, peripheral populations at these range edges are potentially of great interest in terms of understanding how corals might be able to adapt to climate change, as well as undergoing climate-induced poleward range shifts.

Not much is understood about the genetic variation of corals at their range edges. One reason for this is the difficulty in identifying ecologically relevant species and populations due to high degrees of morphological variation, the presence of cryptic species and potential interspecific hybridization. Recent advances in sequencing technology have resulted in new methods such as RADSeq (Restriction Site-Associated DNA Sequencing) which can be used for cost-effective studies on inter- and intra-species variation, population structure and local adaptation.

The high-latitude coral reefs on the east coast of South Africa lie at the extreme edge of coral distribution yet exhibit high levels of hard and soft coral diversity. We used RADSeq to study intra- and inter-species variation and population structure in two high-latitude coral “species-complexes”, the scleractinian Stylophora pistillata complex and the alcyonacean, Sinularia brassica.

For Stylophora, samples with wildly divergent morphologies were obtained from a broad environmental range (tropical to temperate). Genetic analysis revealed two distinct clades, which were unrelated to morphological differences, clear ecologically driven population structure as well as signatures for local. For Sinularia, in-depth genetic sequencing revealed the presence of morphologically indistinguishable cryptic species not distinguishable using conventional markers.

These results highlight the need for in-depth studies on the local and regional level, as well as the importance of understanding and conserving marginal/extreme populations that might harbour critical genetic diversity and traits for the future.

Virtual
Oral
A-2179

Detection DNA of multispecies dinoflagellate cysts in the sediment from three estuaries of Makassar Strait and fishing port using PCR with CO1 primer

Rukminasari, N.
Faculty of Marine Science and Fisheries, Universitas Hasanuddin, Fisheries, Makassar, Indonesia

nita.r[at]unhas.ac.id

Abstract

Most of dinoflagellate had a resting cyst in their life cycle. This cyst was developed in unfavorable environmental condition. Conventional method for identifying dinoflagellate cyst in natural sediment require morphological observation, isolating, germinating and cultivating the cysts. PCR technique is a highly sensitive method for detecting dinoflagellate cyst in the sediment. However, there was lack of study to detect DNA of dinoflagellate cyst in the sediment from Indonesian waters, specifically from Makassar Strait. The research question of this study: Could the PCR technique detect DNA of multispecies dinoflagellate cysts in the sediment from three estuaries of Makassar Strait?. The hypothesis of this study: DNA of multispecies dinoflagellate cyst in the sediment could be detected using PCR technique with CO1 primer. The aim of this study was to detect and identify multispecies dinoflagellate cysts from three estuaries of Makassar Strait and fishing port's sediment. Dinoflagellate cyst DNA was extracted from 16 sediment samples. PCR technique using COI primer was running. The sequencing of dinoflagellate cyst DNA was using BLAST. Results showed that there were two clades of dinoflagellate cysts from four locations of study. Clade 1 was dominated by samples from the Jeneberang Estuary (JB), Maros Estuary (M) and Pangkep Estuary(P), while clade 2 was dominated by samples from the Paotere Port (PP). The genetic distance was varied between DNA dinoflagellate cyst samples ranging from 0.5 -0.6. The closest genetic distance was between sample of JB1 and sample of JB2, while the farthest genetic distance was sample PP1 and PP2. PCR technique could be used in detecting DNA of multispecies dinoflagellate cyst in the sediment, however the primer CO1 was not suitable for identifying dinoflagellate cyst DNA due to only picking one DNA, which was a diatom (*Licmophora* sp). For the futher research, we suggested for using several type of primer to increase the number of DNA dinoflagellate cyst in the sediment that could be detected using PCR technique.

Virtual
Oral
A-2110

Untangling azooxanthellate species relationships in Scleractinia (Cnidaria, Anthozoa) based on a target-enrichment approach

Vaga, C. F.[1, 2], Galvão de Lossio e Seiblitz, I.[1], Quek, R.[3], Quattrini, A.[4], McFadden, C.[5], Huang, D.[3], Kitahara, M. V.[2, 6]
[1]Universidade de Sao Paulo, Zoology, São Paulo, Brazil
[2]Center for Marine Biology, University of Sao Paulo, Sao Sebastiao, Brazil
[3]National University of Singapore, Department of Biological Sciences, Singapore, Singapore
[4]Smithsonian Institution, National Museum of Natural History, Washington DC, United States
[5]Harvey Mudd College, Claremont, United States, [6]Federal University of Sao Paulo, Santos, Brazil

claudia.vaga90[at]gmail.com

Abstract

Scleractinian corals engineer entire shallow and deep-water reefs, which are among the most complex, productive, and biologically diverse ecosystems on Earth. Despite their ecological and economic importance, studies aimed at untangling the phylogeny of Scleractinia have been historically hampered by the omission of azooxanthellate species in phylogenetic reconstructions, uneven species sampling between families, and a strong bias for the use of mitochondrial and ribosomal markers. In the last decade, high throughput methods have been developed to enable the access and handling of vast amounts of data in large-scale phylogenetic studies. In addition, target enrichment has been proven robust for inferring phylogenies across many taxa at relatively low cost. In this study, 2,490 phylogenetically informative loci were target enriched in more than a hundred species, including the largest number of azooxanthellate species sequenced to date, species from remote locations (e.g. deep sea), and Brazilian endemics. Furthermore, we conducted a preliminary diversification rate analysis to infer rate shifts across time. In addition to including the first molecular data of some species, this study helped to clarify the phylogenetic relationships within and among families and genera of Scleractinia. The data presented here represent a significant step in improving our understanding of the evolutionary history of Scleractinia.

Virtual
Poster
A-1651

A standardized assessment of Indonesian marine biodiversity with Autonomous Reef Monitoring Structures (ARMS) and DNA metabarcoding

Cahyani, N. K. D.[1, 2], Anggoro, A. W.[1], Casey, J.[3], Pertiwi, N. P. D.[4, 5], Sembiring, A.[4], Kurnianto, D.[6], Dailami, M.[7], Madduppa, H.[8], Meyer, C. P.[9], Rohwer, F.[10], Barber, P. H.[1]
[1]University of California, Los Angeles, Los Angeles, CA, United States
[2]Faculty of Science and Mathematics, Diponegoro University, Biology, Semarang, Indonesia
[3]CRIOBE, École Pratique des Hautes Études, Perpignan, Perpignan, France
[4]Yayasan Biodiversitas Indonesia (Bionesia), Denpasar, Bali, Indonesia
[5]Faculty of Mathematics and Natural Sciences, Universitas Pendidikan Ganesha, Singaraja, Bali, Indonesia
[6]Reseach Center for Oceanography, Indonesian Institute of Sciences, Ancol Timur, Jakarta, Indonesia
[7]Faculty of Fisheries and Marine Science, Universitas Brawijaya, Malang, Indonesia
[8]Marine Science and Technology, Faculty of Fisheries and Marine Science, Bogor Agricultural University (IPB), Bogor, Indonesia, [9]Department of Invertebrate Zoology, Smithsonian National Museum of Natural History, Washington DC, United States
[10]Biology Department, San Diego State University, San Diego, CA, United States

ditacahyani[at]ucla.edu

Abstract

The Coral Triangle is the epicenter of marine biodiversity, but growing threats imperil this diversity and the ecosystem services it provides. A key to sustainable management of the Coral Triangle is biodiversity monitoring in order to detect ecosystem change. We used Autonomous Reef Monitoring Structures (ARMS) in conjunction with DNA metabarcoding to assess marine biodiversity across Indonesia, the largest region within the Coral Triangle, providing a standardized high-throughput method for elucidating the baseline composition of reef-associated benthic communities. We also tested for congruence between microbial and eukaryotic patterns across the archipelago along well established gradients of known metazoan diversity. ARMS were deployed for three years (2013-2016) in locations ranging from Aceh, a low diversity region in western Indonesia, to Raja Ampat, a region in eastern Indonesia that is the center of diversity in the Coral Triangle. Across 75 ARMS, we targeted three loci (COI, 18S, and 16S) with DNA metabarcoding, producing more than 260 thousand amplicon sequence variants from 132 million DNA sequences. The eukaryotic community was dominated by *Arthropoda*and *Porifera*, while microbial taxa were dominated by *Proteobacteria*, *Chloroflexi*, *Bacteroidetes*, and *Acidobacteria*. While region was the most important factor in structuring eukaryotic diversity, microbial community composition was largely driven by size fraction (motile and sessile) and showed no regional diversity patterns. The combination of ARMS and metabarcoding offers unique insights into patterns of marine biodiversity across a broad range of taxonomic groups. This method also provides a taxonomically diverse baseline of local biodiversity across Indonesia, giving resource managers a powerful tool to monitor future changes in this biologically and economically important region.

Session 2C - How is coral reproduction and dispersal affected by the environment?

Conceptualized by: **Jacqueline Padilla-Gamino** [1], **Yossi Loya**[2], **Saki Harii**[3], **Elizabeth Lenz**[4], **Tom Shlesinger** [2]

[1] University of Washington (Seattle, USA)

[2] Tel Aviv University (Tel Aviv, Israel)

[3] Sesoko Station (Okinawa, Japan)

[4] Hawaii Institute of Marine Biology (Kaneohe, HI, USA)

Chaired by: **Jacqueline Padilla-Gamino** [1], **Yossi Loya**[2], **Tom Shlesinger** [2]

Oral
A-2080

Environmental drivers of spatial biodiversity and biogeography of coral reef communities in the southwestern Arabian/Persian Gulf

Ben Hamadou, R.[1, 2], Bouwmeester, J.[3], Burt, J. A.[4], Goergen, E. A.[1], Al-Jamali, F.[1], Padierna, M. L.[1], Range, P.[2]
[1]Qatar University, Dept. of Biological and Environmental Sciences, Doha, Qatar
[2]Qatar University, Environmental Science Center, Doha, Qatar
[3]Smithsonian Conservation Biology Institute, Hawaii Institute of Marine Biology, Kaneohe, United States
[4]New York University Abu Dhabi, Center for Genomics and Systems Biology, Abu Dhabi, United Arab Emirates

benhamadou[at]qu.edu.qa

Abstract

Arabian Gulf coral reef communities have adapted and persisted in one of the world's most extreme environments coral reefs are known to exist. However, the increased frequency of stress from increasing sea temperatures, salinities, and sustained coastal development, has resulted in changes in coral reef communities across the region in recent years. We conducted, starting in 2015 a comprehensive assessment of the status of reef-building coral communities at 15 reef sites (ranging in depth from 1 to 23m and from very near shore to 123km from shore) in the SW Arabian Gulf was conducted to investigate potential spatial and environmental drivers of changes in coral communities. Using six 30 m photoquadrat surveys at each site, coral cover, abundance, and species biodiversity were obtained. A strong north-to-south gradient of declining live coral cover (38% to 13%) and species richness (28 to 7 species) was observed, with an additional reduction of species richness in coastal areas (i.e. 2 species: *Porites harrisoni* and *Cyphastrea microphthalma*). Surveys in late summer 2017 revealed 100% bleaching in inshore coral communities and resulted in the complete loss of coral cover, in 2 out of 5 surveyed inshore sites, resulting in a shift to a non-coral ecosystem composed of mostly rubble and turf-algae. Species turnover (Beta-diversity) and canonical correspondence analyses determined that environmental factors such as depth, distance from shore, and sea surface temperatures played a significant role in driving the spatial patterns of coral biodiversity and biogeography and predicting functional shifts under future regional climate scenarios.

Oral
A-1149

Effects of Elevated Temperature on Reproduction and Larval Settlement in Leptastrea purpurea

Galanto, N.[1], Sartor, C.[1], Moscato, V.[2], Lizama, M.[1], Lemer, S.[1]
[1]University of Guam, Marine Laboratory, Mangilao, Guam
[2]Boston University, Boston, United States

nikkogalanto[at]gmail.com

Abstract

As global ocean temperatures continue to rise, severe declines in coral reef health and diversity are reported on a global scale. Recovery of coral reefs relies on reproduction and increased rates of successful recruitment, which can vary tremendously across coral species. We investigated the effects of increased temperatures in the environment of parental colonies on larval production, size, settlement and survival, in the heat resistant coral *Leptastrea purpurea* in Guam. Thanks to two tank experiments (eleven and four weeks, respectively) conducted over two consecutive years we found that larvae released by heat-treated parents (30 °C) were significantly smaller in size but greater in number, had normal settlement behavior and increased post-settlement survival rates compared to those released by control parent colonies (28 °C). We conclude that changes in the environment of parental *L. purpurea* colonies triggers an anticipatory maternal effect which leads to the release of preconditioned larvae with an increased chance of survival.

Oral
A-1253

"Big bang" reproduction in the lined fireworm Pherecardia aff. striata at Reunion Island, southwestern Indian Ocean

Guillaume, M. M. M.[1], Hoarau, G.[2], Bruggemann, J. H.[3], Kudenov, J.[4]
[1]Muséum National d'Histoire Naturelle, BOrEA, Paris, France
[2]Colours of Reunion, Saint-Pierre, Réunion
[3]Université de La Réunion, ENTROPIE, Saint-Denis, Réunion
[4]University of Alaska Anchorage, Biological Sciences, Anchorage, United States

mireille.guillaume[at]mnhn.fr

Abstract

Between 2004 and 2022, 14 mass spawning events of the lined fireworm *Pherecardia* aff. *striata* (Amphinomidae) were observed on, or reported from most of the shallow reef flats at Reunion Island, southwestern Indian Ocean, attesting to the broad geographic range of their synchronous reproduction. This amphinomid, which usually lives hidden under the reef coral pavement, then swims freely in the water column, spawns and ultimately dies at the water front. This "big bang" reproduction lasted for a maximum of two nights in a row. (1) On the first night swarming worms came along the beaches with the rising tide after the night-time low tide and continued arriving for 1 to 2.5 hours. If there was a second night, they were already present ca. two hours before low tide. The swarming behaviour that was recorded on videos attested of efficient swimming capacities due to a highly coordinated locomotory mechanism. Positive phototropy was evidenced by their attraction to the observer's dive lights. (2) Spawning took place at the beach front. Dense clouds of gametes were produced by highly fecund males and females. Gametes were released through the nephridiopores, then dispersed in seawater. Agglutinated oocytes immediately scattered upon leaving these orifices. Sperm and semen, however, were expelled as milky white jets. Size range was 10 - 35 cm, most worms being longer than 16 cm. Worm counts were high, exceeding 500 worms on one beach, which may represent a significant proportion of the population. (3) The following morning, fireworm bodies were found lying dead on beaches. These events were closely related to the lunar cycle, generally occurring on the 2nd to the 4th day after full moon, in December. Yet on five occasions they took place in October, November or January, always following the same pattern. The spawning period corresponded to the annual maximum photoperiod, when daily solar global radiation is maximal and SST approaches its annual maximum. Spawning temperatures and solar global radiation differed among years. To our knowledge, this is the first report of synchronous spawning in an amphinomid. It contributes to understanding of reproductive patterns of the coral reef cryptic fauna. Along densely populated coastlines, the knowledge of the reproductive behaviour of fireworms contributes also to human safety for beach recreation or traditional fisheries on coral reefs. It further raises awareness of the wide public to an unexpected reef biodiversity.

Oral
A-1855

Can “going deeper” be a viable refuge for corals?

Liberman, R.[1, 2], Shlesinger, T.[3], Loya, Y.[1], Benayahu, Y.[1]
[1]Tel Aviv university, School of zoology, Tel Aviv, Israel
[2]The Interuniversity Institute for Marine Sciences, Eilat, Israel
[3]Florida Institute of Technology, Institute for Global Ecology,, Melbourne, United States

ronenliberman[at]gmail.com

Abstract

Many species across a wide range of taxa and habitats display phenological shifts and differences in response to both environmental gradients and climate change. Wide-scale declines of numerous ecosystems are currently leading to increased efforts to identify zones that might serve as natural refuges from various disturbances, including ocean warming. . One such refuge was suggested to be that of mesophotic coral ecosystems (MCEs), but whether depth can provide coral populations with a viable and reproductive refuge remains unclear. Given the global coral-reef degradation and the key role that corals play as ecosystem engineers, their reproductive ecology has been widely studied. However, there is still a gap of knowledge regarding coral reproductive phenology along a depth gradient. Filling in this gap may also uncover the environmental cues that regulate coral reproduction, leading to better predictions of population connectivity, and their possible responses to environmental changes. Here, using long-term in-situ observations of the soft coral *Rhytisma fulvum*’s reproductive activity along its entire depth range (0–45 m), we examined the relationship between several environmental factors and the coral’s reproductive phenology and activity over five successive annual breeding seasons. Compared with the shallow depths, a lower number of reproducing colonies was found in habitats deeper than 30 m, highlighting possible constraints on coral reproduction at the deeper margins of their habitat distribution. Our results further revealed that an increase in seawater temperature over 1–2-day intervals during the breeding season correlated with the onset of reproductive activity along the depth gradient, leading to different reproductive periodicities in different depths. These results suggest that differential temperature regime and reproductive timing across depth may create intraspecific temporal reproductive segregation, possibly reducing connectivity between populations along a depth gradient. Moreover, we found high variability between years in both the timing of breeding activities and in the level of reproductive synchrony between corals from different depths. Overall, this study questions whether depth can provide a long-term and viable refuge for corals in the face of global environmental changes.

Oral
A-1779

Decoding reproductive timing and fertilization biology in Dendrogyra, Dichocoenia, and other gonochoric Caribbean corals

Marhaver, K. L.[1], Vermeij, M. J.[1, 2]
[1]CARMABI Foundation, Willemstad, Curaçao
[2]University of Amsterdam, Freshwater and Marine Ecology - Institute for Biodiversity and Ecosystem Dynamics, Amsterdam, Netherlands

kristen[at]marhaverlab.com

Abstract

Decades of natural history observation have made it possible to rear many hermaphroditic corals from mass-spawned gametes. Yet, gonochores remain understudied and underutilized in restoration, despite their potential to survive and recruit in degraded habitats and their ability to achieve fertilization at lower gamete densities and lower population sizes. Over the past decade, we worked to decode the reproductive behavior of gonochoric Caribbean corals including *Dendrogyra cylindrus*, *Dichocoenia stokesii*, and *Stephanocoenia intersepta*. We found that males reliably begin spawning before females and spawning times are remarkably consistent and constrained relative to sunset time, but the date of spawning is far less predictable. We observed *Dendrogyra* and *Stephanocoenia* spawning in two different months and on seven different days in the lunar cycle, and we observed *Dichocoenia* spawning in three different months and across the entire lunar cycle, including a continuous 20-day period in November. Sexual selection could drive both the cohesion of spawning times within a night and the diffusion of spawning nights across the lunar cycle. Taken to the extreme, this shows how mass-spawning gonochores could evolve into year-round, spermcasting brooders. Across the Caribbean, achieving reliable fertilization in gonochores has proven difficult. We found that these species have narrower tolerances in both gamete handling and settlement conditions relative to most hermaphrodites. Further complicating propagation, we found histological evidence that some gonochores may have the capacity for internal fertilization. Thus, some gonochores may not truly be “gamete spawners” but rather “zygote releasers.” Nevertheless, we successfully reared larvae and settlers of all three species, marking the first propagation of *Dichocoenia* and their successful growout to three-year-old juveniles and the successful propagation of *Dendrogyra* to two years of age. Finally, in 2019, we tested 18 different sperm cryopreservation methods with these species to enable gene banking and the long-term preservation of genetic diversity, and we identified two cryoprotectants that successfully recovered post-thaw motility. The reproductive natural history of gonochores gives us a better understanding of coral mating systems as a whole while improving our ability to conserve and restore population genetic diversity of all scleractinians.

Oral
A-1302

Investigating coral growth anomalies on the coral reefs of Qatar

Merabet, S.[1], Sarhan, K.[2], Khalifa, R.[2], Range, P.[2], Khalifa, R.[1, 3], Work, T.[4], Aljamali, F.[1], Bouwmeester, J.[5], Goergen, E.[1], Padierna, M.[1], Moosa, I.[6], Ben Hamadou, R.[1, 2]
[1]Qatar University, Department of Biological and Environmental Sciences, Doha, Qatar
[2]Qatar University, Environmental Science Center, Doha, Qatar
[3]University of Hawaii, Hawaii Institute of Marine Biology, Manoa, Honolulu, HI, United States
[4]U.S. Geological Survey, National Wildlife Health Center, Honolulu, HI, United States
[5]Hawaii Institute of Marine Biology, Smithsonian Conservation Biology Institute, Kaneohe, HI, United States
[6]Sidra Medicine, Department of Pathology, Doha, Qatar

sara.merabet[at]qu.edu.qa

Abstract

Coral reefs are dynamic marine ecosystems providing valuable goods and services and their health is crucial for countless ecologically and economically important marine organisms. Unfortunately, the world's coral reefs are in decline due to local stresses, global climate change and an increasing frequency and severity of coral disease outbreaks. Coral diseases have been studied in many world seas; however, little is known about their types and prevalence in the Arabian Gulf reefs, including in Qatar. This research aims to address this gap by examining one type of coral disease (growth anomalies – GAs). Our objectives were to characterize the growth anomalies on two dominant coral genera on Qatari reefs, *Dipsastraea* and *Platygyra* in terms of spatial distribution (i.e., frequency of occurrence (FOC)= no. sites with GAs/total sites surveyed), prevalence (no. colonies affected/total colonies surveyed), their histological characterization and their effect on reproductive output. The FOC for *Dipsastraea* was 44.4% with an avg. prev. of 2.26% whereas, *Platygyra* had a FOC of 11.1% and avg. prevalence of 3.3%. Our results showed a higher FOC and prevalence of GAs in *Dipsastraea* compared to a similar study in Abu Dhabi (GA: FOC=37.5%, avg. prev.=0.09%), while *Platygyra* had a lower FOC, but higher prevalence (FOC=62.5% and avg. prev.=0.52%). A number of morphological differences occurred in growth anomalies compared to healthy tissues. For instance, *Platygyra* GAs had a higher polyp height, fewer algal symbionts, wider valleys and more eggs per area of mesentery. For *Dipsastraea*, polyps in growth anomalies tended to be larger (polyp diameter, perimeter and area) and had longer basal body walls. Gametes were not present in the *Dipsastraea* GA samples, but were observed in samples from healthy colonies collected during the same period. This baseline information was established for coral diseases in Qatar waters and further investigations are ongoing to establish causes and consequences of coral diseases to the resilience of Qatari coral reefs.

Oral
A-2213

Reproduction, parental effects and physiological recovery after a bleaching event

Padilla-Gamino, J.[1], Nunn, B.[1], Brown, T.[1], Axworthy, J.[1], Rodrigues, L.[2]
[1]University of Washington, Seattle, United States
[2]Villanova University, Villanova, United States

jpgamino[at]uw.edu

Abstract

Coral reefs, one of the most diverse ecosystems in the world, are being critically impacted by thermal stress due to global warming and are among the most threatened ecosystem on Earth. Discovering the mechanisms involved in tolerance and recovery of corals after thermal stress is of fundamental importance to predict the consequences of climate change. To date, most studies have focused on the potential of corals to survive and recover from stress. However, the persistence of corals will not only require the survival of adults, but will also depend on the organism's ability to continue sexual reproduction and the quality of their offspring. In this study we examined reproductive capacity, symbiont and microbial transmission to eggs and long-term physiological recovery (nine months) in corals that were bleached experimentally. We found that bleached corals were able to
reproduce but gamete development was delayed and spawning occurred later in the summer. Symbiont diversity in bleached and non-bleached adults was similar nine months after the bleaching event with Cladocopium sp. as the dominant symbiont type. However, their eggs contained mainly Durusdinium sp. (for both bleached and non-bleached parents). Having gametes with different symbiont types may have important implications for larval thermal tolerance and survival. Microbial diversity did not differ between bleached and non-bleached tissues. However, we found differences between life history stages. Adult tissue had
higher abundance of Staphylococcus sp., Propionibacteriaceae, Corynebacteriaceae, Bacilli and Actinobacteria whereas Alphaproteobacteria was found in greater proportion in the eggs. Current analyses are focused on comparing a suite of additional physiological traits in eggs and their parental colonies (bleached and non-bleached). These include endosymbiont densities,
chlorophyll, lipids, and shotgun proteomics.

Oral
A-1013

Do reef corals 'remember' their age?

Rapuano, H.[1, 2], Shlesinger, T.[3], Roth, L.[4, 5], Bronstein, O.[2, 4], Loya, Y.[6]
[1]Tel Aviv University, Life Sciences, Tel Aviv, Israel
[2]Steinhardt Museum of Natural History, Tel AVIV, Israel
[3]Florida Institute of Technology, Melbourne, United States
[4]Tel aviv university, Life Sciences, Tel AVIV, Israel
[5]Steinhardt Museum of Natural History, Tel Aviv, Israel
[6]Tel aviv university, Tel Aviv, Israel

nosponge[at]yahoo.com

Abstract

Natural constraints on organisms possessing a unitary body plan appear almost absent from colonial organisms. Like unitary organisms, however, coral colonies seemingly delay reproduction until reaching a critical size. Elucidating ontological processes, such as puberty and aging, in colonial organisms is complicated by their modular design – potentially allowing unlimited growth, while facilitating colony size reduction through partial mortality and fragmentation, which distorts size-age relationships. We explored how the enigmatic relations between size and age in colonial animals manifest and influence their sexual reproductive performance. We fragmented large, sexually-mature colonies of five coral species into sizes below the known size at first reproduction and nurtured them for prolonged periods, examining their reproductive capacity and trade-offs between growth rates and reproductive investment. Most small and large fragments from all studied species showed similar reproductive capacity regardless of their size, and growth rates hardly affected reproduction. Our findings suggest that once the ontological milestone of puberty is reached, corals retain the ability to reproduce irrespective of colony size, highlighting the key role that aging might have in colonial animals, which are commonly considered non-aging.

Oral
A-1054

Sexual reproductive patterns of fire corals at the Gulf of Eilat/ Aqaba

Roth, L.[1], Shlesinger, T.[2], Loya, Y.[1]
[1]Tel-Aviv University, Zoology, Tel-Aviv, Israel
[2]Institute for Global Ecology, Florida Institute of Technology, Melbourne, United States

lachanroth[at]gmail.com

Abstract

Calcareous hydrozoans of the genus *Millepora*, commonly referred to as fire corals, are abundant coral-reef framework builders, contributing substantially to the reef's three-dimensional structure. Yet, despite having an important ecological role, they are largely overlooked in coral-reef studies. Therefore, basic knowledge on thess key taxa is highly scarce, including information regarding one of the most fundamental life-history traits that significantly contributes to fitness — reproduction. Unlike other cnidarian reef-builders (e.g., scleractinian corals), the sexual life cycle of *Millepora* includes an additional reproductive stage of a tiny pelagic medusa which contains the gametes. Here, we present a long-term study spanning six consecutive years, and describe multiple aspects of the sexual reproductive cycle of three *Millepora* species existing in the Gulf of Eilat/ Aqaba, Red Sea. *In-situ* observations of reproductive events of the three species were conducted during 2016–2021, and the timing and number of colonies reproducing were recorded. Additionally, samples of *M. dichotoma* and *M. exaesa* were examined via histological cross sections throughout one year, and the medusae developmental process was studied in detail. Medusae development and gametogenesis were found to span over a short period of only several weeks during June–August. The three *Millepora* species displayed a temporal reproductive isolation (i.e., no overlap in the timing of reproduction). *M. exaesa* and *M. platyphylla* were observed to release medusae only once or twice during a reproduction season. By contrast, *M. dichotoma* was observed to release medusae 4–6 times, usually in ~two-week intervals, leading to some correlations between reproduction timing and new and full moon phases. Accordingly, *M. dichotoma* demonstrated different medusae developmental stages occurring simultaneously. The observed fast reproductive development may be the reason why *Millepora* species can reproduce multiple times during a given season. Moreover, developing medusae and gametes within a brief period of time might be beneficial for this taxon in directing most of their energy throughout most of the year towards other basic life processes. Producing multiple occurrences of mass medusae release that likely result in a genetically diverse population within a short time-span suggest that *Millepora* species may possess unique resilience potential and recolonization capabilities following disturbances.

Poster
A-1936

Coral larval recruitment failure and subsequent recovery in the wake of mass bleaching and disease outbreak across US Virgin Island coral reefs.

Arrington, B.[1], Gochfeld, D.[2], Olson, J.[3], Ritson-Williams, R.[4], Dade, L.[5], Brandt, M.[5]
[1]University of the Virgin Islands, St Thomas, U.S. Virgin Islands
[2]University of Mississippi, University, United States
[3]University of Alabama, Tuscaloosa, United States
[4]California Academy of Sciences, San Fransico, United States
[5]University of the Virgin Islands, St. Thomas, U.S. Virgin Islands

brad.arrington15[at]gmail.com

Abstract

Caribbean coral health and cover has seen significant decline in recent years due to global and local stressors. Decline in coral cover on Caribbean coral reefs increases the space available for other competitors, including sponges and macroalgae, which have been shown to negatively impact both recruitment of new corals and survival of these recruits, further perpetuating macroalga-dominated reef states. Coral reefs in the US Virgin Islands have recently been impacted by a severe bleaching event in 2019 and the emergence of Stony Coral Tissue Loss Disease in 2019. Total coral benthic coverage declined at the selected study sites from 11.9% cover in 2015 to 6.2% cover in 2020. This study examined coral recruitment rates at six coral reef sites surrounding St. Thomas, US Virgin Islands, by installing 15cm^2 terracotta tiles across the reefs. A near complete failure of coral recruitment was found in 2019 and 2020 compared to previous samplings periods (2015 – 2017). However, 2021 recruitment rates rebounded to the previously recorded levels in 2015-2017, indicating possible coral recruitment recovery. Continued monitoring is on-going to determine long-term impacts and track coral recruitment recovery.

Poster
A-1464

Impacts of water quality impairment on scleractinian coral early life history stages

Dade, L.[1], Lillis, A.[2], Trotz, M.[3], Brandt, M.[1]
[1]University of the Virgin Islands, St. Thomas, U.S. Virgin Islands
[2]The Nature Conservancy, St. Croix, U.S. Virgin Islands, [3]University of South Florida, Tampa, United States

lindsaymdade[at]gmail.com

Abstract

Coral reproduction and juvenile survival are essential for reef recovery and persistence, thus, investigating factors that impact these processes is important for the conservation of coral ecosystems. In the Caribbean, wastewater contamination is a frequent occurrence due to antiquated treatment systems and poor maintenance of on-site disposal systems. Water quality may be a major factor determining the success of restoration efforts. To investigate the impacts of water quality on coral reproduction and early life history survival, coral larvae were experimentally treated with ammonium-enriched seawater to determine if elevated nitrogen levels impacted larval motility, survival, and recruitment, as well as post-settlement survival. In addition, eight reef sites were chosen in the northern USVI to assess water quality, coral recruitment rates, and coral juvenile density. It was predicted that larval behavior and survival would be negatively affected in ammonium-enriched treatments and that coral recruitment and juvenile densities would be significantly lower on reefs with higher nutrient and fecal indicator bacteria levels.
To experimentally assess the impacts of elevated nitrogen on coral larvae survival, motility, and settlement of an endangered species of spawning coral, *Orbicella annularis* gametes were collected and reared in the land-based nursery at the Nature Conservancy headquarters, St. Croix, USVI. Larvae were treated with ambient seawater, artificial seawater, low ammonium seawater, and high ammonium seawater. In the field, water quality testing was performed for each of the 8 study sites to analyze turbidity, dissolved inorganic nutrients (DIN), chlorophyll, *enterococcus* bacteria, fecal coliforms, and *E. coli*. At each site, coral recruitment rates were evaluated using settlement tiles and coral juveniles were quantified in belt transects. Preliminary analysis indicates that there was little effect of nitrogen on coral larvae motility, survival, settlement, and post-settlement survival. Coral recruitment levels varied among sites and the dominant family represented across all sites was Agariciidae. The results of this study will have direct implications for best practices in restoration as well as management recommendations on the relationship between water quality and coral recovery.

Poster
A-1274

Moonlight and darkness regime as proximate cues for coral spawning

De la Torre Cerro, R.
Newcastle University, CoralAssist lab, School of Natural and Environmental Sciences, Newcastle, United Kingdom

r.de-la-torre-cerro2[at]newcastle.ac.uk

Abstract

Coral spawning synchrony depends on a complex interplay between physiological processes such as gametogenic cycles, circa-diel - circa-lunar rhythms, and responses to environmental cues. Synchrony in spawning time is therefore a key characteristic of coral reproduction particularly for broadcast spawners which rely on external fertilisation. Although spawning synchrony is vital for ensuring persistence of coral populations, there is still much uncertainty about the environmental cues that trigger spawning on a particular night, usually shortly before or after the full moon. Recent research has suggested that night of spawning is influenced by rapid increases in sea surface temperature (SST) and by the increasing darkness period after sunset that takes place after the full moon. However further empirical tests in controlled conditions are needed to find out whether a period of darkness before moonlight could actually be a cue for spawning time and synchrony, and how different coral families and species respond to this factor. We conducted a field experiment in Palau, where the spawning season of *Acropora digitifera* is usually split between March and April. March spawners usually initiate spawning between 5-6 days after the full moon while April spawners tend to do so closer to the full moon. We manipulated the timing and length of darkness period prior the full moon in split spawners in order to test for the effect of darkness on spawning time and synchrony. We used opaque and transparent lids to cover colonies for a 10-day period in March and April, evaluating whether colonies spawned on each night. We documented differences on colonies spawning time in the prolonged darkness treatments respect to these colonies kept with ambient light conditions. Additionally, we performed regression analysis using historic spawning data in Palau and three other geographical locations to test for the effect of length of darkness period before moonlight on determining peak night of spawning of species belonging to four common widespread reef building coral taxa; Acroporidae, Euphylliidae, Merulinidae and Poritidae. Our results provide new insights about phenological cues of coral reproduction and synchrony and should foster further discussion about the light-darkness interplay and its relevance for preventing breakdowns in coral synchrony.

Poster
A-1474

Stony Coral Spawning Hubs in Southeast Florida

Hefley, H. E., VanWynen, C. M., Hayes, N. K., Figueiredo, J., Gilliam, D. S.
Nova Southeastern University, Department of Marine and Environmental Science, Dania, United States

hh572[at]mynsu.nova.edu

Abstract

In the Southeast Florida Coral Reef Ecosystem Conservation Area (ECA), a Stony Coral Tissue Loss Disease (SCTLD) disease outbreak significantly reduced the abundance of disease susceptible corals. Because abundance has significantly declined, the likelihood of eggs and sperm from different colonies naturally encountering each other has been severely reduced, limiting successful recruitment that drives reef recovery. Increasing coral density region-wide can be done through asexual and sexual forms of reproduction. On a local-scale, coral density can be managed by relocating colonies to specific sites to bring sexually mature colonies together during spawning events, essentially creating an *in-situ* spawning hub for select species. Two spawning hubs offshore southeast Florida, USA, were established in July 2020. The process of selecting the spawning hub sites was facilitated using a bio-physical larval dispersal model to identify sites with the greatest potential to produce a greater number of larvae that settles on a greater number of reefs. Five stony coral species were relocated to the spawning hubs from July 2020 through January 2022 (63 *Pseudodiploria clivosa*, 52 *P. strigosa*, 27 *Diploria labyrinthiformis*, 24 *Orbicella faveolata*, and 3 *Colpophyllia natans*). All five species are hermaphroditic broadcast spawners and have identified spawning windows. The relocated colonies were monitored monthly for 3 months, and then quarterly, for survival, and predation and disease. Natural colonies susceptible to SCTLD located around the hubs were also monitored for survival, and predation and disease. Annual spawning observations and gamete collections are scheduled. This restoration activity promotes species recovery by supporting recruitment driven by natural sexual reproduction and by providing sites where efficient spawning observations and gamete capture can occur. Spawning observations will advance our understanding of stony coral reproductive ecology while gamete capture will support our ability to rear larvae in land-based nurseries furthering species recovery opportunities.

Poster
A-1108

Climate Change, UV and Oil – A hot and sticky mess for corals?

Nordborg, M.[1, 2, 3], Negri, A.[1, 3]
[1]AIMS[at]JCU, Townsville, Australia
[2]James Cook University, College of Science & Engineering, Townsville, Australia
[3]Australian Institute of Marine Science, Townsville, Australia

mikaela.nordborg[at]my.jcu.edu.au

Abstract

Petroleum oil extraction and use in the vicinity of coral reefs is likely to continue for the foreseeable future with the potential for spills to result in catastrophic impacts on affected reefs. Additionally, shipping is predicted to increase in many areas of importance, including the Great Barrier Reef region. However, information on the effects of petroleum oil toxicity to tropical marine species, including corals, is very limited. Coral reefs occur in environments frequently exposed to high ultraviolet light (UV) intensities, which can significantly increase the toxicity of petroleum oils due to the presence of phototoxic compounds. Additionally, reef-building corals are under increasing pressure from global climate change, with even less information available on the potential interactions between oil toxicity and elevated temperature to tropical corals. Here we present the results from the first study of the cumulative effects of exposure to heavy fuel oil, elevated temperature and ultraviolet light on a reef-building coral. *Acropora millepora* larvae were exposed to seven concentrations of dissolved aromatics from a standard heavy fuel oil at several treatment temperatures. Exposure lasted for 48 h and was performed under visible light in the absence or presence of UV in a fully crossed design. Inhibition of larval settlement was observed at low concentrations for all treatment combinations. These results will provide insights into how the risks posed by oil spills may change in the coming century and could be applied to re-evaluate the risks associated with oil spills under marine heatwave conditions during the annual coral spawning season.

Poster
A-1316

The Phylogenetics and Population Genomics of massive Porites corals on Guam

Primov, K., Burdick, D., Lemer, S., **Combosch, D.**
University of Guam, Marine Laboratory, Mangilao, Guam

comboschd[at]triton.uog.edu

Abstract

Massive *Porites* are among the most widespread, major reef builders on Indo-Pacific coral reefs. They have also been identified as comparatively resilient to stressors, including increasing sea surface temperatures and eutrophication. This resilience enabled them to inhabit diverse environments, from oceanic fore reefs to shallow backreefs and turbid river deltas, where few other corals persist. Interestingly, corals in turbid environments tend to exhibit higher bleaching resilience during heat waves than those in nearby clear water habitats. It is still unclear, however, if these differences are driven purely by environmental factors or are also due to intra- or inter-specific differences since massive *Porites* species are notoriously difficult to distinguish morphologically.
Here, we use a ddRAD-Seq approach to characterize the extent of species diversity among massive *Porites* in three Southern Guam river deltas and four adjacent fore reef sites. We identified six distinct genetic clades of massive *Porites* that most likely constitute different species. Interestingly, five out of these six clades were predominantly or exclusively found on fore reefs but one clade predominantly occurs in river deltas. This "Riverine" clade exhibited minor, yet significant genetic structure among populations while no significant population structure was detected among populations of the two largest fore reef clades. Symbiodinacea characterizations revealed that all five assessed clades were dominated by *Cladocopium*, regardless of sampling habitat. *Breviolum* and *Durusdinium* were identified in a few samples and interestingly, *Breviolum* were only found in corals sampled in river deltas. These results testify to the high species diversity of massive *Porites* on Guam and suggest that differential bleaching response may be due to interspecific differences in the coral host, potentially facilitated by the presence of different secondary symbionts.

Poster
A-1367

Gametogenesis of Acropora downingi on the Coral Reefs of Qatar

Sarhan, K.[1], Range, P.[1], Goergen, E.[2], Padierna, M.[2], Khalifa, R.[1], Hamza, S.[1], Hizam, Z.[1], Aljamali, F.[2], Ben Hamadou, R.[1, 2]
[1]Qatar University, Environmental Science Center, Doha, Qatar
[2]Qatar University, Department of Biological and Environmental Sciences, Doha, Qatar

kholoud.sarhan[at]qu.edu.qa

Abstract

The restoration of coral reefs is becoming essential as they are declining due to environmental changes and local anthropogenic activities; therefore, it is critical to understand and determine the implications of this decline to the reproductive biology of corals. Despite the harsh and unique marine environment of the Arabian Gulf, coral reef research in the region is limited. This study investigated the reproductive characteristics of the branching coral, *Acropora downingi*, based on histological and gross dissection techniques of samples collected in 2019, 2020 and 2021. Results indicate the presence of oocytes from October to March and spermatocytes between January to March. Oocytes started appearing in October and matured through March, reaching stage IV, which is a strong indication of imminent spawning. A similar trend was recorded for spermaries, although their cycle is much shorter. Therefore, spawning will take place in April or May, depending on the lunar cycle and on the rate of increase of seawater temperature. Direct observations of colonies in the field and in aquaria are currently underway, to define the spawning period with greater precision. This is the first study on the reproduction of coral reefs in the State of Qatar. Identifying the gametogenic cycle and spawning period of corals is critical to understanding their resilience to environmental change and to inform the planning of conservation and restoration actions.

Virtual
Oral
A-1269

Performance of innovative materials as recruitment substrates for coral restoration

Leonard, C.[1], Hedouin, L.[1], Lacorne, M.[2], Dalle, J.[3], Lapinski, M.[3], Blanc, P.[4], Nugues, M.[5]
[1]EPHE-UPVD-CNRS, UAR 3278 CRIOBE, Moorea, French Polynesia
[2]Université des Antilles, Pointe-à-Pitre, Guadeloupe, [3]Seaboost, Montpellier, France
[4]TotalEnergies, Pau, France, [5]EPHE-UPVD-CNRS, UAR 3278 CRIOBE,, Perpignan, France

camille.leonard[at]etu.ephe.psl.eu

Abstract

Artificial reefs and, more recently, ecoengineering are frequently advocated as possible tools to counteract the loss of tropical coral reefs worldwide. Despite increasing availability of novel materials, there is limited understanding of how different materials and their physical and chemical properties can influence coral recruitment success and early benthic community development. Through two experiments deployed on the forereef of Mo'orea, French Polynesia, we investigated the efficacy of eight innovative materials and four different surface complexities as recruitment substrates for corals and other sessile benthic communities. Tiles were removed and analyzed regularly to monitor the growth and survival of recruits. In the first experiment, settlement tiles were lined up vertically to mimic cryptic habitats that are sheltered from predation. Six innovative materials, including 3D printed concrete, fiberglass polymer, and flax-based polylactic acid, produced similar coral recruitment to control materials (Portland concrete and PVC). Two materials (porous concrete and ceramic foam) produced lower recruitment. Porous concrete was characterized by a high abundance of non-coralline encrusting red algae, which negatively correlated with coral recruitment, while ceramic foam was prone to erosion. In the second experiment, four different surface complexities were tested on horizontal tiles exposed to predation. The number of recruits was highest with increasing complexity. Porous concrete tiles, that had the lowest success when sheltered from predation, were most successful compared to smooth materials when exposed to predation. By replicating the experiments two years in a row, we found that total coral recruitment was 3 times higher in 2021 compared to 2020. This could be explained by a reduced reproductive output following the 2019 bleaching event in Mo'orea. The results suggest the structural micro-complexity and durability of an artificial material and the composition of the benthic communities colonizing it can strongly influence coral recruitment. This study highlights several innovative materials and textures as suitable recruitment substrates for coral restoration and provides a better understanding of the properties of artificial materials that are critical for coral recruitment success, survival and growth.

Virtual
Oral
A-2134

Multispecific synchronous coral spawning on Pulau Bidong, Malaysia, South China Sea

Tan, C. H.[1], Jaafar, S. N.[2], Idris, I.[3], Baird, A.[4]
[1]Research and Education on Environment for Future Sustainability (REEFS) Research Interest Group, Faculty of Science and Marine Environment, Universiti Malaysia Terengganu, Kuala Nerus, Terengganu, Malaysia
[2]Research and Education on Environment for Future Sustainability (REEFS) Research Interest Group,Faculty of Science and Marine Environment, Universiti Malaysia Terengganu, Kuala Nerus, Terengganu, Malaysia
[3]South China Sea Repository & Reference Centre (RRC), Institute of Oceanography and Environment (INOS), Universiti Malaysia Terengganu, Kuala Nerus, Terengganu, Malaysia
[4]ARC Centre of Excellence for Coral Reef Studies, James Cook University, Townsville, Queensland, Australia

tanchunhong[at]umt.edu.my

Abstract

Multispecific synchronous spawning appears to be a feature of all speciose coral assemblages having now been reported from at least 25 locations in the Indo-Pacific. Nonetheless, there are many aspects of coral spawning that remain poorly understood, and many regions for which there is little data. In particular, there are few records of coral spawning from the South China Sea. Here, we document multispecific synchronous spawning of scleractinian corals on Pulau Bidong (5 37'S; 103 03'E), an inshore island on the east coast of Peninsular Malaysia. Underwater visual surveys were conducted one to two days before full moon to identify the maturity of coral gonads by randomly braking coral branches and examined the gonad condition. These surveys indicated that only 17% of Acropora colonies (n = 825) had mature oocytes and 1% had immature oocytes. Following these visual surveys, in-situ observations were conducted on SCUBA between the hours of 1930h to 2200h from the 22nd to the 25th March 2019 to observe coral spawning. We found that a total of 15 species of scleractinian corals in four genera were observed to spawn, including Acropora spp. and Montipora spp. Spawning was first observed on the 22nd, one night after the full moon on 21st, when a small number of colonies of three species (Montipora crassituberculata, M. samarensis and Lobophyllia sp) released gametes. Then, six species spawned on the subsequent night: Acropora cf loripes, A. nasuta, A.gemmifera, A. muricata, A. nobilis and A. florida. In the third observation night, four species (Merulina ampliata, Porites cf lutea, L. radians and A. florida) spawned. A similar series of in-situ spawning observations conducted one month later between the 19th to 22nd April 2019, recorded only one A. muricata colony spawning on 21st April 2019. Following monthly sampling recorded white visible oocytes in August 2019. This suggested another mass spawning period later of 2019 (i.e., September or October) coincident with a 2nd period of Acropora spp. spawning on Pulau Tioman (Marine Protected Area about 350 km south of Pulau Bidong), and consistent with a 2nd spawning period on many other equatorial reefs. Information on the temporal and spatial variation in coral spawning is important in predicting the connectivity between reefs, and crucial for the efforts in coral reef protection and conservation.

Session 2D - How will the coral populations of today affect the ecology and recovery of coral reefs in the future?

Conceptualized by: **Kelly E. Speare** [1], **Aaron C. Hartmann**[2], **Kristen L. Marhaver**[3]
[1] University of California, Santa Barbara (Santa Barbara, CA, USA)
[2] Harvard University (Cambridge, MA, USA)
[3] CARMABI Research Station (Curacao)

Chaired by: **Kelly E. Speare** [1], **Kristen L. Marhaver**[3]

Oral
A-1695

Long-term population increase in a Pocillopora community, Devil's Crown, Galápagos Islands, Ecuador

Brinker, E., Feingold, J.
Nova Southeastern University, Halmos College of Arts and Sciences, Fort Lauderdale, United States

ean.brinker[at]outlook.com

Abstract

Corals in the genus Pocillopora are ecologically important reef-building corals in the Eastern Tropical Pacific, and are susceptible to bleaching and mortality during temperature shifts associated with El Niño-Southern Oscillation (ENSO) events. Prior to 1983, the semi-enclosed elliptical (150 x 85 m) basin of Devil's Crown supported one of the largest and densest known aggregations of Pocillopora in the Galápagos Archipelago. However, during the severe 1982-83 ENSO warm-phase event, these corals died and their skeletons were subsequently bioeroded, leaving no living Pocillopora or even remnant reef structure. This study documents Pocillopora re-colonization of Devil's Crown beginning in 1995, and population increases and reductions associated with ENSO warm- and cool-phase events. Snorkel surveys over the entire coral habitat were conducted at approximately annual or biennial intervals over 37 years (1984-2021). Population shifts, in terms of colony number and projected 2-dimensional surface area, document responses to ENSO events. No live Pocillopora were observed within the basin of Devil's Crown from 1984-1994, with the first live colonies observed in 1995 (n = 5, total live tissue area = 849 cm2). A slow increase occurred over 9 years when 61 colonies were observed in 2004, with greater than doubling of the population over the next 3 years to 154 colonies in May 2007 (total live tissue area = 37,742 cm2). Mortality associated with a strong ENSO cool-phase event later in 2007 left 11 colonies alive in 2009, a decrease of 93%. This remnant population increased over the next 10 years to 285 colonies (total live tissue area ~ 123,000 cm2) in survey in 2019, the largest population recorded since 1983. Preliminary data from 2021 suggests an additional increase over 2019, with 418 recorded colonies. This is a long-term (37 y) trend of ecologically meaningful recovery following complete extirpation of an important reef-building species from Devil's Crown. These data are a welcome report of positive change in a local coral habitat during a period of global decline in coral cover.

Oral
A-1058

Decomposing the demographic patterns of survival, growth, and recruitment is crucial for predicting the viability of subtropical coral populations

Cant, J.[1, 2], Reimer, J.[3, 4], Sommer, B.[5, 6], Cook, K.[2], Kim, S.[7], Sims, C.[7], Mezaki, T.[8], O'Flaherty, C.[2], Brooks, M.[2], Nakamura, M.[9], Malcolm, H.[10], Pandolfi, J.[7], Salguero-Gómez, R.[11, 12, 13], Beger, M.[2, 12]
[1]University of St Andrews, Centre for Biological Diversity, St Andrews, United Kingdom
[2]University of Leeds, School of Biology, Leeds, United Kingdom
[3]University of the Ryukyus, Molecular Invertebrate Systematics and Ecology Laboratory, Nishihara, Okinawa, Japan
[4]University of the Ryukyus, Tropical Biosphere Research Centre, Nishihara, Okinawa, Japan
[5]University of Technology Sydney, School of Life Sciences, Sydney, Australia
[6]University of Sydney, School of Life and Environmental Science, Sydney, Australia
[7]The University of Queensland, Australian Research Council Centre of Excellence for Coral Reef Studies, Brisbane, Australia
[8]Kuroshio Biological Research Foundation, Nishidomari, Otsuki-cho, Kochi, Japan
[9]Tokai University, School of Marine Science and Technology, Shimizu, Shizuoka, Japan
[10]Solitary Islands Marine Park, Department of Primary Industries, Coffs Harbour, Australia
[11]University of Oxford, Department of Zoology, Oxford, United Kingdom
[12]University of Queensland, Centre for Biodiversity and Conservation Science, Brisbane, Australia
[13]Max Planck Institute for Demographic Research, Rostock, Germany

jic2[at]st-andrews.ac.uk

Abstract

The exposure of coral assemblages to high environmental variability may grant them resilience towards future increases in climatic variability. Yet our lack of understanding for the determinants of the coral population performance within variable environments hinders forecasting the future reassembly of reef communities. Exposed to enhanced seasonal variation and broader scales in abiotic conditions, hard corals at higher latitudes represent ideal natural analogues for evaluating the mechanisms mediating the success or failure of coral populations within variable environments. Using Integral Projection Models, we compare the short- (*i.e.*, transient) and long-term (*i.e.*, asymptotic) demographic characteristics of tropical and subtropical coral assemblages to evaluate how thermal variability influences coral population performance and resilience. Exploring spatial variation across the dynamics of functionally different competitive, stress-tolerant, and weedy coral assemblages in Australia and Japan, we show that coral assemblages trade-off long-term performance for transient potential in response to thermal variability. Next, we apply a transient Life Table Response Experiment to decompose how variation among the survival, growth, and recruitment patterns of tropical and subtropical coral assemblages define their relative capacities for embracing recurrent disturbance. We illustrate how coral assemblages can reduce their susceptibility towards environmental variation by exploiting volatile short-term demographic strategies, underpinned by the survival and fragmentation of large colonies. However, we also reveal considerable variation across the vulnerability of competitive, stress-tolerant, and weedy coral assemblages towards future increases in thermal variability. In particular, competitive corals possess a diminished capacity for elevating their transient potential in response to environmental variability. Accordingly, despite their current exposure to high thermal variability, future climatic shifts threaten the structural complexity of coral assemblages, derived mostly from competitive coral taxa within highly variable subtropical environments, emulating the degradation expected across global coral communities.

Oral
A-1182

Implications of senescence, gamete incompatibility and relatedness in larval cultures of the critically endangered elkhorn coral (Acropora palmata)

Chamberland, V. F.[1], Miller, M. W.[2], Latijnhouwers, K. R. W.[1], Bennett, M.-J.[1], Conn, T.[3], Osborne, C.[3], Vasquez Kuntz, K.[3], Doblado Speck, T.[4], Baums, I. B.[3]
[1]SECORE International, CARMABI Foundation, Willemstad, Curaçao
[2]SECORE International, Miami, United States
[3]Pennsylvania State University, Department of Biology, State College, United States
[4]SECORE International, Puerto Morelos, Mexico

v.chamberland[at]secore.org

Abstract

The highly clonal Caribbean elkhorn coral, Acropora palmata, may undergo many asexual 'generations' of fragmentation, growth and re-fragmentation resulting in small colonies which may be hundreds- or even thousand-year-old genets. One consequence of such a long life history is the potential to accumulate molecular and cellular defects such as deleterious somatic mutations, telomere erosion and oxidative damage, potentially contributing to senescence and reduced reproductive output with age. Yet, the effect of aging is difficult to test in corals because young genets cannot be easily identified in the wild.

Here, we utilized colonies that were raised from larval recruits, outplanted to Curaçaoan reefs with known age of 6-10 years, and have spawned yearly since the age of 4. We tested the hypothesis that young genets produce more and higher quality gametes and/or fitter offspring than 'old' genets. Gamete bundles were collected from 10 individual 'young' (6- to 10-yr-old) and 16 'old' colonies (genets) during natural spawning events in August 2019, 2020 and 2021, (i) to quantify size and number of eggs per bundle, (ii) to conduct over 75 independent replicate crosses among ‘young’ and 'old' parents to assess fertilization success, and (iii) to run assays tracking larval survival, settlement and post-outplanting survival rates of the two age treatment groups.

Altogether, our findings do not support age as a driver of declines in reproductive success in *A. palmata*. Instead, fertilization assays revealed strong effects of genet combinations on fertilization success, rather than age, and highlight the importance of gamete incompatibility issues in this species. We also found differing effects of temperature stress exposure on larval families, independent of parental age groups. Surprisingly, a kinship analysis revealed that several of the young, lab-bred genets included in this study are closely related (1st to 4th degree kinship), warranting further investigations into the mechanisms leading to such limited genetic diversity in restored coral populations originating from larval cultures.

Oral
A-2245

Linking population dynamics of the genus Pocillopora to indices of heterotrophic resource availability

Edwards, C.[1], Fox, M.[2], Kodera, S.[1], Pedersen, N.[1], Petrovic, V.[3], Conner, K.[4], Williams, G.[5], Kuester, F.[3], Smith, J.[1], Zgliczynski, B.[1], Sandin, S.[1]
[1]Scripps Institution of Oceanography, UC San Diego, La Jolla, United States
[2]Woods Hole Oceanographic Institution, Woods Hole, United States
[3]Calit2, UC San Diego, La Jolla, United States
[4]University of Hawaii, Manoa, Honolulu, United States
[5]School of Ocean Sciences, Bangor University, Bagor, United Kingdom

clint[at]ucsd.edu

Abstract

While the relationship between large-scale environmental forcings and aggregate measures of coral community change (e.g., percent cover) are well understood, mechanistic understandings of the drivers of coral vital rates are less well known. Variation in the utilization of heterotrophic resources is one mechanism that has been shown to have significant effects on coral condition, survivorship and reproductive capability. How differences in the utilization of heterotrophic subsidies scales to variation in vital rates at the population level, however, remains largely unknown. Using a well resolved temporal, oceanographic, and physiological dataset, we test candidate hypotheses of the effect of heterotrophy on the realized population dynamics of the abundant coral taxon Pocillopora. We collected large-area imagery from 2013-2019 at 16 100m^2 plots on the fore reef (10m stratum) at Palmyra Atoll (USA; central Pacific) to track the fates of thousands of Pocillopora colonies and describe population dynamics. Sampling in 2015 coincided with a warm water event during which Palmyra experienced 11.9 DHW, resulting in severe and widespread bleaching, and allowing us to estimate the bleaching response of individual Pocillopora colonies. Results reveal Pocillopora populations to be highly dynamic through time, with significant fluctuations in recruitment and mortality rates. We show that levels of heterotrophy vary among sites, which was determined using stable isotope analysis, with interactions between colony size, growth rates and survivorship of colonies. At the site level the percentage of colonies experiencing bleaching in 2015 ranged from 63.4%-94.0% and we detected some evidence for differences in mortality rates the following year. However, we did not detect significant changes in overall growth rates of Pocillopora between 2015 and 2016. Island-scale differences in connectivity between fore reef sites and plankton-rich lagoonal waters as well as differences in reef slope, which influences nutrient delivery from internal waves, were linked to patterns in Pocillopora demography, with notable effects on survivorship. Results are supportive of hypotheses that suggest greater access to heterotrophic resource subsidies during bleaching events can reduce coral mortality.

Oral
A-2039

Impact of Coral Bleaching 2016 in Japan

Kimura, T.
Palau International Coral Reef Center, Koror, Palau

bxq02107[at]nifty.ne.jp

Abstract

The third global coral bleaching was occurred in 2016 following the bleaching 1998 and 2010. Since 2003, nationwide coral monitoring has been conducted as one of the programs under the Ministry of the Environment, Japan. The result of the monitoring showed the largest impact of bleaching at the Sekisei Lagoon in Okinawa showing over 50% of mortality.

Oral
A-2112

Multiple demographic dimensions predict fitness and abundance in reef coral assemblages

McWilliam, M.[1], Dornelas, M.[2], Alvarez-Noriega, M.[3], Baird, A.[4], Connolly, S.[5], Madin, J.[1]
[1]Hawaii Institute of Marine Biology, Kaneohe, United States
[2]University of St Andrews, St Andrews, United Kingdom
[3]Australian Institute of Marine Science, Townsville, Australia
[4]ARC Centre of Exellence for Coral Reef Studies, Townsville, Australia
[5]Smithsonian Tropical Research Institute, Balboa, Panama

mjmcwilliam[at]outlook.com

Abstract

Life history traits are promising tools to predict species commonness and rarity because they influence a population's fitness in a given environment. Yet, species with similar traits can have vastly different abundances, challenging the prospect of robust trait-based predictions. Using long-term demographic monitoring, we show that coral populations with similar morphological and life history traits show persistent (decade-long) differences in dominance and rarity. Morphological groups predicted species positions along two, well-known life history trade-off axes (the fast-slow continuum and size-specific fecundity). However, integral projection models revealed that fitness was more variable within morphological groups, and was consistently higher in dominant species relative to rare species. Within-group fitness differences projected large abundance differences among similar species in short timeframes, and were generated by small but compounding variation in growth, survival, and reproduction. Our study shows that easily-measured traits (e.g., morphology) predict demographic strategies, yet small life history differences can accumulate into large differences in fitness and abundance among similar species. Quantifying additive effects of traits on fitness is therefore essential to anticipate species abundances.

Oral
A-1201

Differences in ploidy and the prevalence of clonal propagation between Montipora capitata and Pocillopora acuta from Kāne‘ohe Bay, Hawai‘i

Stephens, T.[1], Strand, E.[2], Putnam, H.[2], Bhattacharya, D.[1]
[1]Rutgers University, Department of Biochemistry and Microbiology, New Brunswick, United States
[2]University of Rhode Island, Department of Biological Sciences, Kingston, United States

ts942[at]sebs.rutgers.edu

Abstract

It is widely accepted that standing genetic variation is a major driver of fitness and resilience in natural populations, with high variation providing species with the best “defense” against changing environments. This is of fundamental importance when considering threatened species such as stony corals that form the foundation for biodiverse marine ecosystems. Here, we used RNA-seq data generated from 132 *Montipora capitata* and 119 *Pocillopora acuta* colonies from Kāne‘ohe Bay, O‘ahu, Hawai‘i to study the extent of genetic variation and differences in genome ploidy between the two species across the bay. Using a population genomics framework, we found that the majority of *P. acuta* colonies likely spread throughout the bay via asexual reproduction and are descended from potentially only a few genets. We also found that 75 (63%) of the *P. acuta* samples were triploids and that they appear to have almost exclusively spread throughout the bay via asexual reproduction. Unsurprisingly, we find that the expression profiles of genetically related samples are highly correlated, with this affect observed most strongly between samples, such as the triploids, which are derived from asexual reproduction. The strength of these correlations is notable given that the samples were part of a mesocosm experiment and had been exposed to a variety of different stress treatments and collected at different times. In contrast to the results from *P. acuta*, the *M. capitata* colonies were all diploids, with almost no samples identified that were derived from asexual reproduction. The expression profiles of the *M. capitata* samples also reflect their relatively more distant relationships. While this result is not unexpected, given that genetically related individuals are known to have highly similar expression profiles, the limited amount of genetic variation observed in the *P. acuta* population in the bay may have significant implications for the adaptive capacity of this species during future periods of environmental stress. Furthermore, the significant differences between the reproductive strategies, life histories, and genome configurations between these two Hawaiian coral species, which are found together across the bay, represents an unexplored avenue of research into how coral genomes evolve in response to stress. This is particularly relevant given the urgency of climate change and the large focus that has developed around designing more resilient marine ecosystems.

Oral
A-2064

Taking a leaf out of the terrestrial book: a scaling law for assessing coral population trends

Wulstein, D.[1], Madin, J.[1], Oliver, T.[2], Falster, D.[3]
[1]Hawaii Institute of Marine Biology, Kaneohe, United States
[2]National Oceanic and Atmospheric Administration, Pacific Islands Fisheries Science Center, Honolulu, United States
[3]University of New South Wales, Sydney, Australia

devynnmw[at]hawaii.edu

Abstract

With intensifying frequency of disturbance, coral population and community dynamics are increasingly defined by bursts of mortality, fragmentation, or shrinkage, followed by periods of recruitment and growth. Meanwhile, coral reef scientists are increasingly thinking more about restoring corals much like replanting trees in areas devastated by fire or logging. Therefore, characterizing the size, density, and diversity of coral communities during recovery windows has become an important goal in coral reef ecology. In terrestrial ecology, episodic growth and mortality events are characterized by the self-thinning rule, N= K<size>^a relationship between population density (N) and mean individual size (<size>), which can help to inform patterns of biomass rise and collapse within an ecosystem. In the above equation, K is a constant often related to environmental parameters and is the exponent defining the relationship typically seen with the value of - 0.5. Identifying the scaling law for particular species across biogeographical scales and over various abiotic conditions has been a fundamental aspect of terrestrial restoration practices, particularly in forestry. However, the universality and application of the self-thinning rule to reef building corals is largely unknown. Here, we explore self-thinning in coral assemblages over a large biogeographical scale and identify the factors governing the differences in the density-mortality relationship. Using the Rapid Ecological Assessment data collected via NOAA's NCRMP, we estimate the density-size relationships for reef patches across multiple scales (reef patch, site, and sector scale) and varying community assemblages. The morphology specific density-mortality relationships reveals a striking deviation from the aggregated self-thinning power-law where both K and are substantially changed. This and further explorations such as those including additional data disaggregation (e.g., the level of species richness) provide insight into the mechanisms defining the self-thinning relationship for corals. These results will build a baseline for understanding the population structures and ecological trajectories of reefs over a range of community succession states (e.g., post-disturbance or near climax) and help to define the demographic processes that are contributing to those systems.

Poster
A-1227

The Population Genetic Structure of Acropora pulchra in Guam

Rios, D., Combosch, D.
University of Guam, Marine Laboratory, Mangilao, Guam

comboschd[at]triton.uog.edu

Abstract

Staghorn Acropora corals are ecologically important as locally dominant reef-builders, and habitat structurers for fishes and invertebrates. However, many staghorn species are particularly susceptible to coral bleaching, caused by warming sea surface temperature. In Guam, staghorn *Acropora* suffered an estimated 50% loss, spanning a three-year period marked by multiple bleaching events (2013-2015). These declines have the potential to reduce genetic variation in affected species, thus impeding their ability to adapt to changing environmental conditions.
In this study, we determine the presence of population structure of *Acropora pulchra* in Guam. We analyze genome-wide ddRAD sequence data of 150 *A. pulchra* samples from five remaining staghorn populations around Guam. Standard population genetic analyses are used to determine levels of genetic and genotypic diversity, population structure, and gene flow. We also assess signatures of selection and local adaptations in *A. pulchra* populations around Guam, by comparing multiple FST outlier approaches.
Presently, there are no peer-reviewed population genetic data for any coral species in Guam, which stresses the importance of this study. The resulting population genetic data will be used to determine populations of high conservation priority to better inform conservation and restoration management. In addition, resulting genetic data will advise operations of the University of Guam's coral nursery to focus efforts on growing and transplanting genetically diverse and resilient staghorn fragments to restore their populations around Guam. This study facilitates proper conservation and restoration of *A. pulchra*, by providing a detailed understanding of its basic population genetic framework, structure and dynamics.

Virtual
Oral
A-1041

How a scleractinian coral can 'cheat' the intermediate disturbance hypothesis

Jogee, N.[1], Newman, S.[2], Robinson, D.[3], Gallimore, S.[2], Exton, D.[4], Burdett, H.[5], Kamenos, N.[6], Hennige, S.[7]
[1]The University of Edinburgh, Edinburgh, United Kingdom
[2]Banyan Tree Global Foundation, Phuket, Thailand
[3]Newcastle University, Newcastle, United Kingdom
[4]Operation Wallacea, Lincoln, United Kingdom
[5]Heriot-Watt University, Edinburgh, United Kingdom
[6]University of Glasgow, Glasgow, United Kingdom
[7]University of Edinburgh, Edinburgh, United Kingdom

nadia.jogee[at]ed.ac.uk

Abstract

Tropical coral reefs are one of the planets most valuable ecosystems, yet they are threatened by human driven climate change. One consequence of climate change is increased disturbance events, such as coral mass-bleaching events, leading to mortality. The intermediate disturbance hypothesis predicts that rapidly colonising species will be the 'winners' after frequent and severe disturbances. However, some corallith forming coral species are relatively resilient to bleaching. The role that these corallith survivors have post-disturbance is largely unknown. We show how across two Maldivian islands the corallith forming *Porites rus* capitalises on disturbance driven reduction of coral cover and the provision of new substrate to rapidly expand its range by 455% in one year. Four years post-disturbance, the community composition had changed from being previously structurally complex, to a community of low complexity dominated by algae and *P. rus.* We show here that *P. rus* expansion is through its propensity to form many resilient, and mobile coralliths enabling it to increase its cover in a time when other corals are dramatically reduced in abundance and cover. This study will help reef managers predict what the future of reefs might look like, but also shines a light on the changes that might be occurring on reefs that are not as closely monitored.

Oral
A-1781

Early life stage bottlenecks determine rates of coral recovery following severe disturbance

Speare, K. E., Aplin, A., Enright, L., Burkepile, D. E.
University of California, Santa Barbara, Ecology, Evolution, and Marine Biology, Santa Barbara, United States

kellyspeare[at]gmail.com

Abstract

Disturbances that reduce the abundance of corals are increasing in frequency and intensity with global climate change. Understanding why some coral communities recover quickly whereas others recovery slowly or never recover is key to understanding drivers of community resilience. From 2007-2010 coral reefs on the outer reef around Moorea, French Polynesia experienced a series of severe disturbances that reduced coral cover from ~46% in 2005 to <1% in 2010. Reefs around Moorea rapidly recovered from these disturbances, with some reefs exceeding pre-disturbance coral cover within five years. Although there was widespread recovery of stony corals, deeper reefs (17m) recovered significantly more slowly than shallower reefs (10m). We investigated the drivers of variation in coral recovery between depths using a combination of time-series data from the Moorea Coral Reef LTER and *in situ* experiments. Time-series data from coral settlement tiles deployed twice annually *in situ* showed that rates of coral settlement did not differ between depths, suggesting that differences in the supply of new corals did not drive different rates of recovery. Next, we used annual photographs of permanently marked quadrats to track the fate of >1200 individual coral colonies from 2011-2018 to quantify rates of coral recruitment, growth, and survival at 10 and 17m. Rates of coral recruitment were 3× higher at 10m compared to 17m, and rates of recruit survival were higher at 10m. There were no differences in coral growth between depths. These results point to early life stage bottlenecks after settlement as the driver of differences in rates of coral recruitment and coral recovery between depths. Finally, we used a series of *in situ* experiments to evaluate possible mechanisms driving these early life stage bottlenecks. We conducted a fish exclusion experiment to evaluate the role of top-down pressure in driving different rates of coral recruit survival between depths. When fishes were excluded, coral recruit survival did not differ between depths. However, when fishes were not excluded, coral recruit survival was significantly lower at 17m, suggesting that top-down pressure by corallivorous and herbivorous fishes may be an important source of coral recruit mortality. Taken together, our work shows that early life history bottlenecks can drive rates of coral community recovery after disturbances, and that top-down pressure likely plays an important role in shaping these bottlenecks.

2D - How will the coral populations of today affect the ecology and recovery of coral reefs in the future?

Session 2E - What are the Patterns, Causes and Consequences of Intraspecific Variation in Marine Larval Dispersal and Population Connectivity?

Conceptualized by: **Malin Pinsky** [1], **Peter Buston** [2], **Michael Berumen**[3], **John Majoris**[3], **Laura Gajdzik**[3]
[1] Rutgers State University (New Brunswick, NJ, USA)
[2] Boston University (Boston, MA, USA)
[3] KAUST (Thuwal, Saudi Arabia)

Chaired by: **Michael Berumen**[3]

Oral
A-2017

Population structure of deep-sea octocoral Acanella arbuscula (Isididae) across the North Atlantic, using SNPs generated from UCE sequencing

Gordon, J.[1], Wareham-Hayes, V.[2], Rogers, A.[3], Howell, K.[4], Taylor, M.[1]
[1]University of Essex, Life Sciences, Colchester, United Kingdom
[2]Department of Fisheries and Oceans, St. Johns, Canada
[3]Rev Ocean, Lysaker, Norway
[4]University of Plymouth, Plymouth, United Kingdom

jessica.gordon[at]essex.ac.uk

Abstract

Deep-sea coral gardens provide essential ecosystem services to marine organisms at various stages of their life histories, providing shelter, breeding grounds, and food. These vulnerable marine ecosystems are targets for fishing, because they host economically important species. Trawling destroys cold water coral reefs, and areas subjected to repeated bottom fishing activity have experienced the terrestrial equivalent of clear cutting a forest, with little signs of recovery post-trawling. Large gardens of *Acanella arbuscula* growing in soft sediments, which can stretch several kilometers, are uprooted and destroyed when contact with fishing gear occurs. These octocorals are ecologically important, because *A. arbuscula* are known to host species of ophiuroid sea star, polychaete, nematode, copepod, anemones, barnacle, and crinoid feather star. They are slow growing (1cm/yr) and require at least three years to reach sexual maturity. In order to protect these vulnerable marine ecosystems, understanding population connectivity is essential to informing marine protected area (MPA) design. To investigate population connectivity of *A. arbuscula* across the North Atlantic, specimens were collected at multiple parallel depth bands from Newfoundland and Labrador (Canada), Greenland, Scotland, The Celtic Sea (Ireland), and The Sea of Biscay (Spain). Identifying source populations for recovery and overall connectivity across the North Atlantic will support the design of an effective MPA network. This population structure will be inferred from the analysis of single nucleotide polymorphisms (SNPs) generated through high throughput sequencing of ultra-conserved elements. Furthermore, the SNPs will be used to test the depth differentiation hypothesis across the North Atlantic which proposes that there is greater genetic differentiation across depth ranges as opposed to geographical distance. It is suspected that some barriers to connectivity exist including those associated with currents, temperature, salinity, oxygen, and nutrient availability.

Oral
A-1613

A connectivity portfolio effect stabilizes marine reserve performance

Harrison, H.[1, 2], Bode, M.[3], Williamson, D.[4], Berumen, M.[5], Jones, G.[1]
[1]James Cook University, Townsville, Australia
[2]Australian Institute of Marine Science, Townsville, Australia
[3]Queensland University of Technology, Brisbane, Australia
[4]Great Barrier Reef Marine Park Authority, Townsville, Australia
[5]King Abdullah University of Science and Technology, Thuwal, Saudi Arabia

hugo.harrison[at]jcu.edu.au

Abstract

Variability in larval dispersal patterns can lead to temporal fluctuations in the replenishment of local populations. Here we show that asynchronous recruitment contributions from four individual marine reserves on the Great Barrier Reef create temporal stability in recruitment via a connectivity portfolio effect. This dampening effect reduces the variability in larval supply from individual reserves by a factor of 1.8, which effectively halves the uncertainty in the recruitment contribution of individual reserves. Thus, not only does the network of four marine reserves generate valuable larval subsidies to neighbouring habitats, the aggregate effect of individual reserves mitigates temporal fluctuations in dispersal patterns and the replenishment of local populations. Our results indicate that networks of marine reserves yield previously unrecognized stabilizing benefits that ensure a consistent larval supply to replenish exploited fish stocks.

Oral
A-1473

Reproductive behavior of Gomphosus varius (Labridae) in relation to current patterns at a spawning aggregation site: Implications for larval dispersal

Kawahigashi, K.
University of Guam, Marine Laboratory, Mangilao, Guam

kaohi95[at]gmail.com

Abstract

A spawning aggregation is an effective and common reproductive strategy among reef fish species, in which conspecific fish congregate for the sole purpose of mating. The bird wrasse, *Gomphosus varius* (Labridae), is a tropical reef fish that forms residential spawning aggregations at specific sites daily if local population densities are relatively high. In this study, the ecological and oceanographic characteristics of *G. varius* was analyzed to further inform reef fish spawning aggregations dynamics. Finger Reef, Apra Harbor, Guam is a multi-species spawning aggregation site for several wrasse species, *G. varius* included. This species utilizes a lek-like mating system while aggregating, and a haremic mating system when not. The objectives of this study were to understand the social and territorial dynamics of this wrasse's lek-like mating system, determine the optimal oceanographic and environmental conditions at a given site that promote spawning, and determine the dispersal patterns of pelagic *G. varius* eggs from this site. From October 2018 to April 2021, field observations were conducted at Finger Reef to determine if *G. varius* spawning patterns correlate with tidal, lunar and seasonality patterns, aggression rate and population dynamics. Surface drifters were also released at different tidal, lunar and seasonality patterns to examine intraspecific variation in initial larval dispersal. The reproductive behavior of *G. varius* is tied closely to male territorial behavior and daily tidal fluctuations, specifically the first diel high tide. Rates of courtship and aggression were positively correlated, indicating that male fish have higher reproductive success when more effort is put into defense of a mating territory. Lunar phase and population density are secondary contributors to reproductive success because they are tied intrinsically to the tidal changes and male territoriality that drive this reproductive system, respectively. Eggs and larvae from Finger Reef are initially dispersed away from the reef and generally drift into the main ocean current during typical dry season conditions. A proportion of the larvae may self-recruit during rainy season conditions, or become trapped in nearshore wave-driven water movements. *Gomphosus varius* spawns continuously despite shifts in seasonality, however, seasonal changes affect where larvae may ultimately disperse.

Oral
A-1713

Connectivity of Indian Ocean coral reefs

Kochzius, M.[1], Benjamen, D. M.[1], De Pauw, A.[1], Dissanayake, K.[1], Hui, M.[2], Huyghe, F.[1], Ng'endo Ikinya, W. A.[1, 3], Nuryanto, A.[4], Otwoma, L.[1, 3], Ratsimbazafy, H. A.[1, 5], van der Ven, R.[1, 6], Van Nieuwenhove, A.[1]
[1]Vrije Universiteit Brussel (VUB), Marine Biology, Brussels, Belgium
[2]Institute of Oceanology, Chinese Academy of Sciences, Key Laboratory of Experimental Marine Biology, Qingdao, China
[3]Kenya Marine and Fisheries Research Institute (KMFRI), Mombasa, Kenya
[4]Jenderal Soedirman University, Faculty of Biology, Purwokerto, Indonesia
[5]University of Toliara, Institut Halieutiques et des Sciences Marines, Toliara, Madagascar
[6]Wageningen University, Marine Animal Ecology Group, Wageningen, Netherlands

marc.kochzius[at]vub.be

Abstract

So far, connectivity of coral reefs in the Indian Ocean was rather understudied and no comprehensive picture could be drawn based on the available data. However, this has changed in recent years and meanwhile a growing number of connectivity studies based on genetic data (mitochondrial DNA sequences and nuclear microsatellites) are published or under way. Even though there are differences in spatial scale, study region and genetic marker used, some general pattern of gene flow are emerging. Here, we present results for seven coral reef taxa, the stony corals *Acropora tenuis* and *Seriatopora hystrix*, the reef fishes *Amphiprion akallopisos* and *Acanthurus triostegus*, the giant clams *Tridacna maxima* and *T. squamosa*, the cephalopod *Octopus cyanea* and the blue sea star *Linckia laevigata*. On the large scale of the Indian Ocean and adjacent seas, the following genetically differentiated regions can be observed: (1) Western Indian Ocean, (2) Red Sea, and (3) Eastern Indian Ocean. This genetic structure is congruent with large-scale oceanographic pattern, such as the narrow connections of the Red Sea the Indian Ocean and the large stretches of open ocean between the Western and Eastern Indian Ocean. Prevailing currents and isolation-by-distance are apparently shaping the genetic structure of all these different taxa in the same way. On a regional scale within the Western Indian Ocean the picture is not so clear-cut, because at this scale the length of the pelagic larval duration and other life history traits probably play a much larger role than on a basin-wide Indian Ocean scale. However, the following genetically differentiated regions could be revealed: (1) North Madagascar, (2) South/Southwest Madagascar, (3) Southwest Madagascar and northern Mozambique Channel, (4) South Mozambique and (5) East African Coastal Current (Tanzania and Kenya). Future studies including more species and samples sites, as well as utilising genome-wide SNPs analysed by Next-Generation-Sequencing are needed in combination with biophysical modelling to receive a comprehensive picture of connectivity in the Western Indian Ocean. This is urgently needed for a proper spatial arrangement of marine protected areas in a Western Indian Ocean-wide network that matches the general connectivity pattern. This will enable sustainable management of marine living resources in the Western Indian Ocean in order to reach the sustainable development goal 14 (life below water).

Oral
A-1766

The influence of eddies on coral larval retention in the Flower Garden Banks

Limer, B., Bloomberg, J., Holstein, D.
Louisiana State University, Oceanography and Coastal Science, Baton Rouge, United States

blimer1[at]lsu.edu

Abstract

Local population maintenance on coral reefs is enhanced by larval retention within reef patches. It is thought that retention has an especially important role in maintaining coral cover in isolated systems such as the Flower Garden Banks (FGB) of the NW Gulf of Mexico (GoM). Mesoscale cyclonic and anticyclonic features (eddies) are known to spin off from the GoM’s Loop Current and pass over the FGB. We developed a biophysical coral larval dispersal model to investigate the role that eddies play in larval retention within and between the East and West FGB. The model tracked virtual *Orbicella faveolata* and *Porites astreoides* larvae and was parameterized to account for their contrasting life histories. Eddies were detected using sea surface height data and compared with simulated larval dispersal pathways to assess the retentive characteristics of these features. The results suggest that local retention and between-bank connectivity are consistently high, especially early on in the dispersal of *P. astreoides.* Simulated larvae of both species routinely experienced retention due to eddy recirculation within 30 days of dispersal. Recirculating retention appears possible up to four months into the dispersal window in spawning species, albeit rare. Large pulses of incoming virtual larvae were associated with eddies passing over the FGB, which suggests that larvae are capable of dispersing from and returning to coral reefs in the NW GoM. Due to the nature of Loop Current eddy shedding, opportunities for retention are inherently ephemeral and stochastic, but eddy propagation could serve as a reliable reseeding mechanism for FGB coral populations. Larval retention in the region may be enhanced by a peak in late summer eddy propagation occurring at the time of mass spawn events. Our model lends support to the hypothesis that FGB reefs may be largely self-sustaining and have the potential to supply downstream reefs with larvae, and thus could behave as a remote climate change refugium.

Oral
A-1050

Spatial conservation prioritisation based on coral reef genetic connectivity in an urbanised seascape

Ong, J. H., Tay, Y. C., Quek, R., Afiq-Rosli, L., Chang, J. J. M., Pwa, K. H. V., Chan, W. W. R., Huang, D.
National University of Singapore, Department of Biological Sciences, Singapore, Singapore

ong.jinghui[at]u.nus.edu

Abstract

The integration of data on biological connectivity between different sites and habitats in spatial conservation planning has become increasingly important as conservation moves beyond focusing on species representation. Genetic connectivity is essential for the long-term viability of populations, but despite its importance, genetic data are not commonly used to inform the planning of marine protected areas. In this study, we address this gap by assessing genetic connectivity across the urban coastal seascape of Singapore using a broad taxonomic range of reef species, including anemones and corals. Genome-wide single-nucleotide polymorphisms were used to estimate population structure, from which genetic connectivity was inferred. Connectivity patterns were incorporated into Marxan Connect for spatial conservation prioritisation to identify areas important for maintaining gene flow and genetic diversity for the continued persistence of biodiversity and ecological functions. Our findings support the importance of taking genetic connectivity into account in conservation decision-making.

Oral
A-1929

Genetic structure and connectivity of an island endemic reef fish in the Eastern Tropical Pacific Marine Corridor

Rodriguez Moreno, M.[1, 2], López Victoria, M.[3], Zapata, F. A.[2], Bernardi, G.[4], Salas, E.[5], Feldheim, K.[6], Devloo-Delva, F.[7], Maes, G.[8], Van Herwerden, L.[9]
[1]ECOMARES - Biological Research & Conservation Foundation, Cali, Colombia
[2]Universidad del Valle, Cali, Colombia
[3]Pontificia Universidad Javeriana, Cali, Colombia
[4]University of California, Santa Cruz, United States
[5]Fishbio, Santa Cruz, United States
[6]Field Museum, Chicago, United States
[7]CSIRO National Collections & Marine Infrastructure, Canberra, Australia
[8]KU Leuven, Leuven, Belgium
[9]James Cook University, Townsville, Australia

melinarodmo[at]gmail.com

Abstract

The Eastern Tropical Pacific (ETP) region has some of the smallest isolated islands in the tropics and harbors a rich marine endemic fauna. The reef fish island endemics are characterized by their small geographic range. Their absence from other areas can be intuitively related with a limited dispersal capacity as vast and deep oceanic waters separate the islands between them and also the islands from the continental coasts. To examine the dispersal ability of an island endemic in the ETP (*Stegastes arcifrons*), the population structure and connectivity across its whole geographic range were analyzed. Three different molecular approaches were used: genome-wide neutral single-nucleotide polymorphisms (SNPs), mitochondrial control region sequences and microsatellites. A restricted connectivity among island was hypothesized, as a result of their limited dispersal ability. Contrary to expectations, a high connectivity between populations in Gorgona, Malpelo and Cocos was found. Genetic differentiation was evidenced only between the Galapagos population and all other populations. Both nuclear markers (neutral SNPs and microsatellites) showed marginally significant genetic differentiation, while mtCR results were highly significant pointing out to a historical geographic isolation among populations. This study demonstrates that *S. arcifrons* has a greater dispersal capacity than expected from its geographic distribution. Oceanographic features can help to explain observed genetic patterns, as the circulation patterns in the ETP are highly dynamic and influenced by the periodic oscillation events of El Niño and La Niña. This study represents the first empirical evidence of genetic connectivity among oceanic islands of the Eastern Tropical Pacific Marine Corridor for organisms with life history traits similar to those of *Stegastes*. The genetic divergence found in Galapagos reaffirms the importance of this marine reserve for the conservation of biodiversity.

Oral
A-1224

Intra- and interspecific comparisons of population connectivity and population structure of corals around Guam

Torrado, H., Primov, K., Rios, D., Combosch, D.
University of Guam, Marine Laboratory, Mangilao, Guam

comboschd[at]triton.uog.edu

Abstract

Genetic diversity and connectivity are main drivers of population resilience to environmental changes. On Guam, coral reefs suffered a rapid decline in the last decade, mainly due to repeated bleaching events between 2013 and 2017. So far, virtually nothing was known about coral genetic diversity and connectivity around Guam. Our lab started to address this knowledge gap by studying a subset of major reef-building corals, using a powerful, 100% on-island/in-house ddRAD-Seq approach. Different projects focus on major dispersal routes, identify source/sink populations, assess local adaptations to different environments and quantify effective population sizes. For example, we compare differences in population structure among bleaching resistant and bleaching susceptible coral species or corals in different habitats around Guam. We are also collaborating closely with a local reef restoration project to inform and guide their restoration efforts. In this talk, I will give an overview of our current studies on the island of Guam (Mariana's archipelago, Micronesia, West Pacific). The focus of this talk will be on our work with different congeneric Acropora species. Using two forereef and one backreef species, we found remarkable differences in their effective population size, population structure, connectivity and local adaptations. This allows us to dig into the patterns, causes and consequences of intraspecific and interspecific population genomic variation in small islands across several coral species.

Oral
A-2042

Island Scale Genetic Diversity and Connectivity of the Octocoral, Heliopora coerulea on Guam

Townsend, A.
University of Guam, Marine Laboratory, Mangilao, Guam

altownsend06[at]gmail.com

Abstract

Coral reefs are considered one of the most vulnerable ecosystems on the planet. In the Western Pacific, coral reefs in various regions have been experiencing a continual 1-2% decline in coral cover since the 1980’s. Reefs around the island of Guam are no exception to the degradative effects of global climate change, and the anthropogenic stressors that are associated with a deteriorating reef habitat. The hermatypic octocoral known as “blue coral” or *Heliopora coerulea* is a unique example of one of the notable reef-building corals, with little research having been conducted regarding this species in Guam. The *H. coerulea* group is comprised of more than one distinct morphology, some of which may exist around Guam in site specific areas or populations. Populations of reef associated organisms are influenced by prevailing ocean surface currents and eddies, which have the potential to heavily contribute to larval distribution and genetic connectivity patterns. In this study, the population genetic structure of *H. coerulea* on Guam was assessed, in addition to examining the occurrences of different morphologies amongst populations via Multiplexed inter simple sequence repeat (ISSR) Genotyping by sequencing (MIG-seq). 110 *H. coerulea* samples representative of four major isolated populations surrounding Guam were genotyped and analyzed. Genetic analysis revealed limited population structure and low genetic diversity, indicating elevated levels of genetic connectivity amongst populations within study sites. High levels of connectivity around the island suggest that the hydrodynamic forces in effect are sufficient in maintaining viable populations. Morphological analysis revealed no clear correlation between sites and morphologies, indicating other factors are influencing morphology amongst populations. Guam’s reproductively connected populations of *H. coerulea* continue to promote genetic diversity between conspecifics, which help mitigate the negative effects of a changing climate and small or genetically unconnected populations. Hydrodynamic forces and current management practices regarding the distribution patterns of *H. coerulea* are adequate in maintaining biodiverse populations on Guam and continue to provide a stepping stone for connectivity of other *H. coerulea* populations throughout the Marianas Archipelago and the rest of the Western Pacific.

Poster
A-1670

Sensory basis of orientation behaviour in fish: CRY4 – a potential protein for magnetoreception in fish?

Laurien, M., Gerlach, G.
Carl von Ossietzky University; IBU, Oldenburg, Germany

malien.laurien[at]uni-oldenburg.de

Abstract

Various coral reef fish species have pelagic larval stages lasting from days to several weeks; during this period, they are subject to dispersal in the ocean until they settle at a reef. Recent research clearly shows that dispersal direction is not random. Marine fish larvae can use olfactory, auditory and visual cues for orientation in the pelagic environments. Additionally, many organisms use magnetic field information to orient in local spaces or to navigate over long distances. Two different mechanisms have been suggested for the perception of the magnetic field involving magnetites and/or cryptochrome 4 (CRY4). The protein CRY4 has been proposed to mediate light-dependent radical pair magnetoreception in a variety of animals. Although magnetoreception has been studied extensively, especially in birds, the role of *cry*4 magnetoreception in fish is still largely unknown. Previous studies in birds suggest that cryptochrome based magnetoreception is mediated by a FAD binding domain and a tryptophan triad, which is essential for the formation of radical pairs sensitivity to magnetic field changes.

In the first stage of this study, we use phylogenetic analysis and a gene tree to understand whether some migratory fish species do possess CRY4. Comparative analysis of the CRY4 and its flanking regions among teleost and birds (*Erithacus rubecula*) show a great similarity in their amino acid composition. Especially the important tryptophan triad seems to be a highly conserved region in the CRY4 sequence; surprisingly it seems to be missing in salmonidae. Furthermore, we examine potential CRY4 sequences in different coral reef fish, such as *Amphiprion ocellaris* and *Ostorhinchus doederleini*, which has been shown to have a magnetic compass orientation. We also conduct behavioural and molecular experiments on the Atlantic herring (*Clupea harengus*), a well-known oceanodroumos long distance traveler in the Baltic Sea.

This project will help to unravel the evolutionary background of magneto-perception in teleost fishes.

Poster
A-1667

Investigating compass- and map-based orientation in the cardinalfish Ostorhinchus doederleini by performing behavioural experiments in the field

Spiecker, L.[1], Curdt, F.[1], Kingsford, M. J.[2], Winklhofer, M.[1], Mouritsen, H.[1], Gerlach, G.[1]
[1]Carl von Ossietzky University Oldenburg, Institute of Biology and Environmental Sciences, Oldenburg, Germany
[2]James Cook University, ARC Centre of Excellence for Coral Reef Studies and College of Science and Engineering, Townsville, Australia

lisa.spiecker[at]uni-oldenburg.de

Abstract

The life cycle of most coral reef fishes includes a dispersal phase, during which larvae that hatched at the reef, get taken away by the currents and spend a few days to weeks in open waters before they return to a reef environment to settle. We demonstrated self-recruitment of up to 60% of the cardinalfish *Ostorhinchus doederleini* by genetically assigning juveniles to the reef population where they were about to settle. To be able to find their way to a reef or even their natal reef, the larvae might use sensory based orientation capabilities. *O. doederleini* larvae can use sun compass orientation, magnetic compass orientation as well as olfactory and auditory cues to find their way, but we still don't know whether larvae imprint on cues of their natal reef directly after hatching and whether they use an evolutionary shaped inherited mean swimming direction to counteract currents that took them away from their natal reef. By testing orientation of *O. doederleini* juveniles which were about to settle in the Swain reefs (southern Great Barrier Reef) and displacing them thereafter by about 180 km to One Tree Island (OTI), we tested the hypotheses: (1) *O. doederleini* settlers caught in the Swain reefs show a current counteracting orientation to the north; (2) *O. doederleini* change their orientation behaviour after displacement. At the Swain reefs, 60 settlers showed on average a southerly direction, which contradicts the main current-counteracting-orientation hypothesis. After displacing the tested larvae to OTI and retesting them, we did not detect a significant deviation in their average swimming direction, which points to a non-map-based, but clock-and-compass based orientation mechanism.

Poster
A-1638

Clonality, genetic structure, and connectivity of the scleractinian Pocillopora acuta across multiple spatial scales in the Philippine archipelago

Torres, A. F.[1, 2, 3], Rondolo, I. B.[4, 5], Ravago-Gotanco, R.[1]
[1]Marine Science Institute, University of the Philippines Diliman, Quezon City, Philippines
[2]Department of Earth Sciences, Natural History Museum, London, United Kingdom
[3]Institute for Biodiversity and Ecosystem Dynamics, University of Amsterdam, Amsterdam, Netherlands
[4]University of the Philippines Los Baños, Los Baños, Philippines
[5]Department of Biological Sciences, University of Santo Tomas, Manila, Philippines

a.torres[at]nhm.ac.uk

Abstract

Determining levels of genetic diversity and inferring spatial patterns of gene flow can provide insights on mode of reproduction and ecologically relevant scales of dispersal of a species. For organisms with wide-ranged dispersal capacities, examining gene flow at multiple spatial scales is necessary. Such information can serve as basis for developing resilience-based coastal management interventions. In this study, patterns of clonality, genetic structure, and population connectivity were characterized in the widely distributed reef-building coral *Pocillopora acuta* across the Philippines. Multi-locus genotypes (MLGs) generated from 14 polymorphic microsatellite loci were used to examine 21 populations of *P. acuta* (N = 821 colonies) across multiple spatial scales: transect scale (40 m), reef scale (20 km), passage scale (180 km), island group scale (650 km), and biogeographic region scale (1,200 km). Transect, reef, and passage-scale observations of clonal richness and MLGs shared among populations suggest the contribution of both parthenogenic and sexually produced *P. acuta* larvae to recruitment, with evidence for realized larval dispersal up to 110 km. Varying levels of disturbance based on relative wave exposure likely drive differences in colony size frequency distributions and clonal richness among reef-scale comparisons. Levels of genetic differentiation increased with spatial scale from reef (F_{ST} = 0.0279), passage (F_{ST} = 0.0781), island group (F_{ST} = 0.0821), and biogeographic region (F_{ST} = 0.0717). Significant genetic differentiation may already be observed between populations 5 km apart. Estimates of population structure were further supported by Bayesian model-based individual assignment tests and multivariate analyses and largely confirmed by AMOVA. Varying rates of relative migration were inferred within reef systems and across biogeographic regions, with the western coast of Luzon showing relatively higher levels of connectivity compared to the rest of the sites. This study provides ecological insights on the persistence and propagation of *P. acuta* in an oceanographically and geographically complex archipelago. The limited dispersal across multiple spatial scales underlines the relevance and importance of designing and implementing small- to medium-scale management initiatives geared towards maintaining genetic diversity of populations and metapopulations and protecting pathways of connectivity between reefs and biogeographic regions.

Virtual
Oral
A-1510

Strong genetic structure and limited connectivity among populations of Clark's Anemonefish (Amphiprion clarkii) in the centre of marine biodiversity

Ducret, H.[1], Timm, J.[2], Rodriguez-Moreno, M.[3], Huyghe, F.[4], Kochzius, M.[5]
[1]Université Libre de Bruxelles, Bruxelles, Belgium
[2]University Bremen, Life Sciences, Bremen, Germany
[3]Universidad del Valle, Ciudad Universitaria Meléndez, Cali, Colombia
[4]Vrije Universiteit Brussel, Life Sciences, Bruxelles, Belgium
[5]Vrije Universiteit Brussel, Life Sciences, Brussels, Belgium

hugo.ducret[at]ulb.be

Abstract

Populations of anemonefish species often show signs of local isolation due to limited dispersal potential and oceanographic conditions. Additionally, anthropogenic pressure, such as overharvesting and coral reef exploitation causes reduced population size, eventually leading to local extinction. The understanding of the genetic population structure, as well as the influence of both historical and current connectivity, is required to design effective marine protected area (MPA) networks. In this study, the genetic structure of Clark's Anemonefish *(Amphiprion clarkii*) based on 209 individuals from 16 samples sites in the Indo-Malay Archipelago (IMA) is assessed through mitochondrial control region (mtCR) sequences and eight nuclear microsatellite loci. Results provided evidence of a significant genetic structure (mtCR: $\Phi_{st} = 0.42$, $\Phi_{ct} = 0.64$; microsatellites: $F_{st} = 0.01$, $F_{ct} = 0.05$). Genetic breaks were identified among Western (Padang Karimunjawa), Central (Sulawesi, Borneo, Bali, Komodo, Timor) and Eastern (Biak) IMA populations, with almost no gene flow. This matches with patterns obtained for congeneric and other coral reef taxa. Due to the restricted connectivity among these three regions, it is suggested to consider them as separate management areas in the design of MPA networks.

Virtual
Oral
A-1479

Genome-Wide SNP data revealed species delimitation and spatial genetic structure of precious corals (Anthozoa: Octocorallia: Coralliidae) in Japan

Takata, K.[1], Nonaka, M.[2], Iwase, F.[3], Iguchi, A.[4], Yuasa, H.[5], Taninaka, H.[6], Iwasaki, N.[7], Uda, K.[8], Suzuki, T.[8], Kikuchi, T.[9], Nagai, S.[10], Yasuda, N.[1]
[1]The University of Tokyo, Graduate School of Agricultural and Life Sciences, Yayoi, Japan
[2]Okinawa Churashima Foundation, Okinawa Churashima Research Center, Motobu, Japan
[3]Shikoku Marine Life Laboratory, Otsuki, Japan
[4]National Institute of Advanced Industrial Science and Technology, Geological Survey of Japan, Tsukuba, Japan
[5]Tokyo Institute of Technology, School of Life Sciences and Technology, Ookayama, Japan
[6]University of the Ryukyus, Faculty of Science, Nishihara, Japan
[7]Rissho University, Faculty of Geo-Environmental Science, Kumagaya, Japan
[8]Kochi University, Faculty of Science, Kochi, Japan
[9]University of Miyazaki, Faculty of Medicine, Miyazaki, Japan
[10]Japan Fisheries Research and Education Agency, National Research Institute of Fisheries Science, Yokohama, Japan

kenzi.f923[at]gmail.com

Abstract

Precious corals belong to family Coralliidae (Anthozoa: Octocorallia) are economically and biologically important taxa inhabited in the deep sea, although these corals are recently highly threatened by over-exploitation. To effectively conserve precious coral species, identifying species boundaries is primely important. In addition, examining genetic structures of intra-species is also crucial because coral populations are mutually connected via larval dispersal. Recently, the species status of *Pleurocorallium konojoi* and *P. elatius* has been doubted because traditional genetic markers could not discriminate the two species. In addition, no meta-population structure of precious corals (*Corallium japanicum*, *P. konojoi* and *P. elatius*) in Japan has been estimated due to the lack of relevant genetic markers. We applied a genome-wide SNP analysis called MIG-seq and first demonstrated *P. konojoi* and *P. elatius* are different species. Secondly, we examined spatial genetic structure of *C. japanicum* to estimate the spatial extent of larval and gamete dispersal of *C. japanicum* in Kochi area. We found significant spatial genetic structure of *C. japonicum* up to 11 km, implying over-harvesting within this spatial range increase the risk of local extinction in Kochi.

Session 2F - Coralline algae: what are their global contributions to coral reefs now and in future oceans?

Conceptualized by: **Christopher Cornwall** [1], **Steeve Comeau**[2], **Guillermo Diaz-Pulido**[3], **Maggy Nugues**[4]
[1] Victoria University of Wellington (Wellington, New Zealand)
[2] Sorbonne Université (Villefranche-sur-mer, France)
[3] Griffith University (Brisbane, Australia)
[4] PSL Research University (Perpignan, France)

Chaired by: **Maggy Nugues**[4]

Oral
A-1629

Climate change conditions differentially impact CCA species with implications for coral recruitment.

Sneed, J.[1], Campbell, J.[2, 3], Looby, A.[3, 4], Paul, V.[3]
[1]Smithsonian Marine Station, Fort Pierce, United States
[2]Florida International University, Miami, FL, United States
[3]Smithsonian Marine Station, Fort Pierce, FL, United States
[4]University of Florida, Gainesville, FL, United States

sneedj[at]si.edu

Abstract

Coral reefs are diminishing worldwide. Recruitment of new individuals to degraded reefs is critical for natural recovery and is influenced by many factors, including the composition of the benthic community that larvae detect via chemoreception. Many coral species are attracted to and settle preferentially on some crustose coralline algae (CCA) (e.g. *Hydrolithon boergesenii*) over others (e.g. *Paragoniolithon solubile*). Calcifying organisms like CCA are particularly susceptible to ocean acidification, therefore, as seawater temperatures increase (ocean warming) and pH levels decrease (ocean acidification) as a result of climate change, this interaction may be compromised. Here we examine the effects of ocean warming and acidification on the calcification, photosynthetic efficiency and microbiome community composition of two CCA species, *H. boergesenii* and *P. solubile*. We also examined the effects of these seawater treatments on the settlement preferences of three coral species, *Acropora palmata*, *A. cervicornis* and *Porites astreoides*. *A. palmata* and *P. astreoides* demonstrated a preference for *H. boergesenii* over *P. solubile* in choice experiments after short-term treatment (7-21 days) and this preference was not affected by seawater treatment. *A. cervicornis* did not demonstrate a CCA preference under any treatment. *P. astreoides* did not demonstrate a CCA preference in no-choice assays and settlement was not affected by seawater treatment even after the longest exposure (102 days). Treatment had minimal effects on the CCA microbiome. *P. solubile* was more susceptible to ocean warming and acidification in terms of reduced net calcification and photosynthetic efficiency compared to *H. boergesenii*, indicating that future changes in seawater conditions may allow the preferred settlement substrate, *H. boergesenii*, to become relatively more abundant on reefs.

Virtual
Oral
A-2066

Calcification, growth and mineralogy of coralline algae in coral reefs: Mechanisms, patterns and environmental controls

Diaz-Pulido, G.[1], Lewis, B.[1], Ordonez, A.[1, 2], Bergstrom, E.[1], Garcia-Urueña, R.[3], Jeong, S.[1], Kennedy, E.[1, 4], Nash, M.[5], Page, T.[1], Troitzsch, U.[5]
[1]Griffith University, School of Environment and Science, Nathan, Australia
[2]The University of Queensland, Brisbane, Australia
[3]Universidad del Magdalena, Santa Marta, Colombia
[4]Australian Institute of Marine Science, Townsville, Australia
[5]Australian National University, Research School of Earth Sciences, Canberra, Australia

g.diaz-pulido[at]griffith.edu.au

Abstract

The crustose coralline algae (CCA) are a group of calcifying red algae that deposit calcium carbonate in the form of high-magnesium calcite, and as such contribute to the construction of reef framework. Coralline algae have a long evolutionary history (>139 mya), but recent environmental anthropogenic stressors such as ocean acidification threaten their persistence in tropical reefs. In this talk, we will provide an overview of recent research conducted in our lab aiming at understanding the mechanisms and patterns of calcification in tropical coralline algae, and the influence of the environment on their growth, calcification and mineralogical composition, particularly in the Great Barrier Reef (GBR) and the Caribbean. We are making progress to unravel the molecular basis of calcification in CCA and have now identified RNA molecules (transcriptomes) involved in biomineralization and other key processes in a number of CCA species (T. Page work). Because biomineralization in the CCA occurs in the cell walls, we are studying the monosaccharide and polysaccharide constituents of the cell wall and their potential role in calcification (E. Bergstrom work). Understanding the calcification process requires fundamental research on species boundaries and phylogeny of the corallines, as well as knowledge of the distribution of species across reef habitats. This knowledge allows us to examine the influence of water quality, seasonality, and upwelling (Caribbean) on calcification and mineralogical composition of key reef-building species, and to obtain growth and calcification baselines of CCA along the GBR. Finally, there is considerable variability in the responses of CCA species to ocean acidification, and our recent experiments suggest that this variability may also be explained by the evolutionary history of the coralline algae. Our work is critical for advancing the understanding of the influences of human activities on the ecology of coralline algae, and on the critical roles they play in the functioning of reef ecosystems.

Virtual
Oral
A-1558

Microscopic and molecular tools to identify crustose coralline algae from Roatán (Honduras) and the Florida Keys (USA)

Giorgi, A., Olson, J. B.
The University of Alabama, Biological Sciences, Tuscaloosa, United States

agiorgi[at]crimson.ua.edu

Abstract

Crustose coralline algae (CCA) are a group of red seaweeds belonging to orders Corallinales, Hapalidiales and Sporolithales that are considered to be effective environmental triggers to induce larval settlement and metamorphosis for numerous marine invertebrates, including scleractinian corals. However, because of the difficulties associated with taxonomic identification of individual species, these algae are often lumped together and, as a result, knowledge regarding the potential of individual species to facilitate coral recruitment is still sparse. Thus, before being able to address the role of CCA in the recruitment of scleractinian larvae, detailed descriptions of crustose coralline algae encountered on reefs in the Florida Keys, USA, and Roatán, Honduras, are needed. A combination of morpho-anatomical observations obtained through dissecting and scanning electron microscopy and comparative analyses of four genetic markers, two plastidial (*psbA*, *rbcL*) and two nuclear (SSU, LSU) genes, were used to describe the algae. Species delimitation analyses were implemented to evaluate species boundaries for this group. The results suggested that the coralline algae from these locations belonged to five subfamilies (Neogoniolihoideae, Metagoniolithoideae, Hydrolithoideae, Lithophylloideae and Melobesioideae) and eleven genera (*Neogoniolithon, Paragoniolithon, Spongites, Porolithon, Harveylithon, Dawsoniolithon, Hydrolithon, Titanoderma, Roseolithon, Phymatolithon* and one unidentified genus belonging to the Lithophylloideae).
Molecular analyses indicated that a far greater number of species were present than were revealed using microscopic characters, reinforcing the idea that morpho-anatomical features alone are not sufficiently reliable or variable to adequately identify species of coralline algae. This study improves the current knowledge of CCA diversity in Roatán and in the Florida Keys and provides the requisite information to conduct recruitment studies to more accurately determine the role of CCA as settlement inducers for scleractinian larvae.

Session 3A - Open Session: Ecosystem functions and services

Conceptualized and chaired by: **Andreas Haas**[1], **Christian Wild**[2], **Anna Woodhead** [3]
[1] NIOZ and Utrecht University (Texel, The Netherlands)
[2] University of Bremen (Bremen, Germany)
3 Lancaster University (Lancaster, UK)

Oral
A-1394

An emerging coral disease outbreak decimated Caribbean coral populations and reshaped reef functionality

Alvarez-Filip, L., González-Barrios, F. J., Pérez-Cervantes, E., Molina-Hernandez, A., Estrada-Saldívar, N.
Universidad Nacional Autónoma de México, Puerto Morelos, Mexico

lorenzoaf[at]gmail.com

Abstract

Diseases are major drivers of the deterioration of coral reefs and are linked to major declines in coral abundance, reef functionality, and reef-related ecosystems services. An outbreak of a new disease is currently rampaging through the populations of the remaining reef-building corals of the Caribbean region. The outbreak was first reported in Florida in 2014 and reached the northern Mesoamerican Reef by summer 2018, where it spread across the ~ 450-km reef system in only a few months. Rapid spread was generalized across all sites and mortality rates ranged from 94% to < 10% among the 21 afflicted coral species. Most species of the family Meandrinadae (maze corals) and subfamily Faviinae (brain corals) sustained losses > 50%. This single event further modified the coral communities across the region by increasing the relative dominance of weedy corals and reducing reef functionality, both in terms of functional diversity and calcium carbonate production. This emergent disease is likely to become the most lethal disturbance ever recorded in the Caribbean, and it will likely result in the onset of a new functional regime where key reef-building and complex branching acroporids, an apparently unaffected genus that underwent severe population declines decades ago and retained low population levels, will once again become conspicuous structural features in reef systems with yet even lower levels of physical functionality.

Oral
A-1665

Ecosystem functioning on coral reefs: cryptobenthic fishes, context-dependency, and shifting baselines

Brandl, S.
The University of Texas Marine Science Institute, Port Aransas, United States

simon.brandl[at]austin.utexas.edu

Abstract

Conserving coral reef ecosystem functioning represents the gold standard of reef management in the Anthropocene. Yet, while some properties of coral reefs are generally seen as more ‘functional’ than others, the ecological processes that underpin these properties and their environmental or anthropogenic drivers remain surprisingly poorly defined. In my talk, I demonstrate the ubiquitous environmental contingency of ecosystem functioning on coral reefs, which ultimately result in different community properties and, therefore, a wide range of interpretations of coral reef functioning and resulting management targets. Specifically, by first focusing on the smallest coral reef fishes–cryptobenthic fishes–I show that reef systems separated by as little as a few hundred meters can display fundamental differences in their energy and nutrient fluxes. These marked local scale differences are reflected in the prevalence of four simplified coral reef regimes on a global scale. Using benthic and fish and communities on coral reefs worldwide, I demonstrate that a small suite of environmental and anthropogenic variables can predict the regime affiliation of a given coral reef, highlighting that local environmental and anthropogenic context is crucial in determining our expectations of what a ‘functional’ coral reef looks like. Finally, I show that this expectation has undergone clear shifts over the past decades, as several reefs across a wide range of locations have transitioned from systems dominated by corals and small-bodied fishes to systems characterized by primary producers and large-bodied fishes. Thus, while it is critical to consider local context in the formation of management targets for coral reef functioning, we need to be aware of shifting baselines that may blur reference conditions for functional coral reefs worldwide.

Oral
A-1048

Understanding the drivers of functional trait diversity and composition change on the Bocas del Toro coral reefs

Briand, J.[1], Guzman, H.[2], Sunday, J.[1]
[1]McGill University, Montreal, Canada
[2]Smithsonian Tropical Research Institute, Naos Marine & Molecular Laboratories, Panama City, Panama

julia.briand[at]mail.mcgill.ca

Abstract

Anthropogenic disturbances are altering coral reef ecosystems globally. Historically, reef communities have been shaped by more local anthropogenic disturbances across gradients of environmental conditions, whereas, in recent decades, reef communities are increasingly impacted by global anthropogenic disturbances like climate change. Although trait-based functional change often underlies shifts observed at the community or ecosystem level, we have limited understanding of how coral reef composition and function differ across background environmental gradients altered by anthropogenic disturbances. Here, we quantify spatial and temporal variation in the composition and function of 11 coral reefs across an inshore to offshore environmental gradient in the Bocas del Toro archipelago located along the Caribbean coast of Panama. Specifically, we assess changes in benthic cover, coral species, and coral functional traits over a period of 15 years and 3 bleaching events. Our results reveal that the composition and function of inshore and offshore reefs were distinct and shaped by an environmental gradient likely altered by local anthropogenic disturbances. Inshore reefs experienced greater losses in reef-building coral species and diversity, but both inshore and offshore reefs became functionally similar over time. These findings indicate that inshore reefs are less resilient to global disturbances than offshore reefs due to long-term exposure to local disturbances. However, reef function may homogenize across inshore and offshore conditions under climate change. This work expands on our existing knowledge of successional shifts in coral communities over the past few centuries and addresses the role of prior disturbance in coral reef resilience.

Oral
A-1790

Impacts of stony coral tissue loss disease (SCTLD) on the persistence of a keystone reef fish species

Budd, K.[1], Brandt, M.[1], Sikkel, P.[1, 2], Nemeth, R.[1]
[1]University of the Virgin Islands, St Thomas, U.S. Virgin Islands
[2]Rosenstiel School of Marine and Atmospheric Science, University of Miami, Marine Biology and Ecology, Miami, United States

budd.kayla.a[at]gmail.com

Abstract

Stony coral species are the architects of reef habitats. As such, changes to their distributions and abundance have cascading impacts on a variety of other community members. Stony coral tissue loss disease (SCTLD) is the newest element affecting reef-building corals. SCTLD stands out from many other diseases both in its ability to cause rapid, complete mortality of large coral colonies and to affect a wide range of coral species (>20 species). Impacted coral species include those frequently utilized as cleaning stations by Caribbean cleaner gobies (*Elacatinus spp.*). This study examined the abundance and persistence of these cleaners at sites where SCTLD was well-established (endemic), recently established (epidemic), and not yet or recently appeared (emergent). Timed surveys were conducted at nine reefs in the U.S. Virgin Islands between October 2019 and March 2021. Monitoring sites were established at six of these sites by tagging 25 cleaning stations at each of two endemic and two epidemic, and 50 cleaning stations at each of two emergent sites. Goby abundance on tagged corals was monitored at these sites from March 2020 to April 2021. Results of timed surveys show overall, site-level goby abundance to be 50% less in the endemic zone than each of the other two zones, which were not significantly distinct. Tagged cleaning stations experienced an overall decline in goby population through time. However, surveys of the surrounding study area showed relative population stability at most sites. These results suggest that as a reef is affected by SCTLD, gobies remain within the site but abandon affected cleaning stations for other substrate.

Oral
A-1758

Coral settlement and recruitment relationships with reef fish foraging and trait diversity

Chow, C.[1], Bolton, C.[1], Boutros, N.[2], Brambilla, V.[1], Fontoura, L.[3], Hoey, A.[4], Madin, J.[5], Pizarro, O.[6], Torres-Pulliza, D.[5, 7], Woods, R.[7], Zawada, K.[8], Barbosa, M.[1, 9], Dornelas, M.[1]
[1]Centre for Biological Diversity, School of Biology, University of St Andrews, St Andrews, United Kingdom
[2]Australian Centre for Field Robotics, University of Sydney, Sydney, NSW, Australia
[3]Department of Environmental Sciences, Faculty of Science and Engineering, Macquarie University, Sydney, NSW, Australia
[4]ARC Centre of Excellence for Coral Reef Studies, James Cook University, Townsville, QLD, Australia
[5]Hawai'i Institute of Marine Biology, University of Hawai'i at Mānoa, Kāne'ohe, HI, United States
[6]Norwegian University of Science and Technology, Trondheim, Norway
[7]Department of Biological Sciences, Macquarie University, Sydney, NSW, Australia
[8]Centre for Compassionate Conservation, School of Life Sciences, University of Technology Sydney, Ultimo, NSW, Australia
[9]Department of Biology & CESAM, University of Aveiro, Aveiro, Portugal

fycc1[at]st-andrews.ac.uk

Abstract

The process of coral recruitment is crucial to the healthy functioning of coral reef ecosystems, as well as recovery following disturbances. Fishes are key modulators of this process by feeding on algae and other benthic taxa that compete with corals for benthic space. However, foraging strategies within reef fish assemblages are highly diverse and the effect of foraging diversity on coral recruitment success remains poorly understood. Here, we test how the foraging traits of reef fishes affect coral settlement and juvenile success at Lizard Island, Great Barrier Reef. Using a multi-model inference approach incorporating six metrics of fish assemblage foraging diversity (foraging rates, trait richness, trait evenness, trait divergence, herbivore abundance, and benthic invertivore abundance), we found that herbivore abundance had positive effects on both coral settlement and recruitment success. However, foraging trait diversity had a negative correlation with coral settlement but not with recruitment. Coral settlement tended to be higher at sites with less trait diverse fish assemblages, specifically in trait divergence and richness. Moreover, these two trait diversity metrics were more strongly associated with coral settlement success compared to herbivore abundance. Our findings provide evidence that impacts mediated by fish foraging on coral juveniles can potentially be harmful during settlement, but the space-clearing effect overall remains advantageous. We show here that the variation of fish biodiversity across reefs can be a partial driver to spatially uneven patterns of coral recruitment and reef recovery.

Oral
A-1115

Macroalgae habitats as a subsidy of fish and nutrition for coral reefs

Dunne, A.[1], Coker, D.[1], Tietbohl, M.[1], Ellis, J.[2], Berumen, M.[1], Jones, B.[1]
[1]King Abdullah University of Science and Technology, Thuwal, Saudi Arabia
[2]University of Waikato, Tauranga, New Zealand

aislinn.dunne[at]kaust.edu.sa

Abstract

Macroalgae canopies are common in coastal tropical regions around the globe, providing habitats for a range of organisms. The potential for coral reef fish to use these productive vegetated environments as nursery habitats or feeding grounds creates a pathway between habitats through which organisms and nutrition might flow. In this study, we evaluate the habitat and food functions of *Sargassum* macroalgae canopies for coral reef fishes in Saudi Arabia's central Red Sea. Through *in situ* surveys across coral reefs and marine vegetated habitats, we documented 29% of local coral reef fish species in *Sargassum* macroalgae habitats, much more than in neighboring seagrass and mangrove habitats. Macroalgae also hosted a large proportion of herbivorous coral reef species and non-juvenile fish, suggesting that adult reef fish could be using macroalgae habitats as feeding grounds. To investigate whether organic material from these habitats is being transferred to coral reefs via herbivorous fish feeding and movement, the gut contents of fish specimens from two common herbivorous fishes (*Naso elegans* and *Naso unicornis*) were collected from coral reefs at varying distances from these vegetated habitats. On inshore reefs close to macroalgae canopies, *Sargassum* made up a large part of these species' diets (up to 41% on one reef) while benthic surveys revealed little to no *Sargassum* growing directly on surveyed coral reefs, suggesting that the vast majority of *Sargassum* seen in the guts of reef fish is being consumed in nearby algal canopies. Using size-dependent carbon consumption and nutrient excretion rates from the literature, we then estimate the amount of carbon consumed and nitrogen and phosphorus excreted due to the consumption of *Sargassum* macroalgae. Consumption and excretion of *Sargassum*-derived material varied by reef location depending on the biomass and diet composition of fish on each reef, highlighting how variations in fish populations can affect rates of nutrient cycling. Determining whether fish are making these connections between vegetated habitats and coral reefs will help us understand both the role of marine vegetation as subsidies to coral reef fish communities, and the role of fish as a vector of organic matter to nutrient-poor coral reefs. This understanding of the biological linkages between tropical coastal habitats can inform coastal planning decisions and the need for a holistic approach to habitat protection and fisheries management.

Oral
A-2107

The functional geometry of coral reefs

Madin, J.
Hawai‘i Institute of Marine Biology, Kaneohe, United States

jmadin[at]hawaii.edu

Abstract

Corals and the reefs they build are remarkable physical structures that exhibit a great array of forms. In spite of this variability, recent research suggests that three features--physical vulnerability, structural turnover and space utilization--might unify coral reef structures. Physical vulnerability is determined by the distribution of structures vertically (e.g., colony shape factor in corals or height range of reef patches), and so a measure of mechanical instability. Structural turnover is associated with the amount of surface area per unit structure (e.g., sphericity in corals or rugosity of reef), which reflects the acquisition-conservation dimension of trait ecology. Space utilization is related to how surfaces fill a structure's volume (e.g., fractal dimension), which determines both access to resources and how the structure is used by other reef taxa. Measuring these three features of coral reefs in a standardized manner would greatly help us monitor and understand the functioning of these systems as they change.

Oral
A-1742

Functional vulnerability on Fijian coral reefs: a trait-based assessment the impact of spearfishing selectivity on herbivory and sediment removal

McAndrews, R.[1, 2, 3], Bejarano, S.[2], Ferse, S.[4]
[1]Boston University, Boston, United States
[2]Leibniz Centre for Tropical Marine Research, Bremen, Germany
[3]Universitat Bremen, Bremen, Germany
[4]Future Earth Coasts International, Bremen, Germany

ryan.mcandrews[at]my.jcu.edu.au

Abstract

The removal of algal biomass and the production and re-distribution of sediments are among the critical ecological functions fishes perform on coral reefs. In Fiji, many of the fishes known to contribute to these functions are harvested by spearfishers. The extent to which spearfishing can impinge upon the functions sustained by these fishes is however unclear. Moreover, much remains to be learned about the drivers of spearfishers' behaviour, especially targeting, opportunistic catch, and avoidance. We assembled a matrix of traits to characterise species' contributions to one or more of the abovementioned functions. Trait values were obtained from published literature and behavioural observations collected via underwater cameras. To compare species and groups, we constructed a multidimensional representation of the fishes' functional roles. We contrasted this space to one based on a second matrix of traits that characterise a species' importance to markets and fishers' preferences. We also conducted underwater visual censuses to estimate the availability of different species to the fishery and compared this to a six-month survey of the largest market in Suva, in order to investigate the overall selectivity of the fishery. We quantify 11 traits exhibited by species that define their functional role. Furthermore, we identify six distinct functional groups either unique or only partially redundant among each other. The impact on each of these groups by the Fijian spear fishery differs among more than within groups. By comparing information from published literature, behavioural observations, market censuses, fisher interviews, and transects, we were able to break the three functional roles down to seven unique components and quantify vulnerability to spearfishing for each. Using the two trait matrices, we were able to visualise how the constituency of functional roles may change with fishing intensity, gear, and timing. We were also able to identify the characteristics of spearfisher decision-making that place some functions under higher risk than others. Highlighting the traits that make fishes both functionally important and highly desired in markets is useful to accurately characterise the impacts of fishing on ecosystem functioning. Ultimately, this information can guide local communities and other resource custodians to minimise the impact on ecosystem functioning while maintaining a fishery upon which many depend.

Oral
A-1437

Modelling the drivers and futures of coral reef ecosystem services

McLean, M.[1], MacNeil, A.[1], Mouquet, N.[2], Langlois, J.[3], Arif, S.[1], Loiseau, N.[2], Guilhaumon, F.[4], Mouillot, D.[3]
[1]Dalhousie University, Biology, Halifax, Canada
[2]The French National Centre for Scientific Research, Montpellier, France
[3]University of Montpellier, Montpellier, France
[4]The Research Institute for Development, Montpellier, France

mcleamj[at]gmail.com

Abstract

Coral reefs provide critical goods and services to millions of people throughout the tropics. Unfortunately, reef ecosystems are rapidly degrading due to the combined effects of global warming, overfishing, pollution and more. Many important conservation and restoration efforts are underway, however, in the face of such severe threats, managers will not be able to conserve all species, and preserving coral reefs in their current form will be unlikely. Given that millions of people depend directly on coral reefs for their livelihoods, scientists and managers are shifting focus toward managing and protecting ecosystem functions and services rather than species or organism groups. Until recently, directly quantifying ecosystem functions and services on coral reefs at large scales was not feasible, and scientists relied on proxies such as overall fish biomass. However, recent advancements in bioenergetic modelling have enabled scientists to estimate the ecosystem services provided by reef fishes, a dominant contributor to overall ecosystem services and a critical link to human wellbeing. The key now to move forward with managing ecosystem functions on coral reefs is to identify the social and ecological conditions that promote or degrade ecosystem services, and to project the future status of ecosystem services under various climate and management scenarios. To achieve this goal, the international project REEF FUTURES was initiated in 2019, with the goals of quantifying ecosystem services on coral reefs globally, identifying their drivers, and projecting their futures. Here, we use Bayesian hierarchical models in tandem with causality inference in the form of directed acyclic graphs (DAGS) to uncover the social and ecological drivers of the ecosystem services provided by reef fishes worldwide. As a case study, we focus on aesthetic value – the intrinsic beauty provided by reef fish communities, which provides the foundation for both personal connection with biodiversity as well as economic gain through tourism. We demonstrate the utility of our framework, particularly the importance of proper causal inference in statistical modelling, and we reveal the key determinants of aesthetic value in coral reef fish assemblages.

Oral
A-1161

Reef ecosystem service bundles reveal priority areas for marine conservation

Pellowe, K. E., Lade, S. J.
Stockholm University, Stockholm Resilience Centre, Stockholm, Sweden

kara.pellowe[at]maine.edu

Abstract

Millions of people around the world depend on the ecosystem services (ES) that reef systems provide, including income and nutrition. In addition, reefs contribute to critical global and regional processes through the cycling of nitrogen, phosphorus, and carbon. Ecosystem service bundles analysis is one approach to study the spatial distributions of ES produced by reefs, and to identify synergies and trade-offs among ES. Further, this approach can be used to identify characteristics that contribute to the production of certain suites of ES. Such information may help support the design of marine management that optimizes the delivery of ES according to regional priorities. We apply an ES bundles analysis approach to a dataset of 1,827 reef sites for six ecosystem services (aesthetic value; biomass productivity; nutritional value; nitrogen (N) cycling; phosphorus (P) cycling; and inorganic carbon (C) cycling) to understand: (1) what types of ecosystem services (ES) tend to co-occur; (2) what are the trade-offs and synergies among multiple ES; and (3) what are the social-ecological conditions of reefs that contribute to the delivery of distinct suites of ES? Finally, we explore (4) what do ES bundles reveal about priorities for marine conservation?

We assess synergies and trade-offs among ES using correlation analysis. We use k-means cluster analysis to group reefs into clusters according to their ES profiles and analyse differences among clusters using Tukey multiple pairwise comparisons. We identify three clusters of reefs with distinct ES profiles. Reefs with the highest biomass and species richness deliver the highest levels of aesthetic value, N cycling, P cycling, and C cycling. Reefs with the lowest biomass and species richness have the highest levels of productivity and low levels of the other ES, consistent with degraded reefs, while some reefs have service values between the two extremes. We find synergies among the services of N cycling, P cycling, and C cycling, and between aesthetic value and the three cycling ES. On the other hand, we find trade-offs between productivity and aesthetic value, as well as productivity and the three cycling ES. The reef cluster with high productivity and low levels of other ES may be potential targets for future conservation interventions. Since distinct ES bundles may be desirable in different contexts, understanding trade-offs among ES is important for the design of marine policy that supports regional priorities.

Oral
A-1633

Successional ecology on coral reefs - perspectives from across the tropics

Sandin, S. A., 100 Island Challenge team
UC San Diego, Scripps Institution of Oceanography, La Jolla, United States

ssandin[at]ucsd.edu

Abstract

Coral reefs are dynamic and complex systems, and hence have ability to teach us about fundamental principles of community ecology. One long-standing interest is learning how ecological communities organize, considering changes in structure and function during succession, and timelines for community development. Our team has been using data from geographic gradients complemented with extended observational time series to consider the foundations of ecological succession, exploring in detail mechanisms and patterns linked with the evolution of community structure.

Following a disturbance, succession on coral reefs shows some consistencies. In general, the average sizes of fishes and corals increase, and these larger organisms show increased capacity to resist negative effects of subsequent disturbances. Species interactions (both trophic and competitive) become increasingly organized with succession, creating more stability of population and community structure.

Remote islands of the central Pacific show evidence of resistance and resilience of coral assemblages to warm-water events. We report evidence of moderate thermal shocks followed by rapid recovery of coral populations (accelerated by partial mortality with regrowth) and strong shocks followed by prodigious recruitment of "r-selected" corals with subsequent arrival of more "K-selected" taxa. Islands with significant human populations show less consistency in community changes following disturbance, with idiosyncratic trajectories from island to island. The evidence is consistent with re-organization of coral reef community structure in many locations, with taxa (or adapted taxa) able to perform relatively better under novel conditions replacing historically dominant taxa. Despite taxonomic change, evidence of directional successional change (i.e., increasing size structure and increasingly organized species interactions) following disturbance is apparent even in areas with appreciable human use of coral reef resources.

The structure of coral reefs is never static, especially given the rapid environmental changes today. As such, describing and predicting future coral reef structure and functioning demands a dynamical perspective, a perspective organized through our understanding and quantification of ecological succession.

Oral
A-1527

Towards a productivity-based management of tropical reefs in the Anthropocene

Seguin, R.[1], Mouillot, D.[2], Cinner, J.[3], Stuart-Smith, R.[4], Maire, E.[5], Graham, N.[5], McLean, M.[6], Laurent, V.[7], Loiseau, N.[2]
[1]UMR Marbec University of Montelllier, Pradines, France
[2]MARBEC, Univ Montpellier, CNRS, IFREMER, IRD, Montpellier, France, Montpellier, France
[3]ARC Center of Excellence for Coral Reef Studies, James Cook University, Townsville, QLD, Australia, Townsville, Australia
[4]Inst. for Marine and Antarctic Studies, Univ. of Tasmania, Hobart, TAS, Australia, Hobart, Australia
[5]Lancaster Environment Center, Lancaster University, Lancaster, United Kingdom, Lancaster, United Kingdom
[6]Department of Biology, Dalhousie University, Halifax, Nova Scotia B3H 4R2, Canada, Nova Scotia, Canada
[7]ENTROPIE, IRD, UR, UNC, CNRS, IFREMER, Noumea, New Caledonia, France, Noumea, New Caledonia

raphael.seguin[at]outlook.fr

Abstract

The biomass of fishes present on shallow reefs provides important information on ecological condition and some of the critical services that reef systems provide to humans, particularly through fisheries. Metrics of reef condition and fisheries status based on fish biomass have been widely applied, yet most are naïve to the dynamic nature of the processes that drive biomass production, which are important for informing management aimed at addressing the underlying causes of declining fish biomass. We proposed a new framework, comprising three management strategies based on fish standing biomass and productivity which were calculated on 2,027 reef sites over 39 countries. At these large scales, fish productivity and biomass were strongly related to human gravity and regional patterns in oceanic primary productivity, with high biomass and productivity values associated with low human pressure and high primary productivity, respectively. Based on the distribution of reefs showing alternative scenarios of standing biomass and productivity, we propose a framework of three management strategies (as well as one “base” category), which apply thresholds to determine the most suitable form of protection to apply through spatial management (e.g. Marine Protected Areas). We found that 3.5% of the sites have low fish biomass and productivity, where alternative fisheries like seaweed and bivalve aquaculture are recommended. We identified 24% of high productivity sites where we suggest adaptive management: establishment of partially protected areas sustaining local fisheries when needed, or full protection when possible given their capacity for recovery. For the 5% high biomass sites, we urgently need full protection to maintain high reproductive capacity through large individuals. Our framework can thus guide management strategies by incorporating both static and process-oriented measures, tailoring each strategy to local priorities based on biodiversity and socio-economic objectives.

Oral
A-1563

Understanding the distribution of coral reef values globally

Spalding, M.[1], Burke, L.[2]
[1]The Nature Conservancy, Siena, Italy
[2]World Resources Institute, Washington DC, United States

mspalding[at]tnc.org

Abstract

From a biodiversity perspective the value of coral reefs has rarely been underestimated. By contrast, while reefs provide critical contributions to human health and wellbeing, such values are rarely enumerated beyond small-scale case studies. Global assessments of "nature's contribution to people" or ecosystem services have the potential to transform perceptions and to alter approaches to coastal management and development. We describe three recent studies that have developed high resolution global data describing the importance of reefs for tourism, fisheries and coastal defence. In an effort to ensure that values associated with non-monetised uses are not lost, these studies use a range of metrics – including predicted fish harvest, people protected and visitor numbers – alongside monetary estimates,. These maps are intended to play a critical role in directing investments, guiding policy and driving management. They can also shape public opinion, reaching beyond the "conservation engaged" to new audiences. We describe the outputs from these global maps, while also drawing attention to finer-scale approaches using similar principles to develop information at scales of value for site-scale utilisation.

Oral
A-1876

Multi-method insights into the feeding ecology of browsing herbivorous reef fishes

Tietbohl, M.[1], Berumen, M.[2]
[1]King Abdullah University of Science and Technology, Red Sea Research Center, Thuwal, Saudi Arabia
[2]King Abdullah University of Science & Technology, Red Sea Research Center, Thuwal, Saudi Arabia

matthew.tietbohl[at]kaust.edu.sa

Abstract

Browsing herbivorous fishes play key dietary functional roles on coral reefs through their consumption of macroalgae, which can vary through space and time. Once considered largely functionally redundant, recent observational and morphological evidence point towards more diversification within the feeding ecology of these fishes and posits there is much more resource partitioning within this group than previously assumed. However, quantifying differences in dietary targets is challenging as browsing fishes are more difficult to collect and observe feeding than other species. To further investigate the feeding ecology of browsing herbivorous fishes, stomach content analysis and stable carbon isotope ratios of bulk muscle tissue ($d^{13}C$) and essential amino acids ($d^{13}C_{EAA}$) of nominally “browsing” coral reef fishes were compared from Red Sea reefs. These complementary analysis allowed for more detailed information into resource partitioning. Stomach content analysis showed short term dietary targets for browsing coral reef fish varied not only between species, but between reefs. Brown, fleshy algae made up a much greater proportion of dietary items on inshore reefs, compared to smaller, foliose brown algae on offshore reefs. Bulk isotope analysis displayed partitioning between several browser species along the carbon isotope axis, supporting differences in dietary targets for most species. Variation between shelf positions was also observed, with a number of species having larger isotopic niches on offshore reefs, implying greater dietary diversity on reefs without large macroalgae biomass. We also found strong differences in $d^{13}C_{EAA}$ values among a subset of nominally browsing fishes that were not clearly apparent from bulk $d^{13}C$ values alone. We found within the “browser” group, different species’ $d^{13}C_{EAA}$ values were distinct among species, with the largest differences found between rabbitfishes and surgeonfishes. The differences in carbon isotope values support the notion of larger functional diversity within browsing fishes, at least insofar as their mixture of dietary resources. The combination of three different techniques demonstrate the feeding ecology of browsing herbivorous fishes is much more complicated than previously thought with large variation in dietary and nutritional targets. As such, it is imperative to consider the diversity of ecological roles each of these fishes play as distinct and important parts of productive coral reef ecosystem.

Poster
A-1168

The limited influence of giant clams (Tridacna spp.) on coral reef fishes

Price, N.[1], Meng, Y.-Z.[1], Zhang, W.-Y.[1], Wen, C. K.-C.[1, 2]
[1]Tunghai University, Department of Life Science, Taichung, Taiwan
[2]Tunghai University, Center for Ecology and Environment, Taichung, Taiwan

nathanwprice92[at]gmail.com

Abstract

The abundance of giant clams (*Tridacna* spp.) on coral reef ecosystems is declining, mainly due to overfishing. Giant clam restocking has been implemented to combat this and has become the focus of recent research, however few studies have failed to investigate the effects of giant clam restoration on fish communities. Therefore, we investigated the influence of giant clams on fish assemblages in Lyudao, Taiwan. Specifically, we examined relationships between giant clam density and fish abundance and species richness. We examined the short-term effects of giant clam restocking by comparing fish abundance, species richness and fish groups (mobile, resident and cryptic) before and after restocking. We also explored the habitat preferences of *Pseudocheilinus hexataenia* and *Neoglyphiodon melas*, by offering various habitat types including giant clams and giant clam shells in a controlled setting. During field observations, fish abundance and species richness were positively correlated with giant clam density, however no fishes were recorded using giant clams as a direct habitat. There were no significant differences in fish abundance, species richness and fish groups before and after giant clam restocking, regardless of density. In the controlled setting, *P. hexataenia* showed a clear rejection for the giant clam, and *N. melas* generally preferred other habitat types rather than giant clam. This research advances our understanding of the influence giant clams have on coral reef fishes and highlights the importance of other conservation efforts over giant clam restocking.

Poster
A-2228

Spatial data on reef fish behaviour promises new insights into ecological functions and reef resilience

Streit, R.[1], Cumming, G.[2], Bellwood, D.[1]
[1]James Cook University, Townsville, Australia
[2]ARC Centre of Excellence for Coral Reef Studies, Townsville, Australia

robert.streit[at]my.jcu.edu.au

Abstract

As coral reefs around the world are impacted by global climate change, ecological conditions are shifting. In this new context, ecology needs new, robust measures to assess ecological functions and how they may affect reef resilience. To date, we have amassed a great deal of information on the "who" and the "how" of providers of important ecosystem functions, for example herbivorous fishes. However, we know relatively little of the "delivery of function" across space and time, i.e. the "where" and "when" of critical ecosystem processes. Using explicitly spatial approaches to data collection and analysis, we highlight the utility of embracing an underutilised, yet critical, aspect of fish behaviour when examining functional ecology on reefs: space use by reef fishes. For example, using a novel video- and photogrammetry-based approach, we are able to map feeding by the entire local herbivore community in fine detail over within-reef scales. Even in the presence of a diverse herbivorous fish community, we found that core feeding areas covered only 14% of available reef space and different functional groups tended to feed next to one another. Thus, the delivery of critical ecosystem functions appears to be less comprehensive and far patchier than previously thought. Further exploration of spatial data on fish behaviour promises additional insights into the responses of fish communities to transitioning coral reefs and habitat degradation, helping to elucidate the connectivity and persistence of ecosystem functions through space and time. Given the shifts that coral reefs are undergoing, moving beyond static proxies of ecosystem function and embracing process-focused assessments of spatial and temporal dynamics appears more critical than ever. Considering how fishes use space is a promising starting point.

Virtual
Oral
A-2136

Functional divergence from ecological baselines on Caribbean coral reefs

Melo-Merino, S. M.[1], Lira-Noriega, A.[2], González-Barrios, F. J.[3], Reyes-Bonilla, H.[4], Álvarez-Filip, L.[3]
[1]Posgrado en ciencias del Mar y Limnología, UNAM, Ciudad de México, Mexico
[2]Instituto de Ecología A.C., Xalapa, Mexico
[3]Unidad Académica de Sistemas Arrecifales, Inst. de Ciencias del Mar y Limnología, Universidad Nacional Autónoma de México, Biodiversity and Reef Conservation Laboratory, Puerto Morelos, Mexico
[4]Universidad Autónoma de Baja California Sur, Departamento de Biología Marina, La Paz, Mexico

saram.melo[at]gmail.com

Abstract

Understanding how emergent ecological assemblages have diverged from natural states is fundamental in predicting future functioning and services of ecosystems. Coral reefs are of particular concern due to their high susceptibility to anthropogenic stressors. Yet, little is known about their pre-disturbance ranges of natural states, and most reports of decline are based on a limited number of sites and high levels of uncertainty. Here, we used a novel approach to estimate the physical functionality of reefs across marine ecoregions based on habitat suitability and morpho-functional traits for coral species. We calibrated ecological niche models for 49 reef-building corals of the Greater Caribbean based on occurrence records and environmental predictors, which we combined with species-specific functional coefficients derived from morpho-functional traits reflecting their contribution to the reef three-dimensional structure to estimate the reef functional potential (RFP). We then assessed the degree of divergence of western Caribbean reefs by comparing our physical functionality estimates against recent field data evaluations. We found spatial variability in RFP across the Caribbean, with the highest mean value in the western Caribbean and the lowest in areas with marginal environmental conditions. Hotspots of RFP exist along the coast of Belize and the southeast of Cuba. Overall, 84% of sites along the western Caribbean showed a substantial reduction in their physical functioning, with the highest reductions occurring within hotspots, implying that reefs displaying the greatest changes have high initial RFP. We conclude that combining niche models with species morpho-functional traits is a valuable and promising approach to estimate the large-scale functional potential of communities and the degree of change in the absence of ecological baselines. These findings have important implications and could be used to guide efforts to preserve coral reefs functionality and define priority conservation areas in the Caribbean.

Virtual
Poster
A-2135

Ecological properties of a coral reef from the tropical eastern Pacific through a mass balance model

Hermosillo-Núñez, B.[1], **Calderon-Aguilera, L.**[1], Cupul-Magaña, A.[2], Rodríguez-Zaragoza, F.[3]
[1]CICESE, Marine Ecology, Ensenada, Mexico
[2]Universidad de Guadalajara, Puerto Vallarta, Mexico
[3]Universidad de Guadalajara, Zapopan, Mexico

brendahermozillo[at]gmail.com

Abstract

Coral reefs in the eastern tropical Pacific live under harsh conditions due to nutrient-rich and turbid waters and a narrow shelf. As a first step to challenge the deep reef refugia hypothesis, we conducted surveys (25x2 m belt transects for benthic invertebrates,25x4 m for fishes) at Yelapa (20o 29'-105o 26'), a coral reef in Bahía de Banderas, Mexico during May, and October 2021. We built a trophic model using Ecopath with Ecosim to assess the ecosystem's structure, development, and organization. We identified 34 functional groups comprising 30 consumers and four primary producers plus detritus. The Total system throughput was 111,657.4 t/km2/y, and the net system production was 29677.86 t/km2/y, whereas the mean trophic level of the catch was 3.34. The transfer efficiency (Lindeman spine) from trophic level II to III was 16.4%, 11.4% from III to IV, 8.1% from IV to V, and decreasing thereinafter. Mixed Trophic Impacts showed that grunts, groupers, snappers, wrasses, zooplankton, and phytoplankton produced the highest trophic effects on other functional groups. Network analysis suggests that Yelapa is a mature and organized ecosystem (total ascendency 39%, overhead 61%) but, in turn, is less resistant to perturbations. Detritus, phytoplankton, zooplankton, and chlorophyte contributed 80% of the total *ascendency.* Eels and morays, Cortez sea chub, and sea cucumbers accounted for the system complexity. There were 19 pathways with a mean length of 2.895; Throughput cycled (excluding detritus) = 1,554 t/km2/y , and Finn's cycling index = 1.663% of total throughput. We propose Yelapa should be included in a monitoring program to assess the effects of climate change and human activities, mainly pollution, coastal development, and tourists, extending sampling to the mesophotic zone.

Session 3C - Coral reef metabolism and biogeochemical processes (organism to ecosystem): What are current state and future trajectories of reef functioning?

Conceptualized by: **Yvonne Sawall**[1], **Chiara Pisapia**[2], **Andreas Andersson**[3]

[1] BIOS Bermuda Institute of Ocean Sciences (St. George's, Bermuda)

[2] California State University, Northridge (Northridge, CA, USA)

[3] Scripps Institution of Oceanography (La Jolla, CA, USA)

Chaired by: **Yvonne Sawall**[1], **Jasper de Goeij**[2]

[1] BIOS Bermuda Institute of Ocean Sciences (St. George's, Bermuda)

[2] University of Amsterdam (Amsterdam, The Netherlands)

3C - Coral reef metabolism and biogeochemical processes (organism to ecosystem): What are current state and future trajectories of reef functioning?
Oral
A-1288

Coral Reef Arks: A standardized in situ mesocosm and potential reef restoration tool

Baer, J.[1], Carilli, J.[2], Hartmann, A.[3], Chadwick, B.[4], Hatay, M.[5], van der Geer, A.[1], Aquino, J.[1], Ballard, A.[1], Scholten, Y.[6], Barnes, W.[6], Little, M.[1], Brzenski, J.[7], Liu, X.[5], Haas, A.[6], Rohwer, F.[1]
[1]San Diego State University, Biology, San Diego, United States
[2]Naval Information Warfare Center Pacific, Oceanography, San Diego, United States
[3]Harvard University, Boston, United States
[4]Coastal Monitoring Associates, San Diego, United States
[5]San Diego State University, Engineering, San Diego, United States
[6]Royal Netherlands Institute for Sea Research, Microbial Ecology, Texel, Netherlands
[7]San Diego State University, Computational Modeling, San Diego, United States

jlbaer[at]eckerd.edu

Abstract

All coral reefs are slightly different, and these differences make it challenging to compare ecological processes on different reefs. This is particularly relevant when designing conservation and restoration efforts. Here we introduce Coral Arks as a tool to study and compare coral reef processes in disperse sites. Coral Arks are anchored, midwater structures that create a standardized platform for studying reef assemblages and parsing the connectivity underpinning them. Modeling and *in situ* tests show that the structures provide an inexpensive, seaworthy platform for experimentation and the standardized structure means that most of the physics of Coral Arks can be compared across disparate sites. Addition of Autonomous Reef Monitoring Structures (ARMS), passive settlement structures enabling translocation of cryptic reef biodiversity to Coral Arks, effectively turn these structures into floating zoos for conservation and potential tools for restoration. Coral Arks are currently being used as coral mitigation tools and systems to study ecosystem-level assemblies in Puerto Rico and Curacao. We find that many of the characters of healthy coral reefs are present on these Arks, including high oxygenation and low microbialization, relative to nearby seafloor control sites at the same depth. By providing researchers and practitioners with a standardized tool to build a coral reef community, Coral Arks can help design stronger conservation and restoration methodologies, set more realistic targets for ecosystem rehabilitation, and improve collaboration between groups around the globe.

3C - Coral reef metabolism and biogeochemical processes (organism to ecosystem): What are current state and future trajectories of reef functioning?
Oral
A-1535

Global coral reefs exhibit declining calcification and increasing primary productivity: insights from a meta-analysis

Davis, K.[1], Colefax, A.[2], Tucker, J.[3], Kelaher, B.[3], Santos, I.[4]
[1]Leibniz Centre for Tropical Marine Research, Submarine Groundwater Discharge, Bremen, Germany
[2]Scieye, Goonellebah, Australia
[3]Southern Cross University, Coffs Harbour, Australia
[4]University of Gothenburg, Gothenburg, Sweden

kay.davis[at]leibniz-zmt.de

Abstract

Long-term coral reef resilience to multiple stressors depends on their ability to maintain positive calcification rates. Estimates of coral ecosystem calcification and organic productivity provide insight into the environmental drivers and temporal changes in reef condition. Here, we analyse global spatiotemporal trends and drivers of coral reef calcification using a meta-analysis of ecosystem-scale case studies. Ecosystem calcification estimated from local changes in seawater carbonate chemistry was driven by wave action, seasonality, depth, and benthic calcifier cover. The relationship between ecosystem calcification and calcifier cover indicates that current and future declines in coral cover will significantly affect the global reef carbonate budget, even before considering the effect of sub-lethal stressors on calcification rates. Well-studied reefs exhibited declining calcification over time, corresponding with increasing organic productivity. Therefore, coral reefs are experiencing a shift in their essential biogeochemical functioning and could become net dissolving worldwide around mid-century. However, our prediction capabilities are limited by the lack of available data, particularly from tropical locations. The rate of calcification decline presented here is likely to respond non-linearly as mass-stress events become more frequent and severe.

Oral
A-1077

Nitrogen fixation and denitrification activity differ between coral- and algae-dominated Red Sea reefs

El-Khaled, Y. C.[1], Roth, F.[2, 3], Rädecker, N.[4], Tilstra, A.[1], Karcher, D. B.[5], Kürten, B.[6], Jones, B. H.[7], Voolstra, C. R.[7, 8], Wild, C.[1]
[1]Bremen University, Bremen, Germany
[2]Stockholm University, Stockholm, Sweden
[3]University of Helsinki, Helsinki, Finland
[4]École Polytechnique Fédérale de Lausanne, Lausanne, Switzerland
[5]Australian National University, Canberra, Australia
[6]Jülich Research Centre GmbH, Rostock, Germany
[7]King Abdullah University of Science and Technology, Thuwal, Saudi Arabia
[8]University of Konstanz, Konstanz, Germany

yek2012[at]uni-bremen.de

Abstract

Coral reefs experience phase shifts from coral- to algae-dominated benthic communities, which could affect the interplay between processes introducing and removing bioavailable nitrogen. However, the magnitude of such processes, i.e., dinitrogen (N_2) fixation and denitrification levels, and their responses to phase shifts remain unknown in coral reefs. We assessed both processes for the dominant species of six benthic categories (hard corals, soft corals, turf algae, coral rubble, biogenic rock, and reef sands) accounting for > 98% of the benthic cover of a central Red Sea coral reef. Rates were extrapolated to the relative benthic cover of the studied organisms in co-occurring coral- and algae-dominated areas of the same reef. In general, benthic categories with high N_2 fixation exhibited low denitrification activity. Extrapolated to the respective reef area, turf algae and coral rubble accounted for > 90% of overall N_2 fixation, whereas corals contributed to more than half of reef denitrification. Total N_2 fixation was twice as high in algae- compared to coral-dominated areas, whereas denitrification levels were similar. We conclude that algae-dominated reefs promote new nitrogen input through enhanced N_2 fixation and comparatively low denitrification. The subsequent increased nitrogen availability could support net productivity, resulting in a positive feedback loop that increases the competitive advantage of algae over corals in reefs that experienced a phase shift.

3C - Coral reef metabolism and biogeochemical processes (organism to ecosystem): What are current state and future trajectories of reef functioning?
Oral
A-1326

Does net calcification recover faster than coral cover after mass disturbance events? -- A case study from Lizard Island

Hu, I.[1], Takeshita, Y.[1], Cyronak, T.[2], Albright, R.[3], Caldeira, K.[4], Coles, A.[3], Eyre, B.[5], Griffin, A.[6], Koweek, D.[7], Mertz, K.[1], Romanó de Orte, M.[4], Warren, J.[1], Wolfe, K.[8]
[1]Monterey Bay Aquarium Research Institute, Moss Landing, United States
[2]Nova Southeastern University, Fort Lauderdale, United States
[3]California Academy of Sciences, San Francisco, United States
[4]Carnegie Institute for Science, Stanford, United States
[5]Southern Cross University, Lismore, Australia
[6]Bodega Marine Laboratory, Bodega Head, United States
[7]Ocean Visions, Leesburg, United States
[8]University of Queensland, Brisbane, Australia

irene[at]mbari.org

Abstract

Currently, most measures of reef recovery are item-based, or based on measurements of organism abundance such as percent coral cover, which have been closely tracked after disturbance events. However, recovery success should arguably be measured by how much of the previous ecosystem function can be regained. From a biogeochemical perspective, net calcification (NEC) is one of the most important reef functions, as it is directly tied to the ability of reefs to maintain three dimensional calcium carbonate structure and habitat. However, NEC has rarely, if ever, been monitored consistently before, during, and after mass disturbance events, thus we have little to no direct information on the recovery trajectory of coral reef calcification.
Lizard Island, located in the Northern Great Barrier Reef, suffered severe bleaching and cyclone damage in 2014-2016. Concurrent measurements of NEC and community composition on the South reef flat of Lizard Island were made prior to the disturbance events (1970's, and 2008-2009), and directly afterwards in 2016 and 2017, making this one of the only sites in the world to have data that encompasses the recovery trajectory of NEC. Here, we present NEC and community composition data from this reef flat in 2018 and 2019, extending this unique data set. Autosamplers on the reef flat collected samples for pH and total alkalinity (TA) every 2 hours for 15 days, and NEC rates were calculated by constraining offshore TA and flow rates on the reef flat. On a short-term (hourly) time scale, variability in NEC rates was driven largely by solar irradiance. Across both years, daily integrated NEC rates have recovered to pre-disturbance levels, while coral cover has not increased substantially. This could be related to other calcifying organisms such as crustose coralline algae dominating the NEC signal after the disturbance events. Decoupling between coral cover and NEC suggests that reef function may recover substantially faster than measurements based on coral cover alone suggest. This study brings into question the ability to quantify the recovery of coral reef function by solely measuring item-based metrics, and further investigation into the decoupling between NEC and coral cover warrants further investigation.

3C - Coral reef metabolism and biogeochemical processes (organism to ecosystem): What are current state and future trajectories of reef functioning?
Oral
A-1200

Revealing the invisible wires of nature in Caribbean coral reefs

Kornder, N. A.[1], Barnes, W. J.[1], Rombouts, A. J.[1], Riley, A. K. T.[1], Esser, Y.[1], Webb, A. E.[2], de Bakker, D. M.[2, 3], Mueller, B.[1, 4], Huisman, J.[1], Vermeij, M. J. A.[1, 4], de Goeij, J. M.[1, 4]
[1]University of Amsterdam (IBED), Department of Freshwater and Marine Ecology, Amsterdam, Netherlands
[2]NIOZ Royal Netherlands Institute for Sea Research, Department of Ocean Systems, Den Hoorn, Netherlands
[3]Wageningen University and Research, Wageningen Marine Research, Den Helder, Netherlands
[4]CARMABI Foundation, Willemstad, Curaçao

n.a.kornder[at]uva.nl

Abstract

As the Odum brothers noted halfway into the 20th century, revealing the invisible wires of nature—that is, the flow of energy within ecosystems—is indispensable for understanding the form, function, and diversity of life. The globally ongoing decline of coral reefs suggests a lack of sufficiently protective policies, partly rooted in limited insights into the complex energetics of these ecosystems. Overcoming this limitation requires tested approaches to scale up metabolic activity of benthic reef organisms to higher hierarchies (i.e., community, ecosystem, landscape). Here, we present a static carbon flow model of the food web of a Caribbean coral reef based on extensive field measurements—192 *in situ* incubations of common benthic reef organisms—and a broad compilation of published data of production and respiration rates, and net fluxes of planktonic, detrital, and dissolved organic carbon. The model can simulate different reef communities using abundance data (e.g., biomass, volume) of their constituting organisms to generate predictions of carbon flows between these organisms (i.e., Odum's invisible wires). To test our model, we measured net carbon fluxes of six *in situ* reef patches with known abundances. Entering those abundances into our model and deriving net carbon fluxes from its predictions demonstrated close agreement between modeled estimates and real measurements (n = 6). For the leeward reefs of Curaçao, our model predicts a net heterotroph system (daily PR = 0.6–0.9), yet mainly fueled by gross primary production (1.6–2.4 mol C m^{-2} d^{-1}). Motile animals obtain most of their energy via benthic grazing and predation (0.1–0.2 mol C m^{-2} d^{-1}). However, autotrophs release four times more carbon as dissolved organic matter (0.4–0.8 mol C m^{-2} d^{-1}), which sponges and heterotrophic bacteria retain (75–100 %) and shunt (20–80 %) to detritivores and filter feeders, respectively. Our validated model facilitates systematic investigation of the relationships between structure and function in Caribbean coral reefs, provides a framework to test the stability of such relationships across different geographical regions and time, and can thus engender the necessary knowledge to improve protection of coral reefs and their ecological services throughout the 21st century.

Ciliary currents regulate the oxygen distribution in the boundary layer of a coral with a patchy Symbiodinium distribution

Pacherres, C. O.[1, 2], Ahmerkamp, S.[3], Koren, K.[4], Holtappels, M.[2], Richter, C.[2]
[1]University of Copenhagen, Department of Biology, Helsingør, Denmark
[2]Alfred Wegener Institute for Marine and Polar Research, Bentho-Pelagic-Processes, Bremerhaven, Germany
[3]Max Planck Institute for Marine Microbiology, Biogeochemistry, Bremen, Germany
[4]Aarhus University Centre for Water Technology, Department of Biology, Aarhus, Denmark

cesar.pacherres[at]bio.ku.dk

Abstract

Most tropical shallow-water corals live in photosymbiosis with dinoflagellate algae (zooxanthellae), where the photosynthetic production of oxygen (O_2) by the zooxanthellae may lead to excess O_2 in the diffusive boundary layer (DBL) above the coral tissue surface. When advection is low, cilia-induced mixing of the coral DBL is vital to remove excess O_2 and prevent photo-inhibition and –damage that may lead to coral bleaching and mortality. Here, we combined novel particle image velocimetry using O_2-sensitive nanoparticles (sensPIV) with chlorophyll (Chl*a*)-sensitive hyperspectral imaging to visualize the microscale distribution and dynamics of ciliary flows and O_2 in the coral DBL in relation to the distribution of Chl*a* in the coral tissue of the reef building coral, *Porites lutea*. Curiously, we found an inverse relation between O_2 in the DBL and zooxanthellae Chl*a* in the underlying tissue, with patches of high O_2 above the coral mouth areas (low Chl*a*) alternating with areas of low O_2 concentrations at the coral periphery (high Chl*a*). The spatial segregation of Chl*a* and O_2 is related to ciliary induced vortical flows causing a lateral redistribution of O_2 in the DBL. In a 2D transport-reaction model of the coral boundary layer, we show that parts of the O_2 surplus is allocated to areas containing less Chl*a* densities, thus minimizing oxidative damage and enhancing O_2 net fluxes in the DBL. Mass transfer at the coral DBL is, thus, not uniform but spatially complex due to ciliary currents, with important implications in coral’s oxidative stress response as well as bleaching and recovery.

3C - Coral reef metabolism and biogeochemical processes (organism to ecosystem): What are current state and future trajectories of reef functioning?
Oral
A-1948

The Effects of Light Intensity and Flow Speed on Biogeochemical Variability within a Fringing Coral Reef in Onna-son, Okinawa, Japan

Rintoul, M.[1], Courtney, T.[1, 2], Dohner, J.[1], Giddings, S.[1], Kekuewa, S.[1], Mitarai, S.[3], Monismith, S.[4], Pezner, A.[1], Andersson, A.[1]
[1]Scripps Institution of Oceanography, La Jolla, United States
[2]University of Puerto Rico at Mayagüez, Department of Marine Sciences, Mayagüez, Puerto Rico
[3]Okinawa Institute of Science and Technology, Marine Biophysics Unit, Onna, Japan
[4]Stanford University, Department of Civil and Environmental Engineering, Stanford, United States

msrintou[at]ucsd.edu

Abstract

Ocean pH and dissolved oxygen (DO) are declining due to global warming and ocean acidification, which could alter the functioning of marine ecosystems, including coral reefs. To understand the potential impacts of these perturbations on coral reefs, it is critical to understand the interactions and feedbacks between seawater chemistry, reef metabolism, and physical processes. Shallow coral reef environments experience large temporal and spatial variabilities in pH and oxygen due to local reef metabolism, but these variations are strongly modulated by physical and hydrodynamic processes. In this study, we measured incident wave height, pressure, photosynthetically active radiation (PAR), pH, DO, and current speed and direction during a three-week study on a fringing reef system in Okinawa, Japan to investigate the relationship between physical processes and biogeochemical variability. The effect of PAR and flow speed on pH and DO variation was explored on the reef crest, within the lagoon, and in a channel. pH and DO increased during the day and decreased at night at each site. Mean PAR and current speeds explained 25-84% of the variance in the daytime pH and DO data across all sites, while mean current speed alone accounted for 35-69% of the variance in the nighttime pH and DO data. Current velocities within the reef system were predominantly driven by waves but modulated by the tide. Flow speeds at each site were modelled using incident significant wave height and depth. Modelled flow speeds and PAR explained 53-92% of the observed daytime pH and oxygen variability, while 46-81% of the nocturnal pH and DO variability was accounted for by modelled flow speeds. These results highlight the role physical processes play in controlling pH and DO variability on coral reefs and improve our ability to evaluate the effect of global changes on local seawater pH and DO variability. The results also suggest it may be possible to predict a significant proportion of biogeochemical variability on coral reefs using simple physical measurements.

3C - Coral reef metabolism and biogeochemical processes (organism to ecosystem): What are current state and future trajectories of reef functioning?
Oral
A-1623

Diurnal and seasonal variation of coral and algal respiration and its drivers

Sawall, Y.[1], Bakker, R.[1], Adamson, N.[2], Padillo-Anthemides, N.[3]
[1]Bermuda Institute of Ocean Sciences, St. George's, Bermuda
[2]University of California San Diego, San Diego, United States
[3]Florida International University, Miami, United States

yvonne.sawall[at]bios.edu

Abstract

Inorganic carbon uptake (photosynthesis) and release (respiration) are fundamental processes of the energy and carbon budget of coral reef photosynthesizers. While it is known that photosynthesis (P) rates drive daytime respiration rates, our understanding of diurnal pattern of respiration (R) as a function of light and / or P is not yet well described, due to the shortage of daytime R measurements under natural light conditions. Consequently, we also lack knowledge about the seasonal dynamics of R and its drivers. In this study, we investigated the diurnal pattern of R rates (day and night) via outdoor incubations, along with measurements of P, in three Bermuda coral species, in three seasons. Additional investigations with algal species were conducted in fall. While some species showed a slight early morning depression, all species increased R rates in the morning until reaching a peak early or mid-afternoon, 0.5 to 3h after the peak in P. Subsequently, R decreased again until reaching rather constant night-time R rates. Differences in night-time and peak day-time R rates (ΔR) were similar between coral species and highest in fall (2-fold) and lowest in spring (1.5-fold). In the 3 algae species investigated, ΔR varied between 1.3 and 2.3-fold in fall. R rates varied substantially between seasons being highest in all coral species in summer and lowest in fall. Drivers of these patterns and implications with respect to the coral and algae energy and carbon budgets will be discussed.

3C - Coral reef metabolism and biogeochemical processes (organism to ecosystem): What are current state and future trajectories of reef functioning?
Oral
A-1609

Coral Reef Ecosystem Metabolism Over Twenty Years on Palau's Barrier Reef

Shamberger, K.[1], Cohen, A.[2], Lentz, S.[2], Barkley, H.[3], DeCarlo, T.[4], McCorkle, D.[2], Gouezo, M.[5], Golbuu, Y.[6], Rengiil, G.[6]
[1]Texas A&M University, Oceanography, College Station, United States
[2]Woods Hole Oceanographic Institution, Woods Hole, United States
[3]National Oceanic and Atmospheric Administration, Honolulu, United States
[4]Hawaii Pacific University, Honolulu, United States
[5]Southern Cross University, East Lismore, Australia
[6]Palau International Coral Reef Center, Koror, Palau

katie.shamberger[at]tamu.edu

Abstract

We measured net ecosystem calcification (NEC) and production (NEP) on Palau's northwest barrier reef in March 2012, November 2013, and January 2015. A previous study measured NEC and NEP in the same location in July 1994 and September 2000, providing a unique opportunity to examine changes in environmental conditions and community metabolism over 20 years. The previous study documented a decline in NEC (from 130 to 74 mmol m^{-2} d^{-1}) and NEP (from to 97 to 25 mmol m^{-2} d^{-1}) from 1994 to 2000 and attributed these declines to a decrease in coral cover following the 1998 global bleaching event. We collected carbonate chemistry, temperature, salinity, and current velocity data continuously over one 4-day deployment in both 2012 and 2013 and over two 4-day deployments in 2015, and performed ecological surveys in 2015. Average offshore salinity, temperature, and inorganic nutrient concentrations were similar across all time periods. Coral cover on the reef flat was lower in 2015 (<5%) than in 2000. Aragonite saturation state of offshore source water to the reef has decreased by approximately 0.2 from 1994 to 2015. All our 2012-2015 daily NEC estimates indicate that the reef is net calcifying, with an average NEC of 93 ± 15 mmol m^{-2} d^{-1}. In addition, our average 2012-2015 NEC estimate is higher than the 2000 estimate, even though coral cover and saturation state are lower than in 2000. However, average 2012-2015 NEC is lower than the pre-bleaching 1994 estimate. Our recent daily NEP estimates indicate that the reef is net respiring, with an average 2012-2015 NEP of -213 ± 140 mmol m^{-2} d^{-1}, in contrast to the 1994 and 2000 NEP estimates that showed the reef was net photosynthesizing. Recent work in the laboratory and on other reefs has shown the potential for heterotrophy to support coral reef ecosystem calcification, even under low saturation state. It is possible that a shift from net photosynthesis to net respiration could aid in maintaining net calcification on Palau's northwest barrier reef under continuing global change. However, the variability in our hourly NEC and NEP data is large, making it difficult to determine whether changes between a few estimates made many years apart are within the natural variability of the system. Our results suggest that characterizing the natural variability of a coral reef ecosystem is a critical first step in determining environmentally and anthropogenically driven changes in coral reef metabolism now and in the future.

3C - Coral reef metabolism and biogeochemical processes (organism to ecosystem): What are current state and future trajectories of reef functioning?
Oral
A-1453

Predicting the effects of submarine groundwater discharge on coral reef biogeochemistry and ecosystem functioning

Silbiger, N.[1], Hagedorn, B.[2], Zeff, M.[1], Jorissen, H.[3], Barnas, D.[1], Kerlin, J.[1], Maine, B.[2], Justis, E.[2], Sparagon, W.[3], McClintock, R.[3], Nelson, C.[3], Donahue, M.[4]
[1]California State University, Northridge, Northridge, United States
[2]California State University, Long Beach, Long Beach, United States
[3]University of Hawaii at Manoa, Honolulu, United States
[4]Hawaii Institute of Marine Biology, Kaneohe, United States

nyssa.silbiger[at]csun.edu

Abstract

Submarine groundwater discharge (SGD) is a worldwide phenomenon in coastal ecosystems. The unique physicochemical environment created by SGD, including high nutrients, low pH, and cool water, can alter key ecosystem functions. SGD fluxes are affected by physical parameters that are expected to change with climate change (e.g., sea level rise and precipitation), but changing SGD fluxes and its impact on coastal biogeochemical and ecological processes is often excluded from climate change predictions. With a focus on coral reefs, we use high resolution time-series data from two different SGD sites in Mo’orea, French Polynesia to 1) better understand the interacting effect of tides, waves, and precipitation on SGD flux and 2) determine how changing SGD alters reef ecosystem metabolism. We then developed a model to predict how changing physical parameters affect the local biogeochemical conditions near the two SGD seeps. We broadly show that waves have a significantly higher effect on SGD flux than tides in Mo’orea, a microtidal habitat. Further, we show a substantial pulse of low pH, low salinity, cool, and high nutrient water onto the reef from SGD that lead to changes in net ecosystem production and calcification on the reef. As the unique biogeochemistry from SGD can affect ecological processes on coral reefs, our model can uncover how changing physical conditions may lead to altered coral reef ecosystem functioning via changes in SGD.

Unraveling the land-to-reef continuum: Spatial distribution of stable isotope signatures of benthic reef communities along the coast of Curaçao

van de Loosdrecht, N. C. J.[1], Sánchez Barranco, V.[2], Vermeij, M. J.[1, 3], Visser, P. M.[1], de Goeij, J. M.[1, 3]
[1]University of Amsterdam, Institute for Biodiversity and Ecosystem Dynamics/Department for Freshwater and Marine Ecology, Amsterdam, Netherlands
[2]Royal Netherlands Institute for Sea Research (NIOZ), Texel, Netherlands
[3]Caribbean Research and Management of Biodiversity Foundation (CARMABI Foundation), Willemstad, Curaçao

n.c.j.vandeloosdrecht[at]uva.nl

Abstract

In coastal waters, water quality is affected by nutrients and other substances of oceanic, terrestrial, and even aerial origin. Tropical coral reefs are residing in oligotrophic (i.e. nutrient-poor) waters often fringing coasts of islands and therefore directly influenced by relatively small changes in nutrient input from both sea- and land-based sources. However, surprisingly little is known on the actual fluxes of terrestrial versus oceanic inputs and its effect on coral reef benthic communities. As part of the larger “SEALINK” project, consisting of nine, interdisciplinary PhD projects from several universities and research institutes in the Netherlands and Curaçao, we aim to link the terrestrial processes to the coral reef health in the Dutch Caribbean islands. Therefore, as first step, the spatial distribution of ^{13}C- and ^{15}N-stable-isotope signatures of different benthic reef communities (i.e., sediment, sponges, macroalgae) were assessed at 18 reef sites along a depth gradient on the fringing reefs of Curaçao. The ^{13}C- and ^{15}N-isotopic signatures will provide insights in the sources and proportion/distribution of nutrients along the coast. In addition, a mix of 30 metals were measured in aforementioned benthic communities and in ground water at the same sites to potentially provide a fingerprint, and potential relative level of, terrestrial input at each site. Both stable isotope and metal data are currently analysed, and will be presented at the ICRS. Based on this exploratory effort, we will perform future in-depth food web analyses at sites with least and most terrestrial input to understand how terrestrial sources influence local reef nutrient fluxes and trophodynamics of benthic communities.

Poster
A-1428

Investigating the biogeochemical functioning of the coral reef cryptobiome across contrasting habitats via in situ incubations

Daraghmeh, N.[1], Gabriel Rosado, J.[1], Roth, F.[2, 3], Justo, M. S.[1], Langner, U.[1], Cadiz, R.[1], Gil Ramos, G.[1], Saderne, V.[1], Benzoni, F.[1], Berumen, M.[1], Daffonchio, D.[1], **Carvalho, S.**[1]
[1]King Abdullah University of Science and Technology, Thuwal, Saudi Arabia
[2]Baltic Sea Center, Stockholm University, Stockholm, Sweden
[3]Faculty of Biological and Environmental Sciences, Tvarminne Zoological Station, University of Helsinki, Helsinki, Finland

susana.carvalho[at]kaust.edu.sa

Abstract

Approximately 75% of coral reef biodiversity comprises small-sized organisms inhabiting hidden spaces in the reef framework; they are often referred to as the 'reef cryptobiome'. A large proportion of these organisms are cavity-dwelling suspension feeders, including ascidians, sponges, and bryozoans that play an important role in organic carbon (C) and nitrogen (N) (re)-cycling, sustaining the high biodiversity of coral reefs in oligotrophic environments. Very limited knowledge exists regarding how nearby reef communities drive the biodiversity patterns of the reef cryptobiome and how changes in its structure can alter the rates of C and N transformation at the reef scale. Unbalancing the rates and directions of C and N transformation can be detrimental for reef functioning, and may result, for example, in the competitive advantage of algae over corals through shifts in organic and inorganic resources. The development of Autonomous Reef Monitoring Structures (ARMS) - cubic like units composed of 9 PVC plates alternating open and closed layers - has enabled a standardized way to non-destructively sample the reef cryptobiome across multiple spatial and temporal scales. Here, we use an innovative approach combining ARMS and acrylic incubation chambers to investigate differences in C and N dynamics of pioneer cryptobenthic communities among reef habitats. Four replicate ARMS units were deployed at four well-defined habitats in a central Red Sea reef (Tahala reef, 22°N). The habitats, named after their dominant features, are: 1). Plating coral dominated; 2) Branching coral dominated; 3) Algal pavement; 4) Rubble. All habitats were found at the same depth profile and under similar exposure. ARMS were deployed for seven months and before recovery, each unit was incubated in situ and water samples collected for flux measures of dissolved and particulate organic C and N (i.e., DOC, POC, DON, PON) and dissolved inorganic nutrients (i.e., NO_3^-, NO_2^-, NH_4^+, and PO_4^{3-}). We hypothesize that varying biogeochemical characteristics - indicative of the functional role of these communities as C and N sources and/or sinks - occur among habitats reflecting compositional changes in the pioneer communities. Given the importance of cryptobenthic communities, this study will help us understand potential implications for coral reef functioning under phase-shift scenarios.

Poster
A-1304

Dissolved and particulate substances around the island of Curaçao

Sanchez Barranco, V.[1], Bertoncelj, V.[2], van de Loosdrecht, N. C.[3], Mienis, F.[1], de Nooijer, L.[1]
[1]NIOZ, OCS, Den Hoorn, Netherlands
[2]NIOZ, COS, Den Hoorn, Netherlands
[3]UvA, IBED, Amsterdam, Netherlands

virginia.sanchez[at]nioz.nl

Abstract

Water quality is a decisive factor for coral reef health and growth. Yet, the effect of land-derived substances on reefs structure and biodiversity is not fully understood, but is necessary for developing effective management approaches. Such an understanding starts with a spatio-temporal characterization of the most relevant environmental parameters in relation to 1) land-based activities and 2) presence and health of coral reefs.
As part of the SEALINK project, we assess the spatial and temporal distribution and deposition of particulate and dissolved substances around the island of Curaçao. This allows connection of on-shore activities with coral cover and estimating net fluxes towards and from the reef. This will be achieved by analyzing environmental parameters and the geochemical composition of substances in the water column and sediment in different areas around the island, where coral cover and dominant reef species (i.e. sponge, soft coral or hard coral) differ. A field survey combined a large collection of sediment and water samples (DIC, TA, DOC, Si, NH_4, PO_4, NO_2, NO_3, SPOM, SPM) along the south coast of Curaçao, including pristine, close to the city and touristic areas.
First results indicate a distinct biogeochemical signature (i.e. significant differences in the concentrations of PO_4, NO_3, DIC, Si and total alkalinity) of 3 areas, the East (pristine), middle (city) and the West (touristic) of the island. They also show that an important explanatory variable is hard coral cover, which differs highly between these three areas. This dataset also allows integration of hydrodynamics (e.g. tidal movements) as an causal factor in reef composition/ presence.

3C - Coral reef metabolism and biogeochemical processes (organism to ecosystem): What are current state and future trajectories of reef functioning?
Virtual
Oral
A-1502

Sponge-derived DOM is assimilated by coral holobionts

Reigel, A.[1], Easson, C.[2], Apprill, A.[3], Freeman, C.[4], Fiore, C.[1]
[1]Appalachian State University, Biology, Boone, United States
[2]Middle Tennessee State University, Biology, Murfreesboro, United States
[3]Woods Hole Oceanographic Institution, Marine Chemistry and Geochemistry, Woods Hole, United States
[4]College of Charleston, Biology, Charleston, United States

reige012[at]gmail.com

Abstract

Sponge holobionts play a vital role in reef ecosystems by assimilating dissolved organic matter (DOM) from diverse sources including algae and corals, and releasing these nutrients as particulate detritus that is consumed by reef detritivores in a cycle known as the “sponge loop.” Sponges have also been implicated as a source of DOM on reefs, but it is unknown whether vital reef macrofauna, such as corals, are able to assimilate dissolved carbon (C) and nitrogen (N) produced by sponges. To test this, we used a stable isotope ‘pulse-chase’ experiment to investigate the incorporation of 13C- and 15N-enriched sponge-derived DOM into the tissues of three Caribbean corals. Corals included two scleractinians (*Acropora cervicornis*, *Orbicella faveolata*) and a gorgonian (*Eunicea flexuosa*). To obtain 13C- and 15N- enriched sponge-derived DOM, a community of six common Caribbean sponge species were incubated with inorganic 13C and 15N tracers in a 4-hr ‘pulse’. Enrichment in 13C and 15N was observed in all sponge species following the ‘pulse.’ Enriched sponges were then placed in aquaria with coral fragments for a 6-hr ‘chase’ period, in which corals were sampled at the start, middle (3-hrs) and end. Both coral and their associated zooxanthellae assimilated sponge-derived DOM during the incubation, but incorporation rates varied across species and between fractions. *A. cervicornis*, and its zooxanthellae, incorporated both 13C and 15N at a higher rate than the other two coral species. For all species, coral tissue appeared to reach maximum incorporation of 13C and 15N sometime between 0-3 hrs. In contrast, the zooxanthellae of *O. faveolata* had the highest 13C incorporation at 6 hrs. Similarly, *A. cervicornis* zooxanthellae had the highest 15N incorporation, at 6 hrs. Our results indicate that sponge-derived DOM may be an important source of C and N for Caribbean corals, particularly for bleached or stressed corals that are known to rely more heavily on heterotrophic feeding following the loss of their symbionts. These data also support a novel narrative that a high abundance of sponges is not necessarily counterproductive to coral success.

Session 3D - How do metabolic processes underpin the health and function of reef ecosystems?

Conceptualized and chaired by: **Jasper de Goeij**[1]
[1] University of Amsterdam (Amsterdam, The Netherlands)

Oral
A-1078

Towards a mechanistic understanding of coral recruitment: Light-dependent settlement of Leptastrea purpurea larvae triggered by a single bacterial cue

Kellermann, M. Y.[1], Petersen, L.-E.[1], Fiegel, L. J.[1], Nietzer, S.[1], Ahlers, N.[1], Abele, D.[2], Bickmeyer, U.[2], Schupp, P. J.[1, 3]
[1]University of Oldenburg, ICBM, Environmental Biochemistry Group, Wilhelmshaven, Germany
[2]Alfred-Wegener-Institut Helmholtz-Zentrum für Polar- und Meeresforschung (AWI), Department of Biosciences, Bremerhaven, Germany
[3]Helmholtz Institute for Functional Marine Biodiversity at the University of Oldenburg (HIFMB), Oldenburg, Germany

matthias.kellermann[at]uni-oldenburg.de

Abstract

The climate change associated rise in sea surface temperatures is a major driver of worldwide coral bleaching and associated to coral mass mortalities, especially in recent years. An important mechanism of coral reef recovery is the recruitment of sexually reproduced coral larvae. Previous research on coral larvae settlement has shown that bacterial biofilms associated with crustose coralline algae (CCA) and specific bacterial genera such as *Pseudoalteromonas* are pivotal for successful larvae settlement. However, the search of effective settlement inducing compounds and the understanding of the molecular processes behind are still in their infancy.

To study the searching behavior as well as the settlement process of coral larvae, we used the brooding scleractinian coral *Leptastrea purpurea*, which is capable to release larvae on a daily basis. From a large variety of marine bacterial isolates, derived from the CCA *Hydrolithon reinboldii* from Guam (USA), we were able to not only identify multiple bacterial strains but also isolate a single bioactive chemical compound from the highly pigmented bacterium *Pseudoalteromonas rubra*, which induce and facilitate larval settlement. Depending on the light setting and concentration of the isolated cue cycloprodigiosin, we were able to achieve settlement rates of 90%.

Finally, we propose an underlying chemical mechanism of the identified settlement cue cycloprodigiosin and highlight the importance of light intensity within the complex transformation of a free-swimming coral planula to a sessile recruit. We believe that a deeper understanding of the coral larvae settlement process at the structural level is urgently needed to develop effective approaches for reef restoration and ultimately combat the negative trend of coral decline.

Oral
A-1380

A Novel in Situ Approach for Examining the Form and Functional Potential of Biogenic Volatile Organic Compounds (BVOCs) Emitted by Benthic Reef Taxa

Olander, A.[1], Lawson, C.[1], Raina, J.-B.[1], Ueland, M.[2], Suggett, D.[1]
[1]Climate Change Cluster, University of Technology Sydney, Sydney, Australia
[2]Centre for Forensic Science, University of Technology Sydney, Sydney, Australia

axel.olander[at]student.uts.edu.au

Abstract

All organisms on earth release biogenic volatile organic compounds (BVOCs) as a result of their metabolic activity. BVOCs are known to vary between taxa and both directly and indirectly regulate diverse ecophysiological functions in response to environmental change; consequently, “volatilomics” holds the potential to diagnose organism taxonomy, phenotype, health state and ecological functioning via non[1]invasive capture of BVOCs. Although coral reefs and reef taxa are known "hotspot" marine emitters of specific BVOCs (e.g. DMS, isoprene), their broader volatilomes - and changes in these emissions in response to anthropogenic stressors - have received little attention to date. Using ex situ screening approaches, we first confirmed that temperate and tropical reef taxa emitted diverse volatilomes using two-dimensional gas chromatography paired with time-of-flight mass spectrometry (GCxGC-TOFMS). We then adapted benthic incubation chamber-based approaches, commonly used to examine environmental control of reef taxa metabolism, to characterise dynamic BVOC emissions from diverse coral reef benthic organisms in situ. We describe the design and deployment of this novel in situ incubation chamber, built to capture BVOC emissions via thermal desorption tubes. We present trial deployments and BVOC retrieval for key benthic algae and coral from Heron Reef (Great Barrier Reef, Australia), and outline the next steps required to optimise future deployments. Finally, we demonstrate the ability of this system to standardise BVOC sampling across diverse benthic taxa, and discuss its utility in screening for 'volatile biomarkers' of reef health, diversity and functioning.

Oral
A-2052

Oxylipin-mediated signalling in the cnidarian-Symbiodiniaceae symbiosis

Rosset, S. L.[1], Ashley, I. A.[1], Oakley, C. A.[1], Grossman, A. R.[2], Suggett, D. J.[3], Weis, V. M.[4], Davy, S. K.[1]
[1]Victoria University of Wellington, School of Biological Sciences, Wellington, New Zealand
[2]Stanford University, Stanford, United States
[3]University of Technology Sydney, Sydney, Australia
[4]Oregon State University, Corvallis, United States

nina.rosset89[at]gmail.com

Abstract

We still know very little about the molecular communication involved in regulating the cnidarian-Symbiodiniaceae symbiosis. One class of signalling molecules implicated in inter-kingdom communication in various host-microbe interactions is oxylipins, a complex array of lipid mediators based on the oxidation of polyunsaturated fatty acids that regulate diverse physiological processes including inflammation, immunity, and metabolic homeostasis. A down-regulation in the expression of core genes involved in oxylipin synthesis has been observed in the symbiotic vs. aposymbiotic state in the model cnidarian Aiptasia, yet only when colonised by homologous (*Breviolum minutum*) and not by non-homologous (*Durusdinium trenchii*) symbionts, implying that host oxylipin signalling is suppressed in an optimal symbiosis. Here we employ a directed lipidomic approach using high resolution tandem mass spectrometry to characterise oxylipin profiles of the host and symbionts in Aiptasia colonised by either *B. minutum* or *D. trenchii*. We assess the effect of the symbiotic state on oxylipin synthesis by comparing oxylipin profiles in the symbiotic and aposymbiotic/cultured host and Symbiodiniaceae. A large diversity of oxylipins were identified. Contrary to expectation, the symbiotic state induced a predominant increase in the synthesis of many oxylipins within both the host and symbionts. In particular, a significant increase in docosahexaenoic acid-based oxylipins in the symbiotic state, oxylipins thought to have inflammation-resolving activities, may play a role in dampening host immunity. The magnitude of this response may, in turn, relate to symbiont compatibility in this model cnidarian. By analysing temporal fluctuations of oxylipin species of interest across the diel cycle we aim to pinpoint whether a molecular host-symbiont dialogue orchestrated by these signalling lipids takes place. We will present our results and discuss their implications for understanding the mechanism of symbiosis regulation. Insight into the molecular signalling that regulates cnidarian-Symbiodiniaceae symbiosis homeostasis and distinguishes different host-symbiont pairings is critical for the development of novel tools for coral reef monitoring and conservation and is crucially facilitated by the application of specialised omics technologies.

Oral
A-1671

Metabolomic profiling reveals rapid juvenile plasticity in response to acute heat stress in comparison to adult coral colonies

Sweet, M.[1], Burian, A.[1], Reverter, M.[2]
[1]University of Derby, Derby, United Kingdom
[2]Plymouth University, Plymouth, United Kingdom,

m.sweet[at]derby.ac.uk

Abstract

Coral reefs are suffering unprecedented global rates of decline and human assisted evolution (HAE) is a method which is increasingly being proposed as a key rescue measure aimed to increase reef resistance to climate warming and habitat degradation. A major challenge to capitalise on the potential of HAE is the effective ex-*situ* crossing of geographically distant populations. In this study, we successfully implemented *ex-situ* coral spawning, which allowed us to perform transgenerational heat stress experiments with Acropora species from two distinct geographical locations (Australia and Singapore). We jointly measured adult acute heat stress resistance and the metabolic stress response of adults and juveniles from 14 different crossing. The metabolic stress response was much stronger in juveniles but also detectable in adults. In adults, there was no obvious links between stress resistance and metabolic stress response. However, juveniles from more stress resistant parents were more metabolically stable (i.e. more similar to unstressed parents) and showed less metabolic drift when stressed. Importantly for HEA studies, we found a strong inheritance component shaping the metabolomic profiles of juveniles. Consequently, we screened metabolic profiles for compounds that were associated with higher stress resistance. The resulting candidate compounds will require further testing, but provide a first target list for coral breeding, pathing the way for the advancement of HAE applications in reef conservation.

Session 3E - How will ecosystem services from coral reefs change?

Conceptualized by: **Anna Woodhead** [1], **Ruth Thurstan**[2], **Tomas Chaigneau**[2], **Susan Yee** [3]
[1] Lancaster University (Lancaster, UK)
[2] University of Exeter (Exeter, UK)
[3] US Environment Protection Agency, Gulf Ecology Division

Chaired by: **Anna Woodhead** [1]

Oral
A-1495

Coral structural complexity loss highly threatens the coastline

Carlot, J.[1, 2, 3], Vousdoukas, M.[4], Rovere, A.[5], Lenihan, H. S.[6], Kayal, M.[7], Karambas, T.[8], Adjeroud, M.[1, 2, 3, 9], Harris, D.[10], Hedouin, L.[3, 11], Parravicini, V.[1, 2, 3]
[1]PSL Université - EPHE-UPVD-CNRS, UAR 3278 CRIOBE, Perpignan, France
[2]Centre de Synthèse et d'Analyse sur la Biodiversité - Fondation pour la Recherche sur la Biodiversité (CESAB-FRB), Montpellier, France
[3]Laboratoire d'Excellence "CORAIL", Paris, France
[4]European Commission, Joint Research Centre (JRC), Ispra, Italy
[5]Centre for Marine Environmental Sciences (MARUM), Bremen, Germany
[6]Bren School of Environmental Science and Management, USCB, Santa Barbara, United States
[7]Institut de Recherches & Developpement (IRD) - UMR ENTROPIE, Noumea, New Caledonia
[8]Department of civil Engineering, Aristotle University of Thessaloniki, Thessaloniki, Greece
[9]Institut de Recherches & Developpement (IRD) - UMR ENTROPIE, Perpignan, France
[10]School of Earth and Environmental Sciences, The University of Queensland, Brisbane, Australia
[11]PSL Université - EPHE-UPVD-CNRS, UAR 3278 CRIOBE, Papetoai, French Polynesia

jay.crlt02[at]gmail.com

Abstract

Coral reefs offer natural protection from oceanic waves to more than 500 million people and are threatened by intensifying anthropogenic disturbances and climate change. However, studies quantifying how current perturbations affect the capacity of reefs to dissipate wave energy through time are sparse. Here, we combined ecological time series and hydrodynamic data with numerical models to assess the natural protection offered by coral reefs at Mo'orea (French Polynesia) over ten years, including one major disturbance-recovery cycle (both Crown-of-thorns starfish outbreak and cyclone Oli occurring respectively in 2007 and 2010). We first showed that the relationship between coral reef structural complexity and wave dissipation is not linear. More precisely, we revealed that structural complexity has twice the potential to dissipate an offshore wave of 3m compared to an offshore wave of 1m. Second, we used the 2% exceedance wave run-up height ($R_{2\%}$) as a proxy for wave overwash and flooding to compare the capacity of reefs to dissipate extreme waves in 2010 (low structural complexity; *i.e.,* 1.58 ± 0.33) and 2016 (high structural complexity; *i.e.,* 3.87 ± 0.28). Our results revealed that structural complexity loss will drastically increase the flooding risk on the coast. More precisely, a $R_{2\%}$ with a 100-years return under 2016 structural reef conditions will become 50 times more frequent if coral reef structural complexity deteriorates such as it was the case in 2010. Our findings confirm the value of reefs habitats for coastal protection and highlight the importance of maintaining high structural complexity to cope with the risk of flooding in coastal areas.

Oral
A-1879

Fishers perceptions of ecosystem service change associated with climate-disturbed coral reefs

Woodhead, A.[1], Graham, N.[2], Robinson, J.[2], Norstrom, A.[1], Bodin, N.[3, 4], Marie, S.[3], Balett, M.-C.[3], Hicks, C.[2]
[1]Stockholm Resilience Centre, Stockholm, Sweden
[2]Lancaster University, Lancaster Environment Centre, Lancaster, United Kingdom
[3]Seychelles Fishing Authority, Victoria, Seychelles, [4]Sustainable Ocean Seychelles, Beaubelle, Seychelles

anna.j.woodhead[at]gmail.com

Abstract

Coral reef ecosystems are changing under continued anthropogenic pressures. Reefs underpin important ecosystem services that contribute to the wellbeing of millions of people. To date, few studies have investigated if or how people perceive changes in coral reef ecosystem services and to what extent those changes matter. In this talk, we explore the following questions: 1) have reef fishers perceived changes in coral reef ecosystem services?; 2) do perceptions of change correlate with fishers' characteristics?; and 3) which changes are most important to this group?

Data were collected in the Seychelles where reefs were affected by bleaching in the 1998 and 2016 marine heat waves (>90% and >70% mortality of live coral cover respectively). Working with the Seychelles Fishing Authority, we conducted 41 interviews with trap fishers to capture perceptions of change in four ES (fishery, coastal protection, habitat, and recreation services), as well as the opinions and background of interviewees.

Combining quantitative and qualitative approaches, we show that fishers have perceived changes in the four services. Fishers who reported a higher number of changes in ES were more educated, had invested more in their fishing, spent time underwater and had more dependents. Descriptions of change highlighted its diverse nature and stressed the importance of understanding relationships between ecosystem services.

Changes in habitat and fishery services were most significant to fishers. Individuals who were more educated and used a greater variety of fishing gears, reported changing habitat services as most significant. Fishers who had to rely on casual work, in addition to fishing, tended to report changing fishery services as the most significant. Reasoning behind the significance of changes was diverse, indicating that change means different things to different people. This study has identified important factors and considerations to help in managing for future ecosystem services and for understanding the wellbeing implications of changing reefs.

Virtual
Oral
A-2140

Similar functional composition on fish assemblages despite contrasting levels of habitat degradation on shallow Caribbean coral reefs.

Olán-González, M.[1], Álvarez-Filip, L.[2]
[1]Posgrado en Ciencias del Mar y Limnologia, Universidad Autónoma de México, Puerto Morelos, Mexico
[2]Biodiversity and Reef Conservation Laboratory, Unidad Académica de Sistemas Arrecifales, Universidad Nacional Autónoma de México, Puerto Morelos, Mexico

nelo.olan[at]gmail.com

Abstract

Functional approaches based on traits provide an opportunity to evaluate how changes in habitat degradation affect the structure and dynamics of biological communities. In coral reefs, global analyses have shown consistent patterns in the functional diversity of reef-associated fish assemblages across ecoregions despite marked differences in reef physical structure, coral diversity, and reef condition. These large-scale patterns raise the question of whether the same consistency on the fish functional diversity exists at smaller spatial scales between reefs with different states but subject to similar environmental conditions. Here, we compare the functional diversity of fish assemblages on two shallow Caribbean coral reefs with different levels of habitat degradation. Limones reef is primarily constituted by stands of Acropora palmata (>25% of reef's cover), while Bonanza is a reef with extensive areas of relic Acropora structures and is covered mainly by algae. As expected, we found a significantly greater number of fish species, biomass, and density of individuals in Limones. The increased number of individuals and species per unit area determined that functional richness and functional evenness also differed among reefs. However, a more detailed analysis revealed a similar functional trait composition of fish assemblages, exhibiting an important area of overlap among reef sites. Furthermore, no differences were observed in functional originality (the average functional uniqueness of species within an assemblage) and functional dispersion (mean distance of individual species from the centroid of all species in the community) regardless of the level of habitat degradation. Our findings suggest that differences in functional richness and evenness among reefs are driven by a greater niche complexity provided by the stands of Acropora palmata. However, the higher structural complexity of Limones reef did not contribute to host species with different functional traits. Therefore, reef condition seems not to influence trait composition and functional redundancy at small-spatial scales. This is likely because most Caribbean fish species are not strict habitat specialists and because both studied reefs are subject to similar ecological and environmental conditions.

Session 3F - What are the roles of nutrients in coral reef survival?

Conceptualized by: **Michael Fox**[1], **Kristen Davis**[2], **Jörg Wiedenmann**[3], **Gareth Williams**[4]
[1] Woods Hole Oceanographic Institution (Woods Hole, MA, USA)
[2] University of California (Irvine, CA, USA)
[3] University of Southampton (Southampton, UK)
[4] Bangor University (Bangor, UK)

Chaired by: **Michael Fox**[1], **Jörg Wiedenmann**[3], **Gareth Williams**[4]

Oral
A-1702

Trophic plasticity of subtropical corals in response to seasonal fluxes

Chei, E.[1], Conti-Jerpe, I.[1, 2], Pons, L.[1], Baker, D.[1]
[1]The University of Hong Kong, School of Biological Sciences, Hong Kong, Hong Kong SAR China
[2]University of California, Berkeley, The Museum of Vertebrate Zoology and Department of Integrative Biology, Berkeley, United States

echei[at]connect.hku.hk

Abstract

Scleractinian corals are mixotrophic organisms that use both autotrophic and heterotrophic pathways to fulfill their metabolic needs. Corals span a spectrum of trophic strategies that vary in their dependence on associated algal symbionts. Similarly, some species can increase heterotrophic feeding to compensate for the loss of autotrophic nutrition, improving the likelihood of survival and recovery when stressed or bleached. Trophic strategy therefore plays a significant role in regulating coral responses to environmental stressors. However, few species have been investigated, and there is little understanding of nutritional flexibility across taxa. Here, we examined whether seven coral genera shift their trophic strategy between seasons with known fluctuations in water quality and climate. Corals were sampled in Hong Kong during the wet and dry seasons, and a Bayesian statistical model was applied to $\delta^{15}N$ and $\delta^{13}C$ stable isotope values to determine the isotopic niches (proxies for trophic niche) of paired coral hosts and symbionts. Using a novel index (Host Evaluation: Reliance on Symbionts [HERS]), trophic strategy was evaluated along a continuum of mixotrophy for each season. Results showed that all genera exhibited shifts in their nutritional mode between wet and dry seasons, although the magnitude of trophic plasticity varied greatly between genera. Most genera were more heterotrophic in the dry compared to the wet season, likely as a mechanism for tolerating lower temperatures and decreased irradiance during these months. These findings demonstrate widespread but variable capacity for trophic plasticity in corals, and they may help predict species distributions and community structure of future reefs.

Oral
A-1355

The effect of temperature and nutrient depletion on the uptake and assimilation of nitrogen compounds in the scleractinian coral Stylophora pistillata

Crehan, O.[1], Davy, S.[1], Grover, R.[2], Ferrier-Pagés, C.[2]
[1]Victoria University of Wellington, School of Biological Sciences, Wellington, New Zealand
[2]Centre Scientifique de Monaco, Marine Biology Department, Quai Antoine 1er, Monaco

oscar.crehan[at]vuw.ac.nz

Abstract

Coral mortality during a bleaching event can be prevented or exacerbated depending on the abundance of different nitrogen compounds. Thus, the availability of nitrogen likely plays an important role in a coral's response to bleaching. While research has been conducted on the uptake of dissolved inorganic nitrogen (nitrate and ammonium) during bleaching, it is not yet known how temperature effects the uptake of dissolved organic forms, such as urea and dissolved free amino acids, nor how these change in relation to the other compounds at both high and low temperature. The effect of nutrient-depleted conditions, such as those experienced in stratified waters, on the uptake of these compounds is also unknown. In this study, we aimed to create a nitrogen budget for the scleractinian coral *Stylophora pistillata* by determining the uptake and transfer of nitrate, ammonium, urea, and dissolved free amino acids. To this end, *Stylophora* nubbins were gradually exposed to temperatures of 22, 26, 30, and 34 °C. After two weeks (one for the 34 °C corals) at the target temperature, half of the corals were placed in nutrient-depleted water for 24 hours. The nubbins were then individually incubated with ^{13}C-labelled bicarbonate and ^{15}N-labelled nitrate, ammonium, urea, or dissolved free amino acids to determine uptake rates and the incorporation of nitrogen and carbon in the Symbiodiniaceae and animal tissues. Initial analysis has already shown 76-fold and 157-fold increases in ^{15}N incorporation in the host and symbiont, respectively, after exposure to the nutrient depleted water and an incubation with ^{15}N ammonium. Further analyses are currently underway and will be presented.

Oral
A-1376

Spatiotemporal risk characterization of seawater quality on Bonaire’s nearshore reefs

Hoekema, L.[1, 2], Dogruer, G.[1], Becking, L.[2, 3], Francisca, R.-L.[4], Meesters, E.[1]
[1]Wageningen Marine Research, Den Helder, Netherlands
[2]Wageningen University and Research, Wageningen, Netherlands
[3]Naturalis Biodiversity Center, Leiden, Netherlands
[4]Stichting Nationale Parken Bonaire, Kralendijk, Caribbean Netherlands

lisa.hoekema[at]wur.nl

Abstract

Although Bonaire’s waters harbours one of the richest reefs of the Caribbean, it has not evaded the unprecedented global decline of these unique and precious reef systems. Recent research suggests a significant impact of local stressors on coral reef functioning. Planned intensification of Bonaire's coastal activities will increase run-off, sedimentation, and eutrophication, which, potentially induce detrimental changes to the system. However, identifying adverse effects of nutrient run-off on the coral reefs in field conditions remains challenging. Nevertheless, a new local monitoring infrastructure may help to evaluate the risks posed by nutrient pollution by detecting the frequency and origin of harmful concentrations. With strong support of local stakeholders, we aim to apply an integrated seawater quality management plan on Bonaire. For this, we measure baseline levels and spatiotemporal variation of dissolved inorganic nutrients (NH_4, NO_2, NO_3, PO_4^{3-}) and physiochemical water quality parameters (chlorophyll-a, temperature and turbidity).
We present spatial water quality data from thirty-seven study sites collected from November 22th to December 1st (2021) at 5 and 10m depth on the reef slope. A subset of 11 locations was selected for subsequent twice-monthly temporal monitoring. Preliminary data (NOV 2021-Feb 2023) are presented of this ongoing 3-year monitoring project. Furthermore, to apply an integrated approach, reported elemental (C, N) and stable isotope composition ($\delta^{15}N$) data of *Dictyota spp.* algae were incorporated to identify nutrient pollution sources and signals of eutrophication. The risk posed by nutrient pollution on coral reefs was characterized by applying a deterministic risk quotient approach. We compared environmental exposure levels to identify nearshore reef areas of high and low concern. Given the varying range of spatio-temporal data, a best/worst-case and the averaged risk scenario are presented.

The outcome provides insight into both local pressure from and resilience to external nutrient loading of coral reef ecosystems, by detecting spatiotemporal variation in nutrient and physiochemical water quality parameters. Ascertaining local deviations from water quality reference levels, will aid effective management, help restore reef resilience, and increase our chances of mitigating the global decline in coastal reef systems.

Oral
A-1348

Effect of nutrient depletion on symbiotic corals

Mardones, M. L., D' Angelo, C., Wiedenmann, J.
University of Southampton, Ocean and Earth Science, Southampton, United Kingdom

mlmv1c20[at]soton.ac.uk

Abstract

Scleractinian corals are integral to the formation of modern coral reefs, but their survival is now threatened by changing environmental conditions. Amongst them, the effects of increasing temperatures on symbiotic corals are widely studied. However, the disturbance of nutrient supply to tropical coral reefs, another projected consequence of ongoing climate change, is less understood. We aimed to characterise the response of a representative range of eleven coral species to nutrient depletion which may result from increased thermal stratification of the water column. We exposed corals with different growth morphologies (foliose, branching, and encrusting) to nitrogen (N) and phosphorous (P) depleted conditions over an 8-month period. We monitored different proxies of coral health, including symbiont density and photosynthetic efficiency as well as host coral growth. Our results show that most species exposed to N and P depletion lose up to 80% of their symbionts, followed by a complete stagnation of growth and subsequent mortality. These findings indicate that nutrient depletion in warming oceans may aggravate the detrimental effects of heat stress on the survival capacity of zooxanthellate corals.

Oral
A-2225

How coastal groundwater discharge and reef circulation produce zones of coral stress

Oberle, F.[1], Storlazzi, C. D.[1], Prouty, N. G.[1], Cheriton, O. M.[1], Swarzenski, P. W.[2]
[1]US Geological Survey - Pacific Coastal and Marine Science Center, Santa Cruz, United States
[2]International Atomic Energy Agency, Monaco, Monaco

foberle[at]usgs.gov

Abstract

Why is coral mortality elevated more in some parts of a reef than in others? Do we know what drives such heterogeneities? Answers to these questions often lie in the physicochemical controls that govern entire reef platforms and their ecosystems, but such data are difficult to obtain and even harder to interpret. Water circulation and residence times and coastal groundwater discharge strongly influence the degree to which reef organisms are exposed to variable temperatures and chemical conditions of surrounding waters and hence different stressors; understanding these controls is thus necessary to interpret spatial patterns in coral health. We here present two large reef experiments from the Makua Reef on Kauai, Hawaii, and the Faga'alu Reef on Tutuila, American Samoa, using a novel approach by combining cutting-edge oceanographic circulation analysis methods with coastal groundwater discharge rate estimates. From these sites the following data were integrated: a) coastal groundwater discharge rates were derived from newly developed radon time series buoys, b) spatial temperature fluctuations were obtained from unmanned thermal aerial systems and CTD profilers, c) reef-circulation patterns were obtained from Lagrangian surface current drifters, d) wave climate information was derived from a suite of pressure sensors, and e) nutrient and pathogen loading were estimated from discrete water sampling. Together, these observations reveal a high degree of spatial heterogeneity in coral stressors. In addition, areas of the Makua Reef that were classified as zones of higher coral stress were co-located with the locations where Coral Black Band Disease had previously been identified. The combined analysis of reef circulation, coastal groundwater discharge rates, and nutrient and/or pathogen loading estimates are used to classify reef zones that are subject to higher levels of stress, and thus will help managers identify reef areas that require higher levels of protection and/or mitigation.

Oral
A-2195

Understanding the dominant production sources of oceanic coral reefs

Polunin, N. V. C.[1], Zhu, Y.[2]
[1]School of Natural & Environmental Sciences, Newcastle University, Newcastle upon Tyne, United Kingdom
[2]Havforskningsinstituttet, Bergen, Norway

nick.polunin[at]newcastle.ac.uk

Abstract

The potential contribution of pelagic production sources to the food webs and ultimately fishery production of oceanic coral reefs has been underestimated, not least because these reefs were perceived to exist typically in oligotrophic waters. There is now better understanding of localised upwelling effects and growing evidence that pelagic sources can be important. Carbon stable isotopes can help differentiate distinct production source types, and we use these and nitrogen stable isotope data (these ô^{15}N data as proxies of food-chain length) to explore the relative importance of reef and pelagic production sources in 11 reefs (5 Caribbean, 6 Indo-Pacific) from published and unpublished data. We do this by triangulating the data for pelagic sources (more negative δ^{13}C values, low δ^{15}N), reef benthic primary producers (less negative δ^{13}C, low δ^{15}N), and apex-predator fish (high δ^{15}N values). This indicates that food webs can be pelagic-driven (3 of the 11 cases), reef-benthic driven (6 cases) or substantially contributed to by both production sources (2 cases). At two locations with extensive fish community biomass data, a Bahamas site with a benthic-driven triangle had low biomass of planktivores relative to apex predators, while a pelagic-driven Maldives site had planktivore biomass greatly exceeding that of apex predators. Imprecision in the data arises for example from the range of ô^{13}C values in benthic sources, and the present information is too limited to discern any geographical or other patterns. One idea is that the fisheries of pelagically-subsidised reefs may be more sustainable because ‘new’ production is derived from the exogenous sources.

Oral
A-1018

Depth zonation in reef fish traits and their biophysical drivers

Richardson, L.[1], Heenan, A.[2, 3], Williams, I.[4], Green, M.[3], Delargy, A.[5], Neubauer, P.[6], Williams, G.[3]
[1]Bangor University, School of Ocean Sciences, Menai Bridge, United Kingdom
[2]Global Fishing Watch, Brighton, United Kingdom
[3]Bangor University, Menai Bridge, United Kingdom
[4]Red Sea Development Company, Saudi, Saudi Arabia
[5]University of Massachusetts, Dartmouth, United States
[6]Dragonfly Data Science, Wellington, New Zealand

l.richardson[at]bangor.ac.uk

Abstract

Gradients in primary production are a major structuring force of coral reef ecosystems. Recent advances in remote sensing and oceanographic modelling have connected horizontal gradients in chlorophyll-a (a proxy for primary production), to the composition of benthic and fish assemblages across scales. Specifically, the cover of hard coral and the biomass of reef fishes - particularly planktivores and piscivores - are typically greater on islands characterised by higher levels of primary production. This provides important insight into the role of primary production in governing the extent to which reefs will naturally vary in their fisheries carrying capacity. What is unclear, however, is the role that depth gradients in primary production and proximity to sources of upwelling may play in structuring high-diversity patterns of reef fish species composition and their contributions to ecosystem function. This limits our understanding of the natural ecological organisation of coral reefs and how changes in biophysical gradients under climate change are likely to impact reef structure and function. Here, we combine trait-based characterisations of reef fish assemblages, high-resolution satellite data, and in situ oceanographic sampling across 24 unpopulated islands in the central western Pacific over a 9 year period to elucidate zonation patterns in reef fish functions and how they link to vertical gradients in primary production and upwelling dynamics. By revealing the extent to which biophysical gradients influence the functional ecology of reef fish assemblages in relatively unimpacted reef areas, we may then better understand how natural and human drivers interact to determine the ecological organisation of coral reef ecosystems.

Oral
A-1714

The effect of small-scale variation in primary production on reef fish productivity

Roche, R.[1], Heenan, A.[1], Taylor, B.[2, 3], Schwarz, J.[4], Fox, M.[5, 6], Williams, G.[1], Southworth, L.[1], Turner, J.[1]
[1]Bangor University, School of Ocean Sciences, Menai Bridge, United Kingdom
[2]Australian Institute of Marine Science, Crawley, Australia, [3]University of Guam, Mangilao, Guam
[4]University of Plymouth, School of Biological and Marine Sciences, Plymouth, United Kingdom
[5]Woods Hole Oceanographic Institution, Woods Hole, United States
[6]King Abdullah University of Science and Technology, Red Sea Research Center, Thuwal, Saudi Arabia

r.roche[at]bangor.ac.uk

Abstract

Within the oligotrophic 'desert' of primary productivity in tropical oceans, islands and atolls with augmented levels of primary production support higher reef fish biomass and reef organism abundance. This pattern occurs as external energy subsidies are delivered onto reefs via a range of mechanisms (e.g., current-driven upwelling, internal waves, wind-driven mixing). However, these processes do not deliver energetic subsidies uniformly and the influence of this spatial variation in primary production on reef fish growth is largely unknown. In particular, it is not yet clear how small scale (100s of metres) variability in food delivery onto a reef interacts with reef depth and slope, and may affect the productivity of reef fish communities. This study utilises 3 atoll reef systems within the Chagos Archipelago, covering ~200 km of latitude in the central Indian Ocean, to examine how planktonic food availability influences fishes. The growth rate of the planktivorous bicolour damselfish, *Chromis fieldi,* measured through otolith growth rings was used as a proxy for reef fish productivity. Fish were collected at moderate (~17.5 m) and shallow (~10 m) depths at 17 sites with tissue samples of each fish taken for stable isotope analysis ($\delta^{13}C$ and $\delta^{15}N$). Surface zooplankton (~1 m depth, >200 μm) and particulate organic matter (POM; 8–10 m depth) were collected from each site, providing an estimate of isotopic baseline values for the primary planktonic food resources across atolls. We hypothesize that: 1) sites where physical oceanographic models suggest greater ocean mixing and upwelling have enriched $\delta^{15}N$ and depleted $\delta^{13}C$ values, indicative of productivity derived from deeper oceanic nutrient sources, 2) growth rates of *Chromis fieldi* follow a similar pattern, with increased growth rates at high productivity sites and at greater depths, 3) reef slope is an important variable in explaining primary productivity gradients occurring around atolls. This study provides insights into the role of small-scale variation in planktonic food availability and reef geomorphology in influencing coral reef food webs.

Oral
A-1905

Deciphering the expression and regulation of nitrate reductase by Symbiodiniaceae from different coral species

Stévenne, C.[1], Grover, R.[2], Ferrier-Pagès, C.[2], Plumier, J.-C.[1], Roberty, S.[1]
[1]University of Liège, Ecophysiology and Animal Physiology (InBioS), Liège, Belgium
[2]Centre Scientifique de Monaco, Monaco, Monaco

chloe.stevenne[at]uliege.be

Abstract

Coral holobionts are very efficient at assimilating nitrogen through heterotrophic feeding or the uptake of dissolved inorganic nitrogen. Although NO_3^- is the most abundant source of nitrogen in the ocean, corals preferably uptake NH_4^+ due to its reduced state and energetically favorable assimilation. However, in conditions of low availability of environmental NH_4^+, coral holobionts are capable of depleting environmental NO_3^-. Symbiodiniaceae are vital partners of the symbiosis for nutrient assimilation. In addition to providing translocated photosynthates, they account for most of the uptake of dissolved inorganic nitrogen. While the uptake of NH_4^+ by the coral host and its symbiotic partners is a well-known process, NO_3^- assimilation is poorly studied. Coral hosts are unable to reduce nitrate as they lack the necessary enzymes, whereas Symbiodiniaceae have been shown to express the enzyme nitrate reductase (NR). However, the evidence supporting the active reduction of nitrate by the symbiotic algae during symbiosis is scarce and equivocal. Rigorous studies on nitrate assimilation by Symbiodiniaceae are lacking yet essential for the understanding of coral holobiont functioning. We have previously shown that the expression and regulation of NR in free-living Symbiodiniaceae of two different strains is a dynamic and reversible process impacted by NO_3^- and NH_4^+ concentrations. In particular, we noted the active degradation of NR in the presence of NH_4^+. NR has never been identified in *in hospite* coral symbionts. We investigated the expression of NR in Symbiodiniaceae during symbiosis. For this purpose, different coral species were depleted in nitrogen before they were exposed to an enrichment in NO_3^-. Expression of NR in the symbionts was investigated using western blotting and qRT-PCR. In addition, freshly isolated symbionts (FIS) from corals were placed in incubation with NO_3^- following their extraction from coral tissues and the expression of NR was investigated over time. This was performed in order to compare the ability of Symbiodiniaceae to express this enzyme *in hospite* versus *ex hospite*. This study aimed at deciphering the functioning of an essential enzyme involved in coral nutrition, shedding a new light and raising new questions on the process of inorganic nitrogen assimilation by the holobiont.

Oral
A-1930

Fluorescent host pigments as indicators of nutrient stress in symbiotic corals

Wiedenmann, J.[1], Bollati, E.[1], D'Angelo, C.[1], Alderdice, R.[1], Ziegler, M.[2], Pratchett, M.[3]
[1]University of Southampton, Coral Reef Laboratory, Southampton, United Kingdom
[2]Justus Liebig University, Systematics & Biodiversity Lab, Giessen, Germany
[3]James Cook University, Australian Research Council Centre of Excellence for Coral Reef Studies, Townsville, Australia

joerg.wiedenmann[at]noc.soton.ac.uk

Abstract

Over the past decades, coral bleaching has been observed with increasing frequency across the globe during high temperature anomalies. However, bleaching is often patchy and under comparable levels of heat stress, the severity of bleaching responses shows considerable regional differences. Under certain conditions, bleaching corals do not turn white, but develop a stunning display of fluorescent colours. Recent research has established that not only the over-enrichment of the reef waters with dissolved inorganic nutrients is harmful for corals but that also nutrient depletion strongly reduces their stress tolerance. Specifically, it was experimentally shown that in the absence of a basic nutrient supply, corals become significantly more susceptible to heat and light stress-induced bleaching. This presentation will introduce an optical feedback loop as a mechanism that drives colourful coral bleaching during episodes of mild heat or nutrient stress. Our data indicate that changes in the accumulation of both fluorescent proteins and pink-purple chromoproteins from the family of the green fluorescent protein in the host tissue has a clear potential to identify local environmental stress factors, such as nutrient stress, that can exacerbate the impact of elevated temperatures on symbiotic corals.

Oral
A-1871

Regional gradients in upwelling drive tropical island benthic seascapes

Williams, G.[1], Gove, J.[2], Fox, M.[3], Davies, A.[4], Green, M.[1], Turner, J.[1]
[1]Bangor University, School of Ocean Sciences, Anglesey, United Kingdom
[2]NOAA, Honolulu, United States
[3]King Abdullah University of Science and Technology (KAUST), Division of Biological and Environmental Science and Engineering, Thuwal, Saudi Arabia
[4]University of Rhode Island, Graduate School of Oceanography, Narragansett, United States

g.j.williams[at]bangor.ac.uk

Abstract

All water in the ocean is connected and moving. Depth gradients around islands affect, amplify and dissipate these surface and sub-surface currents and waves, which can originate locally or from 1000's of km away and drive ecosystem patterns and processes. Disentangling local and regional physical drivers of coral reef community structure has proved challenging. Interactions between reef communities and the surrounding ocean are complex and confounded by human activities. Here we combine data from several uninhabited Pacific and Indian Ocean islands over a 13-year period to create a synoptic view of how intra-island gradients in upwelling structure coral reef seascapes. We show that benthic communities display pronounced horizontal zonation across scales (100s m to km extents) across numerous geographies in response to gradients in upwelling. We further show that patterns of upwelling across space and time are strongly reflected within the feeding ecology and physiology of numerous reef-dwelling organisms, in particular the trophic ecology of reef-building corals. Our findings demonstrate that regional patterns in physical processes like internal wave activity set natural bounds on upwelling, the delivery of energetic subsidies, and reef community structure and function at intra-island scales. Quantifying the drivers of reef structure and their interactions across scales is key to identifying the natural carrying capacity of reefs and to what degree they can be manipulated and managed.

Poster
A-1548

Coral holobiont functioning under environmental change: Determining the drivers of coral-associated denitrification

Hill, C. E. L.[1], El-Khaled, Y. C.[1], Garcias-Bonet, N.[2], Bonacker, V. A.[1], Hott, L.[1], Fox, M. D.[2], Carvalho, S.[2], Peixoto, R. S.[2], Wild, C.[1], Tilstra, A.[1]
[1]University of Bremen, Marine Ecology, Bremen, Germany
[2]King Abdullah University of Science and Technology, Red Sea Research Center, Thuwal, Saudi Arabia

chill[at]uni-bremen.de

Abstract

Nitrogen (N) plays an intrinsic role in the production of biomass in coral reef environments. In this context, coral reef's main habitat builders, hard corals, have evolved strategies to exploit N whenever possible i.e., via N_2 fixation of associated microbes, enabling their survival and enormous productivity in oligotrophic waters. Despite the value of N for the coral, an N-limited state is required for the coral host to maintain a symbiotic relationship with its symbiotic partners (Symbiodiniaceae). Natural seasonal fluctuations and various anthropogenic activities, such as aquaculture or untreated wastewater disposal, expose coral holobionts to elevated nutrient concentrations that can threaten their health. Recently, novel research identified specific microbes -namely denitrifiers- that help to alleviate the coral from excess N. Yet, detailed knowledge about coral-associated denitrification is lacking. To fill this gap, we firstly aim to understand the extent to which denitrification is limited by the dietary mode of the coral holobiont. We hypothesise that autotrophic corals will exhibit higher denitrification than those that are more heterotrophic, as similarly to N-fixing microbes, denitrifiers may rely on photosynthates released by the coral host. Secondly, we aim to investigate how these differences in dietary mode affect denitrification throughout seasonal nutrient fluctuations, and predict that autotrophic coral holobionts will display the most variable response to seasonal change. Thirdly, we aim to identify potential thresholds at which opposing pathways -namely N_2 fixation and denitrification- are affected under thermal stress and N-eutrophication. We hypothesise that denitrification of coral holobionts increases under these conditions to alleviate the coral holobiont from excess N, as formerly found. To carry out this research, we will use an interdisciplinary set of tools, combining molecular, physiological, and biogeochemical approaches to thoroughly investigate the abovementioned research aims. We will present the first results of this project at ICRS 2022. Our findings will identify coral species particularly resilient or vulnerable to environmental stressors such as ocean warming or eutrophication. This research will also contribute towards a better understanding of the coral microbiome which is a critical step towards the development of new and effective conservation strategies such as probiotic treatments, preserving reefs of today.

Virtual
Oral
A-1317

Impact of nitrogen (N) and phosphorus (P) enrichment and skewed N:P stoichiometry on the skeletal formation & microstructure of symbiotic reef corals

Buckingham, M.[1], D'Angelo, C.[1], Chalk, T.[2], Foster, G.[1], Johnson, K.[3], Connelly, Z.[4], Olla, C.[4], Saeed, M.[4], Wiedenmann, J.[1]
[1]University of Southampton, School of Ocean & Earth Sciences, Southampton, United Kingdom
[2]University of Southampton, School of Ocean & Earth Sciences, United Kingdom
[3]Natural History Museum, London, United Kingdom
[4]University of Southampton, Southampton, United Kingdom

mcb1n17[at]soton.ac.uk

Abstract

Reported divergent responses of coral growth and skeletal microstructure to the nutrient environment complicate knowledge-based management of water quality in coral reefs. By re-evaluating published results considering the taxonomy of the studied corals and the N:P stoichiometry of their nutrient environment, we could resolve some of the major apparent contradictions. Our analysis suggests that Acroporids behave differently to several other common genera and show distinct responses to specific nutrient treatments. We hypothesised that both, the concentrations of dissolved inorganic N and P in the water and their stoichiometry shape skeletal growth and microstructure. We tested this hypothesis by exposing *Acropora polystoma* fragments to four nutrient treatments for >10 weeks: high nitrate / high phosphate (HNHP), high nitrate / low phosphate (HNLP), low nitrate / high phosphate (LNHP) and low nitrate / low phosphate (LNLP). HNHP corals retained high zooxanthellae densities and their linear extension and calcification rates were up to ten times higher than in the other treatments. HNLP and LNLP corals bleached through loss of symbionts. The photochemical efficiency (Fv/Fm) of residual symbionts in HNLP corals was significantly reduced, indicating P-starvation. Micro-computed tomography (μCT) of the skeletal microstructure revealed that reduced linear extension in nutrient limited or nutrient starved conditions (HNLP, LNHP, LNLP) was associated with significant thickening of skeletal elements and reduced porosity. These changes can be explained by the strongly reduced linear extension rate in combination with a smaller reduction in the calcification rate. Studies using increased skeletal density as a proxy for past thermal bleaching events should consider that such an increase in density may also be associated with temperature-independent response to the nutrient environment. Furthermore, the taxonomy of corals and seawater N:P stoichiometry should be considered when analysing and managing the impacts of nutrient pollution.

Virtual
Oral
A-1506

Nutrientscape ecology: An integrative approach for studying nutrient connectivity in tropical coastal environments

Palola, P.[1], Pittman, S.[1], Malhi, Y.[1], Collin, A.[2], Wedding, L.[1]
[1]University of Oxford, School of Geography and the Environment, Oxford, United Kingdom
[2]Ecole Pratiques des Hautes Etudes (EPHE) - Paris Sciences Lettres, Coastal Geoecology Lab (CGeL), Dinard, France

pirta.palola[at]ouce.ox.ac.uk

Abstract

Nutrient connectivity refers to the flow of nutrients from one location to another. This connectivity plays a critical role in shaping coral reef biogenic structure, community composition, ecological functioning and resilience. Consequently, managing nutrient connectivity across the land-sea interface has been identified as a promising strategy for enhancing coral reef resilience to climate change. However, the development of nutrient connectivity management is in many cases hindered by gaps in knowledge about the spatial-temporal patterns of nutrient flows and their ecological significance. In our systematic literature review, we examined the state of science in nutrient connectivity studies in tropical coastal environments with coral reef habitat. We focussed on 1) the main methodological approaches and conceptual frameworks applied in the study of nutrient connectivity; and 2) the current state of knowledge about the effects of nutrient connectivity on coral reef ecosystems.

Our results show that the majority of nutrient connectivity studies are based on traditional field surveys, typically sampling at a single spatial scale within a narrow temporal window forming a collection of snapshots of the system's patterns and processes. Additionally, we found that the ecological consequences of nutrient connectivity may be positive or negative depending on the source and magnitude of the nutrient flow. Underpinned with evidence from the literature, we argue that the application of landscape ecology to the study of coastal nutrient connectivity offers fertile grounds for addressing the knowledge gaps identified and guiding the development of new multi-scale research approaches. This argument is particularly timely, as technological advances in remote sensing and field monitoring present new opportunities to study nutrient connectivity at multiple scales and at high spatial and temporal resolutions. To operationalise the application of landscape ecology in the study of nutrient connectivity, we present the case for introducing the novel nutrientscape concept. The nutrientscape concept integrates the disciplines of landscape ecology, social-ecological systems thinking, and aquatic biochemistry. The interdisciplinary, multi-scale, and spatially explicit study of the coastal nutrientscape could help inform the management of nutrient connectivity and thereby contribute to local efforts to manage human impacts and increase coral reef resilience to climate change.

Virtual
Poster
A-1397

The influence of temperature and food concentration on heterotrophic feeding of tropical soft corals and scleractinian corals.

Lange, K., Reynaud, S., Ferrier Pagès, C.
Centre Scientifique de Monaco, Coral ecology & ecophysiology, Monaco, Monaco

kiara.lange[at]pontapreta.com

Abstract

A switch from scleractinian corals to octocorals has been frequently observed in disturbed environments. As nutrition plays an important role in the distribution and abundance of communities within an ecosystem, a difference in nutritional strategy could explain this phenomenon. While most coral research has focused on scleractinian corals and much knowledge has been accumulated on their nutritional strategies, there are important gaps in our knowledge of soft coral physiology and nutrition. For example, their heterotrophic diet on dissolved organic matter (DOM) assimilation is poorly understood, and the impact of environmental stresses such as temperature has yet to be investigated.
In this study we focused on two soft coral species: *Sarcophyton glaucum* and *Lobophyton sp.* on which we tested their capacity to take up DOM. The experiment was also carried out on two scleractinian species: *Turbinaria reniformis* and *Stylophora pistillata*. This comparison between soft and hard corals will allow us to determine if soft corals are more heterotrophic than hard corals, which could explain why octocorals replace scleractinians in some disturbed environments. To this end, nubbins of each species were individually incubated at different DOM concentrations. The organic carbon and nitrogen fluxes were then established by depletion using a Shimadzu TOC analyser. Experiments were carried out with the four coral species at normal temperature (25°C) and under thermal stress (30°C). The experiments are currently ongoing and we look forward to presenting our full results at the symposium.

Session 3G - Budgetary breakdown: Can reef geo-ecological functions persist in the Anthropocene?

Conceptualized by: **Ines D. Lange**[1], **Tyler Cyronak**[2], **Lauren T. Toth**[3], **Coulson Lantz**[4], **Lorenzo Alvarez-Filip**[5]

[1] University of Exeter (Exeter, UK)
[2] Nova Southeastern University (Dania Beach, FL, USA)
[3] U.S. Geological Survey (St. Petersburg, FL, USA)
[4] Southern Cross University (Lismore, Australia)
[5] Universidad Nacional Autónoma de México (Puerto Morelos, Mexico)

Chaired by: **Ines D. Lange**[1], **Lorenzo Alvarez-Filip**[5]

Oral
A-2211

Climate-driven declines in the physical structure of isolated coral reefs

Bayley, D.
University College London, London, United Kingdom

daniel.bayley.14[at]alumni.ucl.ac.uk

Abstract

The 2015-2016 global coral bleaching episode caused widespread mortality in tropical reefs and alterations to the abundance and diversity of coral assemblages. Coral mortality can be followed by rapid bio-physical erosion of coral skeletons, resulting in simplified reef structure, and a loss of habitat. We use 'Structure from Motion' photogrammetry to quantify changes in the three-dimensional (3D) structure of isolated shallow tropical reefs in the central Indian Ocean. These reefs experience negligible direct anthropogenic pressures, allowing us to disentangle the effects of the prolonged heat anomaly from the normal confounding human impacts. We find significant declines in 3D rugosity (i.e. surface area m-2), fractal dimension, substrate height, and volume on medium and high wave-exposure reefs from 2015-2019. Low wave-exposure seaward reefs and lagoons meanwhile experienced no significant complexity change and increased reef height. Reef community composition preceding heat stress strongly indicated the post-disturbance rate of decline. 3D rugosity of reefs dominated by heat-sensitive branching or tabular morphology species declined fastest. Lagoon communities, dominated by massive / sub-massive morphologies and heterotrophic feeders, were most resilient to elevated temperatures. We demonstrate that temperature anomalies alone are capable of instigating rapid reductions in the structural complexity, substrate volume and function of reefs.

Oral
A-1626

Global patterns and drivers of reef fish carbonate excretion

Ghilardi, M.[1, 2], McLean, M.[3], Salter, M. A.[4], Parravicini, V.[5, 6], Ferse, S. C. A.[1, 2], Rixen, T.[7], Wild, C.[2], Perry, C. T.[4], Wilson, R. W.[8], Stuart-Smith, R. D.[9], Edgar, G. J.[9], Mouillot, D.[10], Bejarano, S.[1]
[1]Leibniz Centre for Tropical Marine Research (ZMT), Ecology, Bremen, Germany
[2]University of Bremen, Marine Ecology, Bremen, Germany
[3]Dalhousie University, Biology, Halifax, Canada
[4]University of Exeter, Geography, Exeter, United Kingdom
[5]CRIOBE, USR 3278 EPHE-CNRS-UPVD, Université de Perpignan, Perpignan, France
[6]Institut Universitaire de France, Paris, France
[7]Leibniz Centre for Tropical Marine Research (ZMT), Biogeochemistry and Geology, Bremen, Germany
[8]University of Exeter, Biosciences, Exeter, United Kingdom
[9]Institute for Marine and Antarctic Studies, University of Tasmania, Hobart, Australia
[10]MARBEC, Université de Montpellier, CNRS, Ifremer, IRD, Montpellier, France

mattia.ghilardi[at]leibniz-zmt.de

Abstract

The carbon cycle is vital to sustaining life on Earth and regulating greenhouse gases. Identifying “missing” carbon sinks and sources is particularly urgent in the Anthropocene. In this context, understanding the role of marine fish in the inorganic carbon cycle is key. Marine teleosts produce and excrete carbonate precipitates at high rates (in reef settings, at least up to 105 g m^{-2} yr^{-1}), thereby removing alkalinity from surface waters and contributing CO_2. If these carbonates are buried or sink and dissolve at depth, this removal of surface water alkalinity becomes a long-term effect. However, if they dissolve in surface waters, the process will have zero net effect. The mineralogy and composition of fish carbonates suggest they are more soluble than many marine carbonates, but their fate once excreted remains unresolved, preventing the estimation of their net impact on seawater chemistry. In response to the recent call for ecosystem function to be at the heart of managing ecosystem futures, investigating the drivers of fish carbonate excretion and its significance on a global scale is crucial.
Here, we focus on reef fishes and investigate the drivers of species- and assemblage-level carbonate excretion and compile carbonate excretion rate data from 85 species and 35 families collected across biogeographic regions. Using a Bayesian framework we tested whether species’ traits, environmental variables, and taxonomic identity are significant drivers of the excretion rates and composition of excreted carbonates. Then, we predicted the average excretion rates and composition of >2000 fish assemblages across >1400 shallow tropical reefs around the world. Lastly, we investigated the environmental and socio-economic drivers of the assemblage-level predictions within a causal framework.
We reveal that fish carbonate excretion rate is mainly driven by body mass and relative intestinal length, while mineralogical composition is taxonomically conserved but also controlled by intestinal length and temperature. Our global maps of carbonate excretion highlight functional hotspots with the highest reef fish contributions to the inorganic carbon cycle. These are found where fish assemblages present high biomass, small size, and high mean trophic level. Ultimately, by identifying key socio-economic drivers of fish carbonate excretion, we provide fundamental knowledge to support local and global decision-making processes aimed at safeguarding ecosystem function.

Oral
A-1881

Two decades of carbonate budget change on Mexican Caribbean reefs: are these reefs being locked into low net budget states?

Molina-Hernandez, A.[1, 2], González-Barrios, J.[2], Perry, C. T.[3], Álvarez-Filip, L.[2]
[1]Posgrado en Ciencias del Mar y Limnología, Universidad Nacional Autónoma de México, Av. Ciudad Universitaria 3000, C.P. 04510, Coyoacán, Ciudad de México, Mexico
[2]Biodiversity and Reef Conservation Laboratory, Unidad Académica de Sistemas Arrecifales, Instituto de Ciencias del Mar y Limnología, Universidad Nacional Autónoma de México, Puerto Morelos, Mexico
[3]College of Life and Environmental Sciences, University of Exeter, Exeter EX4 4RJ, United Kingdom

anamlhz[at]gmail.com

Abstract

The physical persistence and ecological functionality of coral reefs are largely defined by the capacity of reef-building corals, and other calcifiers, to accumulate framework carbonate at a higher rate than it is removed by erosional processes. Nonetheless, the disproportionate decline in the cover of primary reef-building species across the Western Atlantic has resulted in suboptimal carbonate budgets on many reefs. However, our understanding of temporal trajectories of these carbonates budgets is limited, in part because of a lack of historical data on the bioerosion side of the equation. Using data from published and unpublished sources along with detailed information on the main calcifiers and bioeroders for 34 reef sites we explore how carbonate production and bioerosion rates have changed in the last two decades in the Mexican Caribbean. For each site, carbonate budgets were estimated following the ReefBudget census-based approach. Temporal trends of change for bioerosion, calcification and the overall carbonate budget were explored by means of generalized linear models and annual rates of change. Results revealed that carbonate budgets on Mexican Caribbean reefs remained relatively low (under 2 Kg/m-2/yr-1) over the study period (1999-2018) but showed a small but significant increase in the net production during the last decade. This is the result of the maintenance in the abundance and cover of non-framework building corals, and due to a gradual decline in net bioerosion, driven by reduced parrotfish abundance (by up to 60 %) from sites where extractive fishing practices are still allowed. Surprisingly, the reduction of large-sized parrotfish could be acting as an ecological buffer in the decrease of net production in reefs where gross production has increased little or even decreased. However, the absence of these parrotfishes is likely to lock the system into low-budget states as they are also key herbivores that favor reef resilience. Our findings highlight the importance of the ecological-historical context in the interpretation of current carbonate values, especially when oriented to management and conservation efforts and environmental policy.

Oral
A-1420

Where's the sediment in the carbonate budget calculation? : constraining reef-derived sediment generation rates for budget estimates.

Perry, C.
University of Exeter, Exeter, United Kingdom

c.perry[at]exeter.ac.uk

Abstract

Rapidly growing interest in the question of whether reefs can maintain their physical structures and continue to grow at rates that match sea-level rise has led to a wealth of recent carbonate budget studies. However, one key but very poorly quantified element of these carbonate budget studies, is the production and accumulation of reef-derived sediment. This sedimentary carbonate, which derives either directly from the calcareous shelly remains of benthic reef taxa (e.g., molluscs, foraminifera), from the breakdown of calcareous algae (e.g., the calcareous green algae *Halimeda* spp.), and from the by-products of bioerosion (e.g., from urchins, parrotfish, endolithic sponges) is important for three reasons: i) it is a volumetrically important component of the accumulating structure of reefs - and thus directly relevant to measure of reef budgets and growth potential; ii) it comprises the dominant substrate type across most lagoon environments; and iii) it is a critically important source for proximal sediment-dominated beaches and islands. Whilst the taxa and processes that contribute sediment-grade carbonate are well understood, and it is acknowledged that sediment inputs vary with habitat type (and as reef ecology changes), there is little quantitative data on the rates at which different types of carbonate sediment are produced, or the grades (size fractions) of sediment generated. We also have limited data on how the wider suite of ecologically-driven sediment production, cycling and transport processes vary within and between reef systems. This talk considers our current state of knowledge about the processes associated with reef sediment production. An emerging census-based methodology will be introduced and an example of its application from central Indian Ocean sites discussed. Consideration will also be given to how we may better understand the role of reef taxa in influencing sediment generation and cycling – and recent initial attempts to explore these ideas at reef scales discussed.

Oral
A-1435

Incorporating site-specific climate projections and coral adaptive capacity into future trajectories of reef habitat persistence on a Floridian reef

Webb, A.[1], van Hooidonk, R.[1], Besemer, N.[1], Kolodziej, G.[1], Manzello, D.[2], Enochs, I.[3]
[1]University of Miami Cooperative Institute for Marine and Atmospheric Studies, Ocean Chemistry and Ecosystems Division, Miami, United States
[2]Coral Reef Watch, Center for Satellite Applications and Research, Satellite Oceanography & Climate Division, College Park, United States
[3]NOAA Atlantic Oceanographic and Meteorological Laboratory, Ocean Chemistry and Ecosystems Division, Miami, United States

alice.webb[at]noaa.gov

Abstract

Provision of a structural habitat through carbonate deposition is one of the keystones of coral reef functioning. For reef framework to persist, calcium carbonate production by corals and other calcifiers needs to outpace loss due to physical, chemical, and biological erosion. This balance is both delicate and dynamic, and is currently threatened by the effects of ocean warming and acidification. Although the protection and recovery of ecosystem function are at the center of most restoration and conservation programs, decision makers are limited by the lack of predictive tools to forecast habitat persistence under different global change scenarios. To address this, we developed a modeling approach, based on carbonate budgets, that ties species-specific responses to site-specific environmental change using the latest generation of climate models projections (CMIP6). Additionally, we examine the potential effects of coral thermal adaptation by increasing the bleaching threshold in degree increments up to 2°C above the maximum monthly mean. We applied this model to Cheeca Rocks reef, an outlier in the Florida Keys in terms of high coral cover and one of seven reefs targeted in the Mission: Iconic Reefs restoration project. Net carbonate production at Cheeca Rocks projected in this study declined through time in every scenario, regardless of climatology or coral adaptative capacity. The rate of decline, however, was dependent on the scenario ranging from a net erosional state by 2029 to a maintenance of framework accretion until 2100 and beyond. These projections suggest that the reef at Cheeca Rocks will not be able to retain accretion potential rates that keep pace with future SLR projections, even under a decreased emissions scenario coupled with increased adaptive capacity. Reef habitat persistence remains ultimately dependent on the rate and extent of climate change. Increases in thermal tolerance of corals, however, may delay the onset of mass mortalities in time for low CO_2 emissions to be implemented and management interventions to become effective.

Poster
A-1788

Skeletal dissolution: The other side of the Stony Coral Tissue Loss Disease

Medellín Maldonado, F.[1], Cruz-Ortega, I. A.[2], Carricart-Ganivet, J. P.[3], López-Pérez, A. R.[4], Alvarez-Filip, L.[5]
[1]Universidad Nacional Autónoma de México, Posgrado en Ciencias Del Mar Y Limnología, ICML, UNAM, Puerto Morelos, Mexico
[2]Universidad Nacional Autónoma de México, Posgrado De Ciencias Del Mar Y Limnología, Puerto Morelos, Mexico
[3]Universidad Nacional Autónoma de México., Instituto de Ciencias del Mar y Limnología, Puerto Morelos, Mexico
[4]Universidad Autónoma Metropolitana,, Hidrobiología, Ciudad de México, Mexico
[5]Universidad Nacional Autónoma de México, Instituto de Ciencias del Mar y Limnología, Puerto Morelos, Mexico

francisco.medellin25[at]gmail.com

Abstract

It is expected that the massive mortality events of corals in reefs around the world will affect the amount of carbonates that are contributed by these organisms. However, it is also likely that erosion processes increase in recently dead corals, accelerating and increasing CaCO3 loss. Here, we set out to estimate rates of chemical and biological dissolution of newly dead colonies of the species most affected by Stony Coral Tissue Loss Disease (SCTLD) outbreak, caused a high mortality rate in coral populations in the Caribbean. Core samples were obtained from different colonies, when they were alive (2015) and after colonies were completely dead due to SCTLD (2019-2020). Core samples were X-ray scanned to generate porosity and optical densitometry analyses to address changes in skeletal mass. Our results reveal a significant loss of mass in fragments from dead colonies. Endolithic communities were observed within the dead skeletons, suggesting that the very rapid tissue mortality caused by SCTLD facilitates the rapid colonization of endolithic organisms that through their metabolic activity trigger accelerated dissolution in dead corals. Ultimately, our findings demonstrate that these processes may cause drastic CaCO3 losses when the impact is scaled to large geographic areas.

Virtual
Oral
A-2100

Reef functioning of coral systems from the southern Mexican Pacific

Cabral-Tena, R.[1], López-Pérez, A.[2], Alvarez-Filip, L.[3], González-Barrios, F. J.[1, 3], Calderon-Aguilera, L.[1]
[1]CICESE, Ensenada, Mexico
[2]UAM-Iztapalapa, Mexico City, Mexico
[3]UNAM, Puerto Morelos, Mexico

rcabral[at]cicese.mx

Abstract

Functional trait-based ecology can provide critical information regarding the impacts of disturbances on different communities. Every reef coral species has an ecological functional role in the reef ecosystem; for example, growth rates and structural complexity of corals define the reef accretion process and habitat provision. Coral functions in the ecosystem may be redundant or shared by one or more species, so coral reef functioning depends on coral life-history strategies, morphological and physiological attributes and their tolerance to disturbance, which may lead to differential reef functional trajectories. For example, the loss of key-reef building genera in the Caribbean has compromised ecosystem functionality contrary to what has been observed in highly diverse coral communities (i.e. Indo-Pacific) due to inherent functional redundancy, yet the functioning of reefs from depauperate areas with low species richness and community calcification (e.g. Eastern Tropical Pacific) has not been fully described. Here, we assess the reef functioning potential of 11 reef sites from the southern Mexican Pacific (Huatulco, Oaxaca; 15° N, 96° W) through the implementation of the Reef Functional Index (RFI) which considers the calcification rate and structural complexity of each species to generate a species-specific Functional Coefficient (FC). The RFI is obtained through the summation of the product of the abundance (live coral cover) and the FC of each species for the study site. RFI ranges from zero (low functioning site) to one (high functioning site). Average coral cover of the area was 48.5 ±18.09% and average RFI was 0.71 ±0.01, which are higher than recent estimations of both parameters in the Caribbean (14.84% ±7.14% and 0.41 ±0.07 respectively). The relatively high functioning potential of the southern Mexican Pacific reefs is explained by the high dominance of *Pocillopora* spp. (more than 90% of relative abundance) in all sites, which is the group species with the highest FC in the area. Nevertheless, if pocilloporids were replaced by massive species as consequence of an environmental or human induced pressure (as seen in the Caribbean reefs due to the extensive loss of acroporids), RFI of the Huatulco area would drop to 0.31 ±0.03% (~60% loss). Our results highlight the importance of *Pocillopora* spp. on reef framework construction in the ETP, thus, management efforts should prioritize the protection of this genus.

Session 4A - Open Session: Microbial ecology, holobionts and model organisms

Conceptualized by: **Christian R. Voolstra**[1], **Peter J. Schupp**[2], **Rebecca Vega Thurber**[3], **Tilmann Harder** [4]
[1] University of Konstanz (Konstanz, Germany)
[2] University of Oldenburg (Oldenburg, Germany)
[3] Oregon State University (Corvallis, OR, USA)
[4] University of Bremen (Bremen, Germany)

Chaired by: **Christian R. Voolstra**[1], **Peter J. Schupp**[2]

Oral
A-2226

Cryptic competition among coral symbionts

Baker, D., McIlroy, S., Wong, J.
The University of Hong Kong, Hong Kong SAR, China

dmbaker[at]hku.hk

Abstract

Coral fitness is strongly influenced by the identity and relative abundance of the Symbiodineaceae species they harbor, which influence host nutrient acquisition, growth, and stress tolerance. Yet the structuring mechanisms by which symbiodinian communities are established and maintained, like many microbial communities, are poorly understood, especially the potential role of competition among microbial genotypes. To understand how species specific nutrient assimilation was affected by the co-occurrence of potentially competing species, we employed a pulse of stable isotope tracers of both carbon and nitrogen for both isolated (C1 only and D1a only) and mixed (C1 and D1a co-culture) cultures. We developed a new method in which genotype specific fluorescent labeling and flow cytometry were used to sort species out from the co-culture prior to stable isotope analyses. This revealed large, species specific changes in both carbon and nitrogen assimilation of both Cladocopium (C1) and Durusdinium (D1a) when in competition for nutrient substrates relative to growth in isolation, which would likely have been misinterpreted by bulk analyses. While these studies were done in culture, it suggests that competition among symbionts for host resources may be important structuring factor of genetic diversity within the coral holobiont.

Oral
A-1443

Evaluating the impacts of water quality on disease in the endangered coral species, Acropora palmata, in the U.S. Virgin Islands

Bestrom, N.[1], Apprill, A.[2], Trotz, M.[3], Brandt, M.[4]
[1]University of the Virgin Islands, St. Thomas, U.S. Virgin Islands
[2]Woods Hole Oceanographic Institution, Woods Hole, United States
[3]University of South Florida, Tampa Bay, United States
[4]University of the Virgin Islands, St Thomas, United States

bestromng[at]gmail.com

Abstract

Coastal runoff is known to inundate near-shore marine environments with inorganic nutrients, suspended solids, and fecal indicator bacteria, causing increases in algae, smothering of corals, and decreased coral reef health. High levels of fecal coliform bacteria in marine systems, most often due to poor management of onsite wastewater treatment systems, create human health risks and cause disease in marine organisms. In the U.S. Virgin Islands, most of the population relies on either leaky septic or inadequate centralized wastewater systems, and high levels of fecal indicator bacteria have been found in reef-level seawater studies. Acroporid seratiosis, a disease affecting the endangered Caribbean coral species, *Acropora palmata*, has been linked to the presence of the human fecal bacterium, *Serratia marcescens*, in the Florida Keys. However, fecal indicator bacteria levels have not been explored in *A. palmata* habitats, nor has the link between *S. marcescens* and acroporid disease been established in the U.S. Virgin Islands. Therefore, this study assessed fecal indicator bacteria levels through water sample collections at 7 *A. palmata* demographic monitoring locations around the northern U.S. Virgin Islands. Additionally, coral mucus samples from both healthy and diseased *A. palmata* and healthy *Porites astreoides* colonies, as well as sediment and seawater samples were collected and evaluated to determine microbial community composition within the *A. palmata* environment and between healthy and diseased *A. palmata* colonies. While data analysis is still underway, we hypothesize a positive relationship between the inundation of fecal indicator bacteria into reef environments and disease lesions in *A. palmata.* If this link is established, it will allow for disease-sewage linkages to be more readily identified throughout the Caribbean and increase mitigation of sewage runoff to minimize losses of this already endangered species.

Oral
A-1519

Beyond the zooxanthellae, a multifaceted approach to explore coral associated microeukaryotes

Bonacolta, A.[1, 2], del Campo, J.[1, 2]
[1]Institut de Biologia Evolutiva (CSIC-Universitat Pompeu Fabra), Barcelona, Catalonia, Spain
[2]Rosenstiel School of Marine and Atmospheric Science, University of Miami, Department of Marine Biology and Ecology, Miami, Florida, United States

amb195[at]miami.edu

Abstract

Microbiomes associated with animals have a strong influence on host evolution, physiology and ecological functions. Unlike the study of bacterial microbiomes, the study of the microeukaryotes associated with animals has largely been limited to visual identification or molecular targeting of particular groups. Among corals, the most well-known member of the holobiont, apart from the coral itself, is the zooxanthellae, which is indeed a microeukaryote. However, corals are not an exception and we know little about the rest of the microeukaryotes that are part of their microbiome. In recent years we have learned more about microeukaryotic members of the holobiont such as the green algae *Ostreobium* and the apicomplexan corallicollids, but there are many others that have been observed such as labyrinthulids, ciliates or fungi that we know little about and there are many others that have never been reported. Using multiple methodologies such as metabarcoding, microscopy, and single-cell transcriptomics, we have explored the microeukaryotic diversity associated with zooxanthellate and azooxanthellate corals from warm and cold environments. Our data confirms the presence of some of the previously described holobiont microeukaryotes and also reveals the presence of many others such as red algae and the parasitic syndiniales. We observed that the eukaryome varies between coral families, depends on the health status of the host, and can be a predictor of heat tolerance in certain species. We have also started to unravel the complex transcriptomic response of the holobiont under heat-stress, revealing the distinct gene expression of individual coral cells as well as that of the various microeukaryotic symbionts contributing to the physiology of the holobiont. Our research on coral associated microeukaryotes contributes to a better and more comprehensive understanding of the holobiont and our methods will help to establish the basis to fully incorporate microeukaryotes in coral microbiome studies.

Oral
A-1605

Spatiotemporal mapping of Orbicella faveolata algal symbiont communities and their associations with SCTLD susceptibility

Buckley, S.[1], Walker, B.[1], Dennison, C.[2], Baker, A.[2]
[1]NOVA Southeastern University, Halmos College of Arts and Sciences, Dania Beach, United States
[2]University of Miami, Rosenstiel School of Marine and Atmospheric Science, Miami, United States

sb3061[at]nova.edu

Abstract

Variation in algal symbiont communities (Family Symbiodiniaceae) within individual coral colonies has been attributed to changes in phenotypic traits in some coral species. In the threatened coral species *Orbicella faveolata,* this variation has been documented throughout the Caribbean and is related to critical parameters such as bleaching sensitivity. However, its influence on the susceptibility of colonies (or parts of colonies) to stony coral tissue loss disease (SCTLD) has not yet been studied. Here, we tested whether differences in SCTLD susceptibility among *O. faveolata* colonies along Florida's Coral Reef (FCR) are driven by within-colony spatial mosaics of different Symbiodiniaceae taxa across coral surfaces. By mapping and monitoring the spatial distribution of different Symbiodiniaceae over time we test the hypothesis that the appearance and spread of SCTLD lesions is related to the distribution of algal symbionts. Tissue biopsies were collected from 45 colonies along the FCR and the associated Symbiodiniaceae communities characterized using quantitative PCR. The majority of colonies exclusively associated with *Breviolum* with background amounts of *Cladocopium* and *Durusdinium*. Five colonies that exhibited variation in their Symbiodiniaceae communities were selected for three-dimensional modeling using structure from motion software, and additional biopsies will be taken from these colonies four times per year using mini-transects deployed over the colony. Resulting symbiont layers will be will be mapped via spatial grid in GIS and draped over the 3D model then analyzed using spatial statistics to interpolate spatiotemporal patterns. This novel approach will provide a greater understanding of within-colony variation of algal symbiont communities in Florida *O. faveolata* and help understand patterns of SCTLD severity and spread in this valuable coral population.

Oral
A-1468

Microbiome of the pillar coral Dendrogyra cylindrus is predominantly composed of unclassified and endosymbiotic bacteria

Cauvin, A.[1], Carne, L.[2], Marhaver, K.[3], Vermeij, M.[3, 4], Locatelli, N.[5], Baums, I.[5], Paul, V. J.[6], Meyer, J. L.[7]
[1]University of Florida, School of Natural Resources and Environment, Gainesville, United States
[2]Fragments of Hope, Placencia Village, Belize
[3]Caribbean Research and Management of Biodiversity Foundation, Piscaderabaai, Curaçao
[4]University of Amsterdam, Department of Freshwater and Marine Ecology, Amsterdam, Netherlands
[5]Pennsylvania State University, Department of Biology, University Park, United States
[6]Smithsonian Marine Station, Fort Pierce, United States
[7]University of Florida, Department of Soil and Water Sciences, Gainesville, United States

acauvin[at]ufl.edu

Abstract

The pillar coral *Dendrogyra cylindrus* is a taxonomically and physiologically distinct coral species on Caribbean reefs and has faced regional losses primarily due to recurrent disturbances such as thermal stress and disease. Its recovery has been further limited by the lack of sexual recruits. *D. cylindrus* is highly susceptible to stony coral tissue loss disease (SCTLD) and the 2014 outbreak on Florida's Coral Reef has resulted in significant declines in Florida's population of pillar corals. The coral microbiome can impact the health and disease resistance of coral colonies, yet we do not know what constitutes a normal or healthy microbiome in *D. cylindrus*. This information is essential for comparisons of healthy versus diseased specimens in pathogen identification studies and can be applied in restoration efforts as a coral health metric. Therefore, the goal of this study was to characterize the microbiomes of *D. cylindrus* colonies ahead of the disease front. Healthy colonies (n=104) were sampled from two regions (Curacao and Belize) unaffected by SCTLD at the time of sampling and characterized with 16S rRNA amplicon libraries. A total of 7,559 amplicon sequence variants (ASVs) were identified and taxonomy was assigned with the SILVA v. 138.1 database. The most prevalent members of the *D. cylindrus* microbial community are bacterial groups that have previously been associated with cnidarian microbiomes, including *Endozoicomonas* and an unclassified bacterium that closely matches a sequence from the starlet sea anemone *Nematostella vectensis*. Furthermore, geographic region may play a role in structuring the community of the *D. cylindrus* microbiome, with corals from Curacao displaying higher levels of the endosymbionts *Endozoicomonas* and *Spiroplasma* and corals from Belize harboring higher levels of an unclassified proteobacterium previously found in corals. *Spiroplasma*, which is associated with host physiological changes such as male-killing and parasite defense in insects, was detected in 61% of Curacao samples, but in only one of 22 Belize samples. The results of this study provide crucial insight into the understudied microbiome of *D. cylindrus* and may be applied to pathogen identification and coral restoration efforts. Additionally, these results highlight the need for improved reference databases that incorporate coral microbiomes.

Oral
A-1539

Visualization of viral biomarkers in Symbiodiniaceace associated with stony coral tissue loss disease-affected and apparently healthy corals

Coy, S.[1], Utama, B.[2], Deshmukh, H.[2], Lévesque, A.[3, 4], Zeigler Allen, L.[3, 4], Nagasaki, K.[5], Spurlin, J.[1], Kiryu, Y.[6], Perry, N.[6], Kim, J.[1], Lwigale, P.[1], Work, T.[7], MS Correa, A.[1]
[1]Rice University, Biosciences, Houston, United States
[2]Rice University, Shared Equipment Authority, Houston, United States
[3]Scripps Institution of Oceanography, Marine Biology Research Division, La Jolla, United States
[4]J. Craig Venter Institute, Microbial and Environmental Genomics, San Diego, United States
[5]Kochi University, Faculty of Science and Technology, Nankoku, Japan
[6]Florida Fish and Wildlife Conservation Commission, Fish and Wildlife Research Institute, St Petersburg, United States
[7]US Geological Survey, Wildlife Health Center Honolulu Field Station, Honolulu, United States

src10[at]rice.edu

Abstract

Stony corals across the Caribbean are being decimated by stony coral tissue loss disease (SCTLD). Although the causative agent of SCTLD is not elucidated, recent histological studies employing transmission electron microscopy (TEM) detected the presence of filamentous virus-like particles inside Symbiodiniaceae cells, the endosymbionts of corals and other marine invertebrates. Yet, due to the similarities between filamentous virus-like-particles and other intracellular structures (*e.g.* condensates) observed in TEM, there is a need to localize true viral molecular signals inside their proposed hosts. Medical advances have leveraged long double-stranded RNA as a biomarker for virus infection; we adapted this to detect viral infections of reef-associated organisms. Specifically, we quantify total RNA virus infection in marine systems using a dsRNA-targeting antibody, super-resolution confocal microscopy, and statistical analysis of microscopy imagery. We validated our approach using cultivated systems of positive-sense, single-stranded RNA viruses (+ssRNA) that infect free-living marine diatoms and dinoflagellates (n=200-300 cells per sample), and demonstrate that dsRNA increases across infection while metrics of cell health (*i.e*. cell swelling, chromosomal integrity, and photosystem health) decrease. Following this validation, we applied our method as a marine disease diagnostic tool to quantify RNA virus infection within two Caribbean coral species affected differentially by SCTLD (*i.e.* high and low susceptibility, n=4 corals per treatment per species). We used replicate histological samples that pair with the 2021 TEM study by Work et al. that identified filamentous VLPs inside Symbiodiniaceae and tested whether dsRNA co-occurred in these tissues. Presence of dsRNA was compared with Symbiodiniaceae cell health between different disease states and coral susceptibility to SCTLD using confocal microscopy paired with spectral detector and linear unmixing module followed by statistical analyses of microscopy imagery. This work represents the first broad molecular-based microscopy approach to visualize eukaryotic cells infected by RNA viruses in marine environments, including coral reefs. This robust method allows qualitative and quantitative assessments of intracellular virus-host dynamics that can be scaled to understand the impacts of viruses on populations, holobionts, and up to ecosystem levels of biological organization.

Oral
A-1051

Determining the appropriate model to develop a ROS and RNS-scavenging bacterial probiotic aimed at mitigating coral thermal stress

Doering, T.[1], Maire, J.[1], Chan, W. Y.[1], Blackall, L. L.[1], van Oppen, M. J. H.[1, 2]
[1]The University of Melbourne, School of Biosciences, Parkville, Australia
[2]Australian Institute of Marine Science, Townsville, Australia

tdoring[at]student.unimelb.edu.au

Abstract

Reef-building corals are threatened by ocean warming which requires interventions that reduce further coral bleaching and mortality. Under the oxidative stress theory of coral bleaching, bacterial probiotics which scavenge reactive oxygen (ROS) or nitrogen species (RNS) are expected to enhance coral thermal resilience. However, bleaching can occur in the dark, and oxidative stress has sometimes been observed to precede the photoinhibition of algal symbionts. Thus, to find an appropriate system for studying the role of ROS and RNS-scavenging in thermal stress, we compared an established coral model, the sea anemone *Exaiptasia diaphana*, with an emerging coral model, the coral *Galaxea fascicularis*. We conducted two studies determining *in vivo* net intracellular ROS (mainly H_2O_2) and RNS (nitric oxide (NO)) in algal symbionts of *E. diaphana* and *G. fascicularis* during a simulated summer heat wave. Since not all net ROS and RNS are detectable due to their short lifetimes, activities of key enzymes that either scavenge ROS or synthesize RNS were also measured to gain insight into the presence of various types of ROS and RNS. From these measurements as well as an assessment of holobiont phenotypes we inferred an existing yet marginal role of ROS in the thermal stress response of *E. diaphana*. While the *G. fascicularis* data have not yet been fully analysed, our data suggest a more significant role of ROS in its thermal stress response. The role of RNS in thermal stress was ambiguous in both systems. These findings highlight that *G. fascicularis* represents a more suitable model for the development of a ROS-scavenging bacterial probiotic. To achieve this, we are assessing the characteristics and functions of its associated bacteria. We have characterized the bacterial microbiome of *G. fascicularis* from the Great Barrier Reef using 16S rRNA gene metabarcoding, pure cultured a representative fraction of this community and are currently screening these cultures for ROS-scavenging functions via analysis of whole bacterial genomes. Having whole genome sequences from *G. fascicularis*-associated bacteria will allow us to examine potential changes in functions provided by these bacteria during thermal stress from metabarcoding data. The findings of this study will increase our understanding of the value of *E. diaphana* and *G. fascicularis* as a coral models, and will contribute significantly to the emerging field of bacterial probiotics for corals.

Oral
A-1118

Horizontal acquisition of symbionts by bleached Exaiptasia anemones from endolithic Symbiodiniaceae populations

Folkers, M.[1, 2], Hentz, F.[1], Varotti, C.[1], Frankenbach, S.[1], Serôdio, J.[1], Frommlet, J.[1]
[1]Universidade de Aveiro, Departamento de Biologia e Centro de Estudos do Ambiente e do Mar (CESAM), Aveiro, Portugal
[2]Universiteit van Amsterdam, Institute for Biodiversity and Ecosystem Dynamics (IBED), Amsterdam, Netherlands

mainahfolkers[at]gmail.com

Abstract

The horizontal acquisition of symbionts from the environment is an important step for coral recruits and bleached corals in establishing symbiosis. In the environment, symbiodiniaceans are found in planktonic and benthic habitats, but predominantly in reef sands. The recent discoveries of (i) symbiodiniaceans forming calcareous precipitations, called symbiolites, that encase the algae as endolithic cells and (ii) diverse endolithic symbiodiniacean populations in natural reef sands, suggest that the symbiodiniacean life history involves an endolithic stage inside sand grains. Previous research, suggesting that reef sands are an important source of symbionts for coral recruits, led us to the hypothesis that cnidarians can acquire symbionts from endolithic populations. To test this hypothesis, we explored the role of endolithic symbiodiniaceans in the re-establishment of cnidarian-symbiodiniacean symbiosis after bleaching. We assessed (i) if symbiodiniaceans were capable of symbiolite formation after heat-induced expulsion from an *Exaiptasia* host (a cnidarian model organism) and (ii) if bleached *Exaiptasia* anemones could acquire symbionts from symbiolites. *Exaiptasia* anemones were heat-stressed by raising the water temperature from 25 to 32 °C (1 °C per day). Symbiolite formation by expelled symbiodiniaceans was observed 1 month after the heat stress ended. Other *Exaiptasia* anemones were chemically bleached with menthol and Diuron for 4 weeks. Bleached anemones were inoculated for 4 days with either a cultured strain of *Breviolum pseudominutum* (clade B1), comparable to their native symbiont, or *Effrenium voratum* (clade E1), a nonsymbiotic species. Both strains were presented to the anemones either as endolithic cells in symbiolites, as planktonic cells, or a combination of both. To compare the rate of symbiont acquisition, chlorophyll fluorescence was recorded for 2 weeks whereafter symbionts were quantified as endpoints. Anemones inoculated with the B1 strain regained symbionts fastest. The combined inoculation with symbiolites and planktonic cells showed a cumulative effect. Anemones inoculated with the E1 strain showed a slow recovery, which most likely stems from the native symbionts that remained in the anemone after chemical bleaching. This study provides novel evidence for the horizontal acquisition of endolithic symbiodiniaceans by cnidarian hosts, suggesting that sedimentation could be a vital process on coral reefs recovering from bleaching.

Oral
A-1386

Spatial and Seasonal Microbiome Dynamics and Associated Antibacterial Activity in the Scleractinian Coral, Platygyra daedalea, in the Arabian Gulf

Higazy, N.[1], Aeby, G.[1], Beji, M.[1], Range, P.[2], Goergen, E.[1], Padierna, M.[1], Saadaoui, I.[3], Eltai, N.[4], Ben Hamadou, R.[1, 2]
[1]Qatar University, Department of Biological and Environmental Sciences, Doha, Qatar
[2]Qatar University, Environmental Science Center, Doha, Qatar
[3]Qatar University, Center for Sustainable Development, Doha, Qatar
[4]Qatar University, Biomedical Research Center, Doha, Qatar

nh1404517[at]qu.edu.qa

Abstract

Coral-associated microbes are crucial for maintaining coral health and resilience. Environmental factors can influence the microbial community of the coral resulting in dysbiosis, which often correlates with the appearance of disease. However, the foundational understanding of variations in coral microbiomes in response to environmental factors across spatial and temporal scales is limited. Understanding processes that contribute to microbiome stability, such as production of antimicrobial compounds, is also important, but understudied. In this study, 16s rRNA sequencing was utilized to study the spatial and seasonal dynamics of the microbiome of the coral *Platygyra daedalea* on Qatari coral reefs. The core microbiome of *P. daedalea* (genus-level taxa present in 80% of all samples) made up about 5% of all taxa and consisted of 39 genera belonging to 13 phyla and 2 kingdoms. The diversity and composition of microbe communities differed among the 5 study sites (2 located to the northeast and 3 to the east of Qatar) as well as between seasons (summer vs. winter). However, seasonal differences varied among sites suggesting the coral microbiome is responsive to environmental changes and is driven by reef location. Analysis of the free-living microbial communities in seawater adjacent to coral colonies identified potential microbial taxa as indicators of environmental perturbations that can influence coral health. Fifty coral associated bacterial isolates were cultured from *P. daedalea* comprising 13 families belonging to Proteobacteria, Firmicutes and Bacteroidetes. Antimicrobial activity was found among the isolates suggesting that microbial interactions contribute to regulation of microbiome community structure. Specifically, *Pseudovibrio denitrificans* N40 exhibited potent activity against 40% of the cultured bacterial isolates and thus shows great promise for use in coral probiotics. Integrating microbial monitoring in long-term monitoring of reefs can allow for an early diagnosis of environmental condition changes and possible disease outbreaks. Incorporating both metagenomic and culture techniques can open doors for simultaneously establishing and understanding the coral microbiome while promoting the application and development of novel strategies for coral reef restoration efforts.

Oral
A-1257

Cross Pacific ecogenomics of the main coral bacterial symbiont Endozoicomonadacea

Hochart, C.[1], Paolis, L.[2], Ruscheweyh, H.-J.[2], Forcioli, D.[3], Tara Pacific Consortium and Tara Pacific Coordinators, Sunagawa, S.[2], Galand, P.[1]
[1]Sorbonne Université, CNRS, Observatoire Océanologique de Banyuls, Laboratoire d'Ecogéochimie des Environnements Benthiques (LECOB), Banyuls-sur-mer, France
[2]Institute of Microbiology and Swiss Institute of Bioinformatics, Department of Biology, Zürich, Switzerland
[3]CNRS, INSERM, Université Côte d’Azur, Institute for Research on Cancer and Aging (IRCAN), Nice, France

hochart[at]obs-banyuls.fr

Abstract

Coral harbour complex microbial communities that are fundamental drivers of biogeochemical cycling, and contribute significantly to the host health and ecosystem homeostasis. The precise functional role of these communities, however, remains poorly understood. Among these coral-associated microbes, *Endozoicomonadacea*, a globally distributed bacterial family associated with a diverse range of marine hosts, is thought to be a core coral bacterial symbiont. Notably, the presence of this family could be an indicator of coral health, as they are abundant in healthy corals and relatively rare in diseased, bleached, or stressed corals. Recent studies have provided clues about the metabolisms of *Endozoicomonadacea*, including their capability to metabolise dimethylsulfoniopropionate (DMSP) produced by zooxanthellae and their involvement in the host’s nutrition. However, their global distribution and precise functional role within the holoboint remains poorly described. Here we sampled three coral species (*Millepora*, *Pocillopora*, *Porites*) from 32 different islands across the Pacific Ocean during the Tara Pacific expedition. A total of 2400 16S rRNA metabarcoding samples and 270 metagenomic samples were sequenced, and 24 high quality and nearly complete draft *Endozoicomonadacea* genomes (MAGs) were reconstructed. We first demonstrate the wide spread cross-ocean occurrence of *Endozoicomonadacea* and show that the three coral species each harbour specific *Endozoicomonadacea* that corresponded to three new bacterial species. The species were divided into geographically-specific strains that we could link to the genetics of the coral hosts. We then characterise the metabolic potential of *Endozoicomonadacea* and identify species-specific metabolic capabilities. Our ocean scale study demonstrates that different coral species developed different host-*Endozoicomonadacea* association strategies along evolutionary times.

Oral
A-1262

Characterizing the acquisition of Aquarickettsia rohweri, a common bacterial parasite of Caribbean Acropora, from conspecifics and the environment

Klinges, J. G.[1], Koch, H.[1], Baker, L.[2, 3], Bartels, E.[1], Vega Thurber, R.[3], Muller, E.[1]
[1]Mote Marine Laboratory, Summerland Key, FL, United States
[2]University of Miami, Miami, FL, United States
[3]Oregon State University, Corvallis, OR, United States

klingesj[at]oregonstate.edu

Abstract

A pervasive association exists between the bacterium *Aquarickettsia rohweri* and Caribbean *Acropora*, as *A. rohweri* dominates microbiomes of field-collected samples of this coral species. In particular, this bacterial species is highly abundant in genotypes of *A. cervicornis* susceptible to white band disease with reduced abundance in disease-resistant genotypes. *A. rohweri*, a member of the order Rickettsiales, is hypothesized to be an obligate symbiont dependent on the coral holobiont for nutrition and energy. Many other closely-related parasites within Rickettsiales are transmitted vertically, and *A. rohweri* is unlikely to persist in a free-living stage due to its limited metabolic capabilities. This bacterial parasite was therefore expected to be transmitted vertically between host generations. However, phylogenomic analyses of *Acropora* spp. and *A. rohweri* did not reveal the co-evolutionary characteristics expected of a vertically transmitted symbiont. These characteristics could be obscured, however, by horizontal transmission between hosts. The identification of *A. rohweri* in evolutionarily distant aquatic hosts ranging from ctenophores to sponges also strongly supports horizontal transmission of this species. To better understand the transmission dynamics of *Aquarickettsia*, populations of this bacteria were quantified in early life stages of *A. cervicornis* (gametes, planula larvae, early sexual recruits, and year-old juveniles) produced and raised in the land-based nursery at Mote Marine Laboratory in the Florida Keys. These corals were produced via controlled two-parent crosses involving six different genotypes across three annual spawning events. We found that *Aquarickettsia* was absent from captive-raised individuals though present in parental genotypes maintained in Mote Marine Laboratory's in situ coral nursery. In March 2021, offspring were transferred to the same in situ nursery or outplanted to reef plots either near to or far from (> 50 m) adult *A. cervicornis* to determine if proximity to other colonies affected parasite acquisition. Corals were sampled one week, one month, and two months post-transplantation to assess timing of *Aquarickettsia* infection and to examine shifts in the coral microbiome overall due to transplantation. As tens of thousands of *A. cervicornis* are outplanted onto degraded Florida reefs each year, we aim to characterize routes of acquisition of this dominant parasite of *Acropora* to inform improved restoration practices.

Oral
A-1748

Using a model anemone to study holobiont-level responses to thermal and pH stress

Krediet, C.[1], MacVittie, S.[1], Cuyler, E.[2], Rose, B.[1], Hall, E.[2]
[1]Eckerd College, Marine Science, St. Petersburg, United States
[2]Mote Marine Laboratory, Sarasota, United States

krediecj[at]eckerd.edu

Abstract

The relationship between Anthozoans and their symbionts is a topic being carefully studied in order to better understand the process of coral bleaching and how this symbiosis is impacted by rising ocean temperatures. The anemone Aiptasia (*Exaiptasia pallida*) has become a model organism to better understand the relationship between corals and their algal symbionts (family Symbiodiniaceae). The microbial portion of the holobiont and the role that these organisms play in the thermal tolerance of these organisms is still understudied. This project looked at two distinct strains of Aiptasia, CC7 (from Florida), and H2 (from Hawaii and found globally). We have already found evidence for basal differences in the bacterial communities of the two strains with regards to their microbiome composition and thermal tolerance. This study aimed to measure the changes in these microbial communities over time, as well as to analyze the impact of mild heat stress and/or pH stress on the physiology of the holobiont. This study also allows for investigation of the impact of Symbiodiniaceae association by looking at three strains of anemones: CC7-Endo (*Symbiodinium*), H2-Endo (*Breviolum*), and CC7-SSB01 (*Breviolum* from H2). Using T-RFLP analysis, we analyzed the bacterial communities after incubation in one of four treatments (25°C + pH 8.1; 32°C + pH 8.1; 25°C + pH 7.8; 32°C + pH 7.8). Analysis of the changes in overall community composition over time and in response to stress for all strains showed a similar shift in composition. Control anemones behaved similarly over time, even though there were observed changes to the microbiome. Anemones exposed to stress conditions also clustered together, however, CC7-SSB01 exhibited the greatest change in microbial composition in response to thermal stress. We also correlated changes in the microbial community composition with *Symbiodinium* density and holobiont physiological function in order to understand how changes to the microbiome may impact the number and function of the Symbiodiniaceae associated with the host anemone during stress. There were physiological response differences with treatment, rates of photosynthesis were elevated under OA conditions and under elevated temperature while rates of respiration were increased under pH stress and reduced under elevated temperature conditions.

Oral
A-1174

A systematic meta-analysis of Cnidarian microbiomes reveals insights into the structure, specificity, and fidelity of marine associations.

McCauley, M.[1], Goulet, T. L.[2], Chiarello, M.[2], Jackson, C. R.[2], Loesgen, S.[1]
[1]University of Florida, St. Augustine, United States
[2]University of Mississippi, Oxford, United States

mccauleymark[at]whitney.ufl.edu

Abstract

Cnidarian-microbial associations are highly complex, serve underexplored functions in the holobiome, and are affected by climate change. Here, we present a systematic meta-analysis of primarily culture-independent 16S rRNA gene sequences to identify the underlying factors governing microbial communities across Cnidaria. After screening 254 datasets, 12,038 cnidarian samples, along with 4,292 Symbiodiniaceae, Porifera, and environmental samples, were included (~4.6 billion reads). Metadata for 29 host, environmental, experimental, and sequencing parameters were identified for each sample, and quality measures defined.

Each dataset was processed twice. First, datasets were processed separately with identical filtering qualifications to examine the relative abundances of inter-individual amplicon sequence variants (ASVs). Second, datasets were aligned, trimmed to specific hypervariable regions, and processed separately, before their sequence tables were merged, to investigate the diversity and structure of microbial communities across studies.

A total of 86 archaeal and bacterial phyla were identified within Cnidaria, representing a greater diversity than is currently recognized amongst Porifera. While numerous factors, including depth, complexity of body plan, and life stage, significantly influenced the structure and diversity of microbial communities, the most influential parameters were geographical location (water body), and host phylogeny. Fewer than 10% of all sequences were shared across cnidarian orders or water bodies, while less than 5% were identified across depths.

Depth and cnidarian order correlated to significant shifts in the relative abundance of ASVs shared between individuals, with shallow water families in Alcyonacea (soft corals) and Actiniaria (sea anemones) exhibiting strong core microbiomes not observed in Scleractinia (hard corals). Numerous bacterial genera were consistently identified in many cnidarians' core microbiota, including *Endozoicomonas*. By constructing the phylogeny of *Endozoicomonas,* we identified clades that ranged in host specificity from those only identified in spatially restricted families of Scleractinia to generalist clades identified globally within both Cnidaria and Porifera.

This database will serve as a tool that allows for holistic analyses of available data sets, not only to a create baseline for existing cnidarian microbiomes, but importantly to allow for future investigation of stressor-induced dysbiosis.

Oral
A-1859

Inhibition of uric acid synthesis alters the state of the Cnidarian-Alga Symbiosis

Menzies, J.[1], Konciute, M.[1], Moret, A.[1], Cui, G.[1], Pernice, M.[2], Aranda, M.[1]
[1]King Abdullah University of Science and Technology, Thuwal, Saudi Arabia
[2]University of Technology Sydney, Sydney, Australia

jessica.menzies[at]kaust.edu.sa

Abstract

Functionality of Cnidarian symbiosis with Symbiodiniaceae is fundamental to reef ecosystem success. Symbiodiniaceae cells have a complex life history, which, *in hospite,* is controlled by the host. In addition to the endosymbiotic lifestyle, they can exist free-living cells which diurnally alternate between a coccoid, vegetative night-time form to a day-time motile, flagellated cell. Their cell division cycle is gated by external light cues, and correlates with transitions in cell morphology. In contrast, endosymbiotic cells have an elongated G1 phase – demonstrating a de-coupling of cell cycle from 24-hour cycle in response to symbiosis. Furthermore, daughters of dividing endosymbiotic Symbiodiniaceae remain as coccoid cells, de-coupling morphological and cell division cycles. How this occurs remains unknown.
The answer may lie in crystalline uric acid deposits, which are present only in motile, daytime cells, correlating with G1 and S phase. These store excess nitrogen and are quickly metabolized in low nitrogen availability. They also function as an eyespot. The influence of uric acid on the life cycle of free-living and endosymbiotic Symbiodiniaceae is unknown.
In this study, I treated cultures of *B. minutum* with allopurinol, an inhibitor of uric acid synthesis. Flow cytometry showed that allopurinol the reduced growth rate and ratio of coccoid:motile cell cultures. RNA sequencing and differential gene expression analysis identified biological processes enriched in allopurinol treatment. I hypothesize that an intracellular lack of nitrogen imposed lack of uric acid crystals stimulates the General Amino Acid Control pathway. This represses translation, explaining the downregulation of ribosomal proteins, and upregulates amino acid and purine *de novo* biosynthesis pathways. Repression of translation may slow cellular growth and the G1 phase of the cell cycle, reducing number of cells meeting the size threshold for G1/S transition. Without uric acid deposits, cells may lack a functioning eyespot and not receive light cues which usually trigger morphological transitioning. This may suppress the motile morphology of free-living Symbiodiniaceae and cells *in hospite* even though the cell division cycle progresses, albeit more slowly. Genes involved in biosynthesis of flagella, thecal plates and the eyespot are upregulated, suggesting suppression of the motile form may act downstream of transcription.

Oral
A-1910

Friend or Foe? – Do sponge holobionts promote or buffer against the microbialization of reefs?

Mueller, B.[1], Arts, M. G.[2], Haas, A. F.[2], Achlatis, M.[3], van der Zande, R. M.[4], Busch, K.[5], Hentschel, U.[5], de Goeij, J. M.[1]
[1]University of Amsterdam, Department for Freshwater and Marine Ecology, Amsterdam, Netherlands
[2]NIOZ Royal Netherlands Institute for Sea Research and Utrecht University, Den Hoorn, Netherlands
[3]University of Amsterdam, Freshwater and Marine Ecology, Amsterdam, Netherlands
[4]School of Biological Sciences, the University of Queensland, Brisbane, Australia
[5]GEOMAR Helmhotz Centre for Ocean Research, Kiel, Germany

muellerb[at]ymail.com

Abstract

Current phase shifts from coral- to algal-dominance have led to an increase in DOM production on many coral reefs. Algal-DOM is suggested to select for opportunistic microbes, which inefficiently use nutrients to sustain a high microbial biomass and cause fish and coral diseases. Diseased corals are then overgrown by algae, initiating a self-enhancing feedback loop and sustaining the microbialization of coral reefs. Similar to microbes, many sponge holobionts primarily feed on DOM, but also add certain DOM components and inorganic nutrients to the outflowing water. Sponge holobionts may act as “feeding pumps” by providing planktonic microbes with DOM and inorganic nutrients and thereby fuel microbialization. However, can planktonic microbes utilize sponge-processed water and does it still support microbial growth? Thereto, we provided planktonic microbes with water processed by a mixed community of three encrusting sponges, the giant barrel sponge *Xestospongia muta,* as well as unprocessed reef water. In dilution cultures we determined bacterial growth, change in bacterial community composition, as well as the uptake of DOM and inorganic nutrients. A novel DOM untargeted metabolomics approach using high resolution liquid chromatography tandem mass spectrometry allowed to determine which DOM components were removed from reef water processed by sponges and planktonic microbes, respectively. Bioassays indicate nitrogen-limitation in reef water, which was offset by inorganic nutrients (nitrogen and phosphorus) enrichment in sponge-processed water. However, bacterial growth rates on sponge-processes water were 4–5 times lower compared to reef water. Preliminary metabolomics data corroborate these results, by showing that sponges and microbes removed similar DOM components from reef water and thus compete over this DOM as food source. Based on our results combined with the fact that sponges feed very efficiently on planktonic microbes, we hypothesize that sponges may rather buffer against, than promote the microbialization of reefs.

Oral
A-1151

Xenia umbellata (Octocorallia) is a new model organism for studying coral regeneration

Nadir, E.[1], Lotan, T.[2], Benayahu, Y.[1]
[1]Tel Aviv University, School of Zoology, Tel Aviv, Israel
[2]University of Haifa, Department of Marine Biology, the Leon H. Charney School of Marine Sciences, Haifa, Israel

elinornadir[at]mail.tau.ac.il

Abstract

In recent years, the repertoire of model cnidarians has been significantly expanded. However, octocorals have rarely been studied in a laboratory setting, despite their high ecological importance in current and future reefs. In today's changing oceans, physiological attributes of coral growth and regeneration may be critical to restoration efforts, but existing model systems are either too slow or not representative of most coral growth. Xeniid corals are abundant in Indo-pacific reefs and are pioneer organisms in many degraded reefs, with rapid growth rates, high fecundity and successful asexual reproduction. Additionally, due to their popularity in the reef-aquarium trade, their culturing demands are known. These attributes intrigued us to use them as model organisms for laboratory research on regeneration. In order to gain insights into the regeneration capabilities of *X. umbellata*, we performed a series of amputation experiments under laboratory conditions, similar to experiments performed on model cnidarians such as *Hydra* and *Nematostella*. The morphological series of events and their rate in *X. umbellata* regeneration was recorded, the experiments were photographically monitored and analyzed by SEM. Polyps excised from the colonies were grown in tissue culture plates, and all polyp body parts underwent complete regeneration. Polyp bodies reattach and resume growth within 3-8 days of amputation, with cuts closer to the oral disc regenerating more slowly, indicating a potential oral-aboral regeneration-gradient. Polyps regenerated amputated oral discs in 10-14 days, while displaying a characteristic series of morphological events. Polyps can also regenerate from excised tentacles, which undergo dedifferentiation and then follow the same series of events into small polyps in 15-21 days. Our results indicate that *X. umbellata* possesses enormous tissue plasticity and differentiated cells or tissues can be reversibly programmed to regenerate lost body-parts in very short time periods. Regeneration times are comparable to existing model cnidarians, and warrant further investigation. To conclude, this coral provides a reservoir of untapped potential for research on regeneration and body formation in colonial cnidarians.

Oral
A-2051

Teaching an old sea anemone new tricks: Genetic tools to exploit the potential of Aiptasia to study core aspects of cnidarian-dinoflagellate symbioses

Renicke, C.[1], Cleves, P. A.[1, 2], Ling, L.[1], Paul, M. R.[3], Swinhoe, N.[2], Mason, B.[1], Pringle, J. R.[1]
[1]Stanford University - School of Medicine, Department of Genetics, Stanford, United States
[2]Carnegie Institution for Science, Department of Embryology, Baltimore, United States
[3]Stanford University, Department of Biology, Stanford, United States

renickec[at]stanford.edu

Abstract

Coral reefs represent a main reservoir of marine biodiversity and productivity and rely on the symbiosis between corals and endosymbiotic dinoflagellate algae. However, environmental stressors like increased temperatures and pollutants can cause breakdown of symbiosis, followed often by death of the corals. To mitigate these effects, it is of great importance to study not only the physiological and ecological aspects of symbiosis but also to understand the molecular and cellular mechanisms governing the establishment, maintenance, and breakdown of this relationship. Rapid evolution of sequencing technologies has led to a dramatic increase in the available coral and algal genome sequences and huge datasets on gene expression in these organisms under conditions that lead to bleaching. However, reef-building corals have many properties that pose challenges for rigorous, reproducible experiments to test the hypotheses resulting from these analyses. To overcome this problem, we and other groups have worked to establish the small sea anemone Aiptasia and its algal symbionts as a model system for cnidarian-dinoflagellate symbiosis. One major advantage of Aiptasia is that the animals can be fully bleached and propagated indefinitely in the aposymbiotic state, allowing the investigation not only of symbiosis breakdown but also of symbiont acquisition and the impacts of different algal types on holobiont properties. Asexual reproduction allows the generation of large clonal populations of animals, while separated male and female polyps can be induced to spawn regularly to obtain embryos and larvae after in vitro fertilization. A current goal is to establish methods to manipulate Aiptasia genetically to study the processes involved in all stages of symbiosis on a molecular and cellular level. By microinjection of zygotes we can deliver genetic constructs such as RNA, DNA, and translation- or splicing-blocking morpholinos. To transform genetic constructs on a larger scale, we have successfully adapted an electroporation protocol of zygotes for delivery of RNA and DNA for transgene expression and Cas9-sgRNA ribonucleoprotein complexes to create gene knockouts by CRISPR editing. We think that these new tools will help many investigators perform genetic manipulation of Aiptasia by reducing training requirements and equipment costs to a minimum. Once established in Aiptasia, these methods should be adaptable to the manipulation of other symbiotic cnidarians as well.

Oral
A-1716

Virulence as a side effect of interspecies interaction in Vibrio coral pathogens

Rubio-Portillo, E.[1], Martin-Cuadrado, A. B.[1], Rohwer, F.[2], Antón, J.[1]
[1]University of Alicante, Alicante, Spain
[2]San Diego State University, San diego, United States

esther.portillo[at]ua.es

Abstract

The increase in prevalence and severity of coral disease outbreaks related to the global warming has seriously impacted reef-building corals throughout the oceans. Currently it is well known that many coral diseases described are caused by a diverse polymicrobial consortium. We have recently demonstrated that when the coral pathogens Vibrio coralliilyticus and Vibrio mediterranei were inoculated simultaneously on the coral Oculina patagonica, their pathogenic power was higher than when inoculated separately. However, the cause of this possible synergism effect is still unknow and it may be of crucial importance for the understanding of coral diseases and the development of effective disease control strategies. Therefore, the goal of this study is to elucidate mechanisms involved in this pathogenic synergy and the modulation of virulence genes in Vibrio coral pathogens, evaluating their response at transcriptomic levels in co-culture conditions. Our results provide evidence that Vibrio coral pathogens enhance production of multiple virulence factors (e.g. siderophores, secretion system VI, toxins, among others) during co-culture conditions as a physiological response to competition caused by the presence other Vibrio species. Moreover, we also found that in co-culture conditions they also suffer changes in motility by lateral flagella induction or biofilm formation, which could favor coral colonization. Therefore, our results indicate that these Vibrio coral pathogens activate mechanisms that they use to invade and cause harm to their coral hosts in the absence of coral, which thus seem to be activated to attack the competing species in mixed populations. Additionally, we have also demonstrated using aquaria experiments that coral microbiome undergoes changes in its composition, with a sharp increase of potential coral pathogens, as consequence of molecules released by Vibrio coral pathogens. Therefore, we propose that the coral diseases are caused by a diverse polymicrobial consortium that enhanced their pathogenic potential as a side effect of interspecies competition.

Oral
A-1204

Population genetics and symbiont specificity of the cnidarian-algal model, Exaiptasia diaphana

Ruggeri, M.[1], Bedgood, S.[2], Machuca, C.[3], Kenkel, C.[1]
[1]University of Southern California, Biological sciences, Los Angeles, United States
[2]Oregon State University, Integrative biology, Corvallis, United States
[3]California State University Monterey Bay, Seaside, United States

mruggeri[at]usc.edu

Abstract

Exaiptasia diaphana, commonly known as Aiptasia, is a valuable model for coral symbiosis due to its ability to be reversibly bleached and re-infected with homologous or non-homologous symbionts while controlling for host genetic background. Although successful establishment of non-native symbiont types has been observed, some symbiont types fail to reach densities of native symbiont types or are outcompeted by native strains, which could be explained by host-symbiont specificity. Populations in Florida form a unique clade that is distinct from the globally distributed population of Aiptasia and associate with a greater diversity of symbiont types (*Symbiodinium, Breviolum*, and *Cladocopium*) compared to the global population (*Breviolum minutum*). Symbiont communities can also be environmentally determined, but few studies in Aiptasia have explored the role of the environment in shaping symbiont community structure *in-situ*. Here, we aim to test whether subpopulation structure in the host and/or local environments can explain differences in host-symbiont associations. Six natural populations of Aiptasia spanning a latitudinal thermal gradient in Florida were sampled to explore host-symbiont specificity and the effect of local environments on host genetics and symbiont community composition using 2bRAD and ITS2 sequencing. Competitively mapping 2bRAD reads to both the host and representative symbiont genomes indicates that anemones from northern sites are dominated by *Symbiodinium*, *Breviolum*, and *Cladocopium* spp, whereas anemones at southern sites are largely dominated by *Symbiodinium*. No anemones were found to be dominated by *Durusdinium*, suggesting this association likely does not occur in these populations and/or environments. Additionally, Aiptasia populations are highly clonal (R = 0.34) and genetically identical individuals were found to be dominated by different symbiont types. These results provide evidence that Aiptasia-algal symbiosis is highly flexible, and these anemones can likely shuffle or switch their symbionts *in-situ*. Although conclusions are currently limited to the genus-level, the addition of ITS2 amplicon data will allow us to explore whether species level diversity is also present at these sites. Further, analysis of host genetic structure will elucidate whether some Aiptasia populations have more variable symbiont associations than others and can give insight into the evolution of symbiont specificity.

Oral
A-1499

Menthol-induced bleaching as a tool for rearing aposymbiotic foraminifera for symbiosis investigations

Schmidt, C.[1, 2], Stuhr, M.[1], Raposo, D.[3], Pochon, X.[4], Davy, S.[2]
[1]Leibniz Center for Tropical Marine Research (ZMT), Bremen, Germany
[2]Victoria University of Wellington, School of Biological Sciences, Wellington, New Zealand
[3]MARUM, Center for Marine Environmental Sciences, University of Bremen, Bremen, Germany
[4]Cawthron Institute, Nelson, New Zealand

christiane.schmidt[at]leibniz-zmt.de

Abstract

Tropical coral reefs are suffering from recurrent heat waves due to climate change. A direct consequence is bleaching, the loss of the microalgae or their pigments from many symbiont-bearing reef organisms. Among these are larger benthic foraminifera (LBF), important carbonate producers and sensitive bioindicators of environmental conditions, which harbor a wide variety of endosymbiotic microalgae. To better understand symbiont flexibility and variable bleaching responses among and within species, the investigation of the foundational biology of the symbiosis is crucial. Here, we tested a method of menthol-induced bleaching for rearing aposymbiotic hosts. For the bleaching experiments, we used: (a) the diatom-bearing model organism *Amphistegina lobifera,* because of its robustness in the laboratory; and (b) the more sensitive dinoflagellate-bearing foraminifera *Sorites orbiculus.* To induce bleaching, the LBF were exposed to menthol at non-lethal concentrations, based on those published for the model sea anemone *Exaiptasia diaphana*, for a duration of six weeks. Additionally, DCMU (3-(3,4-dichlorophenyl)-1,1-dimethylurea) was added to the water as a photosynthetic inhibitor. Bleaching was not rapid, but gradual, and resulted in a bleaching rate of > 95%, visible with a fluorescence microscope at the end of the experiment. The survival rate of these protists was high. The foraminifera in this bleached state were able to move and extend their pseudopodial network. The next step will be to infect symbionts into bleached foraminifera, with isolated diatom algal cultures, to test the possibility of symbiont switching and enhancing their thermal tolerance. Ultimately, such an approach will contribute towards our understanding of the adaptability of foraminifera to climate change, as well as efforts to create novel holobionts for reef restoration efforts.

Oral
A-1624

The stony coral tissue loss disease resistance research consortium: a holistic approach to understanding disease resistance in Orbicella faveolata

Walker, B.[1], Aeby, G.[2], Baker, A.[3], Garg, N.[4], Hawthorne, A.[5], Meyer, J.[6], Neely, K.[1], Paul, V.[2], Traylor-Knowles, N.[3], Voss, J.[7], Williams, G.[8], Woodley, C.[9], Work, T.[10]
[1]Nova Southeastern University, Halmos College of Arts and Science, Dania Beach, United States
[2]Smithsonian Marine Station at Fort Pierce, Fort Pierce, United States
[3]University of Miami, Rosenstiel School of Marine and Atmospheric Sciences, Miami, United States
[4]University of Miami, Georgia Tech University, Atlanta, United States
[5]U.S. Geological Survey, National Wildlife Health Center, Madison, United States
[6]University of Florida, Gainesville, United States
[7]Florida Atlantic University, Harbor Branch Oceanographic Institute, Fort Pierce, United States
[8]Bangor University, Bangor, United Kingdom
[9]National Oceanic and Atmospheric Administration, National Centers for Coastal Ocean Science, Charleston, United States
[10]U.S. Geological Survey, National Wildlife Health Center, Honolulu, United States

walkerb[at]nova.edu

Abstract

Stony coral tissue loss disease (SCTLD) has devastated most of the coral populations along Florida's Coral Reef over the last five years. Its unique trait of affecting many species at varying infection and virulence rates remains perplexing. A number of species are known as highly susceptible because they typically get the disease first and are decimated quickly. The other less susceptible species (*Orbicella* spp., *Montastraea cavernosa*) appear more resistant to infection because they can persist amongst other diseased corals for years before signs of infection. Once infection signs appear, lesions may rapidly kill a coral, persist slowly for a long time, or in some cases disappear, which begs the question: why are some conspecific individuals more susceptible to the disease and others more resistant?

Large (>2m diameter) *Orbicella faveolata* colonies in Florida waters have been prioritized for intensive disease intervention efforts to stop SCTLD. These successful disease intervention treatments have kept diseased reef-building corals alive providing a unique opportunity to test intraspecific differences between groups of corals with differing infection patterns. Some corals get infected once, some are reinfected numerous times, and some not at all. The consortium's goal is to understand the genetic, biochemical, and physiological underpinnings in the holobiont of individuals between infection categories to characterize risk factors that are driving differences in SCTLD infection rates. These findings are needed to understand the resistance and susceptibility factors of corals to SCTLD.

Multiple core samples from 90 colonies have been collected during three time points and processed. Differences between sample periods, location, SCTLD resistance, depth, pre/post spawning, and other factors will be analyzed. Results are currently being generated and will be presented.

This study will provide a fundamental understanding of *O. faveolata* holobiont at gross morphologic, genetic, biochemical and molecular scales at three time points. It will identify differences in endosymbionts, genotypes, metabolites, microbes, biological pathways, relate metabolites to antimicrobial bioactivity, immune response, and histopathological differences. These differences will provide direction of future research to identify SCTLD, why some corals are more resistant, and indicators for further treatment development and inform restoration strategies.

Oral
A-2016

Metabolic functions of microbes in coral reef waters

Wegley Kelly, L.[1], Nelson, C.[2], Haas, A.[3]
[1]Scripps Institution of Oceanography, La Jolla, United States
[2]University of Hawaii, Manoa, Honolulu, United States
[3]NIOZ, Texel, Netherlands

lwegley[at]ucsd.edu

Abstract

Coral reefs maintain their own unique planktonic microbiomes and distinct biogeochemical properties compared to the surrounding ocean that continually flushes over the platform. Corals and benthic algae contribute significantly to microbial ecology in reef waters by manipulating key environmental parameters (e.g., carbon substrate availability, oxygen concentrations) that influence the abundance and composition of microbes. Microorganisms comprise the majority of biomass in the water column and their role in the decomposition of dissolved organic substrates is critical to nutrient cycling, as well as for channeling nutrients and energy to higher trophic levels. Defining the metabolic roles of reef microbes provides a fundamental understanding of the interplay between macro- and microorganisms in reef ecosystem function. For example, it has been observed that specific pathways in central carbohydrate metabolism are differentially enriched in microbial populations inhabiting coral- versus algae-dominated reefs. Microbial communities in the reef water column also differs substantially between day and night. These diel microbes further illustrated significantly different metabolic profiles indicating a separation of functional roles between diurnal and nocturnal populations. We predict that this division of labor by microbial players allows for the utilization of energetic resources differentially produced over a diel cycle in order to maximize production and recycling in reef ecosystems.

Oral
A-1878

Symbiotic state influences the transcriptional responses to thermal extremes in facultatively symbiotic corals

Wuitchik, D.[1], Aichelman, H.[1], Atherton, K.[1], Kriefall, N.[1], Tremonte, C.[2], Davies, S.[1]
[1]Boston University, Boston, United States
[2]Boston College, Boston, United States

wuitchik[at]bu.edu

Abstract

The symbiosis between coral hosts and algae of the family Symbiodiniaceae is highly sensitive to thermal stress. This tightly interwoven and often obligate symbiotic relationship makes it difficult to uncouple the host's stress response from that of their algal symbiont. Facultatively symbiotic corals living along the East Coast of the United States can exist in symbiotic (brown phenotype) and aposymbiotic (white phenotype) states across their distribution and offer a unique opportunity to uncouple this relationship. Here, we leveraged these naturally-occurring symbiotic states to investigate the role of symbiosis in coral host thermal tolerance. We conducted a common garden experiment and compared the responses of symbiotic and aposymbiotic fragments of two facultatively symbiotic coral species, *Astrangia poculata* and *Oculina arbuscula*, under both hot and cold thermal extremes. Fragments of each species were exposed to three temperature treatments: i) control (18°C), ii) heat stress (18 to 32°C ramp over 15 days), and iii) cold stress (18 to 6°C decrease over 15 days). We quantified the responsiveness of corals to food stimuli daily and at the end of the experiment, when temperatures were most divergent, we sampled for genome-wide gene expression profiling to uncover the molecular signatures of the host's stress response. Behaviorally, both thermal extremes caused polyp retraction and corals appeared to enter quiescent-like states in which feeding ceased. While gene expression analyses are ongoing, preliminary results suggest that symbiotic state influences host gene expression more for *A. poculata* than for *O. arbuscula*. This is particularly evident in the heat stress treatment, where symbiotic *A. poculata* have increased expression of stress-related genes relative to aposymbiotic colonies. This is likely due to the combined effects of reactive oxygen species being produced by both the coral host and their algal symbionts. By studying the effects of thermal extremes in facultatively symbiotic corals and leveraging the power of gene expression profiling, this study will disentangle the role of symbiosis in the generalized stress response, which will transcend our understanding of symbiosis maintenance and bleaching in reef-building corals.

Poster
A-1301

Testing Symbiodiniaceae-Bacterial Relationships During Increased Thermal Stress

Aguirre, E.[1], Coelho, J.[1], Rabot, C.[2], Wang, C.[2, 3], Thrash, C.[1], Kenkel, C.[1]
[1]University of Southern California, Biological Sciences, Los Angeles CA, United States
[2]University of Southern California, Pharmacology and Pharmaceutical Sciences, Los Angeles CA, United States
[3]University of Southern California, Chemistry, Los Angeles CA, United States

emilyagu[at]usc.edu

Abstract

Emerging evidence suggests that microalgal-bacteria interactions support cnidarian holobiont (the animal host and all associated microbes) health, including the ability to acclimate to new environments, such as those expected under climate change. Symbiodiniaceae microalgae, like the coral/anemone endosymbiont, are well-known to be dependent on bacterial products like secondary metabolites, nutrients, and essential elements, but it is unclear if the range of compounds bacteria produce when in association with Symbiodiniaceae are limited by or expanded in the holobiont symbiosis. How do bacteria interact with symbiotic microalgae inside and outside their cnidarian hosts? To answer the latter part of this question, we focused on a ubiquitous bacterial microalgal associate, *Roseibium* (formerly known as *Labrenzia*). This taxon is known to produce an array of compounds, including dimethylsulfoniopropionate (DMSP), an important metabolite that has been implicated in reducing oxidative stress in the cnidarian animal, along with secondary metabolites. We isolated a new *Roseibium* sp. from a three-year monoculture of *Symbiodinium microadriaticum* derived from the anemone *Exaiptasia diaphana*. A draft genome for the isolate was assembled and secondary metabolite potential was determined using the tool antiSMASH. Gene expression responses of both axenic *S. microadriaticum* SSA01 and *Roseibium* sp. Sym1 in isolation and in co-culture will be evaluated under different temperatures to identify emergent functional variation. This data will be paired with an analysis of metabolites to determine what processes are stimulated or altered in response to symbiosis. Specifically, this study will provide qualitative and quantitative information on exclusive metabolite exchange between Symbiodiniaceae and its putative bacterial symbiont, *Roseibium*.

Poster
A-1339

Unraveling the biodiversity and the potential functionality of fungi communities present in the deep-sea coral Desmophyllum pertusum

Chacón, M. A.[1], Santoro, E.[2], Macrae, A.[3], Thomas, T.[4], Peixoto, R.[2]
[1]Federal University of Rio de Janeiro, Rio de Janeiro, Brazil
[2]KAUST, Thuwal, Saudi Arabia
[3]UFRJ, Rio de Janeiro, Brazil
[4]UNSW, Sydney, Australia

mariachaconb6[at]gmail.com

Abstract

Fungal communities associated with shallow corals remain poorly understood, which is even more accentuated for deep-sea corals. In this study, we utilized culture-dependent and culture-independent methods to identify novel fungal communities associated with the deep-sea coral *Desmophyllum pertusum*. Culture media plates were used to obtain a collection of *D. pertusum*-associated fungi. All isolates obtained were isolated and sequenced and culture plates were washed for ITS high throughput and ITS sequencing. Twenty-seven fungal strains were obtained, including twenty-one filamentous fungi and six yeast, from five fragments of the coral *D. pertusum* collected at 670 m depth from Bacia de Campos, Brazil. The isolates were morphologically assigned to three phyla, four classes, nine families, and ten genera. The majority of the isolates were assigned to the phyla Ascomycota and Zygomycota. Sordriomycetes were the most abundant class, followed by Eurotiomycetes, and Dothideomycetes. The most common genera found in the five fragments were *Penicillium sp* (33.3%) and *Nigrospora sp* (18%), followed by *Aspergillus sp, Bipolaris sp,* and *Trichoderma sp* (8.7%). Previous studies showed that *Penicillium sp* and *Aspergillus sp* isolated from deep-sea presented the *nir*K gene, associated with denitrification processes. Similarly, *Nigrospora sp* is known for antimicrobial activities against both gram-positive and gram-negative pathogenic bacteria. Our findings indicate that fungi associated with the deep-sea coral *D. pertusum* may play important roles associated with nutrition and protection activities within this holobiont. We are now analyzing the fungal community associated with *D. pertusum* through direct DNA extraction followed by high throughput ITS sequencing in order to better understand these communities and to quantify the percentage of the cultured fraction obtained in this work.

Poster
A-1178

Exploring the Photo-physiological and Microbial Response of Aiptasia to Synergistic Stressors

Dawson, D., Meyer, J.
The University of Florida, Gainesville, United States

ddawson1[at]ufl.edu

Abstract

The cnidarian microbiome performs a crucial role in host health, participating in energy metabolism, nutrient cycling, and immune system configuration. Coral rely on their intracellular algal symbionts, Symbiodiniaceae, to supply their daily energy needs through photosynthetically derived carbon. However, as a consequence of bleaching triggered by ocean warming, there is a dissociation of the symbiotic algae as a stress response. Local stressors such as nutrient enrichment reduce water quality and interact with ocean warming to decrease thermal tolerance and induce earlier visible signs of bleaching at lower temperatures. The microbial community in the surface mucus layer interacts with environmental disturbances inducing microbial shifting, which can increase coral susceptibility to bleaching, opportunistic microorganisms, and potential pathogens, such as Vibrio spp. Despite knowing climate change and coastal pollution contribute to declining tropical reef coral cover, little is known about how these interacting stressors disrupt the stability of the cnidarian microbiome. While it can be assumed that nutrient enrichment can either be additive or synergistic concerning thermal stress, laboratory-based experiments are essential to clarify the relationship between temperature and nutrient-related photo-physiological and bacterial community shifts in cnidarians. Therefore, this study aims to utilize Aiptasia to investigate the interactive effects of nutrient loading and thermal stress on the cnidarian microbiome. The inclusion of microbial changes and water quality indicators can offer prompt and sensitive recognition of early signs of declining ecosystem health to assist with early warning, impact, or compliance monitoring programs.

Poster
A-1209

Coral nitrogen isotopes as a symbiosis proxy: An experimental study

Donnelly, H.[1], Lin, M.[1, 2], Rivera, H.[3], Valadez Ingersoll, M.[3], Tramonte, C.[1, 3], Davies, S.[3], Wang, X. T.[1]
[1]Boston College, Department of Earth and Environmental Sciences, Chestnut Hill, United States
[2]University of California, Department of Ecology, Behavior, and Evolution, Los Angeles, United States
[3]Boston University, Department of Biology, Boston, United States

donnelhe[at]bc.edu

Abstract

The isotopic composition of skeleton-bound organic nitrogen ($^{15}N/^{14}N$ ratio, or $\delta^{15}N$) in fossil corals has been used to study the origin and evolution of the symbiotic relationship between scleractinian corals and zooxanthellae (Frankowiak et al. 2016; Tornabene et al. 2017). These studies suggested that coral symbiosis can be dated back to at least 200 million years ago. The premise of this application is that, due to the internal nitrogen recycling and minimal ammonium excretion, symbiotic corals lack the typical 3-4‰ trophic enrichment in their $\delta^{15}N$ as observed in animals (e.g., asymbiotic corals). Thus, symbiotic corals are expected to have a lower $\delta^{15}N$ than that of asymbiotic corals living in the same environments. However, this premise has not been sufficiently tested in modern settings. In a laboratory experiment, we investigated the $\delta^{15}N$ differences between the symbiotic and aposymbiotic branches in the same colonies of the facultatively symbiotic coral *Oculina arbuscula*. We found that the $\delta^{15}N$ of the symbiotic branches, among 4 different genotypes, are consistently 3-5‰ lower than that of the corresponding aposymbiotic branches. These results thus provide further evidence supporting the use of $\delta^{15}N$ as a proxy for identifying coral symbiosis in the past, especially when multiple species of corals were present in the same environments.

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Poster
A-1595

Effects of nutrient and temperature stress on the coral microbiome

Gracie, R., Lam, P., Baylay, A., D'Angelo, C.
University of Southampton, Ocean and Earth Science, Southampton, United Kingdom

rlg1g19[at]soton.ac.uk

Abstract

Shallow-water coral reef ecosystems are facing a global decline as a result of climate change, pollution, overfishing and habitat destruction. Heat stress and deteriorating water quality have been identified as major causes of coral bleaching, disease and subsequent mass mortality in reef-building scleractinian corals. Reef-building corals are described as a holobiont, comprising the host cnidaria, endosymbiotic dinoflagellates and a highly diverse and abundant community of bacteria, archaea and fungi – known as the coral microbiome - living on and within the coral skeleton, tissue and mucus. Whilst intense research effort has focused on the symbiosis between host and dinoflagellates, the exact function of the coral microbiome in the coral holobiont is less understood. Furthermore, it is unclear how environmental parameters shape the structure of the coral microbiome. We have used physiological monitoring and metabarcoding of the 16S rRNA gene to investigate the effects of environmental stress on different species of corals and their microbial community, within a closed experimental mesocosm. Our work examines the influence that a combination of nutrient limitation and increased water temperature exerts on the functioning of the coral holobiont and contributes critical knowledge to the understanding of microbial population dynamics in corals. Investigating how environmental stressors shape the coral microbial community, especially when associated with incidences of coral diseases and bleaching, will help determine the effects of nutrient and temperature stress on coral reef ecosystems under a changing climate.

Poster
A-1840

Exploring the role of glutamate signaling in the regulation of the Aiptasia-Symbiodiniaceae symbiosis

Konciute, M., Cui, G., Menzies, J., Moret, A., Aranda, M.
King Abdullah University of Science and Technology, Red Sea Research Center, Thuwal, Saudi Arabia

migle.konciute[at]kaust.edu.sa

Abstract

Corals rely on the symbiosis with photosynthetic algae in order to thrive under oligotrophic conditions. Although symbiosis is essential for corals and other cnidarians' survival in the nutrient poor environments of tropical seas, the molecular mechanisms behind symbiosis maintenance, its regulation and signaling are yet to be identified. Previous studies suggested that the competition on nitrogen between the host and the symbiont might be serving as an important mechanism for regulating their relationship. In addition, 'omics' level studies indicate that glutamatergic signaling could be one of the key pathways involved in regulating the establishment, maintenance, or breakdown of symbiosis. To get a better insight to this promising molecular mechanism we conducted experiments in the model organism Aiptasia (sensu *Exaiptasia pallida*) using 4 different glutamate receptor inhibitors (7CKA, DL-AP4, DL-AP5, gamma-DGG) and glutamate. The treatment with inhibitor 7CKA showed decreased levels of symbionts in re-infected aposymbiotic animals compared to control. Contrary, glutamate treatment seemed to increase the levels of symbionts in re-infected anemones. We are currently performing transcriptome analysis to better understand the effect of used inhibitors and importance of glutamate signaling in regards to regulating the relationship of the host and the symbiont.

Poster
A-1632

Immunolocalisation of metabolite transporter proteins in a model cnidarian-dinoflagellate symbiosis

Mashini, A.[1], Oakley, C.[1], Grossman, A.[2], Weis, V.[3], Davy, S.[1]
[1]Victoria University of Wellington, School of Biological Sciences, Wellington, New Zealand
[2]The Carnegie Institution, Department of Plant Biology, Stanford, United States
[3]Oregon State University, Department of Integrative Biology, Corvallis, United States

a.mashini[at]icloud.com

Abstract

Bi-directional nutrient flow between partners is integral to the cnidarian–dinoflagellate endosymbiosis. However, our current knowledge of the transporter proteins that regulate nutrient/metabolite trafficking is nascent. Four transmembrane transporters were investigated by immunocytochemistry in the model sea anemone *Exaiptasia diaphana* ('Aiptasia'): ammonium transporter 1 (AMT1); V-type proton ATPase (VHA); facilitated glucose transporter member 8 (GLUT8); and aquaporin-3 (AQP3). Anemones lacking symbionts were compared with those in symbiosis with either their typical, homologous dinoflagellate symbiont *Breviolum minutum* or the heterologous species *Durusdinium trenchii* and *Symbiodinium microadriaticum*. AMT1 and VHA were only detected in symbiotic Aiptasia, irrespective of symbiont type. However, GLUT8 and AQP3 were detected in both symbiotic and aposymbiotic states. Furthermore, all transporters were localised to both epidermis and gastrodermis in the host, however localisation patterns in host tissues were heavily influenced by symbiont identity. AMT1, GLUT8 and AQP3 increased in gastrodermis of the hosts that were in symbiosis with heterologous symbionts while VHA decreased. These patterns suggested less beneficial nutritional exchange between partners when in symbiosis with heterologous symbionts and disruption of fixed carbon and inorganic nitrogen fluxes. This study enhances our understanding of nutrient transport and host-symbiont integration, while providing a platform for further investigation of nutrient transporters and the host-symbiont interface in the cnidarian-dinoflagellate symbiosis.

Poster
A-2010

Bacterial communities as an ecological opportunity for Caribbean octocoral diversification

Sarmiento, A.[1, 2], Selke, J.[3], Sánchez, J.[4]
[1]Universidad de los Andes, Faculty of Sciences, Bogota, Colombia
[2]CEMarin, Bogota, Colombia
[3]Justus Liebig University Giessen, Faculties 7 - 11, Giessen, Germany
[4]Universidad de los Andes, Faculty of Sciences, Bogotá, Colombia

a.sarmiento40[at]uniandes.edu.co

Abstract

In Caribbean reefs, octocoral diversity and biomass may be greater than scleractinian corals in some habitats. Octocorals are an important component of benthic communities and provide a three-dimensional habitat for many species. The genus Eunicea is the most abundant and diverse group of octocorals in Caribbean reefs, with more than 30 described species. However, only 16 of these are considered valid to date, underestimating the true diversity of this group. Since one of the predictions for adaptive radiation in this group is niche partitioning for the acquisition of energy resources, microbial symbionts may be the key to deciphering diversification. To assess the role of bacterial communities in the diversification of the group, we performed metabarcoding analyses and established the relationship between Eunicea species and their microbial communities. Our preliminary results indicate that the octocoral microbiome is likely host-specific in Eunicea species.

Poster
A-1481

The effect of thermal stress on Mediterranean gorgonian holobionts

Tignat-Perrier, R.[1], van de Water, J. A.[1], Guillemain, D.[2], Aurelle, D.[3], Allemand, D.[4], **Ferrier-Pagès, C.**[5]
[1]Scientific Center of Monaco, Unité de recherche sur la biologie des coraux précieux, CSM-Chanel, Monaco, Monaco
[2]Aix Marseille Université, CNRS, IRD, IRSTEA, OSU Institut Pythéas, Marseille, France
[3]Institut Mediterranéen d'Océanologie, Campus de Luminy, Marseille, cedex 9, France
[4]Scientific Center of Monaco, Monaco, Monaco
[5]Scientific Center of Monaco, Marine Biology, Monaco, Monaco

ferrier[at]centrescientifique.mc

Abstract

Mediterranean gorgonian populations are declining due to microbial disease and repeated mass mortality events caused by summer heat waves. In the Provence region (France), gorgonians experience each summer long periods of elevated seawater temperatures (higher than or equal to 24 °C). Such temperatures may impact a coral's microbiota, and thereby the overall health and disease
resistance of the host. However, our knowledge on the gorgonian's biological response to such thermal stress remains limited, especially regarding the dynamics within their microbiota. Here we investigated the responses of two gorgonian species (*Eunicella cavolini* and *Paramuricea clavata*) along with the precious red coral *Corallium rubrum* exposed to thermal stress. We simulated an in situ thermal stress event (i.e. increase of the seawater temperature from 15 °C to up to 24 °C) over 2 months, and followed the dynamics and functioning of the gorgonian microbiota using 16S rRNA gene amplicon sequencing and metatranscriptomics. In addition, we measured the total antioxidant capacity, lipid perodixation (oxidative stress) and tissue composition (i.e. lipids, proteins, carbohydrates – energetic status) to evaluate the impact of thermal stress on the host. The preliminary results showed significant, but differential, effects of thermal stress on the gorgonian species. *P. clavata* was specifically sensitive to elevated seawater temperatures, showing a greater loss in energy reserves, reduced feeding ability and partial mortality. First results suggested that thermotolerance may be linked to the antioxidant defense capacity of the host while the microbiota likely plays a limited role in the thermal acclimation of the gorgonians. This study provides insights into how Mediterranean gorgonians and their microbiota may be impacted under future climate change scenarios.

Virtual
Oral
A-1451

Evaluating the stability of gorgonian associated bacterial communities across space and time and their putative roles against coral pathogens

Monti, M., Olson, J. B.
The University of Alabama, Tuscaloosa, United States

mmonti[at]crimson.ua.edu

Abstract

Gorgonians have become common and often dominant organisms on degraded Caribbean reefs as scleractinian corals have decreased in abundance. Compared to scleractinian corals, much less is known about the bacterial communities associated with gorgonians. In response, this study focused on understanding whether gorgonians host bacterial communities that are stable across space and time and if members of the associated bacterial community may provide gorgonians with resistance to coral pathogens. To this end, the prokaryotic communities of two Caribbean gorgonian species (*Eunicea flexuosa* and *Antillogorgia americana*) from reefs in Roatán, Honduras, and the Florida Keys, US, were evaluated in 2019 and 2021. Although a number of bacterial ASVs were conserved between individual gorgonians, revealing a possible stable core community, differences were observed across both large (i.e., Roatan and FL Keys) and local (i.e., between indviduals from the same reef) geographical scales. Ongoing bacterial network analyses will reveal potential interactions between community members and identify possible taxa that may play a role in structuring the gorgonian-associated bacterial communities.
As host-associated bacteria have been implicated in enhancing host health through protection from potential infectious agents, bacteria from the Caribbean gorgonians *Eunicea flexuosa*, A*ntillogorgia americana* and *Gorgonia ventalina* were isolated and tested against six scleractinian coral pathogens to determine whether gorgonian-associated microorganisms could resist these pathogens. The experiments were conducted at three temperatures to capture potential differences in response under varying environmental conditions. The findings suggest that gorgonians support a diverse group of culturable bacteria that have the potential to defend their hosts against pathogens through direct competition as well as through the production of bioactive compounds.

Virtual
Oral
A-1890

What's going on? The functioning of the microbiota of octocorals from the Mediterranean Sea - from a community perspective to symbionts and pathogens

van de Water, J.[1], Voolstra, C.[2], Bosi, E.[3], Vezzulli, L.[3], Allemand, D.[1], Ferrier-Pages, C.[1]
[1]Centre Scientifique de Monaco, Monaco, Monaco
[2]University of Konstanz, Konstanz, Germany
[3]University of Genova, Genova, Italy

jvdewater[at]centrescientifique.mc

Abstract

Corals are keystone species of temperate benthic communities by forming reefs and 'animal forests' and providing habitat for associated fauna. However, their populations have dramatically declined due to local human impacts and disease outbreaks in recent decades. Despite these threats, we have only recently started to reveal the associations between microbes and temperate corals (e.g. gorgonians, precious corals and reef-building corals). For example, gorgonians from the Mediterranean possess a relatively simple but highly stable microbiota, showing a true 'core microbiome' with clear signals of host-microbe co-diversification. The function of the microbes associated with these animals is, however, still unclear. Using a metatranscriptomics approach, we performed a comparative analysis on the functioning of the microbiota of three species (*Corallium rubrum, Paramuricea clavata* and *Eunicella cavolini*), representing taxonomic families with divergent microbiota. In addition, we isolated host-associated bacteria and sequenced their genomes to elucidate the function of specific common symbionts as well as to investigate potential opportunistic pathogens. We found that the functioning of microbiota of the precious coral *C. rubrum* is highly distinct from that of gorgonians, which suggests that corals do not have functionally similar microbiota, but that corals may have selected microbes for particular functions. This reinforces the notion of an evolutionary link between coral host and microbiota. Here, we will present our results on the first comparative analysis of the functioning of the Mediterranean corals' microbiota, which are emerging as ecological models to study coral-microbe symbioses.

Virtual
Poster
A-1812

Competition in the Coral Holobiont: Using FISH-FLOW-SIA to investigate the role of nutrient acccess and acquisition in symbiont genetic diversity

Hayden, R., McIlroy, S., Baker, D.
The University of Hong Kong, Hong Kong SAR, Hong Kong SAR China

rhayden[at]connect.hku.hk

Abstract

The global demise of coral reefs is a vivid reminder of how human activity is causing chaos in the natural world. We are regularly subjected to images of thriving, colourful reef systems contrasted against their white, bleached counterparts. As such, there is a large research effort directed towards mitigating or even preventing the impacts of global climate change on these vital ecosystems. Given the importance of the symbiont community in the overall health and resilience of coral, an increasing amount of this work supports microbiome engineering as a promising approach to building more tolerant corals.

Central to this research is understanding the ecological processes that shape these symbiont communities. As a dominant symbiont, the relationship between *Symbiodiniaceae* and the coral host plays a key role in the functioning of the coral holobiont and is therefore the focus of this study. Through experimental bleaching and reinfection of the stony coral *Galaxea fascicularis*, we investigate how different symbionts compete for resources *in hospite* and the impact this has on host fitness. Specifically, *Cladocopium goreaui* and *Durusdinium trenchii* were chosen, as they have both been shown to maintain stable relationships with *Galaxea* under differing thermal conditions. Previous studies had demonstrated that *C. goreaui* held an exploitative competitive advantage over *D. trenchii* when co-cultured, providing a baseline to build an *in hospite* approach. By artificially bleaching colonies of *G. fascicularis*, communities of either *C. goreaui, D. trenchii* or a combined treatment of both are reintroduced. Fluorescent in-situ hybridisation (FISH) and flow cytometric sorting isolate cells of each species, followed by stable isotope analysis (SIA) to trace the uptake of isotopically-enriched carbon and nitrogen within the symbiont. Variation in nutrient assimilation between symbiont species is expected, although the role of the host in allocating nutrients may alter the competitive response observed in culture experiments. Future work should focus on how environmental factors can influence the mechanisms and outcomes of these interactions, to continue to inform and improve novel approaches to coral reef conservation.

Session 4B - Fifty years of disease studies on coral reefs and other marine communities: What have we learned?

Conceptualized by: **Ernesto Weil** [1], **Caroline Rogers**[2], **Aldo Croquer**[3], **Laurie Raymundo**[4], **Joleah Lamb**[5], **Greta Aeby** [6], **Beatriz Casareto**[7]
[1] University of Puerto Rico (Mayaguez, Puerto Rico)
[2] US Geological Survey (St. John, US Virgin Islands)
[3] Dept. Estudios Ambientales (Caracas, Venezuela)
[4] University of Guam (Mangilao, Guam)
[5] University of California (Irvine, CA, USA)
[6] Qatar University (Qatar)
[7] Shizuoka University (Shizuoka, Japan)

Chaired by: **Greta Aeby** [6]

Oral
A-1417

Coral disease in the Hawaiian archipelago: then and now

Aeby, G.[1], Couch, C.[2], Hunter, C.[3], Shore, A.[4], Ushijima, B.[5], Vargas-Angel, B.[2], White, D.[6], Work, T.[7]
[1]Qatar Uni, Dept. of Biological and Environmental Sciences, Doha, Qatar
[2]Cooperative Institute for Marine and Atmospheric Science, Honolulu, United States
[3]University of Hawaii, Honolulu, United States
[4]Farmingdale State College, Department of Biology, Farmingdale, United States
[5]University of North Carolina Wilmington, Department of Biology & Marine Biology, Wilmington, United States
[6]Hawaii Division of Aquatic Resources, Honolulu, United States
[7]U.S. Geological Survey, Natl Wildlife Health Center, Honolulu, United States

greta[at]hawaii.edu

Abstract

One of the first coral lesions reported was from Kauai in the 1900s, and based on skeletal review in the 1960s, was reported to be a crab-induced growth anomaly. No further research on coral diseases occurred in Hawaii until focal studies on *Porites* growth anomalies and trematodiasis in the 1990s. In 2002, the first systematic baseline disease surveys were conducted in the northwestern Hawaiian Islands (NWHI) and in 2004 the main Hawaiian Islands (MHI). These studies were unique in that they comprised efforts to describe disease at the gross and cellular level which led to a systematic approach to disease investigations. From these surveys, a picture emerged of what types and levels of diseases occurred on Hawaii's reefs, which corals were most affected, and the microscopic morphology of lesions. *Porites* was affected by trematodiasis, growth anomalies and white syndromes (tissue loss diseases) and *Montipora* and *Acropora* had growth anomalies and white syndromes. No other Hawaiian coral genera had disease signs and overall disease prevalence was low (<1%) with the exception of *Porites* trematodiasis. Disease assemblages differed between regions with *Porites* trematodiasis most prevalent on NWHI reefs whereas *Porites* growth anomalies were more common in the MHI. There was an outbreak of *Acropora* white syndrome in the NWHI in 2003, causing significant coral mortality and numerous disease outbreaks in the MHI, especially acute *Montipora* white syndrome (acute MWS) outbreaks in 2010, 2012 and 2014 within Kaneohe Bay, Oahu. Acute MWS occurred during the cool, wet winter months and subsided within a few months. Multiple bacterial pathogens were identified as etiological agents with ciliates, fungi and parasitic corals also associated with lesions. Short-term salinity stress increased a coral's susceptibility to acute MWS with bacterial pathogens subsequently identified in seawater and/or associated with coral or coral-associated fauna. Corals hosting different species of algal symbionts had contrasting disease susceptibilities. Hawaii has integrated disease assessment into its monitoring programs, developed a response plan and created a citizen science program, Eyes of the Reef Hawaii, to help monitor Hawaii's vast expanse of coral reefs. Within the past three decades, our understanding of coral diseases in Hawaii has progressed from identification of types, distribution, and prevalence to understanding underlying etiologies and environmental co-factors.

Oral
A-1087

Tissue loss disease outbreak significantly alters the Southeast Florida stony coral assemblage

Hayes, N., Walton, C., Gilliam, D.
Nova Southeastern University, Halmos College of Arts and Sciences, Dania Beach, United States

nh567[at]nova.edu

Abstract

A stony coral tissue loss disease (SCTLD) outbreak, first widely reported in 2014 in the Kristin Jacobs Coral Reef Ecosystem Conservation Area (Coral ECA) of Southeast Florida, has continued to impact stony coral communities for more than six years. Here, we utilize long-term annual monitoring data from the Southeast Florida Coral Reef Evaluation and Monitoring Project (SECREMP) to assess the impact of the SCTLD outbreak on the stony coral assemblage as well as spatiotemporal and ecological associated variation, expanding upon previously documented regional impacts. SCTLD within the Coral ECA was observed across all habitats and affected 11 stony coral species, where prevalence was greatest in 2016 coinciding with significant declines in coral live tissue area (LTA). Between 2015 and 2018, 59% of Coral ECA stony coral total LTA was lost; after 2018 SCTLD prevalence dropped to < 1% and significant annual LTA declines were no longer recorded. Colony size did not preclude infection or mortality, with 25% of all infections occurring on colonies 5-14 cm in diameter. The indiscriminate nature of the disease and lack of size refugia has altered the stony coral population structure and assemblage composition. Since 2016, the coral assemblage has shifted towards smaller colonies, with a significant decrease in mean colony size. Realized recruits, < 4 cm diameter, of many reef-building species were rarely documented, while eurytopic, generalist species dominated juvenile abundance. Although significant losses were documented, all species recorded prior to the disease event were present in 2020. Our study adds to the growing body of evidence of the severity of the disease outbreak and precarious state of the stony coral assemblage in the Coral ECA. While no stony coral species were completely lost, the stony coral assemblage and population structure of the most abundant species has drastically changed, likely impacting recovery potential to even a pre-outbreak state. We show long-term monitoring projects provide invaluable opportunities to capture such spatiotemporal changes in coral assemblages and may identify potential indicators of recovery.

Oral
A-1963

Improvements to temperature-based nowcasting and forecasting of coral disease outbreak risk

Heron, S. F.[1, 2], Vasile, R.[3], Miller, I.[3], Caldwell, J. M.[4], Liu, G.[5, 6], De La Cour, J. L.[5, 6], Geiger, E. F.[5, 6], Eakin, C. M.[5, 7], Donahue, M.[4]
[1]James Cook University, Physical Sciences, Townsville, Australia
[2]ARC Centre of Excellence for Coral Reef Studies, Townsville, Australia
[3]Australian Institute of Marine Science, Townsville, Australia
[4]Hawaii Institute of Marine Biology, U. Hawaii, Kaneohe, United States
[5]NOAA Coral Reef Watch, College Park, United States
[6]Earth System Science Interdisciplinary Center, Cooperative Institute for Satellite Earth System Studies, University of Maryland, College Park, United States
[7]Corals and Climate, Silver Spring, United States

scott.heron[at]jcu.edu.au

Abstract

Over the past decade, temperature has frequently been identified as key driver for coral disease occurrence. In 2010, NOAA Coral Reef Watch first produced regional, temperature-based predictive tools for coral disease outbreak risk based on 0.5° (~50 km) twice-weekly satellite sea-surface temperature (SST) near real-time data. These incorporated seasonal effects: winter components were posited to influence pathogen loads and host resistance, whilst summertime heat stress correlated strongly with Acropora white syndrome abundance during outbreaks. The advent of 0.05° (~5 km) daily, near real-time SST data led to a product update that not only provides finer spatiotemporal detail but also gives better coverage in coastal areas. Here, we revisit the disease observation dataset used to develop the initial tools for the Great Barrier Reef – from the Long-Term Monitoring Program at the Australian Institute of Marine Science – to undertake comparisons with the finer-resolution products, including survey data collected since the initial tool development. Insights are revealed from differential warming trends between seasons and the effects for host and pathogen. Additionally, we developed short-term model-based forecasts (over several months) of temperature-based risk for coral disease outbreak to complement the satellite monitoring. Together, these products can provide reef managers and stakeholders with advance information on disease risk to support management responses including monitoring, mitigation of other stressors and active intervention to reduce impacts of disease on coral reefs.

Virtual
Oral
A-2131

Ecological consequences of the rapid spread of the Stony Coral Tissue Loss Disease in Cozumel

Estrada-Saldívar, N.[1], Quiroga-García, B.[2], Rivera-Garibay, O. O.[1], Pérez-Cervantes, E.[1], Alvarez-Filip, L.[1]
[1]National Autonomous University of Mexico, Biodiversity and Reef Conservation Laboratory, Unidad Académica de Sistemas Arrecifales, Instituto de Ciencias del Mar y Limnología, Puerto Morelos, Mexico
[2]Comisión Nacional de Áreas Naturales Protegidas., Parque Nacional Arrecifes de Cozumel, Cozumel, Mexico

nuria.estradasaldivar[at]hotmail.com

Abstract

In the Caribbean, disease outbreaks have emerged as significant drivers of coral mortality. The Stony Coral Tissue Loss Disease (SCTLD) is a novel white plague disease first reported off the Florida coast in 2014. This disease affects >20 coral species and is spreading rapidly throughout the Caribbean. In December 2018, the SCTLD reached the SW coast of Cozumel - one of the healthiest reef systems in the Caribbean. In this study, we integrate data from multiple survey protocols conducted between July 2018 and April 2020 to track the progression of the outbreak in the SW Cozumel and to quantify the impacts of the SCTLD on coral communities and the benthic composition of reefs. Because the SCTLD coincided with a prolonged period of thermal stress that concluded in a widespread coral bleaching in the autumn of 2019, we also investigated whether this event further exacerbated coral mortality. Our findings show that the SCTLD spread throughout the SW coast of Cozumel in only two months and reached a peak after only five months. By July-August 2019 most of the afflicted corals were already dead. Species of the families Meandrinidae, Faviinae, and Montastraeidae reached between 33%-95% of mortality. The widespread coral die-off caused a significant decrease of coral cover followed by a rapid increase of algae cover across all surveyed reefs. This resulted in a generalized phase-shift from coral to algae domination that persisted at least until April 2020. In November 2019 the thermal stress reached its maximum level, with more than 15% of surveyed coral colonies bleached. However, we did not find a significant increase in coral mortality at the colony or reef levels; which suggests that coral communities were able to recover from the bleaching event despite being still affected by the SCTLD outbreak. The SCTLD is radically changing the ecology of coral reefs by decimating the populations of several key reef-builders and reconfiguring the benthic composition. Restoring coral populations and reverting the phase-shift we report here will likely require management interventions. Yet, these actions have to be accompanied by stringent controls on climate change, coastal development, and wastewater treatment to improve the coral condition and ecosystem resilience.

Virtual
Oral
A-2127

Ecophysiology of White Plague disease on Acropora muricata from Mauritius Island, Western Indian Ocean

Jogee, S. Y.[1], Jeetun, S.[1], Ricot, M.[1], Taleb-Hossenkhan, N.[1], Mattan-Moorgawa, S.[1], Kaullysing, D.[1], Casareto, B.[2], Suzuki, Y.[2], Bhagooli, R.[1]
[1]University of Mauritius, Biosciences and Ocean Studies, Réduit 80837, Mauritius
[2]Shizuoka University, Graduate School of Science and Technology, Suruga-ku, Shizuoka, Japan

shakeeljogee96[at]gmail.com

Abstract

Coral diseases represent a prominent threat to the health and productivity of coral reefs worldwide. Infectious bacterial diseases such as white plague disease (WPD) are known to cause the rapid loss of coral tissue, leading to significant reduction in coral cover. While the dynamics of this multi-host disease has been well-documented in the Caribbean, where it caused a lot of damage to the local coral reef communities, little is known about the ecophysiology of WPD disease from the South-Western Indian Ocean. Here we report the prevalence and rate of progression of WPD on the main-reef building coral of Mauritius Island, *Acropora muricata,* and its effect on the photo-physiology of the affected coral host. The prevalence of WPD was assessed using 2x50 m belt transects at 17 sites around the island. The progression rate of the disease was monitored by tagging individual WPD-infected colonies using cable ties. The photo-physiology (Chlorophyll *a* fluorescence) of WPD-infected *A. muricata* was assessed using an Imaging-Pulse Amplitude Modulated (I-PAM) Fluorometer. PCR tests using specific primers for the detection of the pathogenic bacteria *Vibrio shiloi*, *Vibrio coralliilyticus* and *Aurantimonas coralicida*, all gave positive results for the diseased coral part only, thereby indicating that one of those coral pathogens could be the cause of WPD. The overall prevalence of WPD recorded on *Acropora muricata* around Mauritius Island was 9.04±8.67%, with an average rate of tissue loss of 0.54±0.02 cm day^{-1}. When compared to the healthy coral part, the maximum quantum yield (F_v/F_m) dropped from 0.59±0.01 to 0.32±0.02 (45.8%), the relative maximum electron transport rate ($rETR_{max}$) dropped from 15.79±1.06 to 6.58±3.82 (58.3%) and the maximum Non-Photochemical Quenching (NPQ_{max}) dropped from 2.87±0.18 to 0.60±0.16 (79.1%) in the WPD-infected coral part The high prevalence which is associated with a rate of progression and the deleterious photo-physiological effects of WPD on *A. muricata* warrants the need for more in-depth characterisation of this disease for better informed decision-making and management actions, especially in an era of climate change-driven global warming of the oceans and the associated changing coral-pathogen interactions

Virtual Oral
A-2141

Effects of coral diseases in the flattening of a Caribbean Coral Reef over 23 years

Randazzo-Eiseman, A.[1], Garza Perez, J. R.[2], Figueroa-Zavala, B.[3]
[1]Universidad Nacional Autónoma de México, UMDI-Sisal, Facultad de Ciencias, Sisal Yucatan, Mexico
[2]UMDI-Sisal, F. Ciencias, UNAM, Sisal, Yucatán, Mexico
[3]Centro Ukana I Akumal, Akumal, Q. Roo, Mexico

rgarza[at]ciencias.unam.mx

Abstract

Coral diseases have been a growing problem for Caribbean reefs because the most severely impacted coral species are major reef-building corals. Besides, coral diseases act synergistically with both global (e.g., bleaching) and local stressors (e.g., pollution), reducing coral reef resilience. In this study, hard coral species cover and coral diseases per species and sites were examined from 1999 to 2021 to explore the temporal pattern of coral disease prevalence in Akumal Reef, located in the North of the Mexican Caribbean, characterized by high local and global stressors. To evaluate the impact of coral diseases on coral traits assemblages, 45 coral species detected were classified into three life-history strategies: competitive, stress-tolerant, and weedy, associated with different framework building capacities. Moreover, an integrated analysis allowed us to estimate the contribution of the main coral diseases to coral assemblages shifts in Akumal reef.Our main results indicate that although framework-builders stress-tolerant and competitive coral species were more abundant in Akumal Reef in the early years of this study, the cumulative impacts of coral diseases outbreaks in the last two decades (white plague, yellow band disease, dark spot disease, and stony coral tissue loss disease), in synergy with the effects of coastal development (increase in nutrient and pollutants) and thermal stress stressors, have changed the Akumal Reef coral assemblage to being currently dominated by species belonging to non-framework and small weedy life history strategy which are associated to a low Reef Functional Index. Due to the importance of coral diseases in shaping coral assemblages, addressing current, and preventing future coral diseases outbreaks, will be key to preserving coral reef functions (*i.e.*refuge, coastline protection). Consequently, understanding the environmental thresholds that drive them is essential for practicing best-management strategies and enhancing the resilience of Caribbean coral reefs.

Virtual
Poster
A-2094

Coral disease in the world's hottest sea, the Persian Gulf

Alidoostsalimi, M.[1], Abrego, D.[2], Aeby, G.[3], Ben Hamadou, R.[3], Burt, J.[4], Howells, E.[2], Bouwmeester, J.[5], Range, P.[6], Riegl, B.[7], Work, T.[8]
[1]University of Melbourne, School of Geography, Earth and Atmospheric Sciences, Melbourne, Australia
[2]Southern Cross University, Faculty of Science and Engineering, National Marine Science Centre, Coffs Harbour NSW, Australia
[3]Qatar University, Department of Biological and Environmental Sciences, Doha, Qatar
[4]New York University Abu Dhabi, Abu Dhabi, United Arab Emirates
[5]Smithsonian Conservation Biology Institute, Virginia, United States
[6]Qatar University, Environmental Science Center, Doha, Qatar
[7]Nova Southeastern University, Florida, United States
[8]United States Geological Survey, Honolulu, Hawaii, United States

m.alidoustsalimi[at]gmail.com

Abstract

Coral disease is a threat worldwide and expected to increase as sea temperatures continue to rise. In the Persian/Arabian Gulf, corals exist in a harsh environment with extreme fluctuations in ocean temperatures and salinity. Summer temperatures commonly exceed 35ºC, yet around 30 coral genera exist representing a hardy subset of corals typical of the Indo-Pacific fauna. Understanding the types and levels of disease on these reefs may elucidate how adverse environmental conditions, including global warming, affect coral health and disease dynamics. The first studies on coral disease in the Gulf were initiated in 1995 off the coast of the United Arab Emirates (UAE) where three types of tissue loss diseases were found: black band disease, white syndrome, and Arabian yellow band disease. Arabian yellow band is unique to this region and presents as progressive subacute tissue loss with an obvious yellow band along the lesion edge. More recently, numerous disease outbreaks have troubled this region. Following hot summer in the UAE, three subsequent white syndrome and black band outbreaks were observed between 2009 and 2012, a white syndrome outbreak followed in 2014 with recurrent outbreaks every summer through 2019. A systematic survey of disease was done in UAE in 2016, and 13 types of diseases were recorded including the first report of bleached patches and growth anomalies in this region. Platygyra growth anomalies were the most widespread disease, average overall prevalence was 2% of all corals in survey sites and a high number of survey sites (5 out of 8) had localized white syndrome outbreaks. Along the Iranian Coast, surveys in 2015 found 3 tissue loss diseases affecting Porites and one tissue loss disease affecting Dipsastraea. Overall disease prevalence was 3.6% and Porites was the most commonly affected coral genus. In Qatar, surveys in 2018 found an overall low prevalence (<0.5%) with white syndrome, focal bleaching and growth anomalies affecting numerous genera. The most widespread disease was Dipsastraea growth anomalies. The Gulf is an extreme coral environment but some comparison with other regions can be drawn. Corals displayed the same lesion types as other regions' corals (tissue loss, discolorations, and growth anomalies). Unique to the Gulf, Porites was commonly affected by tissue loss diseases and yellow band. A higher number of genera were affected by growth anomalies and a high number of localized disease outbreaks was observed.

Session 4D - What are the drivers of similarity and dissimilarity within the microbiome of reefs and reef organisms?

Conceptualized by: **Amy Apprill** [1], **Koty Sharp**[2], **Tracy Ainsworth**[3], **Linda Wegley Kelly** [4]
[1] Woods Hole Oceanographic Institution (Woods Hole, MA, USA)
[2] Roger Williams University (Rhode Island, USA)
[3] The University of New South Wales (Sydney, Australia)
[4] San Diego State University (San Diego, CA, USA)

Chaired by: **Linda Wegley Kelly** [4]

Oral
A-1961

Environmental flexibility of Oulastrea crispata in a highly urbanised environment - a microbial view

Bravo, H.[1], Röthig, T.[2], Corley, A.[3], Prigge, T.[3], Chung, A.[3], Yu, V.[3], McIlroy, S.[3], Sweet, M.[2], Baker, D.[3]
[1]University of Groningen, Groningen, Netherlands
[2]University of Derby, Derby, United Kingdom
[3]The University of Hong Kong, Hong Kong, Hong Kong SAR China

henrique.bravo[at]rug.nl

Abstract

As human populations increase, ongoing urbanisation of coastal areas is driving decreases in marine water quality that threaten fragile marine ecosystems such as coral reefs. Hong Kong (one of the most densely populated cities in the world) remains home to over 70 species of corals. However, over recent years the percent cover and species distributions of coral communities has declined in some areas. Meanwhile, some species appear able to withstand the surprisingly poor water quality caused by high levels of sedimentation and eutrophication in the region. *Oulastrea crispata* is geographically the most widespread scleractinian coral present in Hong Kong, and is known to be able to cope with "extreme" environmental conditions including low salinity, high temperature variation, and high turbidity, nitrogen, and phosphate levels. Recent studies have indicated that coral microbiomes (particularly the bacterial component) support the host under changing environmental conditions. To gain insight into the contribution of the microbiome to the environmental robustness of *O. crispata*, we assessed the associated bacterial assemblages of hosts sampled along a pronounced water quality gradient in Hong Kong. We found an unusually high level of diversity within the coral's microbiome, with no specific patterns of dominance detected (i.e. <10% of the most abundant taxon on average per site). Further, *O. crispata* appears to have a relatively small core microbiome with only 7 taxa shared among all samples. Despite the high diversity and lack of species dominance, significant differences between sites were evident. However, considering 11 of the measured environmental parameters (temperature, salinity, dissolved oxygen, turbidity, pH, ammonia-nitrogen, nitrite-nitrogen, nitrate-nitrogen, total nitrogen, total phosphorus and chlorophyll-a) explained only 25% of the observed variation. These results indicate that the microbiome only reflects part of the environmental flexibility exhibited by *O. crispata*. Accordingly, pronounced microbiome flexibility may not necessarily confer an increased environmental robustness. It remains to be determined however, if certain bacteria-host associations contribute to environmental resilience.

Oral
A-1711

Regulation of coral microbiomes and lipid metabolism: a joint dance or two separate solos

Brodnicke, O. B.[1, 2, 3, 4], Burian, A.[5], Conlan, J.[6], Smith, H.[4], Connellan, K.[4], Høj, L.[2, 3], Kühl, M.[1], Sweet, M.[5], Francis, D.[6], Humphrey, C.[3], Bourne, D.[2, 3, 4]
[1]University of Copenhagen, Department of Biology, Copenhagen, Denmark
[2]James Cook University, AIMS[at]JCU, Townsville, Australia
[3]Australian Institute of Marine Science, Townsville, Australia
[4]James Cook University, College of Science and Engineering, Townsville, Australia
[5]Derby University, Environmental Sustainability Research Centre, Derby, United Kingdom
[6]Deakin University, School of Life and Environmental Sciences, Deakin, Australia

ole.brodnicke[at]bio.ku.dk

Abstract

Coral health is underpinned by a multitude of complex factors including sufficient energy reserves, a consistent supply of essential fatty acids (FAs) and a functioning microbiome. Currently, little is known about the interplay between FA metabolism and the composition of the coral associated microbial communities. Bacteria in the coral holobiont produce a multitude of metabolites and hence may provide the host with essential FAs. Here we correlated changes in the microbiome community patterns and the metabolically important lipids of tissues from five Acropora tenuis genotypes subjected to varied light and diet experimental conditions. Coral microbiomes were dominated by Endozoicomonas affiliated taxa, accounting for 77 to 98 % of retrieved 16S rRNA gene in each coral genotype and coral genotype strongly influenced the Endozoicomonas ASVs (amplicon sequence variants). In contrast to the microbiome, the total lipid concentrations and FA compositions were impacted by both dietary treatments and coral genotypes. The availability of autotrophic and heterotrophic resources modulated the functional and structural lipid content of coral tissues, which provided an indicator for coral health. Network analyses also revealed that the most abundant ASVs were correlated with distinct FAs across experimental treatments, revealing an important metabolic coupling in the coral holobiont or alternatively a joint response to a third factor.

Oral
A-1278

Local Stressors and Marine Heatwaves drive the Community Diversity of Coral-Symbiodiniaceae Symbioses.

Buzzoni, D.[1], Starko, S.[1], Cunning, R.[2], Baum, J. K.[1]
[1]University of Victoria, Victoria, Canada
[2]John G. Shedd Aquarium, Daniel P. Haerther Center for Conservation and Research, Chicago, United States

daisybuzzoni[at]gmail.com

Abstract

Climate change-amplified marine heatwaves now pose the greatest global threat to the future of coral reefs. Simultaneously, most coral reefs are exposed to some degree of local human disturbance, such as fishing or pollution. The algal symbiont communities (family Symbiodiniaceae) hosted by corals can have dramatic consequences for bleaching resistance, heatwave survival and resilience under local stressors. The Pacific Island of Kiritimati (Kiribati) harbours reefs along a steep gradient of local human disturbance and was at the epicentre of the 2015-2016 global coral bleaching event (experiencing a 10-month heatwave). As such, Kiritimati offers a natural experiment to assess the interaction of local and global stressors on coral reefs. Here we report symbiont ITS2 sequencing analyses from samples taken at 9 timepoints over 5 years spanning the heatwave (n= 2,500), from tagged colonies of 7 different coral species across different families and life-history strategies, at sites exposed to varying levels of human disturbance. Although variation in the alpha and beta diversity of partners has previously been reported for different coral and symbiont species, this has not yet been explored across a major stress event, such as a heatwave. Whilst the identity of symbiont taxa associated with coral species did change upon recovery from bleaching and with increased local disturbance (for example *Durusdinium* symbionts increased in abundance at the community level), modified species accumulation models revealed that coral species-specific signatures of alpha and beta Symbiodiniaceae diversity remained relatively stable. The interaction of local stressors and heatwave exposure resulted in changes in the number of partner associations of some symbionts, exemplified by a community-level increase in the diversity of symbionts in the genus *Symbiodinium* upon bleaching recovery under high local disturbance. This study explores changes in both coral and algal partner-specificity in relation to local disturbance and the 2015-16 heatwave, with clear implications for predicting and managing coral resilience in an increasingly disturbed ocean.

Oral
A-1359

Estimating diversity and community similarity in genomic data

Connolly, S.[1], Scott, J.[1], Nguyen, B.[2], Knowlton, N.[3], Leray, M.[1]
[1]Smithsonian Institution, Smithsonian Tropical Research Institute, Panama, Panama
[2]US Naval Research Laboratory, Center for Biomolecular Science and Engineering, Washington, DC, United States
[3]Smithsonian Institution, National Museum of Natural History, Washington, DC, United States

connollys[at]si.edu

Abstract

The application of classical ecological metrics of alpha and beta diversity to genomic data is common practice, facilitated by the provision of built-in functions for undertaking such analyses in commonly used software such as QIIME. However, most classical diversity and community similarity measures implicitly assume that the sample is equivalent to a complete census of the communities of interest, and even those metrics that explicitly account for incomplete sampling typically take account of random ecological sampling error. The analysis of sequence data, however, introduces numerous idiosyncrasies that are not well-characterized by existing diversity statistics. Here, we analyze a combination of simulated and coral reef microbiome data sets to evaluate the robustness of taxonomic richness, evenness, and community dissimilarity, and to explore additional statistical models for estimating these quantities – models not previously used in the analysis of sequence data. Our simulation studies account for both the effects of sampling from an underlying community, and for the effects of subsequent processing (e.g., amplificiation) that occurs prior to the generation of tables of ASV or OTU sequence abundance. We show that, with modifications, previously unused parametric diversity models are likely to be more robust than metrics currently in use, and we outline a workflow that can be used to assess, and potentially correct for, biases most likely to be introduced when such models are applied to sequence data.

Oral
A-2023

Discovery and Characterization of Coral Holobiont Viruses and Their Roles in Reef Health Across Space and Time

Correa, A.[1], Veglia, A.[1], Coy, S.[1], Grupstra, C.[1], Howe-Kerr, L.[1], Work, T.[2], Brandt, M.[3], Mydlarz, L.[4], Thurber, A.[5], Vega Thurber, R.[6]
[1]Rice University, BioSciences, Houston, United States
[2]United States Geological Service, National Wildlife Health Center, Honolulu, United States
[3]University of the Virgin Islands, Center for Marine and Environmental Studies, St. Thomas, U.S. Virgin Islands
[4]University of Texas at Arlington, Biology, Arlington, United States
[5]Oregon State University, College of Earth, Ocean, and Atmospheric Sciences, Corvallis, United States
[6]Oregon State University, Microbiology, Corvallis, United States

ac53[at]rice.edu

Abstract

Viruses are diverse and abundant on reefscapes, yet no virus associated with corals or their microbial symbionts has been fully characterized in terms of its diversity, replication mode or role in colony function. This is mainly due to challenges in 1) confirming the hosts of a given virus; 2) reliably tracking a viral lineage across space, time and colony health states; and 3) isolating and culturing environmental viruses. Here, we summarize advances in understanding and tracking two lineages of positive-sense single-stranded RNA viruses (dinoflagellate-infecting RNA viruses, 'dinoRNAVs', and coral holobiont-associated alphaflexiviruses, 'CHFVs') in coral holobionts that differ in their susceptibility to abiotic stress and disease. We show that dinoRNAVs are prevalent (62%, n=91 of 147 colonies from 3 coral genera) in healthy and heat-stressed Pacific coral holobionts. We present evidence that acute thermal stress shifts dinoRNAVs to a more productive replication mode, based on a fully factorial experiment with *Pocillopora* corals harboring *Cladocopium pocilloporum*, as well as repeated sampling of tagged *Porites lobata* corals harboring *Cladocopium* C15 over a three year period that spanned a reef-wide bleaching event. Next, we present genomic evidence of CHFVs from U.S. Virgin Island coral holobionts that were affected by, exposed to, or not exposed to stony coral tissue loss disease (SCTLD) in a transmission experiment, as well as from SCTLD-affected and apparently healthy coral holobionts on Florida (USA) reefs. We describe ongoing efforts to develop quantitative tools from these CHFV genome assemblies to support the critical next step of characterizing the presence/absence and abundance of CHFVs across coral colonies, to further clarify the potential role of viruses in SCTLD. These projects advance coral reef virology from community-wide averaged patterns towards lineage-specific inferences that more closely mimic the ecological interactions that drive ecosystem impacts.

Oral
A-1075

Microbiome taxonomic and functional composition of fire coral clones during a thermal bleaching event

Dubé, C.[1, 2], **Martineau, G.**[3, 4], Mercier, P.-L.[1], Planes, S.[5], Derome, N.[1]
[1]Université Laval, Institut de Biologie Intégrative et des Systèmes, Quebec, Canada
[2]California Academy of Sciences, San Francisco, United States
[3]University of Hawai'i at Mānoa, Hawaii Institute of Marine Biology, Kaneohe, United States
[4]Université Laval, Institut de Biologie Intégrative et des Systèmes, Québec, Canada
[5]Université de Perpignan, PSL Research University: EPHE-UPVD-CNRS, USR 3278 CRIOBE, Perpignan, France

mg62[at]hawaii.edu

Abstract

Elucidating the role of prokaryotic symbionts in mediating host physiology has emerged as an important area of research. Since corals are the foundational species of coral reef ecosystems, numerous studies have applied molecular techniques to understand the taxonomic and functional diversity of their associated bacteria in response to environmental change. Here, we expand on this research by examining the taxonomic composition and functional activity of bacterial communities associated with fire corals during a thermal bleaching event. One of the most devastating consequences of global warming is coral bleaching, which is the breakdown of the coral-Symbiodiniaceae symbiosis leading to host starvation, and ultimately death. Compelling evidence suggests that coral microbiomes influence host bleaching susceptibility under heat stress, but the extent to which specific changes in microbiome structure and functions occur between and within coral host genotypes during natural climatic events remain unexplored. Using 16S rRNA gene amplicon sequencing on both DNA and RNA, we characterized the bacterial taxonomic and functional diversity associated with fire corals during the massive bleaching event of 2019 at Moorea, French Polynesia. To do so, colonies of *Millepora platyphylla* were collected on the outer reef, among which ten clonal genotypes with clones exhibiting distinct bleaching susceptibility to increased sea temperature (i.e., bleached and unbleached corresponding to stress-sensitive and stress-tolerant, respectively) were selected to assess host genotype specific bacterial community changes. Our preliminary results revealed significant variations in bacterial taxonomic composition (DNA) among host genotypes, and similarly, but to a lesser extent between stress-sensitive and stress-tolerant colonies. We also identified stress-sensitive specific bacteria of the families Rhizobiaceae, Flavobacteriaceae, and Desulfovibrionaceae (among others), while no specific bacteria were identified for the stress-tolerant colonies. So far, our results suggest that bacterial community structure reflects host genotype bleaching susceptibility in fire corals exposed to increased sea temperature with the putative contribution of specific bacterial taxa to maintain host homeostasis in stress-sensitive colonies. Overall, our study will provide important insights into the dynamics of bacterial community composition and functions in corals exposed to thermal stress.

Oral
A-1645

Host-microbial systems as glass cannons: Explaining microbiome stability in corals exposed to extrinsic perturbations

Dunphy, C.[1], Gouhier, T.[2], Vollmer, S.[2]
[1]Okinawa Institute of Science and Technology, Evolution, Cell Biology, and Symbiosis Unit, Onna, Japan
[2]Northeastern University, Marine and Environmental Sciences, Nahant, United States

courtney.m.dunphy[at]gmail.com

Abstract

Although stability is relatively well understood in macro-organisms, much less is known about its drivers in host-microbial systems where processes operating at multiple levels of biological organisation jointly regulate the microbiome.
We conducted an experiment to examine the microbiome stability of three Caribbean corals (*Acropora cervicornis*, *Pseudodiploria strigosa* and *Porites astreoides*) by placing them in aquaria and exposing them to a pulse perturbation consisting of a large dose of broad-spectrum antibiotics before transplanting them into the field.
We found that coral hosts harboured persistent, species-specific microbiomes. Stability was generally high but variable across coral species, with *A. cervicornis* microbiomes displaying the lowest community turnover in both the non-perturbed and the perturbed field transplants. Interestingly, the microbiome of *P. astreoides* was stable in the non-perturbed field transplants, but unstable in the perturbed field transplants.
A mathematical model of host-microbial dynamics helped resolve this paradox by showing that when microbiome regulation is driven by host sanctioning, both resistance and resilience to invasion are low and can lead to instability despite the high direct costs bourne by corals. Conversely, when microbiome regulation is mainly associated with microbial processes, both resistance and resilience to invasion are high and promote stability at no direct cost to corals. We suggest that corals that are mainly regulated by microbial processes can be likened to ‘glass cannons’ because the high stability they exhibit in the field is due to their microbiome's potent suppression of invasive microbes. However, these corals are susceptible to destabilisation when exposed to perturbations that target the vulnerable members of their microbiomes who are responsible for mounting such powerful attacks against invasive microbes. The differential patterns of stability exhibited by *P. astreoides* across perturbed and non-perturbed field transplants suggest it is a ‘glass cannon’ whose microbiome is regulated by microbial processes, whereas *A. cervicornis*’ consistent patterns of stability suggest that its microbiome is mainly regulated by host-level processes.
Our results show that understanding how processes that operate at multiple levels of biological organisation interact to regulate microbiomes is critical for predicting the effects of environmental perturbations on host-microbial systems.

Oral
A-1621

Utilizing next-generation phylogenetics to categorize and identify core microbial communities across distinct Caribbean Scleractinian Families.

Howe, C.[1], Roitman, S.[2], Pollock, J.[3], Zaneveld, J. R.[4], Vega Thurber, R.[5], Medina, M.[1]
[1]Penn State University, Biology, University Park, United States
[2]New England BioLabs, Biology, Ipswich, United States
[3]The Nature Conservancy, Coral Reef Resilience, North Carolina, United States
[4]University of Washington, Biology, Bothell, United States
[5]Oregon State University, Biology, Corvallis, United States

czh245[at]psu.edu

Abstract

As part of the Global Coral Microbiome Project (GCMP), this study aims to categorize and describe core bacterial members across seven Scleractinian families spanning both robust and complex clades, found within the Caribbean. Characterizing core microbial members from the tremendous diversity found in the coral microbiome and discerning how various eco-evolutionary constraints (i.e., host traits, ecology) structure these microbial communities remain a central grand challenge in co-evolutionary biology. Presented here are the results from our analysis of microbial community composition across coral compartments (Mucus Tissue Skeleton) and detection of phylogenetic signals that represent phylosymbiotic patterns between coral clades and associated microbial members. This project is a continuation of a collaborative initiative to establish a global microbial baseline for all 21 major Scleractinian families. Results from this study will help refine deeper eco-evolutionary analysis between corals and their obligate bacterial members.

Oral
A-1888

Testing the resilience of coral microbial networks to disturbance

Kriefall, N.[1], Rippe, J.[2], Castillo, K.[2], Davies, S.[1]
[1]Boston University, Biology, Boston, MA, United States
[2]University of North Carolina at Chapel Hill, Chapel Hill, NC, United States

nicfall[at]bu.edu

Abstract

Microorganisms can provide essential services for their host organisms, and this is especially true for communities of algal symbionts and bacteria hosted by tropical corals. These microbes can interact with the host and with each other through nutrient and metabolic byproduct exchange and can form complex co-occurrence networks, with important implications for coral resilience. It is well-established that these symbioses are perturbed by temperature changes, however the influence of multi-variable storm disturbance events on the resilience of these microbial networks remains largely unexplored. Here, we hypothesized that microbial networks in corals from more environmentally variable reef zones (i.e. inshore) will be more resistant to the temperature and turbidity stressors accompanying superstorms than networks in coral from more stable reef zones (i.e. offshore). We tested this hypothesis by characterizing the response and recovery of coral-associated microbial communities from divergent reef zones in the Florida Keys Reef Tract (FKRT) after the category 5 storm Hurricane Irma in September of 2017. Tissue samples from two congeneric coral species (*Siderastrea siderea* and *S. radians*) at three paired inshore-offshore transects were collected prior to (May 2015), directly after (October 2017), and in the year following Hurricane Irma (October 2018). We performed metabarcoding of these coral samples to genetically identify the relative abundances of algal (ITS2) and bacterial (16S) partners present at each time point, characterized community metrics, and used network analyses to compare community dynamics across time points and reef zones. This study will deepen our understanding of the impacts of storm disturbances on coral-associated microorganisms, which likely impacts coral host fitness.

Oral
A-1233

Temporal gene expression patterns in the coral Euphyllia paradivisia reveal the complexity of biological clocks in the cnidarian-algal symbiosis

Levy, O., Mieka Rinsky, Eviatar Weizman, Hiba Waldman Ben-Asher, Gal Eyal, Bokai Zhu
Bar-Ilan Univerisy, Ramat Gan, Israel

oren.levy[at]biu.ac.il

Abstract

Studying chronobiology in reef-building corals is challenging due to the tightly coupled symbiosis with their photosynthetic algae, Symbiodiniaceae. Although symbiosis requires metabolic synchronization and coordination of cellular processes in the holobiont, the crosstalk between the host and symbiont's clocks is still puzzling. Here, we utilize the mesophotic coral Euphyllia paradivisa to examine temporal gene expression patterns in symbiotic and aposymbiotic morphs exposed to natural light/dark cycles and constant darkness. Our comparative transcriptomic analyses revealed circadian and circatidal cycles of gene expression with a predominant diel pattern in both coral morphs. We discovered a substantial number of transcripts consistently rhythmic under both light conditions, including genes likely involved in the cnidarians' circadian clock. Thus, indicating an endogenous clock, which can oscillate independently from the Symbiodiniaceae clock, exists in E. paradivisa. The analysis further manifests the significant impacts of symbiosis on transcriptional rhythms; and implies that the algae's presence modifies the host's biorhythm.

Oral
A-1403

Mono-specific algal diets shape microbial networking in the gut of the sea urchin Tripneustes gratilla elatensis

Masasa, M.[1, 2], Kushmaro, A.[3], Shashar, N.[1], Guttman, L.[2]
[1]Ben-Gurion University of the Negev, Department of Life Sciences, Eilat, Israel
[2]Israel Oceanographic and Limnological Research, The National Center for Mariculture, Eilat, Israel
[3]Ben-Gurion University of the Negev, Department of Biotechnology Engineering, Beer-Sheva, Israel

matan0mas[at]gmail.com

Abstract

Algivorous sea urchins can obtain energy from a diet of a single algal species, which may result in consequent changes in their gut microbe assemblies and association networks.
To ascertain whether such changes are led by specific microbes or limited to a specific region in the gut, we compared the microbial assembly in the three major gut regions of the sea urchin *Tripneustes gratilla elatensis* when fed a mono-specific algal diet of either *Ulva fasciata* or *Gracilaria conferta*, or an algal-free diet. DNA extracts from 5 to 7 individuals from each diet treatment were used for Illumina MiSeq based 16S rRNA gene sequencing (V3–V4 region). Niche breadth of each microbe in the assembly was calculated for identification of core, generalist, specialist, or unique microbes. Network analyzers were used to measure the connectivity of the entire assembly and of each of the microbes within it and whether it altered with a given diet or gut region. Lastly, the predicted metabolic functions of key microbes in the gut were analyzed to evaluate their potential contribution to decomposition of dietary algal polysaccharides.
Sea urchins fed with *U. fasciata* grew faster and their gut microbiome network was rich in bacterial associations (edges) and networking clusters. Bacteroidetes was the keystone microbe phylum in the gut, with core, generalist, and specialist representatives. A few microbes of this phylum were central hub nodes that maintained community connectivity, while others were driver microbes that led the rewiring of the assembly network based on diet type through changes in their associations and centrality. Niche breadth agreed with microbes' richness in genes for carbohydrate active enzymes and correlated Bacteroidetes specialists to decomposition of specific polysaccharides in the algal diets.
The dense and well-connected microbial network in the gut of Ulva-fed sea urchins, together with animal's rapid growth, may suggest that this alga was most nutritious among the experimental diets. Our findings expand the knowledge on the gut microbial assembly in *T. gratilla elatensis* and strengthen the correlation between microbes’ generalism or specialism in terms of occurrence in different niches and their metabolic arsenal which may aid host nutrition.

Oral
A-1215

Thermal stress, nutrient pollution, and herbivore reduction differentially affect the microbiomes of dominant Moorea stony corals

Vompe, A.[1], Epstein, H.[1], Speare, K.[2], Burkepile, D.[2], Vega Thurber, R.[1]
[1]Oregon State University, Microbiology, Corvallis, United States
[2]University of California, Santa Barbara, Santa Barbara, United States

vompea[at]oregonstate.edu

Abstract

Vibrant coral reef ecosystems are in decline due to anthropogenic pressures such as ocean warming that can be exacerbated by local disturbances like overfishing and nutrient pollution. Together, these disturbances can increase the competitive interactions between corals and algae for open space and trigger phase shifts to macroalgae-dominated states. To better understand the impacts of multiple stressors on reef health, and importantly their mitigation through local management, we designed a manipulative *in situ* experiment to simulate overfishing and nutrient pollution in Mo'orea, French Polynesia. Using 3 coral species (*Acropora retusa*, *Pocillopora verrucosa*, and *Porites lobata*) we examined coral microbiome dynamics in over 600 coral samples from 2.5 years of experimental manipulation. During this experiment, a temperature anomaly resulted in unprecedented bleaching on the reef and further allowed us to test the added impact of thermal stress on these experimental plots. While *P. verrucosa* and *P. lobata* largely survived and recovered, *A. retusa* experienced significant mortality. Analysis of 16S rRNA gene sequences revealed that both the temperature anomaly and host coral species most significantly drove microbiome composition, and that nutrient enrichment and herbivory levels also significantly affected microbiome composition in *P. lobata* and the dominant *P. verrucosa*. Our results also suggest that each host species mounted a different microbiome response to elevated heat stress, and these differing responses may have affected the health and survival trends of these coral species after bleaching. Thus, while short-term thermal impacts from marine heatwaves or other temperature anomalies may dwarf the impacts of local disturbance across host species, the effects of nutrient pollution and overfishing may be host dependent and could result in shifts in benthic communities as reefs recover.

Oral
A-2047

A meta-analysis of the published coral microbiome studies

Weiler, B. A.[1], Kellogg, C. A.[2], Bonacolta, A. M.[1], Whitson, E.[1], del Campo, J.[3]
[1]University of Miami Rosenstiel School of Marine and Atmospheric Science, Marine Biology and Ecology, Miami, United States
[2]St. Petersburg Coastal and Marine Science Center, U.S. Geological Survey, St. Petersburg, United States
[3]Institut de Biologia Evolutiva (CSIC-UPF), Barcelona, Spain

bweiler[at]rsmas.miami.edu

Abstract

While coral microbiome research has been increasing over the past decades, recent years have seen an explosion of studies, due to the increase in accessibility of high-throughput sequencing and environmental concerns regarding declining reef health. The large amount of publicly available 16S rRNA data at NCBI's Short Read Archive (SRA) database present a unique opportunity to explore the diversity and distribution of bacteria across a wide array of healthy and diseased corals from all over the world. Through the reanalysis of the SRA data we can shed new light on the complexity of the coral microbiome, repurposing thousands of samples across nearly one hundred studies to uncover previously masked trends relative to host-associated prokaryotic communities. We aim to (1) describe phylosymbiotic patterns between corals and their microbiomes (2) examine microbe-microbe interactions within the holobiont, (3) characterize the microbial signatures associated with coral diseases through cross comparisons of healthy and diseased organisms, and (4) identify spatial trends in the geographic distribution of coral-associated microbiota. In order to reach our goals, sequences were compiled and curated from SRA for downstream amplicon sequence variant analyses using R packages "dada2" and "phyloseq". Databases of coral-associated microbes' 16S rRNA genes were used as references to taxonomically annotate the sequences. Subsequent network and co-occurrence analyses were conducted to explore holobiont interactions, while host phylogenies were built to be compared with microbiome dendrograms. Closely related corals with similarities in health condition, and/or spatial distribution share key bacteria, a likely signal of phylosymbiosis. Through this approach, a deeper understanding of coral-associated prokaryotes can be uncovered. The results from this meta-analysis will provide a more detailed and integrated framework for future studies involving coral holobiont 'omics and guide coral reef research and conservation.

Poster
A-1147

Dynamics of bacterial assemblages in the face of an acute outbreak of Stony Coral Tissue Loss Disease

Becker, A. A., Freeman, M. A.
Ross University School of Veterinary Medicine, Center for Conservation Medicine and Ecosystem Health, Basseterre, St. Kitts & Nevis

abecker[at]rossvet.edu.kn

Abstract

Reef-building corals are coevolved symbioses formed by the coral polyp, photosynthetic dinoflagellates, and an array of microorganisms (bacteria, archaea, fungi, viruses, and protists) collectively called the microbiome. These coral-associated microorganisms perform key functions that promote coral health and ecosystem homeostasis and therefore hold considerable potential as a monitoring tool. The urgency for defining their structure, persistence and dynamics is being driven by reports on rapid coral decline worldwide due to environmental and anthropogenic stressors, and disease outbreaks. Small-scale spatial and temporal epidemiology of the current Stony Coral Tissue Loss Disease (SCTLD) epizootic underpins the need to increase our understanding of microbial dynamics across different time scales to further unravel coral disease pathogenesis.

The present study focused on expanding our understanding of coral microbial community dynamics in the symmetrical brain coral *Pseudodiploria strigosa*, an important reef-building species in the Caribbean and highly susceptible to SCTLD. By SCUBA diving on a nearshore rocky reef located at the Southeast Peninsula of the Caribbean Island St Kitts (17.2523598, -62.6579568), coral tissue/mucus slurries were collected with blunt sterile syringes from 8 similar sized macroscopically healthy colonies at bi-weekly intervals for 6 months. Temperature and light intensity were recorded at 30 min intervals throughout the study period using calibrated HOBO® pendant loggers. All coral tissue samples were transferred from syringes into sterile tubes before being transported on ice and immediately stored at -80°C. DNA was isolated using MO BIO's PowerSoil kits with modifications and further processed for high-throughput sequencing of the V4-16S rRNA gene variable region. Our results provide microbial baseline data for *Pseudodiploria strigosa* and reveal temporal stability and systematic natural variation in coral-specific core bacterial communities across environmental gradients and individual hosts. During the 6-month study, however, SCTLD emerged on the reef, and we have been able to additionally identify early microbiome perturbations prior to disease onset, which highlights the critical temporal scales and longitudinal baseline analyses required to understand microbial dynamics in the face of a disease outbreak.

Poster
A-2198

Comparative Multi-'omics Approach to Describing the Coral Holobiont

Stewart, J. M.[1], Pollock, F. J.[2], McMinds, R.[3], Zaneveld, J.[4], Vega Thurber, R.[5], Medina, M.[6]
[1]University of Hawaii, Hilo, United States
[2]The Nature Conservancy, Belmont, United States
[3]University of South Florida, Tampa, United States
[4]University of Washington at Bothell, Bothell, United States
[5]Oregon State University, Corvallis, United States
[6]Pennsylvania State University, University Park, United States

jms9[at]hawaii.edu

Abstract

Corals are dying worldwide at an alarming rate due to climate change and local stressors. Knowledge of the microbial community composition, genomic potential, and secondary metabolites associated with the coral microbiome at different scales will help us gain a better understanding of a healthy coral holobiont, and provide insight into what role the bacterial and photosymbiont microbes play in maintaining coral health. In this study, we used a multi-'omics approach to characterize the interactions within putatively healthy corals and their microbiomes. Metabolomics, metagenomics, ITS, as well as 18S and 16S
rRNA genes were used to comparatively examine the coral holobiont compartments from two oceans (eastern Indian and eastern Pacific) and two coral genera. As part of the Earth Microbiome Project (EMP500) and the Global Coral Microbiome Project, mucus, tissue, and skeleton were sampled from clinically normal coral colonies of the Lace coral, Pocillopora damicornis, and the Lobe
coral, Porites lobata, from Panamá and Ningaloo Reef, Western Australia. Seawater was also sampled from both locations to provide background baselines for all comparisons. Preliminary results indicated that the metabolites produced by each compartment present clear partitioning: the metabolomic signature from the tissue of both species cluster significantly together compared to the metabolites of both mucus and skeleton. The microbiome of the two coral species differed between compartments and seawater, suggesting that the microbial community plays roles in different portions of the coral holobiont. Coral tissue of both species possessed a great number of unique compounds, many of which have not yet been characterized. Our study allows us to assess drivers of symbiotic interactions between the coral animal host, Symbiodiniaceae, and other microbes of the mucus and skeleton at the molecular level. This type of holistic approach to describing normal coral holobiont cellular activities is important for restoring coral reefs to a healthy state. Not only can this type of study elucidate the metabolic connections between host and symbionts, but may also reveal undescribed natural products.

Poster
A-1391

Evolutionary links between microbiota and octocorals living in the under-explored mesophotic zone of the Mediterranean and Red Seas

Tignat-Perrier, R.[1], Prioux, C.[1], Guilbert, A.[2], Ballesta, L.[3], Deter, J.[4], Allemand, D.[5], Ferrier-Pagès, C.[1], van de Water, J. A.[1]
[1]Centre Scientifique de Monaco, Monaco, Monaco
[2]Andromède Oceanology, Mauguio, France
[3]Andromède Océanologie, Mauguio, France
[4]UM UMR Institute of Evolutionary Science of Montpellier, Montpellier, France
[5]Centre Scientifique de Monaco, Monaco, France

romie.tignat[at]centrescientifique.mc

Abstract

While shallow populations (above 40 m depth) of Mediterranean octocorals have been impacted by recurrent large-scale disease and mortality events associated with summer heat waves, mesophotic (>40 m depth) populations have not been impacted. The mesophotic zone may thus represent a refuge for these species, but also the perfect environment to study evolutionary relationships between octocorals and their microbiota. Recently, we suggested that phylosymbiotic signals exist between the Mediterranean gorgonian phylogeny and their microbial communities. Here, we expanded our study into the microbiota of Mediterranean octocorals (*Corallium rubrum*, various *Eunicella* spp., *Paramuricea clavata* and its parasite *Alcyonium coralloides*, and the depth-specialists *Callogorgia verticillata* and *Acanthogorgia hirsuta*) collected during the *Gombessa V* and *VI* expeditions, and combined this with samples of a large number of tropical octocoral species collected from the mesophotic zone of the Red Sea during the *ENCOR* expedition. Using next-generation amplicon sequencing, we characterized the microbial communities (bacteria, fungi and protists) of these depth-generalist and depth-specialist octocorals and aimed to assess whether phylosymbiosis indeed exists in octocorals, as well as investigate how microbes may have contributed to a life style at depth. This comparative study on the microbiome of octocorals inhabiting the under-explored mesophotic zone contributes to our knowledge on the importance of the microbiota to octocoral health.

Poster
A-1127

Microbe-mediated interactions between coral reef-inhabiting organisms

Wiederkehr, F.[1], Engelhardt, K. E.[2], Vetter, J.[2], Ziegler, M.[2], Sunagawa, S.[1]
[1]ETH Zürich, Department of Biology, Zürich, Switzerland
[2]Justus Liebig University Giessen, Department of Animal Ecology & Systematics, Giessen, Germany

wiederkf[at]biol.ethz.ch

Abstract

Coral reefs harbour a biodiversity unrivalled by any other ecosystem. The biological foundation of these productive and diverse ecosystems are reef-building corals. Yet, to generate and maintain both diversity and productivity, corals depend on interactions not only with other reef macroorganisms, but also with their associated microbial communities. To effectively conserve reef ecosystems and counteract their unprecedented decline, we therefore need to identify the mechanisms underlying such interactions at multiple scales—from key groups of macroorganisms (stony corals, soft corals, macroalgae, and sponges) down to their microbiome. By collecting both experimental and field data, we might eventually be able to resolve how these microbe-mediated interactions between hosts affect overall reef productivity and diversity. As a first step, we aimed to characterise the microbial community that different reef organisms exude into the surrounding seawater as these microbes potentially interact with and influence surrounding organisms. Taking advantage of a controlled experimental setting, we incubated single stony coral, soft coral, macroalgae, and sponge fragments in artificial seawater. We collected the microbial community of the incubated seawater to assess the diversity and metabolic potential of these microbes. By uncovering taxonomic and functional links between reef organisms at the microbiome level, we aim to contribute towards a more holistic understanding of reef-ecosystem functioning, which may guide conservation and coral-reef restoration efforts to preserve the key functions reef holobionts provide.

4D - What are the drivers of similarity and dissimilarity within the microbiome of reefs and reef organisms?

Oral
A-2074

Microbiome of Sri Lankan Coral Reefs: An Indian Ocean Island

Mohamed Fairoz, M. F.[1], Green, K.[2], Sajith, K. N.[1], Kularathna, K. N.[1], Wegley-Kelly, L.[2], Rohwer, F.[2]
[1]Ocean University of Sri Lanka, Fisheries and Ocean Sc, Fisheries and Marine Sciences, Tangalle, Sri Lanka
[2]San Diego State University, San Diego, CA, USA, Department of Biology, San Diego, United States

fairoz.mfm[at]gmail.com

Abstract

Coral reefs around Sri Lanka have coexisted with human communities for thousands of years and are a continual source of food, economic productivity, and tourism. Although these reef systems sustain nearby populations, little is known about the presence or functional role of microbial communities on reefs dominated by hard corals or fleshy algae. Coral reef benthos cover was recorded, and reef associated water samples were collected, sequenced, and analyzed from seven coral reefs around Sri Lanka. Microbial metagenomes were analyzed to reveal both the taxonomic and metabolic makeup of the microbial communities present at each site. Metagenomic analysis of bacterial phyla showed that Alphaproteobacteria and Gammaproteobacteria were most abundant, constituting up to 79.4% of microbial communities. At the order level, Rhodobacterales dominated the microbial communities across all sites, with the exception of the Paraviwella coral reef, where the order Alteromonadales dominated. This study is the first microbial metagenome dataset of coral reef associated water from the Indian Ocean continental island, Sri Lanka. These data further confirm the need for a comprehensive study of reefs in Sri Lanka aimed at elucidating the processes involved in microbial energy utilization.

Oral
A-1908

The Effect of Coral Bleaching on Coral DOM Exudation and Bacterioplankton Dynamics

Sparagon, W.[1], Arts, M.[2], Quinlan, Z.[3], Koester, I.[3], Comstock, J.[4], Bullington, J.[5], Carlson, C.[4], Wegley Kelly, L.[3], Haas, A.[2], Nelson, C.[1]
[1]University of Hawai'i at Manoa, Center for Microbial Oceanography: Research and Education, Honolulu, United States
[2]NIOZ Royal Netherlands Institute for Sea Research and Utrecht University, Department of Marine Microbiology and Biogeochemistry, Den Burg, Netherlands
[3]University of California, San Diego, Scripps Institution of Oceanography, San Diego, United States
[4]University of California Santa Barbara, Department of Ecology, Evolution, and Marine Biology, Santa Barbara, United States
[5]Stanford University, School of Earth, Energy, and Environmental Sciences, Stanford, United States

sparagon[at]hawaii.edu

Abstract

Coral bleaching, the collapse of the symbiosis between the coral host and the single celled Symbiodiniacaea, is a well-documented and widespread phenomenon in coral reefs across the globe. A substantial body of work has investigated how bleaching alters the dynamics and health of the coral holobiont, but there has been very little research on the implications of coral thermal stress and bleaching on reef water column dynamics. Healthy corals are known to exude compositionally distinct dissolved organic matter (DOM) into the surrounding water column, but the nature of coral DOM exudation during bleaching is largely unstudied. We performed a mesocosm bleaching experiment and measured subsequent DOM exudation and bacterial remineralization to address this knowledge gap. Specifically, we sought to explore the shift in DOM exudation at various bleaching stages in coral assemblages (*Acropora pulchra., Pocillopora verrucosa*, and *Porites rus*) and effects on the community structure and function of reef bacterioplankton. Heated coral assemblages exuded roughly 1.42 times more DOC than their healthy counterparts and coral assemblages under different heat/bleaching regimes exuded compositionally distinct DOM. This DOM yielded markedly different bacterioplankton communities. Bacteria grew to highest abundances on the heated-DOM, reaching concentrations upwards of 3000 cells/µL and exhibiting a unique community structure. Heated-DOM bacterioplankton communities had an overabundance of fast-growing bacteria in the *Pseudoalteromonadaceae* and *Alteromonadaceae* Families as well as some members of *Flavobacteriaceae* and a concomitant reduction in putative oligotrophs including members of the OMG clade. Our results indicate that the immediate impact of coral bleaching extends beyond the coral holobiont and into the adjacent water column, resulting in shifts in DOM and bacterioplankton that may have ecosystem wide consequences for how coral reefs respond to and recover from bleaching events.

Virtual
Poster
A-1063

The role of coral-associated microbial communities in coral reef resilience to climate change

Powell, M.[1], Schoepf, V.[2], Castillo, K.[1, 3]
[1]University of North Carolina at Chapel Hill, Environment, Ecology, and Energy Program, Chapel Hill, United States
[2]Institute for Biodiversity and Ecosystem Dynamics, University of Amsterdam, Department of Freshwater and Marine Ecology, Amsterdam, Netherlands
[3]University of North Carolina at Chapel Hill, Department of Earth, Marine and Environmental Sciences, Chapel Hill, United States

mayapow[at]email.unc.edu

Abstract

Coral reefs are home to more than 25% of marine life and are crucial components of global biodiversity, cultural heritage and local economies. The fragility of coral reefs makes them highly vulnerable to climate change, and this stress has caused coral cover in the Caribbean to decline by 50% since the 1970s, making the region a high research priority. Studying corals and their associated microbiomes that reside in extreme, high temperature environments will provide new insights into how corals will cope under future ocean conditions. These future conditions are exemplified by inland bays in Curaçao, which show uniquely elevated and variable levels of temperature and other local stressors (e.g., high turbidity, low light levels, variable pH). Microbiome restructuring is one of corals' quickest defenses against these environmental stressors. However, the role of the microbiome and microbial association with specific symbionts has yet to be fully explored. The goal of this study is to understand coral-microbial and symbiont interactions and their role in mediating coral stress tolerance and acclimatization across environmental gradients in Curaçao. Combined mucus, tissue, and skeletal samples of *Siderastrea siderea, S. radians,* and *Porites spp.* were collected from inland bays and fringing reefs in Curaçao. DNA extraction from these samples is currently underway to determine symbiont and microbiome composition. In a previous study, symbionts in *S. siderea* were found to be variable across three temperature regimes, while *S. radians* maintained relatively consistent symbiont composition regardless of environmental conditions. Here, we hypothesize that: 1) coral microbiomes in inland bays will exhibit higher proportions of stress resistant and thermally tolerant microbial taxa compared to conspecifics from the fringing reefs, and 2) there will be a small core composition of essential bacteria associated with all corals, as well as a broad diversity of species and symbiont specific microbes. Results will allow us to assess and predict future Caribbean coral health, microbiome and symbiont correlation, and acclimatization capacity. Additionally, our findings will provide a baseline for understanding coral associated bacterial communities for each species and symbiont type, furthering global knowledge of coral-associated microbial genetics.

Session 4E - The jellyfish Cassiopea - a model organism?

Conceptualized by: **William Fitt** [1], **Aki Ohdera**[2], **Monica Medina**[3]
[1] University of Georgia (Athens, GA, USA)
[2] Carnegie Institute (Baltimore, MD, USA)
[3] Pennsylvania State University (State College, PA, USA)

Chaired by: **Monica Medina**[3]

Oral
A-1602

Flipping the perspective! Using the upside-down jellyfish Cassiopea sp. to study cnidarian-Symbiodiniaceae symbiosis

Hung, S.-H., Salazar, O. R., Klein, S. G., Duarte, C. M., Aranda, M.
King Abdullah University of Science and Technology, Thuwal, Saudi Arabia

shiou-han.hung[at]kaust.edu.sa

Abstract

Coral reefs are one of the most biologically diverse and productive ecosystems. Corals heavily rely on the symbiosis with photosynthetic dinoflagellates of the family Symbiodiniaceae, receiving photosynthates in exchange for inorganic nutrients. The breakdown of this essential symbiotic relationship, that leads to the expulsion of Symbiodiniaceae from the coral tissue, is the underlying cause of coral bleaching and wide spread mortality. Symbiodiniaceae are known to establish symbiotic relationships with various marine invertebrates, including many different cnidarians. Similarly to corals, the upside-down jellyfish *Cassiopea* is a cnidarian that develops mutualistic relationships with Symbiodiniaceae. Albeit, it is a more amicable system when compared to hard corals, as it can be easily maintained in the laboratory, has a closed sexual reproductive cycle, and a much shorter generation time. The use of *Cassiopea* as a model organism to investigate symbiosis with Symbiodiniaceae, would provide us with a better understanding of cnidarian symbiosis. The aim of this project is to generate resources that will help in the establishment of *Cassiopea* as a model organism and to gain insight into this cnidarian-Symbiodiniaceae symbiosis through the generation of a high quality genome and the comparison of gene expression profiles from symbiotic and aposymbiotic *Cassiopea* polyps from the Red Sea, which are highly adapted to warm temperatures. This research is expected to set the foundation for the exploration of general mechanisms underlying the association of cnidarians with Symbiodiniaceae and to discover how the symbiotic partners respond to different environmental conditions. This would bring us a step closer to the development of a general cnidarian-Symbiodiniaceae symbiosis model.

Session 4F - What is the current knowledge on understanding and effectively responding to coral disease outbreaks?

Conceptualized and chaired by: **Brian Walker** [1], **Karen Neely**[1], **Erinn Muller**[2], **Josh Voss**[3], **Greta Aeby**[4]
[1] Nova Southeastern University (Fort Lauderdale, Fl, USA)
[2] Mote Marine Laboratory (Sarasota, FL, USA)
[3] Florida Atlantic University (Boca Raton, FL, USA)
[5] Qatar University (Qatar)

Oral
A-1761

Understanding and responding to the dual threats of stony coral tissue loss disease (SCTLD) and mass bleaching in the US Virgin Islands

Brandt, M.[1], Ennis, R.[1], Meiling, S.[1], Townsend, J.[1, 2], Edwards, K.[3], Henderson, L.[4], Smith, T.[1]
[1]University of the Virgin Islands, Center for Marine and Environmental Studies, St. Thomas, U.S. Virgin Islands
[2]National Science Foundation, Alexandria, Virginia, United States
[3]U.S. Virgin Islands Department of Planning and Natural Resources, Division of Coastal Zone Management, St. Thomas, U.S. Virgin Islands
[4]National Oceanic and Atmospheric Administration, St. Croix, U.S. Virgin Islands

mbrandt[at]uvi.edu

Abstract

Coral bleaching and disease outbreaks are both increasing threats to coral reef ecosystems. In early 2019, the highly virulent stony coral tissue loss disease (SCTLD) emerged off of St. Thomas in the US Virgin Islands. In the fall of 2019, temperature stress resulted in significant mass bleaching across the territory. These two threats collided and created unique challenges for scientists and managers who were attempting to develop a plan for and implement a coordinated response to the outbreak of SCTLD while also conforming to a previously approved bleaching response plan. Data collected from long-term monitoring locations before, during, and after the bleaching event revealed negative relationships between disease and bleaching prevalence. Overall, partial mortality and coral cover loss attributable to the short term bleaching event was minimal compared with that due to the ongoing disease outbreak. The slowing of disease activity that occurred concurrently with the increase in bleaching allowed for some disease response efforts to be shifted to assessing bleaching and also to solidifying a multi-pronged disease outbreak response plan. Public messaging during this time was coordinated by managers and scientists to be targeted and timed so as not to dilute the importance and severity of the two threats. However, confusion over citizen science reporting platforms led to the development of a single disease response website that has recently served as a platform for reporting of other events, including an urchin die off. The major lesson learned from this collision of coral reef threats is that regular, verbal communication among local managers, scientists, and other stakeholders is essential for an effective response to simultaneous coral reef threats.

Oral
A-1872

Algal symbionts in the genus Breviolum increase the susceptibility of corals to stony coral tissue loss disease

Dennison, C. E.[1], Karp, R. F.[1], Wen, A. D.[1], Cook, S. M.[2], del Campo, J.[1, 3], Traylor-Knowles, N.[1], Rosales, S. M.[4, 5], Baker, A. C.[1]
[1]Rosenstiel School of Marine and Atmospheric Science, University of Miami, Marine Biology and Ecology, Miami, United States
[2]Nova Southeastern University, Fort Lauderdale, United States
[3]Institut de Biologia Evolutiva (CSIC-UPF), Barcelona, Spain
[4]NOAA Atlantic Oceanographic and Meteorological Laboratory, Miami, United States
[5]Cooperative Institute for Marine and Atmospheric Studies, University of Miami, Miami, United States

caroline.dennison[at]rsmas.miami.edu

Abstract

Coral reefs in Florida and the northern Caribbean have been ravaged by an ongoing outbreak of stony coral tissue loss disease (SCTLD), with the most susceptible coral species tending to host algal symbionts (Family Symbiodiniaceae) in the genus *Breviolum*. To test the hypothesis that *Breviolum* is implicated in SCTLD epidemiology, we used a controlled bleaching and recovery experiment to alter algal symbiont communities (in favor of *Durusdinium trenchii*) in five species of Caribbean coral that are susceptible to the disease (*Colpophyllia natans*, *Diploria labyrinthiformis*, *Meandrina meandrites*, *Pseudodiploria strigosa*, and *Orbicella faveolata*). We then exposed these manipulated corals to SCTLD and compared their responses to those of controls of the same genotype that still hosted their original *Breviolum* (and/or *Cladocopium*). We found that cores predominantly containing *Cladocopium* or *Durusdinium* were significantly less likely to present with SCTLD ($P<0.01$ and <0.0001, respectively) compared with cores dominated by *Breviolum*. In addition, we calculated the relative risk of infection based on the proportion of algal symbionts, and found that colonies exclusively hosting *Breviolum* were 2.5x more likely to present with SCTLD compared to those exclusively hosting *Durusdinium*. In a subsequent comparative susceptibility experiment, we challenged *Acropora cervicornis* (hosting *Symbiodinium*) and found limited SCTLD susceptibility, suggesting a hierarchy among Symbiodiniaceae genera in their susceptibility to SCTLD, in which *Breviolum* >> *Cladocopium* > *Durusdinium* >> *Symbiodinium*. Finally, in the same experiment, we also exposed four species of Indo-Pacific coral (in the genera *Echinopora*, *Pavona*, *Montipora*, and *Pocillopora* containing *Cladocopium* and/or *Durusdinium*) to SCTLD and found little to no susceptibility. Taken together, these results strongly indicate that hosting *Breviolum* is a key risk factor in the susceptibility of corals to SCTLD, but also suggest that additional variation in susceptibility may exist within Symbiodiniaceae genera. Given the limited distribution of *Breviolum* among scleractinian corals in the Indo-Pacific, these findings suggest that the impact and potential spread of the SCTLD pathogen(s) into this region may be less severe than has been documented to date in the tropical western Atlantic.

Oral
A-1334

A highly effective therapeutic ointment for treating corals with black band disease

Eaton, K. R.[1, 2, 3], Clark, A. S.[4, 5], Curtis, K.[6], Favero, M.[6], Hanna Holloway, N.[7, 8], Ewen, K.[7], **Muller, E. M.**[1]
[1]Mote Marine Laboratory, Sarasota, FL, United States
[2]Cooperative Institute for Marine and Atmospheric Studies, University of Miami, Miami, FL, United States
[3]National Oceanographic and Atmospheric Administration (NOAA) Atlantic Oceanographic and Meteorological Laboratory, Ocean Chemistry and Ecosystems Division, Miami, FL, United States
[4]Mote Marine Laboratory, Summerland Key, FL, United States
[5]The College of the Florida Keys, Key West, FL, United States
[6]Ocean Alchemists LLC, Tampa, FL, United States
[7]National Park Service, St. Croix, U.S. Virgin Islands
[8]Scripps Institution of Oceanography, La Jolla, CA, United States

emuller[at]mote.org

Abstract

Infectious disease outbreaks are a primary contributor to coral mortality worldwide, and are shaping contemporary coral communities particularly in the Caribbean. One virulent disease, black band disease (BBD), has been observed on reefs worldwide with documented linear progression rates of up to 1 cm day^{-1}. BBD is considered a microbial consortium of photosynthetic cyanobacteria, sulfate-reducing and sulfide-oxidizing bacteria, and is visually identified by a characteristic dark band that moves across apparently healthy coral tissue leaving behind bare skeleton. Attempts to treat the disease have included methods such as aspiration or chlorinated epoxy, but 30% of the treated corals were reinfected within just a few months. Here, we developed and tested 13 different treatments on *Pseudodiploria* spp. corals affected by BBD at Buck Island Reef National Monument in St. Croix, USVI. A variety of therapies were tested on corals with BBD including hydrogen peroxide-based treatments, ointment laced with antibiotics, and antiviral/antimicrobial-based ointments (termed “Coral Cure”) to compare with untreated corals also showing signs of BBD. Additionally, hemp rope was saturated with a subset of the Coral Cure ointment formulations. These ropes were then applied to the leading edge of the BBD lesion for one week to encourage adhesion and ensure sufficient exposure. Corals were revisited approximately three to five months after the treatment application to assess linear lesion progression rates and presence/absence of lesions - the metrics used to quantify the efficacy of each treatment. Although 11 out of the 13 treatments were largely unsuccessful, two Coral Cure saturated rope formulations halted lesion progression and showed no signs of reinfection for 100% of the corals treated (n = 11 and n = 5, respectively). Comparatively, untreated control corals often remained affected with BBD with subsequent measurable tissue loss. These results provide an easily employable, low cost, and low tech method to effectively treat a worldwide coral disease.

Oral
A-1821

Community composition and the epidemiological modeling of coral disease

Farmer, B.[1], Meiling, S.[2], Brandt, M.[2], Holstein, D.[1]
[1]Louisiana State University, Oceanography & Coastal Sciences, Baton Rouge, United States
[2]University of the Virgin Islands, Center for Marine and Environmental Studies, Charlotte Amalie, U.S. Virgin Islands

bfarme8[at]lsu.edu

Abstract

The emergent and highly infectious stony coral tissue loss disease (SCTLD) continues to decimate coral communities in the Caribbean and Western Atlantic reefs. The multi-host disease affects a range of species which exhibit differing susceptibility and infection trajectories, suggesting that community composition may influence reef-scale epidemiology. Here we developed an epidemiological model using monitoring plots that were established at sites prior to disease onset, monitored through the epidemic stages, and monitored into the endemic stage of SCTLD from 2019 to 2021. A modified Susceptible-Infected-Recovered (SIR) compartment model was fitted to empirical observations and extrapolated to spatial projections of coral communities in the US Virgin Islands to assess the influence of species-specific abundances and susceptibility/infectiousness on patterns of disease spread. We demonstrate that variability in disease response, as a function of community composition, has influenced both the form and duration of what may be the most destructive coral disease outbreak.

Oral
A-1674

Spatially and temporally realistic disease dispersal and epidemic modeling of SCTLD in the US Virgin Islands

Holstein, D.[1], Farmer, B.[1], Bloomberg, J.[2], Brandt, M.[3], Ennis, R.[3], Limer, B.[1], Meiling, S.[3], Rossin, A.[1], Smith, T.[3]
[1]College of the Coast and Environment, LSU, Department of Oceanography and Coastal Sciences, Baton Rouge, United States
[2]Woods Hole Oceanographic Institution, Woods Hole, United States
[3]University of the Virgin Islands, Center for Marine and Environmental Studies, St. Thomas, VI, United States

dholstein1[at]lsu.edu

Abstract

Marine diseases that can survive in the water column and disperse using ocean currents tend to have high rates of spread, and Stony Coral Tissue Loss Disease (SCTLD) - previously limited to the Florida reef tract - has recently been observed spreading throughout the Caribbean and Western Atlantic. Coastal currents that carry coral diseases are often highly directional, suggesting that different habitats may experience different disease exposure depending on habitat spatial arrangement and the distribution of infected sites. Further, transmission and mortality studies suggest that corals of different species have different susceptibilities, infectivities, and mortalities associated with SCTLD, and thus, different coral communities would be expected to have different disease trajectories, and contribute differently to the spread of disease. Here we've developed a spatially and temporally realistic Susceptible-Infectious-Recovered-Dead-Susceptible (SIRDS) compartment epidemic model, based on empirical estimates of coral community distributions, species-specific susceptibility, recovery, and mortality, and local hydrodynamics in the US Virgin Islands. Each site in the model thus has internal disease dynamics, nested within a network of connected habitats. Using optimization methods and empirical patterns, we've been able to interrogate unknown disease parameters. This model has considerable utility in predicting the dispersal of coral disease, and shows promise as a tool for targeting habitats for efficient disease interventions or mitigations.

Oral
A-1964

Experimental transmission of Stony Coral Tissue Loss Disease results in differential microbialresponses within coral mucus and tissue

Huntley, N.[1, 2, 3], Brandt, M.[1], Becker, C.[2], Miller, C.[2], Meiling, S.[1], Correa, A.[4], Holstein, D.[5], Muller, E.[6], Mydlarz, L.[7], Smith, T.[1], Apprill, A.[2]
[1]University of the Virgin Islands, St. Thomas, U.S. Virgin Islands
[2]Woods Hole Oceanographic Institution, Woods Hole, United States
[3]The Pennsylvania State, University Park, United States
[4]Rice University, Houston, United States
[5]Louisiana State University, Baton Rouge, United States
[6]Mote Marine Laboratory, Sarasota, United States
[7]University of Texas at Austin, Austin, United States

nhuntley[at]umich.edu

Abstract

Stony coral tissue loss disease (SCTLD) is a widespread and deadly disease that affects nearly half of Caribbean coral species. To understand the microbial community response to this disease, we performed a disease transmission experiment on US Virgin Island (USVI) corals, exposing six species of coral with varying susceptibility to SCTLD. The microbial community of the surface mucus and tissue layers were examined separately using a small subunit ribosomal RNA gene-based sequencing approach, and data were analyzed to identify microbial community shifts following disease acquisition, potential causative pathogens, as well as compare microbiota composition to field-based corals from the USVI and Florida outbreaks. While all species displayed similar microbiome composition with disease acquisition, microbiome similarity patterns differed by both species and mucus or tissue microhabitat. Further, disease-exposed but not lesioned corals harbored a mucus microbial community similar to those showing disease signs, suggesting that mucus may serve as an early warning detection for the onset of SCTLD. Like other SCTLD studies in Florida, Rhodobacteraceae, Arcobacteraceae, Desulfovibrionaceae, Peptostreptococcaceae, Fusibacter, Marinifilaceae, and Vibrionaceae dominated diseased corals. This study demonstrates the differential response of the mucus and tissue microorganisms to SCTLD and suggests that mucus microorganisms may be diagnostic for early disease exposure.

Oral
A-1912

Examining reef-scale impact of localized stony coral tissue loss disease (SCTLD) intervention

Meiling, S.[1], Williams, L.[2], Quetel, J.[1], Brandt, M.[1], Townsend, J.[1, 3]
[1]University of the Virgin Islands, Center for Marine and Environmental Studies, St. Thomas, U.S. Virgin Islands
[2]Coral World Ocean and Restoration Initiative, St. Thomas, U.S. Virgin Islands
[3]National Science Foundation, Biological Oceanography Program, St. Thomas, U.S. Virgin Islands

sonora.meiling[at]gmail.com

Abstract

Stony coral tissue loss disease (SCTLD) was first observed in St. Thomas, United States Virgin Islands in January of 2019. In merely one year, the disease spread to reefs around the entire island of St. Thomas and to the neighboring island of St. John. Due to the rapid expansion of lesions on corals affected by SCTLD, the benthic communities at affected sites were significantly impacted. In the present study, we monitored permanent radial transects at multiple sites around St. Thomas and St. John to compare disease prevalence and impacts between sites with and without regular treatments (i.e., antibiotic paste application, amputation, culling). Transects were established prior to SCTLD emerging at a site and then monitored at regular intervals immediately following the first observations of SCTLD. Diseased corals were treated with antibiotic paste every month by local Strike Team divers and in some instances diseased corals were amputated or culled. Disease prevalence among all sites was highest approximately six weeks after initial observation of disease and declined through the remainder of the monitoring period. There was no difference in overall disease prevalence between treated and non-treated sites. However, there was lower prevalence of diseased *Orbicella* spp. at treated sites compared with non-treated sites one month post-SCTLD confirmation. This suggests localized intervention efforts are most impactful during the epidemic stage of the outbreak and should be prioritized at newly affected sites. Although the impact of SCTLD was high on individual corals, there was no statistical difference in the coral community composition post-SCTLD (up to 1 year), but there were shifts in diversity. SCTLD has the potential to significantly alter modern Caribbean reefs[SM1] [MB2] , thus further research should investigate treatment techniques that have a range of impact beyond a single lesion.

Oral
A-1662

Treatment of coral diseases: historical perspectives, modern efforts in Florida, and future directions

Neely, K., Dobler, M., Macaulay, K., Gallagher, S.
Nova Southeastern University, Dania Beach, United States

kneely0[at]nova.edu

Abstract

As stony coral tissue loss disease (SCTLD) causes extensive mortality across the Florida Reef Tract and other parts of the Caribbean, a variety of intervention techniques have been trialed in efforts to protect infected colonies in Florida. Initial laboratory tests, followed by large-scale field efforts, explored traditional treatment options (smothering, trenching, and chlorinated firebreaks) as well as more innovative antibiotic delivery pastes. The preferred topical amoxicillin treatments effectively halted 95% of SCTLD lesions. Results from three years of subsequent monitoring data identified a proportion of colonies on which new lesions subsequently developed, but the rate of this varied with coral species and also continually declined with time. Overall, mortality of treated corals was less than 5% after two years. Efforts to scale field treatments to colony or potentially reef-level treatments are considered in a cost-benefit and risk management scenario, balancing the known outcome of doing nothing with the unknown outcomes of novel treatment effects.

Oral
A-1688

Multispecies tissue effects of Stony Coral Tissue Loss Disease in Caribbean Corals

Rossin, A.[1], Bloomberg, J.[2], Green, B.[1], Meiling, S.[3], Brandt, M.[3], Studivan, M.[4], Holstein, D.[1]
[1]Louisiana State University, Baton Rouge, United States
[2]Woods Hole Institute of Oceanography, Woods Hole, United States
[3]University of the Virgin Islands, St. Thomas, United States
[4]University of Miami, Cooperative Institute for Marine and Atmospheric Studies, Maimi, United States

aross68[at]lsu.edu

Abstract

An outbreak of a novel coral disease, Stony Coral Tissue Loss Disease (SCTLD), started in the Florida Keys and now affects most of the Caribbean. While SCTLD was first recognized in 2014, how the disease affects coral tissues and endosymbiont cells is still mostly unclear. SCTLD presents similarly to other white syndromes, which have caused significant coral die offs globally since the 1980s. SCTLD differs in that there are acute multifocal infections on single colonies, there is tissue and mucus sloughing, and lesion progression occurs more rapidly. Additionally, it has been shown that different coral species have varying susceptibilities, mortalities, and potentially immune responses to SCTLD. Histopathological techniques were applied to healthy and infected corals from the U.S. Virgin Islands to quantify the tissue effects of SCTLD infection in seven reef-building species, and describe commonalities and differences in the stress response of multiple species to the disease. Aspects of tissue health investigated include vacuolization of zooxanthellae, degree and location of liquifying necrosis, and density of amoebocytes, among others. The presentation of SCTLD in coral tissues could help to identify a pathogen, infection processes, and could point to avenues for remediation. Identifying patterns of infection across species and habitat types is paramount to understanding this devastating disease.

Oral
A-1349

Coral probiotics to treat stony coral tissue loss disease on Florida's Coral Reef

Schul, M.[1], Reed, S.[1], Pitts, K.[2], Ushijima, B.[3], Paul, V.[2], Meyer, J.[1]
[1]University of Florida, Soil and Water Sciences, Gainesville, United States
[2]Smithsonian Marine Station, Fort Pierce, United States
[3]University of North Carolina Wilmington, Biology & Marine Biology, Wilmington, United States

schul.monica[at]gmail.com

Abstract

Various methods to prevent or treat stony coral tissue loss disease (SCTLD) are being developed due to the rapid and devastating spread of this disease throughout Florida's Coral Reef since it was first observed in 2014. The exact cause of SCTLD is unknown, but it is hypothesized to be caused by an infectious waterborne agent and pathogenic bacteria are important to lesion progression. This project explored the impact of probiotic applications on coral microbiomes offshore in Broward County, Florida. After four years of development, probiotic strain *Pseudoalteromonas* sp. McH1-7 has been shown to produce several antimicrobial compounds and effectively treats and prevents transmission of SCLTD. This study tracked the presence of *Pseudoalteromonas* sp. McH1-7 through digital droplet PCR after application to corals in the field. In addition, changes to the overall coral microbiome structure were assessed with 16S rRNA gene libraries. Two different field application methods were used, along with control treatments. We discovered that coral microbial communities varied between species and individuals, but the variation was not explained by the probiotic treatment type or by collection date. Our results suggest that microbiomes were not significantly altered by probiotic treatment, and the probiotic strain, while effective in preventing additional coral mortality, did not bloom on the coral surface. Additional field trials with an optimized field application treatment are underway at a second Broward County site as well as a site in the Middle Florida Keys.

Oral
A-1892

Intervention strategies for diseased corals in Southeast Florida and potential impacts on mucus microbial communities

Shilling, E.[1], Carreiro, A.[1], Combs, I.[1, 2], Studivan, M.[1, 3, 4], Beal, J.[5, 6], Voss, J.[1]
[1]Florida Atlantic University, Harbor Branch Oceanographic Institute, Fort Pierce, United States
[2]Elizabeth Moore International Center for Coral Reef Research & Restoration, Mote Marine Laboratory, Summerland Key, United States
[3]Cooperative Institute for Marine and Atmospheric Studies, University of Miami, School of Marine and Atmospheric Science, Miami, United States
[4]Atlantic Oceanographic and Meteorological Laboratory, National Oceanic and Atmospheric Administration, Miami, United States
[5]Florida Fish and Wildlife Conservation Commission, Fort Pierce, United States
[6]Ducks Unlimited, Fort Pierce, United States

eshilling2013[at]fau.edu

Abstract

Stony coral tissue loss disease (SCTLD) has spread from Florida to multiple locations in Caribbean coral reefs since 2014. The northern section of Florida's Coral Reef has been heavily impacted, with some reefs experiencing as high as 83% coral mortality. Through a collaborative research partnership, both antibiotic and chlorine intervention treatments have been field-tested on diseased colonies at multiple sites in southeast Florida. The aim of this project was to experimentally assess the effectiveness of intervention treatments against SCTLD *in situ*, as well as examine any secondary impacts on treated coral's surface mucus microbial communities. SCTLD-affected *Montastraea cavernosa* colonies offshore of Broward County were tagged and divided into three treatment groups: 1) chlorinated epoxy, 2) CoreRx/Ocean Alchemists Base 2B plus amoxicillin, and 3) untreated controls. The experimental colonies were then monitored using 3D modelling techniques to track lesion progression as well as healthy coral tissue surface area over an 11-month period. To identify potential impacts of the treatments on coral surface mucus microbial communities, mucus samples were assessed with 16S amplicon sequencing to characterize the community makeup. Results show that the antibiotic treatment is more effective for healing individual lesions, reducing the rate of tissue loss, and preserves a greater proportion of healthy tissue. However, it does not necessarily prevent the development of new lesions on treated colonies. Chlorinated epoxy treatment was no more effective than taking no action on SCTLD affected colonies. Further results from this project will elucidate how treatment impacts the diversity and abundance of different microbial groups in the coral surface mucus layer. This integrative approach is designed to both expand management options for managing coral disease outbreaks as well as contribute to overall knowledge regarding coral health.

Oral
A-1754

Optimizing stony coral tissue loss disease intervention strategies through whole-transcriptome gene expression profiling

Studivan, M.[1, 2, 3], Eckert, R.[3], Shilling, E.[3], Soderberg, N.[1, 2], Enochs, I.[2], Voss, J.[3]
[1]University of Miami, Cooperative Institute for Marine and Atmospheric Studies, Miami, United States
[2]National Oceanographic and Atmospheric Administration, Atlantic Oceanographic and Meteorological Laboratory, Miami, United States
[3]Florida Atlantic University, Harbor Branch Oceanographic Institute, Fort Pierce, United States

studivanms[at]gmail.com

Abstract

Stony coral tissue loss disease (SCTLD) remains an unprecedented disease outbreak since its first observation off Miami, Florida in 2014. Due to its high mortality rate and rapid spread throughout Florida's Coral Reef and to the wider Caribbean, a collaborative effort is being made to describe the disease's impact on coral reefs, including its etiology, transmission, and susceptibility among coral species. Additionally, there is a push for disease intervention strategies that may mitigate the spread of SCTLD across individual coral colonies and reef populations. We conducted an in situ experiment in Southeast Florida to assess molecular responses prior to and two weeks following application of the most widely-used intervention method, CoreRx Base 2B with amoxicillin, on SCTLD-affected *Montastraea cavernosa* in conjunction with fate-tracking and sampling of apparently healthy controls. Through Tag-Seq gene expression profiling of apparently healthy, diseased, and treated corals, we identified transcriptomic modulation of metabolomic and immune pathways following antibiotic treatment suggestive of a recovery process. In a complementary ex situ disease challenge experiment, we exposed fragments of nursery-cultured *M. cavernosa* and *Orbicella faveolata* to SCTLD-affected donor corals in order to compare transcriptomic profiles among clonal individuals from disease-unexposed, exposed/displaying disease signs, and exposed/not displaying disease signs treatment groups. Differential expression analysis revealed strong variation (>7,500 differentially expressed genes [DEGs]) between visually-healthy and visually-diseased individuals for *M. cavernosa*, but relatively muted variation (~575 DEGs) in *O. faveolata*. Suppression of metabolic functional groups and activation of stress gene pathways were apparent in both species, consistent with a hypothesized general coral stress response. In addition to increasing our understanding of SCTLD exposure at a molecular level, this study provides resource managers with transcriptomic evidence that disease interventions with antibiotics appear to be successful, and may help to modulate coral immune responses to SCTLD. These results contribute to feasibility assessments of intervention efforts following disease outbreaks and improved predictions of coral reef health in Southeast Florida.

Virtual
Oral
A-1824

Studies of the ecology and treatment of stony coral tissue loss disease in Florida

Paul, V.[1], Ushijima, B.[2], Gunasekera, S.[1], Meyer, J.[3], Pitts, K.[1], Aeby, G.[1], Häse, C.[4]
[1]Smithsonian Institution, Smithsonian Marine Station, Fort Pierce, United States
[2]University of North Carolina Wilmington, Dept. of Biology and Marine Biology, Wilmington, United States
[3]University of Florida, Dept. of Soil and Water Sciences, Gainesville, United States
[4]Oregon State University, Carlson College of Veterinary Medicine, Corvallis, United States

paul[at]si.edu

Abstract

Studies of the chemical ecology of coral diseases can provide insights into beneficial and pathogenic host-microbe interactions. For example, natural products known as looekeyolides from the black band disease cyanobacterium *Roseofilum reptotaenium* were isolated and characterized with an emphasis on determining their natural functions in the disease. The devastating coral disease outbreak occurring on coral reefs of Florida and the Caribbean, called stony coral tissue loss disease, was initially documented in 2014 and continues to the present day, resulting in eight years of coral mortalities in over 20 coral species. This project examined potential causative agents as well as microorganisms that could be used to treat or prevent infections. The widespread pattern of disease occurrence suggested that multiple modes of transmission are involved, and aquarium studies verified that the disease is transmissible by contact and/or waterborne. In aquarium experiments, disease progression was slowed or halted with antibiotic treatments, suggesting that bacteria are important for disease progression. Various bacteria isolated from diseased corals are potentially pathogenic. Bacteria were also cultured from coral fragments resistant to disease and then screened for antibacterial activity to isolate potential protective bacteria (probiotics). Dozens of strains have been isolated and examined for antibiotic production, and some of those antibiotic compounds have been identified. In aquarium studies, disease progression could be slowed in fragments of *Montastraea cavernosa* in response to different strains of probiotics, and at least one strain could prevent infection of pretreated coral fragments. Treatments with the most effective probiotic strains are being conducted in the field and are showing some effectiveness. Because of the devastating nature of stony coral tissue loss disease, researchers and managers have worked together to identify and answer important questions related to disease ecology and develop potential treatments.

Session 4G - What is the role of benthic holobionts and free-living microbes in element recycling and overall ecosystem functioning?

Conceptualized by: **Benjamin Mueller**[1], **Marta Ribes**[2], **Cynthia Silveira**[3], **Jasper de Goeij**[1]
[1] University of Amsterdam (Amsterdam, The Netherlands)
[2] Institut de Ciències del Mar (Barcelona, Spain)
[3] San Diego State University (San Diego, CA, USA)

Chaired by: **Benjamin Mueller**[1], **Cynthia Silveira**[3], **Jasper de Goeij**[1]

Oral
A-1577

Novel Combination of DOM Characterization Reveals Unique Modifications of Coral and Algae Exudate during Remineralization

Arts, M. G. I.[1], Mueller, B.[2, 3], Wegley Kelly, L.[4], Nelson, C. E.[5], Koester, I.[6], Petras, D.[7, 8], Dorrestein, P. C.[7, 8, 9], Hopmans, E. C.[1], Vermeij, M. J. A.[2, 3], Haas, A. F.[1]
[1]NIOZ Royal Netherlands Institute for Sea Research, 't Horntje, Netherlands
[2]University of Amsterdam, Freshwater and Marine Ecology, Institute for Biodiversity and Ecosystem Dynamics, Amsterdam, Netherlands
[3]Carmabi Foundation, Willemstad, Curaçao, [4]San Diego State University, Department of Biology, San Diego, United States
[5]University of Hawaií at Manoa, Department of Oceanography and Sea Grant College Program, Center for Microbial Oceanography Research and Education, Honolulu, United States
[6]Scripps Institution of Oceanography, University of California, San Diego, United States
[7]University of California San Diego, UCSD Collaborative Mass Spectrometry Innovation Center, San Diego, United States
[8]University of California San Diego, Skaggs School of Pharmacy and Pharmaceutical Sciences, San Diego, United States
[9]University of California San Diego, Center for Microbiome Innovation, San Diego, United States

milou.arts[at]nioz.nl

Abstract

Benthic holobionts, such as corals and algae release parts of their photosynthates as dissolved organic matter (DOM) into the surrounding reef waters. These exudates fuels the local DOM pool and serves as a food source for planktonic microbial communities. Bioassays experiments confirm the composition of microbial communities is a DOM source-specific effect. Here we use high-resolution liquid chromatography tandem mass spectrometry (LC-MS/MS) to characterize the molecular compositions of exudates from dominant Caribbean corals and algae and, in addition, investigate the subsequent alterations to these substrates by coral reef microbes. Exu dates were harvested from turf algae, a macro-alga (*Dictyota sp*.), and a mixed coral assemblage (*Colpophyllia natans, Porites astreoides, Favia fragum, Stephanocoenia michelinii, Siderastrea siderea, and Orbicella annularis*) collected from Piscadera Bay, Curacao. To investigate the modifications of labile organic exudates by reef microbial communities, the DOM composition was determined for each benthic primary producer group, along with coral algae exudate mixtures (1:1), at the begin and the end of the 28 hour batch remineralization cultures. Of the 7863 ion features detected, 3981 features were identified statistically as organism-derived exometabolites in at least one of the treatments. Of these exometabolite features 1,304 (32%) were unique to one of the pure or mixture treatment while only 242 (6%) were shared between all treatments showing high composition specificity. The lability of these organism derived exometabolites was further investigated and showed a significant decrease of the unique exometabolite features. Fifty-two of these treatment specific exudates who show a significant decrease in abundance over time, are connected in the network with a feature that increases in abundance over time. With the mass difference between these two features indicating a potential modification, it is shown that there are treatment specific modifications and that a microbial community metabolizes different compounds depending on the available substrate. Identifying molecular differences in DOM released by different benthic holobionts and in the sequential alteration by the microbial community is crucial to determine carbon fluxes between benthic and pelagic components and thus the molecular mechanisms behind coral reef microbialization.

Oral
A-2034

The Fugacious Feast: Microbial Transformation of Dissolved Metabolites in Coral Reefs

Nelson, C.[1], Wegley Kelly, L.[2], Haas, A.[3], Koester, I.[2], Quinlan, Z.[2], Arts, M.[3], Comstock, J.[4], Petras, D.[5], Carlson, C.[4], Aluwihare, L.[2], Dorrestein, P.[6]
[1]University of Hawaii at Manoa, HONOLULU, United States
[2]Scripps Inst Oceanography, San Diego, United States
[3]Netherlands Oceanographic Institution (NIOZ), Texel, Netherlands
[4]University of California, Santa Barbara, Santa Barbara, United States
[5]University of Tuebingen, Teubingen, Germany, [6]University of California, San Diego, San Diego, United States

craig.nelson[at]hawaii.edu

Abstract

Roughly one third of benthic photosynthesis in coral reefs is released into the water as dissolved metabolites available only to osmotrophs such as Bacteria and Archaea. This exudate release is steady day and night, comprising thousands of compounds of which at least hundreds are labile, fostering rapid microbial growth that selectively removes specific metabolites. Various benthic producers exhibit distinct exometabolomes that select for distinct clades of bacterioplankton. This intricate interaction of a complex enriched metabolite pool and a rapidly responding microbial community appears fleeting: the water column of coral reefs worldwide are typically depleted in both microbes and organic matter relative to the surrounding ocean, suggesting rapid and dynamic (re)cycling, something reef ecologists have long hypothesized as central to reef function. In this presentation I summarize our recent work characterizing the exudates released from reef organisms using untargeted metabolomics, describing how exudates are transformed by and select for reef microbial communities, and exploring approaches for detecting these dynamic interactions in and among reef habitats using high frequency temporal and spatial sampling.

Poster
A-1351

Oxygen as a driver of microbialization on coral reefs

Aquino, J., van der Geer, A., Baer, J., Rohwer, F.
San Diego State University, Biology, San Diego, United States

jaquino3754[at]sdsu.edu

Abstract

Microbialization is characterized as the shift in an ecosystem's trophic structure towards higher microbial biomass and energy use. Algal-dominated reefs have been found microbialized because >25% of benthic oxygen production is lost due to ebullition. To determine how oxygen and reef geometry influences microbialization, travertine limestone structural units with five differing internal complexities were deployed in Curaçao. The working hypothesis is that small holes within more complex units will have lower oxygen concentrations thus driving a microbialized environment. Internal water samples from these five structures were processed for both direct counts and with a novel DNA isolation protocol for extracting viral and bacterial DNA simultaneously. Presenting the results from these studies, we will understand how both geometry and oxygen are important for maintaining the microbialized state on coral reefs.

Session 4H - Beyond diversity: What can we learn from exploring microbial function in coral reef holobionts?

Conceptualized by: **Claudia Pogoreutz**[1], **Anny Cárdenas**[1], **Raquel Peixoto**[2], **Till Röthig**[3]
[1] KAUST (Thuwal, Saudi Arabia)
[2] Federal University of Rio de Janeiro (Rio de Janeiro, Brazil)
[3] University of Derby (Derby, UK)

Chaired by: **Claudia Pogoreutz**[1], **Raquel Peixoto**[2]

Oral
A-2197

Does gene expression of antimicrobial peptides shape the composition of the microbiome during development in Acropora digitifera?

Andrade Rodríguez, N.[1], **Huerlimann, R.**[2], Brunner, R.[1], Cooke, I.[1], Grinblat, M.[1], Ravasi, T.[2], Miller, D.[1]
[1]James Cook University, Townsville, Australia
[2]Okinawa Institute of Science and Technology, Onna-son, Japan

roger.huerlimann[at]oist.jp

Abstract

The study of coral holobionts has been proven essential to understand coral biology and the complexity of the interactions between the coral host and its symbionts. Host associated microbiomes have an integral function in the health and resilience of a coral colony. While the interaction between the host-adult coral, its microbiome and the environment has been researched, not much is known about these interactions during the larval and early settlement stages. While recent research has shown selective changes in the microbiome across the development of coral larvae, no connection has yet been made to the role of the host gene expression. However, it has been suggested that antimicrobial peptides (AMPs) and potential quorum quenching enzymes might be facilitating the changes observed in the microbiome community composition of a developing coral larvae. We therefore hypothesize that the coral host can have an active part in shaping their microbial community through the expression of these peptides and enzymes. Following this hypothesis, the aim of the present study was to determine if there is a correlation between the expression of known and potential AMPs in the developmental transcriptome and microbiome of Acropora digitifera. RNA-seq and 16S metabarcoding was used to generate data on differential gene expression and the microbial community, respectively, for 23 developmental
stages ranging from unfertilized eggs to 21 hours post-settlement. These results will allow us to better understand the symbiotic interaction between corals and its bacterial community. This is essential knowledge considering recent approaches of probiotics to help coral resilience.

Oral
A-1496

Insight into cazymes produced by coral-associated bacteria

Damasceno, T.[1], Vilela, C.[1], Peixoto, R.[1, 2]
[1]Federal University of Rio de Janeiro, Paulo de Goes Institute of Microbiology, Rio de Janeiro, Brazil
[2]King Abdullah University of Science and Technology, Division of Biological and Environmental Science and Engineering, Thuval, Saudi Arabia

damasceno.taissa[at]gmail.com

Abstract

Corals are holobionts, composed of a host and its associated microbiome, which play an important role in the holobiont metabolism related to biological control and biogeochemical cycling. Coral-associated bacteria (CAB) have been widely studied in the last decades, although their enzymatic apparatus is still poorly studied. In this context, CAB can produce carbohydrate-active enzymes (CAZymes) involved in the metabolism of carbohydrates, which has not yet been explored in coral holobionts. We hypothesize that these enzymes may be important for microbiome's adaptation and host survival, by adding new catabolic functions to the coral microbiome. Here, we aim to investigate *in silico* putative genes providing beneficial function for coral holobionts, with special focus on CAZyme genes. Four CAB were isolated from *Mussismilia braziliensis* and *Porites asteroids* and had their genome sequenced and annotated using antiSMASH and dbCAN2. The four CAB were identified as *Bacillus amyloliquefaciens* (2), *Micrococcus luteus* and *Exiguobacterium profundum*, as demonstrated by Multilocus sequence analysis (MLSA). A preliminary antiSMASH annotation was made to screen any putative beneficial secondary metabolite, which indicated that all isolates carry at least 1 gene related to terpene production, which can mediate beneficial and antagonistic interactions among marine microorganisms. All isolates also carry genes involved in antibiotic activity, such as RiPPs (ribosomally synthesized and post-translationally modified peptides) and lanthipeptides, which could support coral protection against pathogens. *M. luteus* and the *E. profundum* also carry siderophore genes, putatively important in iron acquisition for corals. The dbCAN2 annotation demonstrated a total of 186 and 115 CAZymes for *B. amyloliquefaciens* strains, 46 in *M. luteus* genome and 151 in *E. profundum*. Next steps include the analysis of the CAZyme data from these isolates and its comparison with other genomes from the same species obtained from different sources (such as water or soil), in order to identify any specificities related to CAB.

Oral
A-1366

From the lab to the real world: Testing the in situ application of a probiotic consortium in Pocillopora verrucosa in the central Red Sea.

Delgadillo, N.[1], Raimundo, I.[1], Villela, H.[1], Garcias-Bonet, N.[1], Santoro, E.[1], Osman, E.[1], Cardoso, P.[1], Barno, A.[1], Duarte Rosado, J. G.[1], Benzoni, F.[1], Berumen, M.[1], Voolstra, C. R.[2], Peixoto, R.[1]
[1]King Abdullah University of Science and Technology, Marine Science, BESE, Thuwal, Saudi Arabia
[2]University of Konstanz, Konstanz, Germany

nathalia.delgadilloordonez[at]kaust.edu.sa

Abstract

The use of Beneficial Microorganisms for Corals (BMCs), or coral probiotics, has been proposed as a microbial therapy to restore and enhance coral health and resilience. Here, we tested a probiotic consortium on the hard coral *Pocillopora verrucosa in situ* for the first time in a reef located in the central Red Sea. We isolated 350 bacterial strains from healthy corals, of which 6 (one *Halomonas* sp., two *Pseudoalteromonas spp.*, two *Cobetias spp.*, and one *Bacillus sp.*) were selected based on their BMC traits, such as Dimethylsulfoniopropionate (DMSP) degradation, reactive oxygen scavenging, nitrogen fixation, and denitrification. To assess the impact of the probiotic consortium on the native coral microbiome, 30 healthy colonies of *P. verrucosa* (15 BMC-treated and 15 Placebo-treated), as well as seawater and sediment samples, were collected. The experiment was run from August to late November of 2021, with three sampling times (T0, in late August, before the inoculations; T1, in mid-October; T2, until late November), covering seasonal variations. The photosynthetic capacity was measured for each sampling point, and coral fragments of each colony were sampled to evaluate the microbiome and assess their thermal threshold. Inoculations were performed twice a week using 50ml plastic syringes containing 30 ml of the probiotic consortium, released slowly all over the colony. The placebo treatment consisted of a 3.5% NaCl solution and was applied the same way as the BMC-treatment. Even though the temperature increased during the summer period, bleaching signs were not detected, and physiological differences did not manifest over time between the treatments, as all colonies appeared visually healthy. However, ongoing microbiome analysis will provide insights into the incorporation of the BMC consortium into the coral holobiont and its effects on the surrounding microbiome. Here, we present the first attempt to manipulate the coral microbiome on a field scale using selected BMCs. This research provides baseline information and strategies for future *in situ* experiments that aim for active coral intervention for conservation purposes in real-world conditions.

Oral
A-1804

Functional signatures of the microbiomes of octocorals in health and disease

Keller-Costa, T.[1], Lago-Lestón, A.[2], Saraiva, J. P.[3], Toscan, R.[3], Silva, S. G.[1], Gonçalves, J.[4], Cox, C. J.[4], Kyrpides, N.[5], Nunes da Rocha, U.[3], Costa, R.[1]
[1]Instituto Superior Técnico, Institute for Bioengineering and Biosciences, Lisbon, Portugal
[2]Centro de Investigación Científica y de Educación Superior de Ensenada, Ensenada, Mexico
Helmholtz Centre for Environmental Research, Leipzig, Portugal
[4]Centro de Ciências do Mar, Universidade do Algarve, Faro, Portugal
[5]Department of Energy, Joint Genome Institute, Berkeley, United States

tinakellercosta[at]tecnico.ulisboa.pt

Abstract

Contrary to scleractinian corals (Scleractinia), in octocorals (Octocorallia) the functional relationship between host health and its symbiotic consortium is yet to be unveiled. Here, we employed comparative metagenomics to uncover the distinct functional and phylogenetic features of the microbiomes of healthy and necrotic *Eunicella gazella* tissues, healthy *Eunicella verrucosa* and *Leptogorgia sarmentosa* tissues, seawater, and sediments.
Multivariate analyses based on 16S rRNA genes, Clusters of Orthologous Groups of proteins (COGs) and Protein families (Pfams) annotated from 20 Illumina-sequenced metagenomes each revealed separate clustering of the prokaryotic communities of healthy tissue samples of the three octocoral species from those of necrotic *E. gazella* tissue and surrounding environments. While the healthy octocoral microbiome was distinguished by so-far uncultivated *Endozoicomonadaceae*, *Oceanospirillales* and *Alteromonadales* phylotypes in all host species, a pronounced increase of *Flavobacteriaceae* and *Alphaproteobacteria*, originating from seawater, was observed in necrotic *E. gazella* tissue. Increased abundances of eukaryotic-like proteins, exonucleases, restriction endonucleases, CRISPR/Cas proteins, and genes encoding for ion transport and iron storage distinguished the prokaryotic communities of healthy octocoral tissue regardless the host species. An augmentation of arginase and nitric oxide reductase genes, observed in necrotic *E. gazella* tissues, suggests the existence of a mechanism for suppression of nitrite oxide production by which octocoral pathogens may overcome the host's immune system.
This is the first study to employ primer-less, shotgun metagenome sequencing to unveil the functional features of prokaryotic communities in octocorals. We show that the octocoral microbiome is sharply distinct from those of the environmental surroundings, is host genus (but not species)-specific and undergoes severe, complex structural changes in the transition to the dysbiotic state. Host-symbiont recognition, abiotic-stress response, micronutrient acquisition and, a sophisticated antiviral defence arsenal are unique signatures of prokaryotic communities in octocorals. These features likely constitute beneficial traits that contribute to the stabilization of symbiosis in octocorals. In this talk, we will also share new insights from our most recent analyses of viral contigs as well as 66 metagenome-assembled genomes (MAGs) retrieved from this dataset.

Oral
A-1525

Stony coral tissue loss disease susceptibility and resistance: Genomic and microbiome factors in Orbicella faveolata

Klein, A.[1], Sturm, A.[1], Eckert, R.[1], Walker, B.[2], Voss, J.[1]
[1]Florida Atlantic University, Harbor Branch Oceanographic Institute, Fort Pierce, United States
[2]Nova Southeastern University, Halmos College of Arts and Sciences, Dania Beach, United States

kleina2020[at]fau.edu

Abstract

Coral disease is a complex threat involving interactions among the coral host's immune system, microbial symbionts, and surrounding environmental conditions. The most recent coral disease to impact Floridian and Caribbean reefs is stony coral tissue loss disease (SCTLD) which affects at least 24 coral species. *Orbicella faveolata,* an important and threatened hermatypic scleractinian species, demonstrates unique intraspecies variation in response to SCTLD. While some *O. faveolata* colonies appear highly susceptible to the disease and can exhibit multiple active lesions, other nearby colonies do not exhibit lesions and are apparently resistant to the disease. The metagenomic underpinnings that may drive variable disease susceptibility phenotypes are not well characterized. Colonies that have been monitored for the past four years in southeast Florida and the Lower Keys were categorized by the frequency of lesion presence as 1) resistant, 2) moderately susceptible, or 3) highly susceptible. These colonies were genotyped using high-resolution restriction site-associated DNA sequencing, generating a robust suite of single nucleotide polymorphisms (SNPs) to quantify genomic variation and identify loci associated with phenotypic variation in disease resistance. Preliminary data analyses suggest that corals with similar disease susceptibility phenotypes exhibit less genetic differentiation relative to other disease susceptibility phenotypes. Microbial community shifts were identified through high-throughput amplicon sequencing of the V3–V4 region of the bacterial 16S ribosomal RNA gene. These data will be used to identify potential differences in microbial taxa between SCTLD-resistant and SCTLD-susceptible corals as well as shifts throughout time and disease progression. We aim to identify coral genotypes that should be prioritized as restoration candidates and to develop microbial bioindicators and screening approaches that can identify corals with subacute signs of infection. This project is part of the SCTLD Resistance Research Consortium which combines gross morphologic, genetic, biochemical, and molecular approaches and expertise among several research groups. The overarching goal of this collaborative effort is to provide a more holistic understanding of the dynamics of this devastating coral disease.

Oral
A-1923

Prophages in host-associated microbes: the most abundant symbiosis on earth and its relevance in marine holobionts

Little, M.[1], Rojas, M. I.[1], Roach, T. N.[1], George, E. E.[2], Arts, M. G.[3], Wegley Kelly, L.[4], Rohwer, F.[1]
[1]San Diego State University, Biology, San Diego, United States
[2]The University of British Columbia, Evolutionary Biology, Vancouver, Canada
[3]University of Texel, Texel, Netherlands
[4]Scripps Institute of Oceanography, San Diego, United States

marklittle1989[at]gmail.com

Abstract

Bacteriophages are the most abundant biological entity on the planet, the most numerous members of any given food web, and key players in carbon and nutrient cycling. Temperate bacteriophages can incorporate into the genome of their bacterial host and remain there in a mutualistic fashion. These prophages typically encode functions that determine the ecology of their bacterial host, often in beneficial ways such as protection against protist predation, nutrient acquisition, carbohydrate utilization, and superinfection immunity from other phages. Here we surveyed prophages and their functional genomic content in a large database of host-associated bacteria from marine environments around the globe. Strikingly, we observed that host-associated bacteria characterized as pathogens contained significantly higher abundances of prophages in their assembled genomes than non-pathogenic host-associated marine bacteria. This specific trend has been observed in human systems, in the context of human bacterial pathogens and non-pathogenic human associated bacteria. Our data suggests that this trend is prevalent in marine environments across a variety of ecosystems and animals. We are now extending these bioinformatic approaches to understand the abundance and functional profiles of prophages in metagenomic profiles of marine holobionts to understand their role in coral reef benthic communities.

Oral
A-1014

Deciphering the role of tissue-associated Endozoicomonadaceae aggregates in the coral Pocillopora acuta

Maire, J.[1], Tandon, K.[1], van de Meene, A.[1], Damjanovic, K.[2], Blackall, L.[1], van Oppen, M.[1, 2]
[1]University of Melbourne, School of Biosciences, Parkville, Australia
[2]Australian Institute of Marine Science, Townsville, Australia

justin.maire[at]unimelb.edu.au

Abstract

Corals house a variety of microorganisms which they depend on for their survival, such as Symbiodiniaceae and bacteria. Bacteria have recently received extensive attention and are potential candidates for coral bleaching mitigation through their manipulation. Several coral genera are known to contain tight clusters of bacteria within their tissues, called cell-associated microbial aggregates (CAMAs), yet little is known about their composition and role. Here, we analysed the location, structure, composition and functional potential of CAMAs in the coral *Pocillopora acuta.* Using fluorescent *in situ* hybridisation (FISH) on both sections and whole polyps, we showed that CAMAs are widespread in the tentacles of several *P. acuta* genotypes. Transmission electron microscopy was applied to further analyse the structure of these aggregates and showed the presence of a membrane surrounding the CAMAs, although the origin and composition of this membrane remains unknown. By examining the presence of CAMAs by FISH in larvae and adults over two successive generations, we uncovered that larvae of some genotypes, but not all, possess CAMAs, suggesting that they can be vertically transmitted. To assess their taxonomic affiliation, CAMAs were isolated using laser-capture microdissection in both larvae and adults and their composition was analysed using 16S rRNA gene metabarcoding. Two genera in the Endozoicomonadaceae family were detected, *Kistimonas* and *Endozoicomonas*. Within a coral genotype, CAMAs were made up of one major bacterial taxon, but different bacterial taxa were observed in CAMAs of distinct coral genotypes. Finally, the same samples were used for shotgun sequencing to reconstruct *Kistimonas* and *Endozoicomonas* genomes and analyse their functional potential. These results are pending but will be presented. In sum, the location of these bacteria inside the coral tissues and possibly within a host membrane (although the origin of the membrane requires further study) along with their potential vertical transmission, makes them of great interest for microbially mediated conservation strategies. Understanding their function within the coral holobiont will provide further insight into their suitability.

Oral
A-1543

Comparative genomics of stony coral-associated bacteria: what makes a good probiotic strain?

Meyer, J.[1], Ushijima, B.[2], Tittl, J.[3], Schul, M.[4], Reed, S.[1], Paul, V.[5]
[1]University of Florida, Soil and Water Sciences Department, Gainesville, FL, United States
[2]University of North Carolina Wilmington, Department of Biology and Marine Biology, Wilmington, NC, United States
[3]University of Florida, School of Natural Resources and Environment, Gainesville, FL, United States
[4]University of Florida, Department of Environmental Engineering Sciences, Gainesville, FL, United States
[5]Smithsonian Marine Station, Fort Pierce, FL, United States

juliemeyer[at]ufl.edu

Abstract

Interest in beneficial microbes for corals and their application as probiotic treatments has grown around the world. Currently, probiotic treatments using beneficial bacteria are being developed to improve coral heat tolerance and to treat coral disease. In the pursuit of probiotic treatments for stony coral tissue loss disease, we isolated roughly 900 bacteria from disease resistant corals. We sequenced the genomes of 60 potential probiotic strains and an additional 16 healthy coral-associated bacteria from a total of ten Caribbean coral species. These 76 genomes effectively double the number of publicly available coral-associated bacterial genomes and provide a solid foundation from which to discern the genome characteristics indicative of probiotic potential. The most promising strains to date for coral disease treatments are *Pseudoalteromonas* isolates, whose genomes contained high levels of biosynthetic gene clusters including non-ribosomal peptide synthetase (NRPS), Type I polyketide synthase (T1PKS), and ribosomally synthesized and post-translationally modified peptide (RiPP) gene clusters. Biosynthetic genes in *Pseudoalteromonas* correspond with known antimicrobial compounds such as korormicin, marinocine, and pseudoalterin that may be important in coral disease treatment. The genomes of less bioactive strains, such as *Halomonas* isolates, had fewer biosynthetic gene clusters overall, yet nearly all had putative biosynthetic genes for beta-lactones that may be highly potent bioactive natural products. Development of safe and effective probiotic treatments for coral conservation depends on the thorough characterization of beneficial microbes through genome sequencing, chemical ecology, and lab-based physiological assays. This project aims to eventually determine what makes an effective probiotic in order to develop faster and more efficient ways of screening for and identifying additional strains for other coral diseases.

Oral
A-1370

Coral Probiotics: Localization and Mechanisms of Host-Microbiome Interaction

Moreira Cardoso, P.[1], Villela, H.[1], Rosado, J. G.[1], Rosado, P.[1], Vilela, C.[2], Buitrago, M. A.[2], Duarte, G.[2], Assis, J.[2], Hill, L.[2], Borges, R.[3], Thomas, T.[4], Peixoto, R.[1]
[1]King Abdullah University of Science and Technology, Red Sea Research Center, Thuwal, Saudi Arabia
[2]Federal University of Rio de Janeiro, Paulo de Góes Institute of Microbiology, Rio de Janeiro, Brazil
[3]Federal University of Rio de Janeiro, Walter Mors Institute of Research of Natural Products, Rio de Janeiro, Brazil
[4]The University of New South Wales, Centre for Marine Science and Innovation, Sydney, Australia

pedromoreiracardoso28[at]gmail.com

Abstract

Coral reefs are amongst the most diverse ecosystems in the world, and critical to the survival of its main constructing organism, the coral animal, is the symbiosis with algae of the family Symbiodiniaceae. The loss of these endosymbionts from coral tissue, known as coral bleaching, is a common response to stress. Increases in sea surface temperatures have caused peaks of coral mortality by bleaching, creating a need to pursue measures for reef protection. Corals also host an array of organisms forming their microbiomes, which have complex ecological roles and contribute to maintain their health and homeostasis with the algae. The potential function of the microbiome in homeostasis led to the proposal of the term Beneficial Microorganisms for Corals (BMC) to define symbionts that promote coral health and the use of such organisms as probiotics to target coral disease. One of the first attempts to improve coral health with probiotics was a mesocosm experiment testing a BMC consortium on *Pocillopora damicornis* fragments under increasing temperatures and exposed to the pathogen *Vibrio coralliilyticus.* Probiotics were found then to reduce coral bleaching rates. Although specific beneficial mechanisms of the microbes were hypothesized and used to select the consortium, the mode of action have not been thoroughly tested, and the location of the inoculated bacteria in the host's tissues has not been determined. Since locating such bacteria and studying different health proxies of the host are critical to understand the effect of the consortium on coral physiology, another experiment exposing coral fragments to similar conditions has been carried out, using more replicates and including more time points. During the experiment, different proxies were surveyed, such as coral calcification and respiration rates, primary productivity, F_v/F_m, metabolic contents, and bacterial diversity. During the experiment, higher average values of photosynthesis and *Fv/Fm* were found in the BMC treated group during one of the time points during heat stress. The bacteria will be located through fluorescence *in situ* hybridization, with probes targeting the pathogen and the inoculated bacteria. The test's results will be vital to understand the effects of BMCs in coral health and to assist future trials for probiotics, which use could become an important strategy for reef conservation.

Oral
A-1869

Steroid exchanges putatively drive coral-Endozoicomonas symbiosis

Ochsenkühn, M.[1], Abrego, D.[2], Mohamed, A.[1], Amin, S.[1]
[1]New York University Abu Dhabi, Abu Dhabi, United Arab Emirates
[2]Southern Cross University, Coffs Harbour, Australia

mao13[at]nyu.edu

Abstract

Cnidarians are highly complex metaorganisms that have evolved ~530 million years ago. They house specific symbionts and a diverse microbiome with which they exchange a myriad of metabolites to increase their metabolic fitness, adaptation to environmental stress and pathogens. However, our knowledge of the chemical language that structures these symbiotic interactions and influences the fitness of corals is in its infancy. Here, we monitored and sampled 10 colonies of the coral *Acropora* off the coast of the Persian/Arabian Gulf, across a temperature gradient spanning 24°C to 34°C. Coral nubbins were collected and extracted for shotgun metagenomics, 16S rRNA gene profiling and metabolomics analysis. Coral holobiont metabolomes exhibited significant changes in extreme temperatures (34°C) compared with ‘moderate’ temperatures (~27°C), suggesting a stress response. This pattern coincided with significantly different microbial composition observed in the metagenomic and 16S rRNA gene profiles of samples at extreme temperatures. In addition, metagenomically assembled genomes (MAGs) showed potentially opportunistic Rhodobacteraceae MAGs that were more abundant at extreme temperatures, while potential coral symbionts like an *Endozoicomonas* MAG were consistently associated with all coral samples. Surprisingly, functional analysis of 11 bacterial MAGs compared to draft genomes of the coral and the algal symbiont (*Cladocopium*) assembled from these metagenomes indicated the compartmentalization of steroid pathways. *Cladocopium* is the only holobiont member capable of producing terpenoids-based steroids, which can be utilized by the coral to synthesize steroid hormones, such as testosterone. In turn, the *Endozoicomonas* MAG is the only holobiont member with steroid degradation capabilities to androgens (key hormones in animal growth and reproduction). Out of 159 metabolites identified using untargeted metabolomics (LC/MSMS), the coral putatively produces Cholestenone and testosterone that are then putatively converted by *Endozoicomonas* to Androstadienedione and HIP, which may play a role in coral growth/reproduction. This putative symbiotic exchange breaks down at extreme temperatures evidenced by the significant depletion of these metabolites at 32°C and 34°C. These findings shed light on a long-hypothesized symbiosis between corals and *Endozoicomonas* and potentially transform our knowledge of coral symbiosis and responses of the coral holobiont to climate change.

Oral
A-1378

Assessing the symbiotic interplay of photosynthesis and osmoregulation in Aiptasia

Pogoreutz, C., Rädecker, N., Meibom, A.
Ecole Polytechnique Federale de Lausanne, Lausanne, Switzerland

claudia.pogoreutz[at]epfl.ch

Abstract

Osmoregulation is an essential mechanism to maintain cellular homeostasis in constantly changing environments. Photosymbiotic holobionts, such as Cnidaria, are characterized by a constant exchange of nutrients between the symbiotic partners. This exchange induces fluctuations of osmotically active substances (e.g., glycerol) in cells and tissue structures, which create highly dynamic osmotic conditions requiring tight osmoregulation among members of the holobiont to achieve osmotic balance. The dynamics of holobiont osmoregulation may therefore be critical to understanding the metabolic regulation of symbiotic interactions. However, disentangling the uptake, synthesis, and translocation of highly soluble osmolytes between symbiotic partners has proven challenging. Here, we harness the recent development of a new CryoNanoSIMS instrument to visualize and quantify the subcellular distribution of key osmolytes in the intact cnidarian holobiont. We seek to assess mechanisms of osmoregulation *via* osmolyte dynamics between cnidarian host and associated microbes in response to changing osmotic environments in the model system *Exaiptasia diaphana.* The goal is to elucidate the interplay of holobiont nutrient cycling and osmoregulation as a metabolic pacemaker of symbiotic interactions.

Oral
A-1763

Integrating multi-omics tools and microbiome manipulation for coral reef restoration

Roach, T.
San Diego State University, San Diego, United States

smokinroachjr[at]gmail.com

Abstract

All plants and animals host communities of prokaryotes and viruses and have a unique chemical milieu. Together with the macroorganisms, these microbes and chemicals collectively form an ecological unit known as the holobiont. Each of these components have been shown to play critical roles in host health, metabolism, and development. Integrated approaches are now needed to better understand the specific roles of each component of the holobiont. We have developed new methods including a single polyp multi-omics approach to investigate the interactive roles of bacteria, viruses, and biochemicals in corals' resistance to stressors at multiple spatial scales. Our results indicate that there are specific bacteria, viruses, functional genes, and metabolites that are associated with corals' susceptibility to thermal stress and algal overgrowth. We have subsequently used these findings to elucidate biomarkers, which can distinguish thermally tolerant corals from corals that are susceptible to thermal bleaching. This will enable the selection of thermally resilient coral stock for restoration practices. Furthermore, these findings were also used to aid in the design of protbiotic blends to test whether resistance to stressors could be enhanced in three common Pacific reef-building corals (*Pocillipora acuta, Porites compressa,* and *Montipora capitata*). Building on our multi-omics approaches *in situ*, we have designed experimental manipulations to achieve a mechanistic understanding of the specific roles of microbes and metabolites in facilitating coral survival from bleaching and algal overgrowth. These approaches ultimately provide opportunities to design novel reef restoration techniques involving probiotics, phage therapy, gene therapy, and other *precision medicine* techniques.

Oral
A-1477

Coral microbiome manipulation elicits metabolic and genetic restructuring to mitigate heat stress and evade mortality

Santoro, E.[1, 2], Borges, R.[3], Espinoza, J.[4], Freire, M.[4, 5], Messias, C.[6], Villela, H.[1, 2], Leandro, P.[6], Villela, C.[6], Rosado, J. G.[2, 7], Cardoso, P.[1, 2], Rosado, P.[1, 2], Assis, J.[6], Duarte, G.[6], Perna, G.[7, 8], Rosado, A.[6, 7], Macrae, A.[6], Dupont, C.[4], Nelson, K.[4], Sweet, M.[9], Voolstra, C.[1, 7, 8], Peixoto, R.[1, 2, 7]
[1]King Abdullah University of Science and Technology (KAUST), Red Sea Research Center, Thuwal, Saudi Arabia
[2]Federal University of Rio de Janeiro, Institute of Microbiology, Rio de Janeiro, Brazil
[3]Federal University of Rio de Janeiro (UFRJ), Walter Mors Institute of Research on Natural Products, Rio de Janeiro, Brazil
[4]J. Craig Venter Institute, Department of Genomic Medicine and Infectious Diseases, La Jolla, CA, USA., United States
[5]J. Craig Venter Institute, Department of Infectious Diseases and Global Health, School of Medicine, La Jolla, CA, USA., United States
[6]Federal University of Rio de Janeiro (UFRJ), Institute of Microbiology, Rio de Janeiro, Brazil
[7]King Abdullah University of Science and Technology (KAUST), Division of Biological and Environmental Science and Engineering (BESE), Thuwal, Saudi Arabia
[8]University of Konstanz, Department of Biology, Konstanz, Germany
[9]University of Derby, Aquatic Research Facility, Environmental Sustainability Research Centre, Derby, United Kingdom

erikapsantoro[at]gmail.com

Abstract

Beneficial Microorganisms for Corals (BMC) ameliorate environmental stress, but whether they can prevent mortality and the underlying host response mechanisms remain elusive. Here we conducted a multiomics analyses on fragments of *Mussismilia hispida* exposed to bleaching conditions in a long-term mesocosm experiment and inoculated with a selected BMC consortium or saline solution as placebo. A total of six bacteria were selected based on beneficial traits such as nitrogen fixation, nitrification, Dimethylsulfoniopropionate (DMSP) degradation, reactive oxygen species scavenging and antagonistic activity against the coral pathogen *Vibrio coralliilyticus* to compose the BMC consortium. Fragments of *M. hispida* were exposed to high temperature in a 75-days mesocosm experiment, where part of them received the BMC consortium and the others received the placebo treatment. After 30 days of acclimatization at 26°C, the temperature was increased (0.5°C per day) up to 30.5°C for 10 days, and then decreased back to 26°C for 25 days of recovery. Samples were taken at the beginning of the experiment (T0), at the peak of temperature (T1), at the last day of high temperature (T2) and after the recovery period (T3). All corals were impacted by the heat stress at T2, with a reduction of their algae photosynthetic efficiency (F_v/F_m) and visual bleaching signs. However, BMC-treatment seemed to help the coral to evade mortality, by increasing in 40% the survival rate and their F_v/F_m values at the end of the recovery period (T3). Additionally, BMC-treatment demonstrated to mitigate a “post-heat stress disorder” (PHSD), downregulating genes mainly involved in apoptosis and inflammation, but also promoting upregulation of repair and stress protection genes. Patterns of DMSP degradation and lipidic-stock maintenance across time and stress concomitant with the incorporation of members of the BMC consortium in the treated coral microbiome also indicate the role of the beneficial bacterial promoting coral resilience. Therefore, this study provides insights into the responses that underlie probiotic host manipulation. We demonstrate that BMCs trigger a dynamic microbiome restructuring process that instigates genetic and metabolic alterations in the coral host that eventually mitigate coral bleaching and mortality.

Oral
A-1100

Relative abundance of nitrogen cycling microbes in coral holobionts reflects environmental nitrate availability

Tilstra, A.[1], Roth, F.[2, 3], El-Khaled, Y.[1], Pogoreutz, C.[4], Rädecker, N.[4], Voolstra, C.[5, 6], Wild, C.[1]
[1]University of Bremen, Marine Ecology, Bremen, Germany
[2]Stockholm University, Baltic Sea Centre, Stockholm, Sweden
[3]University of Helsinki, Tvärminne Zoological Station, Hanko, Finland
[4]École polytechnique fédérale de Lausanne, Environmental Engineering Institute, Lausanne, Switzerland
[5]University of Konstanz, Department of Biology, Konstanz, Germany
[6]King Abdullah University of Science and Technology, Red Sea Research Center, Thuwal, Saudi Arabia

arjentilstra[at]gmail.com

Abstract

Recent research suggests that nitrogen (N) cycling microbes are important for coral holobiont functioning. In particular, coral holobionts may acquire bioavailable N via prokaryotic dinitrogen (N_2) fixation or remove excess N via denitrification activity. However, our understanding of environmental drivers on these processes *in hospite* remains limited. Employing the strong seasonality of the central Red Sea, this study assessed the effects of environmental parameters on the proportional abundances of N cycling microbes associated with the hard corals *Acropora hemprichii* and *Stylophora pistillata*. Specifically, we quantified changes in the relative ratio between *nirS* and *nifH* gene copy numbers, as a proxy for seasonal shifts in denitrification and N_2 fixation potential in corals, respectively. In addition, we assessed coral tissue-associated Symbiodiniaceae cell densities and monitored environmental parameters to provide a holobiont and environmental context, respectively. While ratios of *nirS* to *nifH* gene copy numbers varied between seasons, they revealed similar seasonal patterns in both coral species, with ratios closely following patterns in environmental nitrate availability. Symbiodiniaceae cell densities aligned with environmental nitrate availability, suggesting that the seasonal shifts in *nirS* to *nifH* gene abundance ratios were probably driven by nitrate availability in the coral holobiont. Thereby, our results suggest that N cycling in coral holobionts probably adjusts to environmental conditions by increasing and/or decreasing denitrification and N_2 fixation potential according to environmental nitrate availability. Microbial N cycling may, thus, extenuate the effects of changes in environmental nitrate availability on coral holobionts to support the maintenance of the coral–Symbiodiniaceae symbiosis.

Oral
A-1547

A survey of healthy Caribbean coral microbiomes: The search for beneficial microbes for coral conservation

Tittl, J.[1], Ushijima, B.[2], Schul, M.[3], Howard, R.[4], Aeby, G.[5], Paul, V. J.[5], Meyer, J. L.[4]
[1]University of Florida, School of Natural Resources and Environment, Gainesville, United States
[2]University of North Carolina Wilmington, Department of Biology & Marine Biology, Wilmington, United States
[3]University of Florida, Environmental Engineering Sciences, Gainsville, United States
[4]University of Florida, Soil and Water Sciences Department, Gainsville, United States
[5]Smithsonian Marine Station, Fort Pierce, United States

jessicatittl[at]ufl.edu

Abstract

The coral microbiome is an important part of the coral holobiont, contributing to host health and acting as a first line of defense against disease. Understanding the healthy coral microbiome could aid in conservation efforts, including coral propagation and restoration, as well as assisted evolution and microbiome engineering treatments to protect corals from disease. In the Caribbean, stony coral tissue loss disease (SCTLD), has spread rapidly and impacts over twenty stony coral species. Interestingly, there appears to be intra- and interspecific variations in susceptibility to SCTLD. We surveyed 175 microbiomes from twelve of these coral species before the arrival of SCTLD in Belize and the Cayman Islands. We sequenced the V4 region of the 16S rRNA gene and detected over 20,000 amplicon sequence variants. Microbiome community structure was correlated with coral species and susceptibility to SCTLD, but not with location. In concordance with many previous studies, coral microbiomes were predominantly made up of Alphaproteobacteria and Gammaproteobacteria. Common genera included the endosymbiotic gammaproteobacterium, *Endozoicomonas*, as well as the alphaproteobacterial genera *Terasakiellaceae* (Rhodospirillales), *Candidatus Aquarickettsia* (Rickettsiales), and *Thalassobius* (Rhodobacterales). Notably, some of these predominant genera have been previously associated with disease, such as *Ca. Aquarickettsia* in white band disease and *Terasakiellaceae* with SCTLD. In addition, blastn searches of predominant amplicon sequence variants revealed exact matches to coral-associated *Pseudoalteromonas* and *Thalassobius* isolates that have been explored for their probiotic potential and have sequenced genomes. Linking potential functions from genomes of isolates to broad geographical and taxonomic surveys of coral microbiomes will provide baseline data that can inform future conservation efforts including microbiome engineering.

Oral
A-1536

Role of the cnidarian-algal symbiosis in structuring denitrifying bacterial communities

Xiang, N.[1], Rädecker, N.[2], Pogoreutz, C.[2], Cárdenas, A.[3], Meibom, A.[2], Wild, C.[4], Gärdes, A.[1], Voolstra, C.[3]
[1]Helmholtz Centre for Polar and Marine Research, Bremerhaven, Germany
[2]École Polytechnique Fédérale de Lausanne (EPFL), Lausanne, Switzerland
[3]University of Konstanz, Konstanz, Germany
[4]University of Bremen, Bremen, Germany

nanxiang[at]uni-bremen.de

Abstract

The coral-algal symbiosis depends on constant nitrogen (N) limitation to regulate algal growth and promote the translocation of photosynthetically fixed carbon (C) to the host. However, anthropogenic changes threaten the stability of this symbiosis. Coral-associated denitrifying bacteria, i.e., prokaryotes capable of reducing nitrate/nitrite to dinitrogen gas, could play a key role in preventing the accumulation of N from the holobiont, to help maintain a functional symbiosis. However, it is still unknown whether the abundance and diversity of denitrifying bacteria differ among different cnidarian symbiotic states. Using the cnidarian model organism Aiptasia, we quantified and characterized the denitrifying bacterial communities in a set of host-algal symbiotic combinations. Relative abundances of denitrifying bacteria were nearly 3-fold higher in symbiotic Aiptasia compared to their aposymbiotic counterparts. In line with this, while denitrifying bacterial communities of aposymbiotic Aiptasia were largely dominated by *Halomonas*, symbiotic Aiptasia showed an increased relative abundance of *Ketobacter* or *Kangiella*. Algal cultures were also associated with denitrifying bacteria, with the prevalence of *Ketobacter* in SSA01 (*Symbiodinium linucheae*), *Hydrogenophaga* in SSB01 (*Breviolum minitum*). Comparably, symbiotic Aiptasia hosted a higher number of exclusive denitrifying taxa compared to their aposymbiotic counterparts and the algal cultures. Taken together, our results reveal that host and symbiont identity contribute to structuring the denitrifier communities of Aiptasia. Yet, these effects may largely reflect the indirect consequences of symbiosis-dependent holobiont nutrient availability rather than an active community structuring by either symbiotic partner.

Oral
A-1734

Bacterial communities of early life stages of corals predict their heat tolerance

Ziegler, M.[1], Howells, E.[2], Hauffe, T.[1], Pogoreutz, C.[3], Burt, J.[4], Voolstra, C.[5]
[1]Justus Liebig University Giessen, Marine Holobiomics Lab, Giessen, Germany
[2]University of Wollongong, Wollongong, Australia
[3]Swiss Federal Institute of Technology in Lausanne, Lausanne, Switzerland
[4]New York University Abu Dhabi, Abu Dhabi, United Arab Emirates
[5]University of Konstanz, Konstanz, Germany

maren.ziegler[at]bio.uni-giessen.de

Abstract

Bacterial communities of mature stony corals may influence the thermal tolerance of their hosts. However, it is currently unknown if bacterial communities of critical early life stages may also influence larval heat tolerance. Here we investigated the effects of thermal origin and parentage on the bacterial communities and heat tolerance of coral progeny. We bred 50 full-sib families from the eggs and sperm of 17 colonies of *Platygyra daedalea* from the thermally extreme Persian Gulf and the thermally moderate Indian Ocean. Using 16S rRNA gene metabarcoding, we first show that bacterial communities across coral life stages differed between these regions. In larvae, bacterial communities between Persian Gulf and Indian Ocean purebred crosses were distinct from each other, but not from regional hybrids. We then subjected coral larvae from the different crosses to a heat stress experiment (27, 33, 36°C) and monitored for survival and bacterial community dynamics. At 36 °C regional hybrids displayed similar survival rates (71 %) to the more heat tolerant Persian Gulf purebreds (72 %), which were significantly higher than in Indian Ocean purebreds (53 %). Temperature treatment was the strongest driver of larval microbial communities and explained 16 % of the total variation. In contrast, relatedness among larval families and mother identity had a minor influence on larval bacterial communities (7 and 1 % variation explained, respectively). We then identified bacterial taxa for which changes in abundance predicted larval survival under heat. Typical bacterial associates of coral larvae such as Marinobacter were positively associated with heat survival, while opportunistic taxa such as Rhodobacteraceae were negatively associated with survival. We conclude that bacterial communities of coral larvae are linked to their heat tolerance. Our findings also highlight the potential of probiotic applications for breeding heat tolerant coral larvae to enhance their survival under warming ocean conditions.

Poster
A-1642

Epigenetic responses to microbiome manipulation in corals

Barno, A.[1], Villela, H.[1], Rosado, P.[1], Cardoso, P.[1], Voolstra, C.[2], Peixoto, R.[1, 3]
[1]King Abdullah University of Science and Technology, Thuwal, Saudi Arabia
[2]University of Konstanz, Konstanz, Germany
[3]Federal University of Rio de Janeiro, Rio de Janeiro, Brazil

adam.barno[at]kaust.edu.sa

Abstract

Coral mortality due to environmental stress has continued to rise in recent years. To counter the rapid coral decline, various techniques have been employed to either manipulate the composition of the microbial community on corals or tinker with coral epigenetics through environmental hardening. The relationship between microbial composition and epigenetics, however, is poorly understood in corals. In other metaorganisms, like humans, microorganisms are known to alter host epigenetics via direct or indirect mechanisms. To determine if similar interactions exist between bacteria and the coral epigenome, we searched for homologs of known epigenetic-modifiers in coral microbiomes. Using both assembled genomes from isolated bacteria and metagenome-assembled genomes from coral holobionts, protein homologs were discovered for Internalin B (InlB), which indirectly modifies epigenetic marks in humans, as well as the direct epigenetic-modifying enzymes Ankyrin-repeat protein A (AnkA), Rv1988 histone methyltransferase, and Rv2966c DNA methyltransferase. To further explore the hypothesis that bacteria can alter the coral phenotype and epigenome, isolated strains of commensal and pathogenic bacteria were inoculated separately and together with the coral *Pocillopora verrucosa* and subjected to a one-month high temperature experiment. The chosen bacterial strains were all isolated from Pocilloporids. Clonal fragments of *P. verrucosa* were collected from the Red Sea and exposed to long-term high temperature stress with a putative beneficial microorganism for corals (pBMC) and/or the opportunistic pathogen *Vibrio coralliilyticus* BAA450 to determine if bacterial exposure can positively and negatively affect coral health. Photosynthetic efficiency and total protein content were analyzed to assess host phenotypic response to each bacterial treatment. In parallel, 16S rRNA gene amplicon sequencing was performed to analyze the microbiome, and methylated DNA was sequenced using an alternative to bisulfite sequencing called Methyl-Seq. This current work is projected to serve as a proof-of-principle of whether exposure to bacteria can cause coral host epigenome modifications that result in holobiont phenotypic changes.

Poster
A-1055

Functional and comparative metagenomics of viral communities in healthy and diseased octocoral tissue and seawater

Marques, M.[1, 2], Keller-Costa, T.[1, 2], Lopes Baeta, R.[3], Lago-Lestón, A.[4], Nunes da Rocha, U.[5], Paez-Espino, D.[6, 7], Kyrpides, N.[6, 7], Costa, R.[1, 2]
[1]Instituto Superior Técnico, Institute for Bioengineering and Biosciences, Lisbon, Portugal
[2]Instituto Superior Técnico, Institute for Health and Bioeconomy, Lisbon, Portugal
[3]Instituto Superior Técnico, Department of Computer Science and Engineering, Lisbon, Portugal
[4]Centro de Investigación Científica y de Educación Superior de Ensenada, División de Biología Experimental y Aplicada, Ensenada, Mexico
[5]Helmholtz Centre for Environmental Research, Department of Environmental Microbiology, Leipzig, Germany
[6]Joint Genome Institute, Department of Energy, Berkeley, United States, 7Lawrence Berkeley National Laboratory, Berkeley, United States

matildesangremanmarques[at]tecnico.ulisboa.pt

Abstract

With an estimated abundance of 10^{30} particles in the marine environment, viruses are a vast reservoir of unexplored genetic diversity. Corals are known to engage in intimate relationships with diverse groups of microeukaryotes, prokaryotes and viruses. However, research on coral-associated viruses is still in its infancy and the virome of octocorals (subclass Octocorallia) has received very little attention. In this study, we use comparative metagenomics to uncover the distinct features of the healthy octocoral virome by contrasting it with the viromes of diseased octocorals and seawater. Seventeen microbial metagenome samples from three octocoral species (healthy and necrotic *Eunicella gazella* tissue (*N*=6), healthy *Eunicella verrucosa* (*N*=4) and *Leptogorgia sarmentosa (N=3)*) and surrounding seawater (*N*=4) were analysed using the viral detection pipeline from Paez-Espino et al. (2017). A total of 9,455 metagenomic viral contigs (mVCs) were identified whereby the number of contigs retrieved from seawater samples (8,782 mVCs) was much higher than the number from all coral samples (673 mVCs). Moreover, the number of mVCs was notably higher in necrotic tissue of *E. gazella* (404 mVCs) compared with healthy tissue (73 mVCs). The low number of viral contigs present in the metagenomes of healthy tissue correlates with a significantly higher abundance of restriction endonucleases, CRISPR/Cas proteins and phage lysogenization regulators present in these samples, suggesting that the octocoral microbiome possesses sophisticated antiviral defense strategies. Multivariate analysis of Clusters of Orthologous Groups of proteins profiles of the mVCs revealed significant functional divergence between the viromes of seawater with those from octocoral samples. Annotation of secondary metabolite biosynthetic gene clusters (SM-BGCs) using antiSMASH v6.0 detected the presence of a homoserine-lactone SM-BGC in the virome associated with necrotic *E. gazella* tissue, suggesting a role for bacteriophages in the regulation of bacterial populations and spread of signalling molecules during the dysbiosis process. We conclude that the virome of octocorals is highly distinct from that of seawater and undergoes structural changes in the transition to the dysbiotic state. Ongoing work focuses on establishing a taxonomic classification of the viral contigs and screening for CRISPR-Cas spacers, in order to predict phage-host associations within the octocoral microbiome.

Poster
A-1392

The Effects of Microbiome Manipulation on the Deep-Sea Coral Eguchipsammia fistula and its Associated Microbial Community

Villela, H.[1], Barno, A.[1], Benzoni, F.[1], R. Voolstra, C.[2], Peixoto, R.[1]
[1]King Abdullah University of Science and Technology, Red Sea Research Center, Thuwal, Saudi Arabia
[2]University of Konstanz, Department of Biology, Konstanz, Germany

helena.villela[at]kaust.edu.sa

Abstract

Corals are holobionts consisting of the cnidarian host and a pool of microorganisms that provide essential functions related to metabolism, protection, and adaptation to environmental conditions. Most shallow water corals associate with microalgal symbionts from the family Symbiodiniaceae (zooxanthellae) that can provide up to 90% of the host's nutritional requirements via photosynthesis. Deep-sea corals, however, mostly inhabit the aphotic zone, where photosynthesis does not occur, and corals are not known to associate with zooxanthellae. Therefore, the role of the associated bacteria may be more substantial in deep water corals compared to shallow ones, especially regarding nutrient input. Though it has been shown that the bacterial community associated with deep-sea corals is flexible and variable, little is known about what drives these changes. Here, we exposed the deep-sea coral *Eguchipsammia fistula* to two microbial manipulation experiments. In a first experiment, we inoculated a cocktail of shallow water coral associated microbes (including zooxanthellae) in the presence or absence of light. The main goal was to determine if microbes associated with shallow water corals can shape the core microbial community associated with the deep-sea corals, i.e., which strains are incorporated by the corals, and how light influences the microbiome flexibility. In a second experiment, we exposed *E. fistula* to the bioluminescent bacteria *Vibrio harveyi* (DSM6904). Both shallow and deep-sea corals are found associated with bioluminescent bacteria. However, the role of these bacteria and the effects of bioluminescence on corals and their microbiomes remain poorly understood. For both experiments, four nubbins of *E. fistula* were kept in tanks under the same conditions, the only difference being the microbial inoculums, which were administered every 48 hours, for 10 days. Using a stereoscope, images of all fragments were taken at the beginning and end of the experiments to assess gross morphology of the extended polyps. DNA and RNA were extracted and sent for sequencing to perform amplicon sequencing analysis of the 16S rRNA and internal transcribed spacer genomic regions, and transcriptomics analysis of the coral host, respectively. Our results will help elucidate the role of deep-sea coral associated microbiomes on the host physiology and discover how exposure to non-native microbes might affect the core bacterial community and, ultimately, the host metabolism.

Virtual
Oral
A-1333

Comparative and Functional Genomics of Beneficial Microorganisms for Corals from Pocillopora damicornis

Rosado Magalhães, P.[1], Cardoso, P.[1], Rosado, J.[1], Schultz, J.[1], Rocha, U.[2], Costa, T.[3], Peixoto, R.[1]
[1]King Abdullah University of Science and Technology, Red Sea Research Center, Jeddah, Saudi Arabia
[2]Helmholtz-Centre for Environmental Research, Department of Environmental Microbiology, Leipzig, Germany
[3]Universidade de Lisboa, Institute for Bioengineering and Bioscience, Lisboa, Portugal

phrosado11[at]gmail.com

Abstract

Environmental factors, microbe-microbe and microbe-host interactions act simultaneously to structure host-associated microbial communities, making the dynamics of the microbiome a challenge to predict. Following this concept, a consortium of Beneficial Microorganisms for Corals (BMC), composed of seven strains, five *Pseudoalteromonas* sp., one *Cobetia* sp. and one *Halomonas sp.*, was recently tested by our group in a thermal stress and pathogen challenge experiment on *Pocillopora damicornis*. The results indicated that the coral microbiome can be manipulated to decrease bleaching. The purpose of this work is to perform an *in silico* analysis of the genome of the *P. damicornis* BMCs used in the previous study aiming to identify potential molecular mechanisms of interaction between members of the consortium and the host. The genomes of the BMC strains were sequenced on an Illumina Miseq platform. The raw sequence reads were trimmed using Trimmomatic v0.36, assembled with SPAdes v3.13.0, and the gene prediction and annotation were performed using the Prokka and PATRIC platform. The pangenome for each genus of BMCs was performed through the Roary program and the categorization of genes was performed from the results of the pangenomic analysis. All *Pseudoalteromonas* strains are likely to belong to the same species. *P. shioyasakiensis* JCM 18891 was the closest type species to our *Pseudoalteromonas* BMCs. The classification of BMCs 6 and 7 based on their genomes were not conclusive at the species level. Through the analysis of annotated genes in BMC genomes, we found genes that encode proteins whose role would bring a potential benefit to the coral, such as protection against oxidative stress, genes related to the synthesis of cobalamin, betaine glycine, ectoines and siderophores, as well as associated with the nitrogen cycle and DMSP degradation. A total of 401 genes with previously described functions were only present in the genome of one or more *Pseudoalteromonas* BMCs, according to the pangenome analysis. Of these, 11 genes may be genes with potential benefits for corals such as genes related to the sulfur cycle, response to oxidative stress, nitric oxide detoxification, among others. None of the genes obtained from the BMCs 6 and 7 pangenome appear to encode proteins with potential benefits for corals. All the BMC traits mentioned above might bring direct benefit to coral and/or their endosymbiotic algae. This information can assist the further selection of BMC.

Session 5A - Open Session: Cold-water and temperate reefs

Conceptualized by: **Claudio Richter**[1], **Covadonga Orejas**[2]
[1] AWI Bremerhaven (Bremerhaven, Germany)
[2] Instituto Español de Oceanografía (Palma de Mallorca, Spain)

Chaired by: **Claudio Richter**[1]

Oral
A-1096

Ontogenetic differences in the response of the cold-water coral Caryophyllia huinayensis to ocean acidification, warming and food availability

Beck, K. K.[1, 2], Schmidt-Grieb, G. M.[1], Held, C.[1], Nehrke, G.[1], Steinhoefel, G.[1], Laudien, J.[1], Richter, C.[1], Wall, M.[1, 3]
[1]Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research, Bremerhaven, Germany
[2]University of Bremen, Bremen, Germany
[3]GEOMAR Helmholtz Centre for Ocean Research, Kiel, Germany

kristina.beck[at]awi.de

Abstract

Cold-water corals (CWC) are exposed to multiple environmental stressors in a changing ocean. Several laboratory experiments have shown that adult CWC can survive at low pH and elevated temperature, but the effects on early life stages are largely unknown, let alone the interactive effects of changing pH, temperature and food availability. We conducted a six-month aquarium experiment to investigate the physiological responses of early juveniles, late juveniles and adults of the CWC *Caryophyllia huinayensis* to multiple environmental stressors by measuring key coral traits (survival, growth and respiration). We examined the single and interactive effects of pH (7.5 and 8.0), temperature (11 and 15 °C) and food availability (low and high) on the three life stages. The treatment levels reflect current conditions in the natural habitat of *C. huinayensis* in Comau Fjord, Chile. All life stages of *C. huinayensis* were more affected by warming than by acidification. At elevated temperature and in the combined treatment of elevated temperature and reduced pH, growth rates of all three life stages decreased after three months. After six months, mortality was highest in early juveniles and adults in these treatments. High feeding did not compensate for the negative effect of elevated temperature on growth and respiration rates of all life stages, but increased the growth rates of early and late juveniles at ambient and low pH conditions compared to low feeding. We identified ontogenetic shifts in resilience to future environmental conditions and highlight the importance of increased food availability for CWC resistance to ocean acidification. Our findings underscore the need to consider potential ontogenetic differences when addressing CWC responses to climate change.

Oral
A-1244

Lophelia-reefs and mounts off Morocco and Mauritania: Habitats, associated fauna and health status

Ben-ayad, H.[1], Buhl-Mortensen, L.[2], Houssa, R.[3], Rhinane, H.[1], Djimera, L.[4], Mohamed Moctar, S. M.[4]
[1]Hassan II university science faculty Ain Chock, Geology, Casablanca, Morocco
[2]Institute of Marine Research, Sustainable development, Bergen, Norway
[3]Institut National de Recherche Halieutique, Casablanca, Morocco
[4]Institut Mauritanien De Recherches Océanographiques Et De Pêches, Cansado Nouadhibou, Mauritania

hayatbenayad6[at]gmail.com

Abstract

Lophelia pertusa, is a reef building cold-water coral (CWC) of deep-water ecosystems that offers habitats for a rich associated fauna. It has been widely studied in the margins of the Northeast Atlantic, where ideal physico-chemical conditions for this species, comparable to the Middle East Atlantic. In 2020 the FAO-NANSEN program conducted a marine survey off southern Morocco and northern Mauritania, using the Research Vessel DR. FRIDTJOF NANSEN. The aim was to document vulnerable habitats in this understudied area, and as part of this objective to map the occurrence of *L. pertusa* reefs and document their health status against surrounding environments including associated fauna. To achieve these objectives detailed mapping of bathymetry and seafloor topography was conducted using multibeam echosounder, including backscatter analysis, to identify reef structures. Water samples and CTD were used to record T, S, pH and O_2 at reef localities. The reef status and associated fauna was documented visually using a video-assisted multiple sampler (VAMS) with an ROV. Based on detailed bathymetry and backscatter output five potential reefs were identified at 400m to 600m at a temperature of 8°C to 11°C and oxygen concentration of 1.3ml/l to 1.6ml/l. Reef localities were covered by 6 video transects that were preliminary annotated on board using the software Campod-Logger followed by a more detailed analysis on land using the Video Navigator software, both programs developed by Institute of Marine Research-Norway. The southernmost reef had the highest percentage of live *L. pertusa*, compared to the reefs north in the study area. The main substrates in the videos were gravel, gravelly sand and the coral sediments (coral rubble and blocks). Different communities were related to these environments. The coral blocks were important habitats for *Conger conger* and *Palinurus* while other species took shelter on live *L. pertusa* e.g., *Cladorhiza corallophila*, *Acesta excavata,* and *Eumunida bella*. Near the reefs crabs e.g., *Paramola*, *Bathynectes* and fishes belonging to *Macrouridae*, and *Scorpaena* family. The main threats to these habitats are climatic changes and bottom trawling. This study adds to the few observations of large and healthy *Lophelia* reefs a low oxygen upwelling area along the west African margin and as such it will aid in the protection of these diversity hotspots.

Oral
A-1250

Coral-reefs off North and West Africa – Environmental settings

Buhl-Mortensen, L.[1], Chierici, M.[2], Houssa, R.[3], Cervantes, D.[1], Mahu, E.[4], Nyadjro, E.[5], Idrissi, M.[3], M'bengue, B.[6], Dia, A.[6], Olsen, M.[1], Mas, C.[1]
[1]Institute of Marine Research, Bergen, Norway
[2]Institute of Marine Research, Tromsø, Norway
[3]National Institute of fisheries research (INRH), Casablanca, Morocco
[4]University of Ghana, Department of Marine and Fisheries Sciences, Accra, Ghana
[5]Mississippi State University, NOAA Northern Gulf Institute, Starkville, United States
[6]Institut Mauritanien de Recherches Océanographiques et des Pêches (IMROP), Nouadhibou, Mauritania

lenebu[at]hi.no

Abstract

Lophelia pertusa is a long-lived, reef-building, cold-water scleractinian found worldwide, and it is the major reef-forming coral in the North Atlantic. Reefs play a large role in the carbon cycling of the deep sea, and the greatest density of reefs has been found along the Norwegian coast. It occurs throughout the Atlantic and is present along the West African coast, in the Mediterranean Sea, the Gulf of Mexico and the Caribbean Sea. It has a temperature preference of 4-12º C and can be found at depths ranging from 39-3000 m, but is mainly found at 200-1000 m. The main environmental factors controlling its distribution are: temperature, salinity, water velocity, substratum type and food availability, other relevant factors are carbonate chemistry (e.g. aragonite saturation), dissolved oxygen and nutrient concentrations in the water column. The latter has become increasingly important as a consequence of the observed ocean changes such as ocean acidification and decreasing oxygen concentrations.
Several cruises within the EAF Nansen Program have been performed on the NW Africa shelf and slope and the Ghana-Ivory coast from 2012, 2017, 2019 and 2020. As part of these surveys three cold water coral sites where studied. A particularly large and old reef has been documented on the Ghana/Ivory shelf and several smaller mounds have been identified off Mauritania. During a 2020 survey along the Mauritania-Morocco shelf/slope, a large and healthy reef was recorded together with several dead and only barely alive reefs. All these findings are particularly interesting as the environment here is in stark contrast to the settings of the North Atlantic reefs. The west African reefs are in an area that has experienced little change during the last ice age, and they are in the oxygen minimum zone with low pH and low aragonite saturation waters observed close to the depth of the coral observations.
In this study we document the environmental setting of the cold-water coral reefs and their health status on the Mauritania-Morocco and Ghana/Ivory coast shelf/slope, including: Landscape (Canyon/shelf-slope), depth of the reef, water masses, currents, temperature (variability), dissolved oxygen concentration, carbonate chemistry (pH, aragonite saturation), nutrients, particles etc. The environmental conditions on these reefs will be discussed in context of other known reefs to add knowledge on the window od adaptation available for *L. pertusa.*

Oral
A-1074

Investigating connectivity and thermal tolerance across the extensive range of the temperate coral Astrangia poculata

Fifer, J.[1], Candelario, K.[1], Gan, Y.[1], Huzar, A.[1], Aichelman, H.[1], Epps, A.[2], Osterberg, J.[3], Ahuja, V.[1], Bussiere, G.[1], Feng, J.[1], Karadimitriou, N.[1], Bahr, K.[2], Baums, I.[4], McAlister, J.[5], Rotjan, R.[1], Davies, S.[1]
[1]Boston University, Boston, United States
[2]Texas A&M University- Corpus Christi, Biology, Corpus Christi, United States
[3]Duke University Marine Lab, Beaufort, United States
[4]The Pennsylvania State University, University Park, United States
[5]College of the Holy Cross, Worcester, United States

jfifer[at]bu.edu

Abstract

Variation in environmental characteristics can result in divergent selection pressures, which can lead to adaptive differentiation across a species' range. *Astrangia poculata* is a scleractinian coral that occupies a wide geographical range (northwestern Atlantic to the Gulf of Mexico) that experiences an annual temperature range of up to 20˚C providing a unique opportunity to understand the roles of phenotypic plasticity and local adaptation in coral thermal tolerance limits. Here, *A. poculata* were collected from seven sites spanning its North American range and thermal performance curve (TPC) experiments were conducted in tandem with population genomic sequencing using 2b-RAD-seq. We describe population connectivity and explore differences in thermal tolerance among populations across this range. We find populations from the Gulf of Mexico are genetically diverged from populations in the North Atlantic and these clusters are not predictive of thermal optimums. Within the North Atlantic, we find a signature of isolation by distance and different thermal optimums between populations. These findings point to similar thermal tolerance of both Gulf and North Atlantic populations despite large oceanographic barriers and genetic separation.

Oral
A-1066

Characterizing the Seawater Biogeochemistry of Deep-Sea Coral Reefs Across the Hawaiian-Emperor Seamount Chain

Hicks, T.[1], Shamberger, K.[1], Roark, E. B.[1], Baco-Taylor, A.[2], Miller, K.[1]
[1]Texas A&M University, College Station, United States
[2]Florida State University, Tallahassee, United States

hicks.tacey[at]tamu.edu

Abstract

Carbon dioxide (CO_2) in the atmosphere has been increasing over the last 200 years as a result of human activities such as fossil fuel burning and deforestation. Oceanic absorption of this anthropogenic CO_2 causes a decrease in ocean pH and calcium carbonate ($CaCO_3$) saturation state (Ω), a process known as ocean acidification (OA). Marine organisms that build aragonite (a form of $CaCO_3$) skeletons, including deep-sea corals, are particularly sensitive to OA because it slows $CaCO_3$ production and increases dissolution. The aragonite saturation horizon (ASH) is the depth in the ocean where aragonite Ω (Ω_{ar}) equals 1, below which $\Omega_{ar}<1$ and aragonite dissolution is favored, and above which $\Omega_{ar}>1$ and formation is favored. Deep-sea corals, like their shallow-water counterparts, build large 3-dimensional structures that support highly diverse ecosystems. Deep-sea coral reef development is hypothesized to be restricted to depths above or near the ASH. However, the ASH is shallowing throughout the ocean due to OA, which may threaten the existence of deep-sea coral reefs. Previous work in the Northwest Hawaiian Islands and Emperor Seamount Chain identified the first deep-sea coral reefs in the North Pacific, with some of the reefs already below the ASH with Ω_{ar}, as low as 0.7. Here we review seawater chemistry data collected from 2014-2019 across a wide geographic range from 19°N – 48°N and 170°E – 164°W, which includes several potential biogeographic regions with respect to deep-sea coral distribution. In addition, several sites have been reoccupied over the study, allowing for the investigation of short (≤7 y) and long (decades) term changes in the biogeochemistry of the region. Initial data indicate that the ASH at our sites ranges from ~490-700 m and comparison to data collected in the region in the 1990s indicates that the ASH may have shallowed ~10-50 m over the last 30 years. We will review spatial and temporal trends in seawater carbonate chemistry, dissolved oxygen, and dissolved inorganic nutrients that will allow us to better understand biogeochemical changes in this remote and poorly studied region. Characterizing the relationship between seawater chemistry and ecosystem distribution is critical to determining how deep-sea coral reefs may be affected by future OA and global change.

Oral
A-1599

Acclimation potential of Mediterranean corals to pH levels expected later this century

Hulver, A. M.[1], Carbonne, C.[2], Teixido, N.[2, 3], Comeau, S.[2], Gattuso, J.-P.[2], Grottoli, A.[1]
[1]The Ohio State University, School of Earth Sciences, Columbus, United States
[2]Laboratoire d'Oceanographie de Villefranche, Villefranche-sur-Mer, France
[3]Stazione Zoologica Anton Dohrn, Integrated Marine Ecology, Ischia, Italy

hulver.2[at]osu.edu

Abstract

Ocean acidification (OA) interferes with calcification of marine organisms and can impede growth and development of Mediterranean corals. Volcanic activity off the coast of Ischia, Italy results in natural CO_2 seeps which causes local OA mimicking levels expected later this century, providing a natural laboratory for evaluating the effect of OA on corals. The corals *Cladocora caespitosa* and *Astroides calycularis* were recently discovered naturally growing in these acidified waters, which is energetically more demanding due to increased chemical challenges in secreting a calcium carbonate skeleton. However, tropical corals have shown that eating zooplankton provides critical nutrition for tissue growth as well as synthesis and maintenance of fat reserves, especially when stressed. Previous studies have shown maintenance of Mediterranean coral skeletal growth rates and photosynthetic function in short-term low pH experiments. We hypothesize that these corals increase incorporation of zooplankton-derived nutrition into their tissues and increase fat reserves as an adaptive mechanism to survive low pH environments. In this experiment, colonies collected from CO_2 seep and non-seep sites were experimentally reared in ambient (pH_T=8.07, present-day conditions) and low pH (pH_T=7.70, OA) seawater for six months. Physiological and biogeochemical analyses of carbohydrates, lipids, and stable isotopes ($\delta^{13}C$) have been completed. Results so far show that lipid concentrations did not vary significantly between collection site or experimental treatment for either species. However, total lipid concentrations were much lower in *A. calycularis* compared to *C. caespitosa*. Further analysis into lipid classes is currently ongoing and will provide insight into incorporation of heterotrophic carbon into the coral tissue. Carbohydrate extraction was only performed on *C. caespitosa*, and no differences were found between collection site or experimental treatment. *C. caespitosa* host $\delta^{13}C$ values were significantly lower in corals collected from CO_2 seep sites as well as corals exposed to experimental low pH, indicating increased heterotrophy in both of these groups. Results of this study will determine if heterotrophic plasticity underlies the adaptive capacity of *C. caespitosa* and *A. calycularis*. If so, then Mediterranean corals may acclimate to OA conditions and be likely to survive this century given adequate zooplankton supply.

Oral
A-1844

The effect of oxygen- and sulphide-stress on the cold-water coral Desmophyllum dianthus

Laudien, J.[1], Abele, D.[1], Meyer, S.[1], Castrillón-Cifuentes, A. L.[2], Försterra, G.[3], Häussermann, V.[3, 4, 5], Richter, C.[1, 6]
[1]Alfred Wegener Institute, Helmholtz Center for Polar and Marine Research, Bioscience, Bremerhaven, Germany
[2]Universidad del Valle, Grupo de investigación en Ecología de Arrecifes Coralinos, Cali, Colombia
[3]Pontificia Universidad Católica de Valparaíso, Escuela de Ciencias del Mar, Valparaíso, Chile
[4]Huinay Scientific Field Station, Huinay, Chile
[5]Universidad San Sebastián, Facultad de Economía y Negocios, Lago Panguipulli, Puerto Montt, Chile
[6]University of Bremen, Bremen, Germany

juergen.laudien[at]awi.de

Abstract

The solitary cold-water coral *Desmophyllum dianthus* (Esper, 1794) thrives in shallow waters of Comau Fjord, Chilean Patagonia, where it forms large banks providing important habitat for a diverse reef community. In 2012, a mass mortality of *D. dianthus* affected 99% of the population, but the cause of the demise is still a matter of debate: observations of Gammaproteobacteria mats near cold seeps indicate a possible role of sulphide poisoning, but hypoxia, noxious blooms or disease associated with the rapid spread of salmon farming have also been invoked. To assess the sensitivity of *D. dianthus* to oxygen and hydrogen sulphide stress, incubation experiments were conducted under laboratory conditions. Continuous oxygen records (optical oxygen sensor spot) revealed that this coral can maintain respiratory independence over a large range of PO_2 and can survive anoxia for at least five hours. However, hypoxia caused a relaxation of the tentacles with potential repercussions on food capture and energy gain. Exposure to non-lethal hydrogen sulphide levels resulted in a significant increase in respiration rate and a decrease in cytochrome-c oxidase activity, possibly affecting the corals' metabolism. Test corals showed a high sulphide detoxification capacity by oxidising the penetrating hydrogen sulphide to non-toxic thiosulphate. We provide evidence that oxygen and hydrogen sulphide stress may have acted in concert to cause the mass mortality of *D. dianthus* in Comau Fjord, a problem likely to be exacerbated in the future by increasing eutrophication from aquaculture and global warming.

Oral
A-1354

Cold-water coral reefs in the Mauritania/Senegal region

Moctar, S.[1], **Buhl-Mortensen, L.**[2], El Vadhel, H.[1], Kide, S.[1], Kutti, T.[2], Sarre, A.[3], Chierici, M.[4], Niang, M.[3], Johansen, Y.[2], Cervantes, D.[2], Mas, C.[2]
[1]Institut Mauritanien de Recherches Océanographiques et des Pêches (IMROP), Nouadhibou, Mauritania
[2]Institute of Marine Research, Bergen, Norway
[3]Centre de Recherches Océanographiques de Dakar Thiaroye (CRODT), Pole de Recherches ISRA de HANN (ISRA), Dakar, Senegal
[4]Institute of Marine Research, Tromsø, Norway

lenebu[at]hi.no

Abstract

Until recently little was known about the occurrence of cold-water reefs off North and West Africa where many areas are dominated by a broad oxygen minimum sone (OMZ). On the Mauritanian coast a 400 km long barrier was investigated by earlier expeditions and several coral mounds were reported with few live colonies. In 2021 the NANSEN program conducted a survey on the coast at the border between Mauritanian and Senegal south of this formerly studied area. A main objective was to conduct visual habitat mapping of the seafloor with focus on cold-water coral reefs. In total 30 video lines were conducted using ROV and 14 of these were targeting structures suspected to be reefs at 450 to 650 meters depth. Bathymetry mapping with multibeam was used to position video lines and terrain and backscatter analysis were conducted. Oceanographic variables were measured near the reefs using a CTD sonde. The occurrence and health state of the corals along video lines was annotated using the software “CampodLogger”on the boat.
Here we present the environment and health status of the 14 new *Lophelia* reef established in the study area all with occurrence of live *Lophelia*. Six of the encountered reefs (43%) were large and healthy with areas having 15% to 50% cover of live colonies. The reefs were in the OMZ and oxygen concentrations down to 1 ml/l were measured at reef sites and temperature was between 8,8 and 11,6º C. The reef health status was compared with their environmental setting including temp, salinity, oxygen, particle load, terrain, and backscatter. A reef habitat prediction model was developed based on a combination of bathymetry, oceanographic setting, and health status of the reefs.
The occurrence of healthy *Lophelia* reefs in the study area is unexpected. The dormant state of reefs found further north on the Mauritanian coast have been explained by the OMZ and the geological and climatic history. Nonetheless, our findings are in line with some earlier observations from cruises conducted by the NANSEN program off Atlantic Africa. A large and healthy reef was discovered at the border between Morocco and Mauritania in 2020 and earlier the first large *Lophelia* reef off west Africa was documented on the Ghana coast, both in low oxygen upwelling areas. There is a need for knowledge-based management of marine resources in these understudied areas and our study shows the importance of visual seafloor mapping to aid to the development of spatial management plans.

Oral
A-1546

Trophic ecology and energetic trade-offs revealed by lipid biomarkers in contrasting phenotypes of the cold-water coral Desmophyllum dianthus

Wall, M.[1, 2], Beck, K.[1, 3], Garcia-Herrera, N.[1, 3], Schmidt-Grieb, G. M.[1], Laudien, J.[1], Höfer, J.[4, 5], Försterra, G.[4, 5], Woll, M.[1], Graeve, M.[1], Richter, C.[1, 3]
[1]AWI, Bremerhaven, Germany
[2]GEOMAR, Kiel, Germany
[3]University of Bremen, Bremen, Germany
[4]Fundacion San Ignacio del Huinay, Puerto Montt, Chile
[5]Pontificia Universidad Católica del Valparaíso, Valparaíso, Chile

marlene.wall[at]awi.de

Abstract

Cold-water corals (CWCs) are globally distributed, emphasizing their opportunistic feeding on a wide variety of energy sources. Yet little is known on food sources, let alone their effects on the energetic status and fitness of the CWCs. Here, we use *Desmophyllum dianthus* in its natural habitat Comau Fjord (Northern Patagonia, Chile) to assess the trophic ecology of this pan-globally distributed CWC in response to differing physico-chemical (variable vs stable) and ecological drivers (food availability). Contrasting coral phenotypes were collected from shallow (20m) and deep (300m) sites with known fitness differences and improved performance (growth, biomass, energy reserves) at 300m water depth. We analyzed the corals´ fatty acid composition to evaluate the utility of fatty acid trophic marker (FATM) profiles to gain insights into nutritional status and assess how fitness trade-offs potentially modulate the corals‘ FATM composition. We find that zooplankton markers (e.g. 20:1n-9) dominated deep coral profiles, while algal markers (e.g. 20:5n-3) were more prominent in shallow ones. The zooplankton diet supports an enriched energy storage capacity of deep corals despite lower zooplankton availability. Concentrations of polyunsaturated FA, including essential FA, were conserved across sites and likely reflect the levels required for coral functioning and survival. Deep-water corals can easily meet these requirements, while shallow corals likely need more energy to remain viable under the highly variable and limiting environmental conditions in Comau Fjord shallow waters. Energy re-allocation and intrinsic FA modifications may cause enrichment of certain biomarkers (i.e. not linked to the availability of the corresponding food) and distort the FATM signal. Our analysis highlights the biological and ecological insights that can be gained from FATM profiles in CWCs, but also cautions the reliability of FATM as diet tracers under limiting environmental conditions.

Poster
A-1198

Effect of temperature on cold-water coral holobiont: are Atlantic specimens more resilient than Mediterranean?

Chemel, M., Galand, P. E., Peru, E., Lartaud, F.
Sorbonne Université, CNRS, Observatoire Océanologique de Banyuls, Laboratoire d'Ecogéochimie des Environnements Benthiques, Banyuls-sur-mer, France

chemel[at]obs-banyuls.fr

Abstract

Cold-water corals (CWC) are deep sea engineers, which form extensive reefs in cold and deep environments around the world, providing rich habitats, nursery grounds and abundant source of food for amount of associated species. CWC reefs are now facing serious anthropogenic threats, particularly in submarine canyons, because of unsustainable fishing activities (e.g., trawling), pollution (by oil, seabed mining, plastics), and global changes (temperature increase, ocean acidification, deoxygenation). A recent work shows that Mediterranean corals, living in waters at 13 to 14 °C, are particularly sensitive to temperature rise, through disruption of microbiota, organic carbon fluxes, nutrition, and skeletal biomineralization, which can lead to death (Chapron et al., 2021). For corals from the NE Atlantic Ocean, who live at lower temperatures than in the Mediterranean Sea (8 to 12 °C), the impacts of rising temperature are poorly described.
The aim of this study was to determine if NE Atlantic corals have the same sensitivity to changing sea water temperature than their Mediterranean counterparts. To determine the effects of warming on the health of Atlantic CWC, fragments of Desmophyllum pertusum, the most sensitive species in the Mediterranean Sea, were exposed to different warming scenarios (control, +3 °C and +5 °C). Coral ecology was studied at the holobiont scale, through the the same parameters used in Chapron et al. (2021) to chacarterize coral health: skeletal mineralization and growth responses, feeding behavior and microbiome diversity.

Poster
A-1277

The microbiome of the deep-sea corals from the South-west Atlantic Ocean

Hill, L.[1], Vilela, C.[1], Garritano, A.[2], Modolon, F.[1], Damasceno, T.[1], Duarte, G.[1], Thomas, T.[2], Peixoto, R.[1, 3]
[1]Federal University of Rio de Janeiro, Department of General Microbiology, Paulo de Goes Institute of Microbiology,, Rio de Janeiro, Brazil
[2]The University of New South Wales, Centre for Marine Science and Innovation & School of Biological, Earth and Environmental Sciences, Sidney, Australia
[3]King Abdullah University of Science and Technology (KAUST), Red Sea Research Center (RSRC), Division of Biological and Environmental Science and Engineering (BESE), Thuval, Saudi Arabia

lilianhill.bio[at]gmail.com

Abstract

Corals are known for symbiotic interactions with their microbiome. Specially, these relationships are particularly interesting in extreme environments. Deep-sea corals thrive in cold waters, under high pressure and in the absence of light and photosynthetic symbionts. Hence, they have built different strategies to assure energetic supplies. It is thought that their associated microbial community may play an essential role for these organisms' nutrition by providing fixed carbon, nitrogen and other nutrients. Due to the difficult access into this ecosystem, there are only a limited number of published studies regarding the microbiome associated with deep-sea corals and none concerning the South-West Atlantic Ocean (SWAO) deep-sea corals. Here report for the first time the preliminary results regarding the microbiome associated with deep-sea corals collected in 5 different sites on the Campos Basin (Brazil). We collected 84 specimens using a remotely operated vehicle at depths ranging from 660 – 829 m. Different soft and scleractinian coral taxa were collected including the worldwide abundant *Desmophyllum pertusum*, other Scleractinea, Octocorallia, Antipatharia, Zoantharia and Alcyonacea. We obtained 4592 zOTUs by high-throughput sequencing of the v4 region of 16S rRNA gene. Initial results show that over 70% of samples shared a microbiome composed of Halomonadaceae, Bacilli and the chemolithoautotrophic archaea Nitrosopumilaceae. This indicates a core microbiome capable of performing roles that might be useful for deep-sea corals to cope with this unique environment (e.g., inorganic carbon fixation and nitrification). Microbiomes differed between taxa and between sites (PERMANOVA; $p<0,0002$ and $p<0,0006$). Scleractinea's microbiome was consistent throughout the sites ($p>0,08$), but both *D. pertusum's* and Octocorallia's microbiome differed between sites ($p=0,03$; $p=0,002$). In most sites, *D. pertusum*'s microbiome was different from other Scleractinea's and Octocorallia's, but Scleractinea's didn't differ from Octocorallia's. This pattern is consistent with *D. pertusum's* around the world, indicating that this coral has a locally consistent conserved core microbiome. We are, however, refining the taxonomy of the specimens collected in order to have a more precise insight into the relationship between the different taxa and their microbiome. In addition, the observed microbiome patterns will be compared with other biotic and abiotic variations across sites.

Poster
A-2187

Species delimitation of Hexacorallia and Octocorallia around Iceland using nuclear and mitochondrial DNA and proteome fingerprinting

Korfhage, S.[1], Rossel, S.[2], Brix, S.[3], McFadden, C. S.[4], Ólafsdóttir, S. H.[5], Martínez Arbizu, P.[1, 2]
[1]Carl von Ossietzky University Oldenburg, Institute for Biology and Environmental Sciences, Oldenburg, Germany
[2]DZMB - Senckenberg am Meer, Wilhelmshaven, Germany
[3]DZMB - Senckenberg am Meer, c/o Biozentrum Grindel, Hamburg, Germany
[4]Harvey Mudd College, Claremont, CA, United States
[5]Marine and Freshwater Research Institute, Hafnarfjörður, Iceland

severin.korfhage[at]uni-oldenburg.de

Abstract

Cold-water corals build up reef structures or coral gardens and play an important role for many organisms in the deep sea. Climate change, deep-sea mining, and bottom trawling are severely compromising these ecosystems, making it all the more important to document the diversity, distribution, and impacts on corals. This goes hand in hand with species identification, which is morphologically and genetically challenging for Hexa- and Octocorallia. Morphological variation and slowly evolving molecular markers both contribute to the difficulty of species identification. In this study, a fast and cheap species delimitation tool for Octocorallia and Scleractinia, and order of the Hexacorallia, of the Northeast Atlantic was tested based on 49 specimens. Two nuclear markers (ITS2 and 28S rDNA) and two mitochondrial markers (COI and mtMutS) were sequenced. The sequences formed the basis of a reference library for comparison to the results of species delimitation based on proteomic fingerprinting using MALDI-TOF MS. The genetic methods were able to distinguish 17 of 18 presumed species. Due to a lack of replicates, using proteome fingerprinting only 7 species were distinguishable. Species that could not be distinguished from one another still achieved good signals of spectra but were not represented by enough specimens for comparison. Therefore, it is predicted that with an extensive reference library of proteome spectra for Scleractinia and Octocorallia, MALDI-TOF MS may provide a rapid and cost-effective alternative for species discrimination in corals.

Poster
A-1283

Exploring the Potential of Beneficial Micro-organisms for Deep-Sea Corals

Leite Spindola Vilela, C.[1], Damasceno, T.[1], Hill, L.[1], Modolon, F.[1], Blasquez, D.[1], Duarte, G.[1], Thomas, T.[2], Peixoto, R.[1, 3]
[1]Federal University of Rio de Janeiro, Paulo de Goes Institute of Microbiology, General Microbiology, Rio de Janeiro, Brazil
[2]The University of New South Wales, Centre for Marine Science and Innovation & School of Biological, Earth and Environmental Sciences, Sydney, NSW, Australia
[3]King Abdullah University of Science and Technology (KAUST), 3Red Sea Research Center (RSRC), Division of Biological and Environmental Science and Engineering (BESE), Thuval, Saudi Arabia

caren_vilela[at]hotmail.com

Abstract

The relationship between corals and their microbiomes is crucial for both the development and health of this holobiont. Previous studies have shown that microbiomes of shallow-water corals can be manipulated through the inoculation of Beneficial Micro-organisms for Corals (BMC), and that this can increase the holobiont's tolerance to stress. However, this kind of approach has never been explored for cold-water corals. Here, we tested microbial manipulation and its effect on the deep-sea coral *Desmophyllum pertusum* (i.e. *Lophelia pertusa*) using different bacteria consortia, derived from either shallow-water or cold-water corals. In parallel, we also evaluated the effects of thermal stress on the *D. pertusum* holobiont, while also tracking the putative protective role of microbiome manipulation. *D. pertusum* colonies were collected at 680m depth from the Campos Basin, Brazil. Corals were maintained in a dark, flow-through mesocosm with either low (5.5°C) or increased temperature (up to 12.5°C) and exposed to either i) a placebo, (saline 0.85%); ii) a consortium of isolates from *D. pertusum* or iii) a consortium of isolated from the shallow-water coral *Pocillopora damicornis*. Both consortia consisted of members of the genera *Pseudoalteromonas* or *Halomonas*, as these taxa have been previously shown to be BMCs in shallow-water corals. Corals were visually scored for health traits, according to a specific assessment pre-defined in the literature that evaluates tentacles, filaments, mucus and tissue. Our results showed that corals exposed to elevated temperatures had a lower health score when compared to corals kept at 5.5°C, as indicated by the increased mucus production and tissue loss. Inoculation of BMCs appeared to accelerate the recovery of corals after temperature stress. We are now investigating whether the inoculation of BMCs have restructured the microbiome associated with *D. pertusum*, and how these changes correlate with the holobiont's health score.

Poster
A-1286

Using YOLOv5 algorithm and Video Navigator Software: New approach for mapping cold water coral habitats

Loulidi, A.[1], Buhl-Mortensen, L.[2], Rhinane, H.[1], Houssa, R.[3]
[1]University Hassan II Faculty of Sciences Ain Chock, Department of Geology, Casablanca, Morocco
[2]Institute of Marine Research, Department of Sustainable Development, Bergen, Norway
[3]National Institute of fisheries Research, Department of Fisheries, Casablanca, Morocco

ali_loulidi[at]hotmail.com

Abstract

The recent decline in the health status of marine habitat communities around the world has pushed the need for innovative assessment tools to quickly and effectively document marine habitat abundance and distribution. Underwater equipment and gears are used to study benthic habitats and fish species associations in order to preserve and maintain these marine ecosystems in a sustainable way. The current work aims to map cold-water coral habitats and their associated communities on the North Atlantic coast of Morocco as part of a PhD-FAO fellowship. To reach this objective, we used video-assisted multiple sampler (VAMS) coupled with a remotely operated vehicle (ROV). These data were collected, in the Moroccan Atlantic Coast, during a scientific survey conducted in 2020 by the FAO-NANSEN program. This scientific paper will present the results of the coupling between two underwater video analysis tools: deep learning methods, in particular, the You Only Look Once version 5 (YOLOv5) algorithm, and the Video Navigator software from the IMR (Institute of Marine Research Bergen-Norway) to map cold-water coral habitats in the Moroccan North Atlantic area. The YOLOv5 algorithm divides an image into a grid system, and each grid detects an organism within itself. It achieves great performance in the detection of marine species automatically, which can increase quantification efficiency. While the Video Navigator software is an annotation program designed to combine position information from the video platform (transponder) with the annotation of observed organisms and substrates made by the analyzer, it is used to 'tagged' biological and substrate entries with: date, time, depth, altitude, latitude and longitude. This secures high resolution spatial information that can allow for future monitoring and mapping of the same site with good precision. In conclusion, the two methods adopted in this study have proven their effectiveness in quickly and efficiently detecting and mapping cold-water corals and their associated communities from underwater video.

Virtual
Oral
A-1389

First description of gorgonian gardens distribution and associated macrofaunal assemblages in Chile: opening the door to conservation actions

Camps-Castellà, J.[1], Prado, P.[2], Brante, A.[1, 3], Hinojosa, I. A.[1, 3, 4, 5]
[1]Universidad Católica de la Santísima Concepción, Departamento de Ecología, Facultad de Ciencias, Concepción, Chile
[2]IRTA, Sant Carles de la Ràpita. Ctra. Poble Nou km 5.5, Sant Carles de la Ràpita, Tarragona, Spain
[3]Centro de Investigación en Biodiversidad y Ambientes Sustentables (CIBAS), Facultad de Ciencias, Universidad Católica de la Santísima Concepción, Concepción, Chile
[4]Millennium Nucleus Ecology and Sustainable Management of Oceanic Island (ESMOI), Universidad Católica del Norte, Coquimbo, Chile
[5]Centro de Investigación Oceanográfica COPAS COASTAL, Universidad de Concepción, Concepción, Chile

jcamps[at]magister.ucsc.cl

Abstract

Gorgonians are one of the most common three-dimensional organisms in circalittoral seascapes that provide key ecological services and human goods. Gorgonian gardens of a new species of the genera *Leptogorgia* sp. are found in Caleta Pichicuy, Chile. Little is known about these populations including depth distribution, colony abundance, structural attributes, and associated macrofaunal assemblages. Hierarchical sampling was conducted at 20 m depth (maximum colony abundances) in order to assess spatial variability in abundance and colony attributes at two spatial scales (among sites and rocky walls). The abundance and composition of the associated vagile and sessile macrofauna was also examined using univariant (species richness, and Shannon index (*H'e*)) and multivariant approaches and compared to that of adjacent bare rocky habitats. Our results showed a high abundance of gorgonians (ca. 28.9 to 36.5 colonies m^{-2}) compared to other gorgonian gardens in the world. For structural attributes, our results showed smaller colonies with thicker holdfasts in more exposed sites, suggesting the influence of hydrodynamic forces. Taxa richness and *H'e* of vagile fauna showed 3 and 2-fold, higher values in gorgonian gardens compared to bare rocky walls, respectively, but no differences were observed for sessile fauna. In addition, PCoA and PERMANOVA evidenced a distinctive assemblages' composition of both vagile and sessile fauna between habitats. Correlation analyses and dbRDA showed, however, little association between structural attributes and associated macrofaunal assemblages (R^2=0.06, and ca. 3 to 9.4 % of the total variation explained, respectively). Interestingly, some commercial species such as *Semicossyphus darwini*, *Graus nigra*, *Loxechinus albus* among others were only observed in gorgonian habitat. Our results constitute the first assessment of structural habitat complexity and accompanying fauna in rose gorgonian gardens and establish the baseline for understanding possible future changes associated to human activities.

Virtual
Oral
A-1034

Skeletal structure alteration of cold-water coral Lophelia pertusa from ocean acidification and rising seawater temperature

Krueger, E.[1], Büscher, J.[2, 3], Hoey, D.[4], Taylor, D.[4], O'Reilly, P.[4], Crowley, Q.[1]
[1]Trinity College Dublin, Department of Geology, Dublin, Ireland
[2]National University of Ireland Galway, Department of Earth and Ocean Sciences, Galway, Ireland
[3]GEOMAR Helmholtz Centre for Ocean Research Kiel, Department of Biological Oceanography, Kiel, Germany
[4]Trinity College Dublin, Department of Mechanical, Manufacturing and Biomedical Engineering, Dublin, Ireland

kruegere[at]tcd.ie

Abstract

Ocean acidification (OA) has provoked changes in the carbonate saturation state that may alter the formation and structural biomineralisation of calcium carbonate exoskeletons for marine organisms. Biomineral production in such organisms relies on available carbonate in the water column and the ability of the organism to sequester ions from seawater or nutrients for the formation and growth of a skeletal structure. Cold-water corals (CWC) are an important sink of inorganic carbon and create vital biodiversity hotspots in the deep oceans. Ocean acidification is considered to make the scleractinian CWCs such as the abundant *Lophelia pertusa* more brittle, but little is known about how the microstructure of coral skeletons are affected. As an important habitat structuring species, it is essential to examine the impact that OA and rising seawater temperatures have not only on living corals, but on the structural properties of dead coral skeletons that are important contributors to the entire reef structure and its stability of CWC reefs and mounds. To understand how the skeletal integrity of *L. pertusa* will respond to these stressors, skeletons of dead corals were exposed to various levels of pCO_2 (400 and 1000 µatm) and changes in temperature (ambient and ambient + 3°C) over a 12-month period. Nanoindentation and compression testing were conducted to assess the structural properties for hardness and fracture toughness of coral skeleton samples. Increased pCO_2 and temperature combinations had varying effects on the structural integrity of the skeletons in altered conditions. Ocean acidification and temperatures are projected to continue increasing leading to concerns for marine calcifying organisms. A change in the skeletal properties of CWCs could prevent carbonate mounds from maintaining their structure, which is vital to these biodiverse ecosystems in the deep ocean.

Virtual
Oral
A-1400

Skeletal properties of the coral Desmophyllum dianthus are related to the aragonite saturation state along a depth gradient in the Mediterranean Sea

Mancuso, A.[1], Prada, F.[2], Marchini, C.[1], Di Fazio, V.[1], Ghiroldi, C.[1], Taviani, M.[3], Montagna, P.[4], Goffredo, S.[1]
[1]University of Bologna, Dept. of Biological, Geological and Environmental Sciences, Bologna, Italy
[2]Rutgers, The State University of New Jersey, Department of Marine and Coastal Sciences, New Brunswick, United States
[3]Institute of Marine Science - National Research Council, Bologna, Italy
[4]Institute of Polar Science - National Research Council, Bologna, Italy

arianna.mancuso2[at]unibo.it

Abstract

Ocean biogeochemistry is now being strongly influenced by the oceanic uptake of anthropogenic carbon dioxide from the atmosphere, leading to an increase in hydrogen ion concentration (i.e., decreases pH) and to a decrease in the carbonate ion concentration, in a process commonly referred to as ocean acidification. Ocean acidification is likely to exhibit its most immediate effects on cold-water corals in deep waters with the shoaling of the aragonite saturation horizon, leading to dramatic declines in rates of calcification. It is now clear that the Mediterranean area will be a hotspot for climate change effects, making it a miniature model of global patterns to occur in the world's marine biota, and a natural focus of interest for research. This study aimed to investigate the effects of decreasing aragonite saturation state (Ωarag) on the biometric and skeletal parameters of *Desmophyllum dianthus* along a depth gradient (400 - 1200 m) in the Mediterranean Sea. The results indicate that as Ωarag decreases, bulk density decreased while skeletal porosity and micro-density increase. This trend could be explained through the inhibition of calcification as Ωarag decreased, leading to a more porous and likely fragile skeletal phenotype. This is one of the few in situ studies conducted on a cold-water coral species in the Mediterranean Sea, providing evidence on their susceptibility to increased ocean acidity.

Virtual
Poster
A-1883

Diversity and genetic connectivity of Alcyonium species (Cnidaria, Octocorallia) from the Falkland Islands region

Meyer, J.[1], Bastrop, R.[2], Juergens, L.[3], Reinicke, G. B.[4]
[1]Helmholz- Zentrum Hereon, Geesthacht, Germany
[2]University of Rostock, Department of Animal Physiology, 18051 Rostock, Germany
[3]Max Planck Institute for Brain Research, Marine Systems at Max Planck Institute for Brain Research, 60438 Frankfurt am Main, Germany
[4]German Oceanographic Museum, Curator of Marine Ecology, Hollow Animals, Molluscs and Echinoderms, 18439 Stralsund, Germany

juliame93[at]gmail.com

Abstract

Octocorallia play important roles in marine ecosystems and may dominate the benthic fauna in the subantarctic. However, the knowledge of their biodiversity and distribution is limited. Species identification using traditional taxonomical methods is burdened with controversies and restricted access to suitable material restrains comprehensive research. Morphologically, octocorals have few characteristics that can be utilized for taxonomy. Colony morphology and sclerite architecture are used for identification, yet these features exhibit an extraordinarily high degree of variability. Genetic tools allow further insights in diversity patterns.
The areas around the Falkland Islands (FI) in the South Atlantic are linked to Antarctic waters and are an internationally important fishing region managed by the Falkland Island Government Fisheries Department (FIFD). In scope to assess the fish stocks and monitoring the biodiversity around the FI the FIFD conducted research cruises and experimental fishing trips.
During 2006-2015, the octocorals in bottom trawls were taken and representative samples were (1) directly preserved in 98% ethanol or (2) occasionally frozen in seawater and later preserved in 98% ethanol. Further, the material was supplemented by additional acquisitions collected by fisheries observers on commercial fishing vessels. Samples of Alcyonium from different stations were investigated with regard to their diversity and genetic connectivity.
Overall, seven species were identified: A. patagonicum, A. haddoni, A. varum, A. sollasi, A. antarcticum, A. glaciophilum, A. yepayek. The combination of the mitochondrial (msh1) and 28S DNA barcodes were used to identify different haplotypes.
The results show discrepancies in taxonomy and genetic analyses. Due to the high variability of the morphological features the DNA barcoding has been hindered by the slow rates of mitochondrial gene evolution and the identification of molecular markers to determine species boundaries within octocorals. However, the morphology shows similarities, and suggests that the species may be closely related. The extent of the material and comparative analysis allows insights in their distribution and variability of morphological characteristics for each population.

5A - Open Session: Cold-water and temperate reefs: Virtual Poster
A-2218

High latitude coral larval recruitment: spatiotemporal process variability in the Gulf of California

Tejada Begazo, C.[1], Calderon-Aguilera, L. E.[1], López-Pérez, A.[2], Cabral-Tena, R. A.[1]
[1]Centro de Investigación Científica y de Educación Superior de Ensenada, Ensenada, Mexico
[2]Universidad Autónoma Metropolitana - Iztapalapa, Ciudad de México, Mexico

tejada[at]cicese.edu.mx

Abstract

To explore if sexual reproduction is present in scleractinian corals at the northern limit of their distribution (28.980 °N -113.470 °W) in a zone subject to upwelling and seasonal variations in sea surface temperature (14 – 30 °C), sampling was performed from August 2018 to October 2019. We placed 42 terracotta recruitment tiles in Bahía de los Ángeles, Baja California. Coral cover was estimated and the height, major diameter, and minor diameter of coral colonies were measured. Astrangia haimei and Porites panamensis recruits were identified on the recruitment tiles, constituting the first quantitative record for the northeastern tropical Pacific. Recruitment of P. panamensis was higher (Llave: 63.09 ± 114 ind m-2 y-1, Rasito:3.21 ± 7 ind m-2 y-1), while A. haimei recruitment at the same sites was 3.85 ± 8 and 1.93 ± 6 ind m-2 y-1, respectively. Recruitment differences between locations were attributed to coral cover (being the abundance of Porites panamensis 15-fold greater in Llave than in Rasito) and large colony size (P. panamensis colonies height means in Llave: 10.53 ± 5.93 cm, height means in Rasito: 4 ± 0.63 cm). Both SST and Chl-a concentrations were also highly correlated with coral recruitment, with higher recruitment rates observed in the warmer seasons when high nutrient concentrations were also present. In contrast to other sites in the eastern tropical Pacific, the highest rate of recruitment was reported at this high-latitude coral community, which, based on the positive high latitude trend, reported by others studies, is likely due to climate change.

Session 5B - What is the different impact of climate change in temperate reefs relative to tropical regions?

Conceptualized by: **Erik Caroselli** [1], **Nuria Teixido**[2], **Jaap Kaandorp**[3], **Zvy Dubinsky**[4], **Stefano Goffredo**[1]
[1] University of Bologna (Bologna, Italy)
[2] Sorbonne Université, CNRS (Villefranche-sur-Mer, France)
[3] University of Amsterdam (Amsterdam, The Netherlands)
[4] Bar Ilan University (Ramat-Gan, Israel)

Chaired by: **Nuria Teixido**[2]

Oral
A-1396

Tropical black corals have higher thermal sensitivity than temperate ones

Godefroid, M.[1], Hédouin, L.[2, 3], Bo, M.[4], Bramanti, L.[5], Consortium, U. T. P.[6], Danis, B.[1], Gouveia, A.[7], Guillaumot, C.[8], Mercière, A.[2, 3], Otero-Ferrer, F.[9], Romans, P.[5], Thoma, M.[4], Zeimes, T.[1], Dubois, P.[1]
[1]Université Libre de Bruxelles, Bruxelles, Belgium
[2]PSL Research University: EPHE-CNRS-UPVD, USR 3278 CRIOBE, Mo'orea, French Polynesia
[3]Laboratoire d'Excellence « CORAIL», Mo'orea, French Polynesia
[4]Università degli Studi di Genova, Genova, Italy
[5]LECOB/CNRS-Sorbonne Université UMR 8222, Observatoire Océanologique de Banyuls-sur-Mer, Banyuls-sur-Mer, France
[6]Under The Pole, Concarneau, France
[7]Universidade de Aveiro, Aveiro, Portugal
[8]CNRS/UB/EPHE, UMR 6282 Biogéosciences, Université Bourgogne Franche-Comté, Dijon, France
[9]IU-ECOAQUA, Universidad de las Palmas de Gran Canaria, Las Palmas, Gran Canaria, Spain

mathilde.an.godefroid[at]ulb.be

Abstract

Black corals (antipatharians) are mainly found from the mesophotic zone and deeper, do not build a calcified skeleton and do not rely on algal symbionts for energy acquisition. For these reasons, they received poor attention so far, despite their role as habitat forming species throughout the world oceans. Recent studies demonstrated their importance as ecosystem-engineer species, using deep diving technologies. At depth, black corals can form dense aggregations, which support a vast range of associated fauna. Several anthropogenic threats on black corals have been evidenced, including overharvesting and deep trawling, which prompted the CITES appendix II listing of antipatharians. On the contrary, the impact of ocean warming on this taxon remained unexplored.
Here, we summarize the results from three distinct experiments intended to explore the thermal sensitivity of black corals from different regions of the world. Fragments of black corals were exposed over 15 days to a range of temperature conditions including those expected to occur in 2100 based on IPCC predictive emission scenarios. Experiments were carried out on species collected at mesophotic depths from the Pacific Ocean (Mo'orea, tropical), the Atlantic Ocean (Canary Islands, subtropical) and in the Mediterranean Sea (Italy, temperate). Endpoints included several physiological responses: oxygen consumption rate, tissue necrosis, mucus production, propagule bail-out and antioxidant capacity.
The results showed that thermal sensitivity of tropical black corals was higher than that of more temperate regions. Tropical species showed classical bell-shaped thermal performance curves (TPC) and appeared particularly vulnerable to increasing temperatures as they live close to their thermal optimum. Past the optimum, most endpoint were affected. Short-term high temperature variability induced by internal waves did not appear to confer thermal resilience to these tropical species. On the contrary, Mediterranean and subtropical black corals showed flat TPC or a linear increase of performance in the investigated range of temperatures and showed no or mild signs of stress, at temperatures up to +5°C from present conditions.
In conclusion, tropical antipatharians from mesophotic depths appear at risk in front on the forthcoming warming of this water mass and internal waves do not create a refuge zone for these taxa. On the contrary, temperate and subtropical species are probably less threatened by ocean warming.

Virtual
Poster
A-1177

Influence of environmental parameters on growth in the solitary non-zooxanthellate coral Caryophyllia inornata naturally living at volcanic vents

Cassarino, C.[1], Mancuso, A.[1, 2], Prada, F.[1, 2], Caroselli, E.[1, 2], Goffredo, S.[1, 2]
[1]University of Bologna, Department of Biological, Geological and Environmental Sciences, Bologna, Italy
[2]Fano Marine Center, The Inter-Institute Center for Research on Marine Biodiversity, Resources and Biotechnologies, Fano, Italy

chiara.cassarino[at]studio.unibo.it

Abstract

Natural volcanic vents represent extreme environments with varying seawater parameters (e.g. pH) that may affect ecological traits of coral populations. Determining growth and population dynamics is crucial to assess corals response to these varying environmental conditions. Coral growth may be described by applying age-based growth models (e.g. von Bertalanffy growth model), which can be derived by size and age data estimated through sclerochronology. The present study focuses on populations of the temperate solitary coral *Caryophyllia inornata* (Scleractinia, Caryophylliidae), naturally exposed to volcanic vents at Panarea Island (Italy). Samples were collected from a submerged cave in four sites at 13-15 m depth and analysed through X-Ray Imaging with Synchrotron Radiation at the Deutsches Elektronen-Synchrotron (DESY; Germany). The resulting scans were elaborated for growth band counts to establish the age of each sample. The mean annual growth rate showed an exponential negative relationship with individual age, as in previous analyses of this species, allowing the application of the von Bertalanffy growth model. Resulting age-length growth curves allow further development of population dynamics models at the four study sites.

Session 6A - Open Session: Unexplored and unexpected reefs

Conceptualized by: **Ronald Osinga**[1], **Gert Wörheide**[2], **Cecilia D'Angelo**[3]
[1] Wageningen University (Wageningen, The Netherlands)
[2] LMU München (München, Germany)
[3] University of Southampton (Southampton, UK)

Chaired by: **Ronald Osinga**[1], **Gert Wörheide**[2]

Oral
A-1043

Coral fluorescence: a prey-lure in deep habitats

Ben-Zvi, O.[1], Lindemann, Y.[2], Eyal, G.[3], Loya, Y.[4]
[1]Scripps Institution of Oceanography, San Diego, United States
[2]The Hebrew University of Jerusalem, Jerusalem, Israel
[3]The University of Queensland, Brisbane, Australia
[4]Tel Aviv University, Tel Aviv, Israel

orbzvi[at]gmail.com

Abstract

Fluorescence, a light wavelength transformation phenomenon, is highly prevalent in reef-building corals, nevertheless, its biological role is still under ongoing debate. This remarkable feature of corals was previously suggested to primarily screen harmful radiation (i.e., a photoprotective role) or to facilitate coral photosynthesis where light is scarce. In mesophotic coral ecosystems (MCEs; 30-150 m depth) stony corals experience a limited, blue-shifted light environment. Consequently, in contrast to their shallow conspecifics, which are believed to depend heavily on photosynthates produced by their associated algal symbionts, mesophotic corals may not be able to rely on autotrophy as their main energy source. Here we experimentally tested an alternative hypothesis for coral fluorescence, as a prey-lure mechanism for plankton, that is further enhanced by the unique light environment of MCEs. We demonstrate that several planktonic taxa exhibit preferential swimming towards fluorescent cues (over non-fluorescence cues) in both the laboratory and the sea. Moreover, compared to other morphs, we recorded higher predation rates in a green fluorescing morph, of the mesophotic coral *Euphyllia paradivisa* in a controlled experiment. The enhanced predation rate was only observed under blue light, which naturally excites fluorescence, while not occurring under red light which does not excite fluorescence. The evidence provided here - that swimming plankton are actively attracted to fluorescent signals - indicates the significant role of fluorescence in the ecophysiology of corals and in the marine ecosystem, in amplifying the nutritional sink adjacent to coral reefs.

Oral
A-1270

Exploring the Extremes- Unexpected findings from the world's largest coral reef surveying effort

Carlton, R.[1], Dempsey, A.[1], Faisal, M.[1, 2], Purkis, S.[1, 3]
[1]Khaled bin Sultan Living Oceans Foundation, Annapolis, MD, United States
[2]Michigan State University, Lansing, MI, United States
[3]University of Miami, Rosenstiel School of Marine and Atmospheric Science, Center for Carbonate Research, Department of Marine Geosciences, Miami, FL, United States

carlton[at]lof.org

Abstract

The decline of coral reefs has been documented starting in at least the early 1980s (Glynn 1993; Pandolfi 2003; Hughes et al. 2018). Climatic and anthropogenic pressures are contributing to the deterioration of reefs, through global bleaching events, overfishing of nearshore fisheries, coastal development, nutrient runoff, and habitat destruction. From 2011 to 2015, the world's most comprehensive assessment of coral reefs to date, the Global Reef Expedition (GRE), was undertaken. On the GRE, an international team of scientists used standardized methodologies to map and survey benthic habitats and reef fish communities to establish a baseline understanding of the world's reefs. The GRE visited over 1,000 unique reefs in 15 countries, completing 5,500 benthic surveys, and 7,300 fish surveys. The GRE focused on unexplored reefs that experienced minimal human interactions, while simultaneously surveying a spectrum of localities subject to direct human influence. The findings from the GRE showcase the ability of reefs to establish beyond their textbook shallow, well-lit, oligotrophic environments. For instance, Prony Bay (New Caledonia) is subject to turbid waters caused by sediment runoff from nearshore nickel mining. Against expectations, the reefs at this site were both diverse and high in live coral cover, even as compared to the remote New Caledonian Entrecasteaux Atolls, which are subject to minimal direct human impact. Similarly, important lessons also come from the Chagos Archipelago (British Indian Ocean Territory). Here, the deep (up to 50 m depth) atoll-lagoon floors were dominated by expansive monospecific carpets of *Heliopora* and *Millepora*, as opposed to barren muds and sands, as usually characterize this deep restricted depositional environment. Elsewhere in the Chagos, close interrelationships were observed between seagrass meadows and corals that grow within them. So strong was this association, that juvenile corals widely used seagrass blades as substrate. These non-traditional cases of reefs thriving in inclement conditions, or in association with organisms typically considered as incompatible, serve to emphasize the breadth of conditions in which corals can survive – an important lesson as reefs are swiftly being eliminated from their more conventional habitats.

Oral
A-1040

Validating eDNA metabarcoding as a low-cost alternative to underwater visual censuses of mesophotic fish diversity in the Coral Triangle

Heard, J., Wyatt, A.
Hong Kong University of Science & Technology, Hong Kong, Hong Kong SAR China

jbheard[at]connect.ust.hk

Abstract

Although interest in mesophotic coral ecosystems (MCEs), which occur at depths of approximately 30-130 m, has grown exponentially in recent years, they remain largely unexplored and poorly understood. This is primarily due to the logistical limitations associated with the amount of time available to research divers to perform observations at these depths. Standardised underwater visual census (UVC) surveys are time consuming and, in the case of mesophotic fish communities, are therefore typically restricted to a single replicate of no more than 100 m^2 per dive. The increased financial costs required to access MCEs relative to their shallow counterparts also often results in limited replication, which can only offer a narrow snapshot of the total ichthyofaunal diversity present in a given MCE. This greatly hampers our ability to address global, or even regional biodiversity questions. For example, despite being the centre for marine biodiversity, MCEs within the Indo-Pacific are among the least documented in the world due to a lack of technical research diving capability within the region. A potential solution could lie in the use of environmental DNA (eDNA) metabarcoding, which has previously been used to make comparative biodiversity assessments of benthic communities across mesophotic depth gradients. We plan to determine if eDNA samples collected from mesophotic depths can provide a reliable proxy for visually derived diversity estimates obtained via UVC. This will then allow for the use of dredges or remote samplers from the surface to collect mesophotic sediment and water samples, providing an alternative method for researchers without technical dive training and/or access to highly specialised equipment. By validating a comparatively inexpensive method for rapidly collecting diversity related-data over far larger scales than currently possible with UVC, we hope to facilitate additional research into the diversity and ecology of mesophotic fishes within the Coral Triangle, as well as other understudied regions.

Oral
A-1318

MaxEnt modelling as a tool to inform discovery of deep-sea coral ecosystems

Nolan, M. K. B.[1], Marchese, F.[1], Kheireddine, M.[1], Chimienti, G.[2], Purkis, S.[3], Isotta Terraneo, T.[1], Rodrigue, M.[4], Eweida, A. A.[5], Jones, B.[1], Benzoni, F.[1]
[1]King Abdullah University of Science and Technology, Red Sea Research Center, Jeddah, Saudi Arabia
[2]University of Bari Aldo Moro, Department of Biology and CoNISMA LRU, Bari, Italy
[3]University of Miami, Center for Carbonate Research, Department of Marine Geosciences, Rosentiel School of Marine and Atmospheric Science, Miami, United States
[4]OceanX, New York, United States, [5]NEOM, Riyadh, Saudi Arabia

megannolan95[at]outlook.com

Abstract

Coral reefs are now one of the most threatened marine ecosystems, due to local anthropogenic pressures and global changes in ocean conditions. Until recently, research has focused on the vulnerability of shallow coral ecosystems, however as climate change continues, effects on deeper coral-dominated ecosystems become more severe. This is coupled with increasing anthropogenic stressors from fishing, oil exploration and construction activities. To understand and study the changes that these deep-sea ecosystems are undergoing, we must first know where they are located. Exploration of deep-sea habitats is costly, challenging and time-consuming, reducing the geographic extent at which it is possible. Methods are also often difficult in remote areas. Therefore, as such ecosystems are relatively sparse, extensive resources may be used attempting to locate them. Species distribution models can be used to identify key areas of interest with much less information, focusing surveys to a smaller extent, and making it much more cost-effective to study. While there are many models aimed at identifying suitable habitat, most require presence-absence data for efficient calibration. MaxEnt is a species distribution modelling software which uses a unique maximum entropy algorithm to find the most dispersed distribution. It requires only presence data, allowing accurate results with less input data. During the OceanX-NEOM ‘Deep Blue’ expedition in the Northern Saudi Arabian Red Sea and the Gulf of Aqaba in 2020, deep-sea coral ecosystems were identified and characterised by ROV and submersible dives. Geomorphometric variables were derived from bathymetry, including measures of aspect, curvature and local-scale rugosity. These variables were used as input data for MaxEnt, along with backscatter, which can provide information about the seafloor substrate, and environmental data from CTD casts and current models. The potential of such models to identify areas of interest is clear, and could become an important tool in order to focus limited conservation funding.

Poster
A-1142

Coral Reef's Diatom (Bacillophyceae) at Bawean Island, East Java, Indonesia

Luthfi, O. M.[1], Witkowski, A.[1], Górecka, E.[1], Dąbek, P.[1], Risjani, Y.[2], Yunianta, Y.[3]
[1]University of Szczecin, Environmental and Marine Science, Szczecin, Poland
[2]Universitas Brawijaya, Faculty Fisheries and Marine Science, Malang, Indonesia
[3]Universitas Brawijaya, Malang, Indonesia

oktiyas.luthfi[at]phd.usz.edu.pl

Abstract

Coral reefs ecosystem are rainforest of the sea which has very rich habitats in biodiversity and can reinforce a wide heterogeneity of organisms owing to their high turnover rate through complex food webs. Diatoms are found inhabiting the coral reef ecosystem as microphytobenthic communities which attach to macroalga, sand also coral rubble. Pulau Bawean (Bawean Island) which is located in the Sea of Java is of a volcanic origin and formed during the Pleistocene epoch. This island has been framed by fringing reef and followed by microcontinents such as Gili Noko (bank reef), Pulau Noko Selayar and Pulau Gili (cays), Pulau Cina, and Pulau Nusa (island), and hundreds of patch reefs. The diatom assemblages from this island are poorly known and understood, so the aim of this study was to fill the knowledge gap of the distribution and abundance of diatom in Pulau Bawean. Samples were collected from sand, rubble, macroalgae, seawater, and dead coral with algae. Light microscopy analysis revealed an extremely high diversity of the diatom assemblages studied with a species richness amounting to several hundred. Based on scanning electron microscopy observations we found at least 7 genera and numerous species of unknown diatoms which are potentially new for science. In terms of abundance, dominance was a few *Halamphora* and *Nitzschia* species that occurred almost at all stations studied. These asymmetric biraphid diatoms have known as cosmopolite and occur from brackish to marine habitat. Several taxa are not clearly identified from Pulau Bawean and require taxonomical identification in the future.

Poster
A-1802

A New Observation of Microatolls in the Galápagos Islands, Ecuador

Orr, A., Feingold, J.
Nova Southeastern University, Department of Marine and Environmental Sciences, Davie, United States

ao640[at]mynsu.nova.edu

Abstract

Microatolls are shallow-water coral colonies shaped like miniature versions of their namesake. They develop their signature ring-like atoll shape due to water depth limitations that prevent living tissue from growing any higher, encouraging outward growth instead. Since incipient sub-aerial exposure is an important component of their formation, they are utilized as indicators of current and past sea level. Additional contributors to their formation include accumulation of sediment on the colonies, which smothers polyps in the center of the structure, overgrowth by algae, and upper surface abrasion by bioeroding organisms. Microatolls are described from numerous locations and form from several species in the Indo-West Pacific. However, microatolls occur at only two known sites in the tropical Eastern Pacific: Caño Island, Costa Rica and the Galápagos Islands, Ecuador, and form from one species, *Porites lobata*. In the Galápagos Islands, early researchers (1970s-1980s) observed microatolls at Urvina Bay, Isabela Island and Devil's Crown, Floreana Island, however they are no longer present at either location. In 2019 several microatolls were discovered in a small embayment on the northern coast of Champion Island, located 4.7km ESE of Devil's Crown. More than 50 *P. lobata* microatolls were observed during the most recent field observations in 2021. The colonies exhibited an irregular microatoll morphology, with a more elongated, scallop-shaped boundary than the typical rounded form. Colony sizes ranged from 0.2m^2 to more than 3.0m^2. Upper surface depressions were covered in sediment and filamentous algae, surrounded by an outer ring of living tissue. The shallowest living portions of colonies were at Mean Lower Low Water (MLLW), consistent with other reports of these formations. Additionally, a resident colony of sea lions (*Zalophus wollebaeki*) in this embayment may be responsible for a novel contribution to microatoll formation. Abrasion by passing sea lions and the opportunistic placement of damselfish (*Stegastes* spp.) algal lawns may further limit vertical coral growth. The volcanic origins and generally steeply sloped, basalt shorelines of the Galápagos Archipelago are not conducive to microatoll formation. However, the embayment at Champion Island provides the critical combination of shallow depth, gentle slope, sedimentation stress, and biotic disturbances to form these distinctive coral structures.

Poster
A-2199

Unexpectedly well-preserved gorgonian communities thriving within Barcelona's city waters

Salazar, J., de Domingo, Á., Biel, M., Baena, P., Santin, A., Gili, J.-M.
Institut de Ciències del Mar (ICM-CSIC), Barcelona, Spain

jsalazar[at]icm.csic.es

Abstract

Gorgonians are one of the main ecosystem engineers on marine benthic ecosystems across a wide range of latitudes and depths. These organisms play a key role in marine benthic communities, and thanks to their complex tridimensional structures, they provide shelter and nursery grounds to marine species acting as habitat-forming species, among other functions. After more than a 5 yearlong experience on restoration projects in the Catalan continental platform[1] and the new RRI participatory approaches of the European project ResBios[2], there were enough evidences to believe on the existence of a dense population of *Leoptogorgia sarmentosa* (Esper, 1791) within Barcelona's waters, which led to the project "Gorgònia Barcelona"[3]. This project was born in 2021 in Barcelona, one of the cities with more inhabitants of the Mediterranean, in collaboration with the Catalan Federation of Subaquatic Activities (FECDAS) and local social associations. This project counts with the support of the City Hall of Barcelona and the community of practices of biosciences & RRI from ResBios.

The framework of the project consists of two base grounds: 1) prospective activities on the study area and regular samplings of *L. sarmentosa* for aquaria experiments regarding future active restoration techniques for the species. 2) the potential development of a new submarine touristic attraction in the city, in collaboration with FECDAS and local social associations. Participatory processes involving different stakeholders (local government actors, educators, policy makers, diving centres, neighborhood institutions, citizenship) are followed.

The project's approach allows not only to set a base ground for experimental analysis and explore improvements on existing marine restoring techniques, but also to conduct epistemological studies and contribute to ocean literacy and to blue economy of the city of Barcelona. In order to face the next challenges of our time we should re-consider our knowledge but also our attitudes and behavior towards marine ecosystems. It is time to move to action and integrate the conclusions of knowledge acquired about marine benthic studies into society and governance. The methodological approach and first results of first year of the experience of the project "Gorgònia Barcelona" will be presented as well as the next steps of the project.

Virtual
Oral
A-2059

Seamounts, Reefs and Canyons of Australia's Coral Sea and Great Barrier Reef Marine Parks: A Comprehensive Deep Sea Study

Carroll, A.[1], Brooke, B.[1], Nichol, S.[1], Beaman, R.[2], Lindsay, D.[3], McNeil, M.[1], Horowitz, J.[2], Bridge, T.[4], Webster, J.[5], Post, A.[1], Huang, Z.[1], McLennan, S.[1], Przeslawski, R.[6], Siwabessy, J.[1], Leplastrier, A.[1], Picard, K.[1], Ekins, M.[4], Cresswell, B.[2], Yokoyama, Y.[7], Williams, S.[5], Barrett, N.[8], Monk, J.[8], Johnson, A.[9], Pizarro, O.[5], Woodroffe, C.[9], Galbraith, G.[2], Henderson, D.[5], Reeks, C.[5], Marais, W.[5], Shields, J.[5]
[1]Geoscience Australia, Canberra, Australia
[2]James Cook University, Queensland, Australia
[3]Japan Agency for Marine-Earth Science and Technology, Yokosuka, Japan
[4]Queensland Museum, Queensland, Australia
[5]The University of Sydney, Sydney, Australia
[6]NSW Department of Primary Industries, Huskisson, Australia
[7]The University of Tokyo, Chiba, Japan
[8]The University of Tasmania, Hobart, Australia
[9]The University of Wollongong, Wollongong, Australia

andrew.carroll[at]ga.gov.au

Abstract

As ocean temperatures increase, a pressing global challenge is to better understand the distribution and characteristics of the critical habitats that support mesophotic and deep-water coral communities. Within Australia's recently established Coral Sea Marine Park lies the Queensland Plateau, one of the world's largest (~280 000 km^2) continental margin plateaus. There is little information about the mesophotic reefs, or the distribution of deeper reef habitats and biodiversity patterns in the region. This paucity of information makes it difficult to assess what role these deep larger-scale features, and their associated habitats, play as refuges for coral and other benthic and pelagic communities in a warming ocean.

This project aimed to address a range of priorities for the Australian Government by mapping, characterizing and sampling (bathyal to mesophotic) a poorly known frontier area of the Australian marine estate. Completed aboard the Schmidt Ocean Institute's research vessel Falkor, our team applied a suite of cutting-edge technologies and national best practice procedures, to address a range of questions about the geological evolution, ecology and biology of the remote canyons, platform reefs and seamounts of the Coral Sea and Great Barrier Reef (GBR) Marine Parks.

We mapped 38,395 km^2 of seafloor, including all the major coral atolls on the Queensland Plateau and an 80-kilometer section of canyons off the northern GBR Marine Park. Using Falkor's remotely operated underwater vehicle SuBastian, we sampled the deepest recorded hard and soft corals in Australia's Coral Sea, collected undescribed species of black coral and carnivorous sponges, acquired ancient continental bedrock beneath the GBR (~40-50 million years old), recorded the first
observation in Australia of the extremely rare fish *Rhinopias agroliba*, and collected over 90 000 high-resolution seafloor images of mesophotic habitats using University of Sydney's/IMOS Autonomous Underwater Vehicle, Sirius. Our cruise also conducted the most comprehensive survey of mid-water gelatinous zooplankton in the South Pacific.

These data will greatly expand the knowledge base for sustainable management of these unique habitats, and establish environmental baselines by building on previous deep-water mapping in these Marine Parks. Here, we provide an overview of the survey and present a summary of preliminary findings, with a focus on mesophotic coral assemblages and deep-water biological communities.

Virtual Oral
A-2238

Algal overgrowth on upper-mesophotic coral forests in the Mediterranean Sea

Chimienti, G.[1, 2], **Maiorca, M.**[2], Poursanidis, D.[3]
[1]CoNISMa, Rome, Italy
[2]University of Bari, Bari, Italy, [3]terraSolutions marine environment research, Heraklion, Greece

dpoursanidis[at]terrasolutions.eu

Abstract

Mediterranean species have generally a cold affinity and are particularly sensitive to increasing temperatures, representing a wake-up call for the effects of climate changes at temperate latitudes. Octocorals such as the so-called gorgonians are among the main habitat formers of the mesophotic zone, being able to create large colony aggregations known as coral forests. Recent literature is highlighting how mesophotic coral forests in the Mediterranean Sea are undergoing mass mortality events. These events are mostly due to rapid heat waves, increasing of mean water temperatures either seasonally or annually, and the consequent lowering to the thermocline. A new, emerging sign of stress is represented by the algal overgrowth on living corals possibly due to the fact that the stressed animal loose its defence against epibionts, being a easily-accessible substrate for the fast growing of macroalgae. This study reports the results of an extensive underwater survey carried out in the National Marine Park of Alonissos Northern Sporades (Greece, Aegean Sea) and Tremiti Islands Marine Protected Area (Italy, Adriatic Sea). Alarming signs of stress were highlighted in two main habitat formers, i.e. the yellow gorgonian *Eunicella cavolini* (von Koch, 1887) and the red gorgonian *Paramuricea clavata* (Risso, 1826) in the upper mesophotic zone (40-60 m depth). Interestingly, a large number of living corals were characterized by massive macroalgal overgrowth that can enhance exponentially the mortality event in a time span of few months, even after the stress event has ceased (e.g. after the heat wave or after the temporal lowering of the thermocline). The increasing number of coral predators, such as the fire worm *Hermodice carunculata* (Pallas, 1766) and the starfish *Peltaster placenta* (Müller & Troschel, 1842), represent further sign of warming stress, particularly in the case of thermophilic or warm-tolerant species. On the other side, the occurrence of lost fishing gears on the studied coral forests is remarkable, reaching up to 75% of occupancy and representing a further stress for the habitat-formers. Underwater surveys are providing new information about the conservation status of vulnerable marine ecosystems structured by octocorals in the upper mesophotic zone. Besides immediate direct effects (e.g. coral mortality), the increasing of macroalgae overgrowth on the corals can threat these habitat formers in a new and more dramatic way.

Session 6B - From refugia to extreme coral habitats: What can we learn? And how can they aid future coral survival?

Conceptualized by: **Emma Camp**[1], **Jessica Bellworthy**[2], **Nadia Santodomingo**[3], **Eslam O. Osman**[4], **Guilhem Banc-Prandi**[2], **Verena Schoepf**[5]
[1] University of Technology Sydney (Sydney, Australia)
[2] Interuniversity Institute for Marine Science (Eilat, Israel)
[3] Natural History Museum (London, UK)
[4] Pennsylvania State University (Pennsylvania, PA, USA)
[5] The University of Western Australia (Perth, Australia)

Chaired by: **Nadia Santodomingo**[3], **Eslam O. Osman**[4], **Verena Schoepf**[5]

Oral
A-1072

Desert dust deposition supplies essential bioelements to Red Sea corals

Blanckaert, A.[1, 2], Omanović, D.[3], Fine, M.[4], Grover, R.[1], Ferrier-Pagès, C.[1]
[1]Centre Scientifique de Monaco, Monaco, Monaco
[2]Sorbonne Université, Paris, France
[3]Ruđer Bošković Institute, Center for Marine and Environmental Research, Zagreb, Croatia
[4]Bar-Ilan University, The Goodman Faculty of Life Sciences, Ramat-Gan, Israel

ablanckaert[at]centrescientifique.mc

Abstract

Climate change-related increase in seawater temperature has become a leading cause of coral bleaching and mortality. However, corals from the northern Red Sea show high thermal tolerance and no recorded massive bleaching event. This specific region is frequently subjected to intense dust storms, coming from the surrounding arid deserts, which are expected to increase in frequency and intensity in the future. The aerial dust deposition supplies essential bioelements to the water column. Here, we investigated the effect of dust deposition on the physiology of a Red Sea coral, Stylophora pistillata, exposed during few weeks to dust deposition. Our results show that 1 mg L^{-1} of dust supplied nanomolar amounts of nitrate and other essential bioelements, such as iron, manganese, zinc and copper, rapidly assimilated by the symbionts. At 25°C, metal bioaccumulation enhanced the chlorophyll concentration and photosynthesis of dust-exposed corals compared to control corals. These results suggest that primary production was limited by metal availability in seawater. A 5°C increase in seawater temperature enhanced iron assimilation in both control and dust-enriched corals. Temperature rise increased the photosynthesis of control corals only, dust-exposed ones having already reached maximal photosynthesis rates at 25°C. All together these observations highlight the importance of dust deposition in the supply of essential bioelements, such as iron, to corals and its role in sustaining coral productivity in Red Sea reefs.

Oral
A-1765

Volcanic sediments structuring mesophotic coral ecosystems on Montserrat, British West Indies

Brandtneris, V.[1], Ennis, R.[2], Estep, A.[3], Holstein, D.[4], Smith, T.[2]
[1]University of the Virgin Islands, Saint Thomas, U.S. Virgin Islands
[2]University of the Virgin Islands, Saint Thomas, United States
[3]Waitt Institute, La Jolla, United States, [4]Louisiana State University, Baton Rouge, United States

viktor.brandtneris[at]uvi.edu

Abstract

The mesophotic realm is often lauded as a potential refuge for coral ecosystems in the face of ongoing climate changes. To better grasp the capacity of mesophotic coral ecosystems (MCEs) to act as long-term refugia, it is necessary to build a better understanding of the physical and environmental drivers of refuge in MCEs. These ecosystems may be sensitive to sedimentation because of lower light in an already light-limited environment and a preponderance of reduced benthic topography and near horizontal living surfaces on plating corals. The island of Montserrat (MNI), located in the Eastern Caribbean, provides a unique environment in which to study the influences both acute and chronic sedimentation on MCEs. Covering approximately 120 km2, the depth of the MNI shelf is predominantly mesophotic, at a ratio of nearly 2:1 mesophotic (~80km2 30-100m) to shallow (~40km2 <30m). The Soufriere Hills Volcano located in the Southern half of MNI began erupting in 1995 for the first time in 400 years. The volcano has deposited large volumes of ash into the nearby ocean and lowland coastal areas and created an environment of extreme and ongoing sedimentation across the nearby shelf system. Across two field expeditions between July 2016 and August 2017, we systematically sampled benthic cover at 477 sites covering the MNI shelf between 26 and 100 meters deep using a remote camera apparatus. Soft sediment accounted for 54% of the mesophotic benthic habitat around Montserrat and hard substrates were predominately covered by macroalgae (mean = 52%), and less so by sponges (mean = 3%) and living stony corals (mean = 0.4%). While low in absolute terms, sponge cover is nearly 50% greater across the MNI shelf than on another Eastern Caribbean mesophotic shelf in the US Virgin Islands, possibly due to enrichment from volcanic ash deposition. A small area of well-developed mesophotic coral reef was identified in the northeastern region of the shelf (coral cover mean = 9%; max = 16%), coincident with reports from fishermen. Extreme sedimentation in the deep, low light environments of MNI appears to have severely hampered the development of coral ecosystems and has resulted in the domination of hard substrates by macroalgae and a ubiquitous distribution of sponges across the shelf system.

Oral
A-1249

Cold temperature tolerance of the threatened Caribbean staghorn coral Acropora cervicornis: implications for assisted migration in Florida

Bremer, R. A.[1], Dennison, C. E.[1], Wen, A. D.[1], Thomas, S. C.[2], Johnson-Sapp, K.[1], Karp, R. F.[1], Routt, B. J.[1], Baker, A. C.[1]
[1]Rosenstiel School of Marine and Atmospheric Science, University of Miami, Marine Biology and Ecology, Miami, United States
[2]University of Florida, Fisheries and Aquatic Sciences, Gainesville, United States

rab376[at]miami.edu

Abstract

Globally, corals are experiencing significant population declines due to climate change and other interacting factors, and it has been suggested that some coral species may shift their distributions poleward in response to increasing ocean temperatures, thus increasing their range. Indeed, in some cases, such as the threatened Caribbean staghorn coral *Acropora cervicornis*, geological records indicate that, in the recent past (6,000-8,000 BP) the northern limit was further already north than its current distribution. Since corals may be unlikely to migrate quickly enough to match current rates of climate change, assisted migration as part of restoration efforts may help resilience of these populations, but only if these species can also tolerate the cooler winter temperatures that accompany these translocations. Here, we tested, both experimentally and in the field, whether cold shock might limit efforts to restore *A. cervicornis* north of its current distribution. Thirty-five genotypes of *A. cervicornis* from Miami-Dade and Broward Counties were common gardened in a coral nursery for one year in Broward County before being fragmented and outplanted to Palm Beach County, just north of the current northern limit for this species. Health and survivorship of transplants were monitored for 4 months starting in the coolest time of the year (February). In addition, a subset of fragments were brought back to the laboratory from where they were acclimated to laboratory conditions before being subjected to a cold shock experiment in which temperature was decreased to 17ºC and 19ºC at a rate of ~4.5ºC per day and maintained at this target temperature for 45 days. Experimental fragments were monitored daily for tissue loss and survivorship, and changes in photochemical efficiency and reductions in symbiont to host cell ratio were monitored using chlorophyll fluorometry and quantitative PCR, respectively. Preliminary results indicate promising survival of *A. cervicornis* when exposed to temperatures consistent with seasonal minimum temperatures and typical winter short-term cold-shock temperatures in Palm Beach County. This study helps assess the feasibility of assisted range expansion as a restoration strategy for *A. cervicornis* to help maximize the persistence of these populations in Florida.

Oral
A-1296

Parental exposure to natural CO_2 vents alters the response to low pH of a temperate coral early life stages.

Carbonne, C.[1], Comeau, S.[1], Plichon, K.[2], Gattuso, J.-P.[1, 3], Teixido, N.[1, 4]
[1]Sorbonne Université, CNRS, IMEV UMR 7093 LOV, Villefranche sur Mer, France
[2]MSc MARRES, Université Côte d'Azur, Nice, France
[3]Institute for Sustainable Development and International Relations, Science Po, Paris, France
[4]Stazione Zoologica Anton Dohrn, Ischia Marine Center, Department of Integrated Marine Ecology, Ischia, Italy

chloe.carbonne[at]obs-vlfr.fr

Abstract

The study of early life stages such as larval development, settlement, survivorship, and recruit growth is critical to better understand the resilience and persistence of coral populations. While the deleterious effects of ocean acidification on calcification and growth on adult corals are well known, the impacts on early life stages are still poorly documented. Here, we investigate whether past-exposure of parental colonies to naturally acidified environments at CO_2 vents can increase the offspring's tolerance to low pH. Larvae of the Mediterranean azooxanthellate coral *Astroides calycularis* were obtained from parent colonies collected from low and ambient pH sites in Ischia, Italy. Larvae were exposed in the laboratory to three pH treatments: ambient (pH_T ~8.05), low (pH_T ~7.7, pH projected for the end of the century under RCP 8.5) and extreme low (pH_T ~7.5, pH as extreme condition, only for the larvae from the CO_2 vent site). Several traits of the early life stages were monitored for 5 months: larval size, settlement success, survival and growth of the recruits. Key differences were observed between the site of origin of the larvae. For instance, larvae from the CO_2 vent site were shorter and exhibited a higher rate of mortality than the larvae from the ambient pH site regardless of the pH treatment they were exposed to. Also, larvae from the CO_2 vent site had a lower settlement success at low and extreme low pH. Our results suggest that future acidification conditions will have an impact on survival and settlement of early life stages. These findings provide new insights into coral recruitment and the ability to respond to present and future ocean acidification conditions.

Oral
A-1081

Light and photoacclimatization drive distinct differences between shallow and mesophotic coral communities in Little Cayman, Cayman Islands

Carpenter, G.[1, 2], Chequer, A.[1], Weber, S.[1], Mass, T.[3, 4], Goodbody-Gringley, G.[1]
[1]Central Caribbean Marine Institute, Little Cayman, Cayman Islands
[2]Louisiana State University, Department of Oceanography and Coastal Sciences, Baton Rouge, United States
[3]University of Haifa Leon H. Charney School of Marine Sciences, Department of Marine Biology, Haifa, Israel
[4]University of Haifa Leon H. Charney School of Marine Sciences, Morris Kahn Marine Research Station, Sdot Yam, Israel

gcarpe3[at]lsu.edu

Abstract

The ecological distribution of coral species from shallow to mesophotic reefs is dependent on light, which varies drastically among local environments. Current definitions of mesophotic coral ecosystems (MCEs) primarily rely on a 30 m recreational SCUBA boundary to define upper limits of the community, however, this boundary does not consider local conditions and physiological adaptions of coral species. Using *in-situ* benthic imagery and chlorophyll fluorescence measurements, we examined species distribution and community similarity, as well as photoacclimatization of two common depth-generalist species (*Montastraea cavernosa* and *Porites astreoides*) across shallow to mesophotic reef zones at Little Cayman Island. Photo-quadrat image analysis revealed a significant shift in coral species assemblages between 25 m and 35 m, which was accompanied by a 30% drop in available surface light, suggesting light is a key driver of coral community composition. Patterns of photoacclimatization across depths differed significantly between the two coral species, with available surface light and the quantum yield of photochemistry in PSII found to be significant determinants of each species' abundance. These results provide valuable baseline data on coral community composition across a broad depth gradient in Little Cayman that can contribute to a growing body of evidence to set an upper boundary of mesophotic reefs based on light availability and photoacclimatization potential of depth generalist species. Additionally, understanding the fundamental drivers of ecology in mesophotic corals, as well as the physiological light parameters of individual species, increases our ability to predict their distribution and identify potential areas that may serve as refuges, thereby increasing the resilience of global coral reef ecosystems.

Oral
A-1611

Fishes on the world's hottest coral reef: ecological and physiological adaptations for survival.

Johansen, J. L.[1], Mitchell, M. D.[2], Vaughan, G. O.[2], Ripley, D. M.[3], Shiels, H. A.[3], Burt, J. A.[2]
[1]Hawaii Institute of Marine Biology, Kaneohe, United States
[2]New York University Abu Dhabi, Abu Dhabi, United Arab Emirates
[3]Manchester Universty, Manchester, United Kingdom

jacoblj[at]hawaii.edu

Abstract

The hottest tropical coral reefs on earth are found in the Arabian Gulf (AG) where summer water temperatures typically reach >35ºC. These water temperatures are comparable to business-as-usual ocean warming projections for tropical coral reefs by 2100, providing a natural present-day laboratory for climate change. Although AG reefs have been exposed to extreme temperatures for several thousand years, fewer than 50 known species of reef fish and 35 species of coral have managed to adapt to survive there. In contrast, <300km away in the Gulf of Oman (GO) more than 500 species of fishes and 100 species of coral exits under thermal conditions typical for present day coral reefs (22-32°C).
In this study we discuss the adaptive changes and compromises that have occurred within two species of reef fishes (*Lutjanus ehrenbergii* and *Scolopsis ghanam*), allowing them to maintain ecological and physiological performance at >35°C and thrive where others cannot. Comparing cardio-respiratory function and swimming performance between AG and GO fishes across 27°C, 31.5°C and 35.5°C, we found significantly increased maximum metabolic rates and aerobic scopes in AG fishes. These changes signify an increased capacity to supply energy for physiological maintenance and critical ecological activities. Accordingly, AG fishes maintained strong swimming abilities at 35.5°C and *S. ghanam*, typically a slow swimming species, showed improved critical swimming speeds useful for prey capture to fuel elevated energetic demand. AG fishes also had higher thermal tolerance compared to GO fishes, which had low survival at 35.5°C. Most strikingly, in spite of exponentially increasing metabolic maintenance costs across temperatures, and recorded improvements in both cardio-respiratory and swimming performance metrics, AG fishes also required significantly less energy to survive. That is, total oxygen consumption at rest and at maximal activity was reduced by up to 55% in AG fishes, thereby lowering the total amount of prey required for survival at 35.5°C. This reduction in total energetic demand was primarily explained by size reductions of AG fishes, reaching less than 1/2 the mass of those from GO. Notably, our results provide strong empirical evidence in support of the "James' population body-size shift hypothesis" and "Atkinson's temperature-size rule" which have been used to project sharp declines in the maximal size and size-at-age of tropical fishes due to climate change.

Oral
A-2194

Spatio-temporal patterns of coral reef benthic communities in the Kiunga-Lamu Archipelago, Kenya - a marginal upwelling reef.

Karisa, J.
Kenya Marine and Fisheries Research Institute, Mombasa, Kenya

jfuraha[at]gmail.com

Abstract

Coral reefs in Kiunga-Lamu archipelago (1.6537°S, 41.5598°E and 2.4776°S, 40.7060°E) are located at the northern limit of true coral reef growth on the East African coast. This area experiences upwelling due to the convergence of a warmer East African Coastal Current from the south and a cooler Somali Current from the north establishing a transitional zone for biological communities. There is a marine reserve within this area extending over 50 km in length by 3-5km in width. Biogeographic studies have shown a coral diversity decline with latitude from the south and high abundance of marginal and rare coral reef species. Bleaching monitoring studies have shown that, while the impact of 1998/99 mass coral bleaching and mortality was uniform across the entire Kenyan coast, there has been very low coral bleaching and mortality records along the Kiunga-Lamu
archipelago. Here, we present results of spatial and temporal patters of benthic communities at this site for a study that spans over two decades (1998-2019). Surveys for benthic communities were done during the north-east monsoon season with two different benthic survey methods being utilised across time; line intercept transect and photoquadrat methods. We determine the effect of habitat (depth, reef type, exposure to waves), management levels (reserve and unprotected) and environmental factors (sea surface temperature, ultraviolet B, Chlorophyll-a and total suspended matter) on benthic communities. Initial results show a highly heterogenous benthic community with depth and reef type significantly contributing to this pattern. With further multivariate analysis, we are discerning potential factors that are structuring benthic communities across time and space, and discussing the role of marginal reefs in supporting the persistence of coral reef communities in this age of climate change.

Oral
A-2192

Molecular mechanisms of coral holobiont heat tolerance on bleaching-resilient, marginal inshore patch reefs of the Florida Keys

Manzello, D., Aguilar, C., Kolodziej, G., Enochs, I.
NOAA, College Park, United States

derek.manzello[at]noaa.gov

Abstract

Florida Keys coral reefs have experienced seven mass bleaching events since 1987. Many reefs have < 5% coral cover, but some inshore patch reefs have maintained higher cover (15-35%). This is counter-intuitive as inshore sites experience marginal conditions (greater thermal variability, turbidity, and sedimentation). It has been hypothesized that inshore corals are acclimatized and/or adapted to heat stress due to naturally hotter (+1°C) and variable temperatures. The response of Florida Keys coral reefs with mass bleaching in 2014 and 2015 highlighted the resilience of the inshore patch reefs. Inshore sites
demonstrated better recovery and higher bleaching resistance than offshore sites. 2015 and 2014 were the two hottest summers on record for the Florida Keys, yet total colony mortality at Cheeca Rocks, an inshore patch reef, was low with 94.7% of > 4000 colonies surviving. There was a reduction in bleaching severity and mortality with the second stronger thermal anomaly in 2015, which suggests that acclimatization may be possible with short recovery. Lab-based experiments have shown that inshore genotypes of the ESA-listed coral Orbicella faveolata exhibit a significantly greater heat tolerance relative to offshore genotypes. Dominance of the algal symbiont community by Durusdinium trenchii was associated with the greatest heat tolerance, however, there was evidence for host adaptation/acclimatization as inshore genotypes dominated by Breviolum were more heat tolerant than corals offshore with the same symbiont type. The most bleaching resistant inshore genotype had unique expression patterns of genes encoding proteins involved in the heat shock response, immunity, and protein degradation. This presentation will summarize these findings and present data from a reciprocal transplant experiment that aims to understand if the inshore-offshore dichotomy in heat resistance is due to acclimatization or adaptation. The existence of corals on the inshore patch reefs at temperatures that are +1°C warmer than offshore sites in the Florida Keys may be an important source of
heat-tolerant genotypes for restoration, as well as provide a roadmap for reef survival in the Anthropocene.

Oral
A-1993

Under pressure; climate change at depth

McWhorter, J.[1], Halloran, P.[2], Mumby, P.[3]
[1]Universities of Exeter and Queensland, Geography/Biological Sciences, Exeter, United Kingdom
[2]University of Exeter, College of Life and Environmental Sciences, Exeter, United Kingdom
[3]University of Queensland, Biological Sciences, Brisbane, Australia

jenmcwho[at]gmail.com

Abstract

Mesophotic reef communities (depths 30-150 m) have been hypothesized to provide a thermal refugia for tropical coral reefs under a warming planet. Bottom temperature climate projections over coral reefs have yet to be studied. Here we explore the idea of thermal protection for corals due to summer stratification across depths 0-50 m. Under increased future stratification we hypothesize that in some locations bottom temperatures below the thermocline could become cooler during summer months, despite, and in fact because, surface temperatures are warming. The results in this study suggest that over large areas of the Great Barrier Reef stratification allows the persistence of cool bottom waters despite sea surface temperature warming but is lost under higher emissions scenarios (SSP3-7.0 and SSP5-8.5). Regardless of increases in stratification under higher emissions scenarios, the bottom temperatures surpass a recognized thermal threshold of 30°C for bleaching at depth on the Great Barrier Reef. Therefore, the upper mesophotic zone (30-50 m) is likely to become more threatened under a warming planet.

Oral
A-1725

#Reefugia: Turbid reefs in the Coral Triangle during the past 30 million years

Santodomingo, N.[1], Waheed, Z.[2], Syed Hussein, A. B.[2], Rosedy, A.[2], Perry, C.[3], Sosdian, S.[4], Rosen, B.[1], Wood, E.[5], Johnson, K.[1]
[1]Natural History Museum, Earth Sciences, London, United Kingdom
[2]University Malaysia Sabah, Borneo Marine Research Institute, Kota Kinabalu, Malaysia
[3]University of Exeter, Geography, College of Life & Environmental Sciences, Exeter, United Kingdom
[4]Cardiff University, School of Earth & Ocean Sciences, Cardiff, United Kingdom
[5]Independent, London, United Kingdom

n.santodomingo[at]nhm.ac.uk

Abstract

The Coral Triangle region of SE Asia contains the most diverse marine ecosystems on Earth. This high biodiversity is at risk due to anthropogenic environmental change, and thus identification of potential ecological refugia is a high priority. New data suggest that shallow turbid habitats may play a critical function as refugia. Our palaeoecological reef studies in the Coral Triangle (East Borneo) have shown that pioneer coral assemblages from 30 Mya were mainly low-relief patch reefs that developed under low light and high sediment inputs – conditions that have recently been shown to mitigate thermal stress on corals. These shallow turbid habitats hosted a high coral diversity from the Oligocene (100 spp.) and the Miocene (234 spp.) with no significant faunal turnover, suggesting that once taxa appear, they can persist on turbid habitats over long periods of time. With the aim of testing the hypothesis of turbid habitats as reef refugia that emerged from our fossil record and to better understand the role of light and sediments as factors involved in the current resilience of these habitats, we surveyed a mosaic of seven turbid and clear-water reefs in Darvel Bay (Sabah). Detailed light profiles during dry and rainy seasons, together with sediment accumulation rates and composition were used to characterize the different sources of turbidity (urban, mangroves, coastal runoff, and river inputs) and seasonal regimes. Coral cover and diversity were estimated from video transects and over 200 coral samples. Preliminary comparisons of ancient and modern turbid reefs show similarities in richness and fauna composition. Live coral cover varies from 33% in the most turbid locality to 55% in the clear water setting. Community composition also changes within this spectrum: acroporids dominate assemblages in clear waters, massive and branching *Porites* are dominant in low turbid settings, while foliose and platy forms of *Leptoseris* are dominant in settings with the highest turbidity. Interestingly, during the 2020 bleaching event, corals in turbid reefs experienced less impact (12.5%) in comparison to corals in clear-water reefs, where more than half of the colonies were bleached. Plastic pollution and increasing coastal development are the major threads of these long-term resilient ecosystems. The combination of fossil and modern data shows that turbid reefs have played an important role as resilient ecosystems over the past 30 million years in the Coral Triangle.

Oral
A-1086

Coral reefs at the edge of environmental limits: A new conceptual framework to re-define marginal and extreme reef systems

Schoepf, V.[1], Baumann, J.[2], Barshis, D.[3], Browne, N.[4], Camp, E.[5], Comeau, S.[6], Cornwall, C.[7], Guzman, H.[8], Riegl, B.[9], Rodolfo-Metalpa, R.[10]
[1]University of Amsterdam, Institute for Biodiversity and Ecosystem Dynamics, Dept. of Freshwater and Marine Ecology, Amsterdam, Netherlands
[2]Mount Holyoke College, South Hadley, United States
[3]Old Dominion University, Norfolk, United States
[4]Curtin University, Perth, Australia
[5]University of Technology Sydney, Sydney, Australia
[6]Laboratoire d'Océanographie de Villefranche sur Mer, Villefranche, France
[7]Victoria University of Wellington, Wellington, New Zealand
[8]Smithsonian Institution, Bocas del Toro, Panama
[9]Nova Southeastern University, Fort Lauderdale, United States
[10]ENTROPIE, Institut de Recherche pour le Développement, Noumea, New Caledonia

verena.schoepf[at]outlook.com

Abstract

The worldwide decline of coral reefs has renewed interest from the scientific community in reef systems that persist at the edge of environmental limits of coral reef development. This is due to their potential to provide insights into how coral reefs might function in future ocean conditions, being resilience hotspots that may harbour naturally stress-resistant coral communities, and to serve as climate change refugia in some cases. These reef systems and coral communities are often referred to as marginal and/or extreme reefs; however, usage of the terms “marginal” and “extreme” has been inconsistent in the literature and formal definitions only exist for marginal but not extreme reefs. This creates significant challenges for better understanding reef systems at the edge of their environmental limits and their lessons for future coral reef survival. It has therefore become necessary to (re-)define reef systems at the edge of environmental limits, particularly because they have been frequently used as natural laboratories by an increasing number of scientists. Here, we argue that marginal and extreme are related but distinct reef systems and provide a new conceptual framework that allows for better characterization and categorization of these important reef systems using a range of both abiotic and ecological criteria. We evaluate the differential potential of marginal and extreme reefs to serve as natural laboratories, resilience hotspots and climate change refugia, and further discuss how we can best conserve and manage these important systems and what the priorities are for future research. Our new conceptual framework provides an important tool to improve our understanding of how corals can persist under suboptimal environmental conditions and how can we leverage this knowledge to optimize strategies for coral reef conservation, restoration and management in a rapidly changing ocean.

Oral
A-1103

Expanding climate refugia for coral reefs: Using coral life histories to classify avoidance, resistance and recovery refugia

Schwarz, A.[1], Darling, E.[1, 2], Fortin, M.-J.[1], McClanahan, T.[2]
[1]University of Toronto, Ecology & Evolutionary Biology, Toronto, Canada
[2]Wildlife Conservation Society, New York, United States

avery.schwarz[at]gmail.com

Abstract

Climate change is leading to widespread losses in coral diversity and cover, necessitating novel conservation strategies. One increasingly popular approach is the identification and protection of coral climate refugia, environments which provide relative safety from climate change. Historically, reef literature has focused on refugia which avoid the worst of climate change. However, emerging frameworks describe three refugia categories: avoidance, resistance and recovery. While avoidance refugia have lower stress levels, resistance refugia sustain stress but are not as heavily affected and recovery refugia can recover more quickly from stress events. While the importance of these categories is being recognized, no empirical tests have been conducted. Here we seek to address whether coral life history data can be used to delineate refugia into the categories of avoidance, resistance and recovery. To answer this question, we provide the first empirical test of reef refugia frameworks at a regional scale, evaluating coral life histories, percent cover, genera richness and herbivore biomass from 606 sites in five countries in the Western Indian Ocean, comprising 35 years of Wildlife Conservation Society data. These sites range in coral cover from 15% - 80% and comprise different life history assemblages, leading us to hypothesize these sites have different characteristics of climate refugia which are important for conservation planning and predictions of coral persistence. Correlation matrices will be used to determine how the variables are correlated. A regression tree will be used to categorize reefs into these categories and a predictive model will be developed to extrapolate these findings to other sites. Our preliminary findings suggest that reefs can be classified reefs into these refugia categories using a combination of life history, percent cover, genera richness and herbivore biomass data. These delineations can be strengthened through key environmental variables, such as fisheries management, and SST metrics: degree heating weeks, skewness and kurtosis. This allows us to understand signatures of regional press and pulse disturbances and see how refugia predictions play out at each site, yielding important implications for future marine conservation planning. By identifying sites in each category, we can protect a more diverse portfolio of reefs, promoting a more effective conservation and climate change plan for reefs in the region and globally.

Oral
A-1630

δTrophic strategies ($\delta^{13}C$ and $\delta^{15}N$) of three species of Caribbean corals across an extreme environmental gradient

Solomon, S., Schoepf, V.
University of Amsterdam, Department of Freshwater and Marine Ecology, Amsterdam, Netherlands

s.l.solomon[at]uva.nl

Abstract

Stable isotopes are a common tool for assessing coral trophic strategies, as the natural abundance of $\delta^{13}C$ and $\delta^{15}N$ of both the coral host and algal endosymbiont are indicators of nutrient exchange between symbiotic partners. The difference between the host and symbiont $\delta^{13}C$ and $\delta^{15}N$ (ie $\delta^{13}C_{host\text{-}symbiont}$) and the degree of isotopic niche overlap can indicate if a coral is more autotrophic or heterotrophic, which can be highly relevant when assessing changes to coral health in response to environmental stressors. The health of coral reefs worldwide is threatened by climate change (ocean warming, acidification) and local stressors, such as pollution and coastal development. Yet, some corals in highly variable or extreme environments tend to have naturally increased stress tolerance to both global and local stressors, allowing them to survive in environments that are, for example, warmer and more acidic than surrounding reefs. The physiological traits associated with stress tolerance in corals from naturally marginal or extreme environments may provide insight into the capacity of corals to acclimatize or adapt to future ocean conditions. We measured the $\delta^{13}C$ and $\delta^{15}N$ of conspecifics (*Siderastrea siderea*, *S. radians, and Porites porites*) from two distinct habitats: the semi-enclosed inland bays of Curaçao, an extreme environment, and fringing reef habitats with benign environmental conditions. The inland bays of Curaçao harbor corals that experience high turbidity, sedimentation and varying degrees of eutrophication. Additionally, the bays experience variable and high average seawater temperatures and low pH compared to surrounding reefs. We sampled corals at three time points across two years, including following the unseasonably warm summer of 2020. Utilizing two approaches ($\delta^{13}C_{host\text{-}symbiont}$,$\delta^{15}N_{host\text{-}symbiont}$ and isotopic niche overlap) we determine if differential trophic strategies is a mechanism of stress tolerance in corals from the inland bays of Curaçao.

Oral
A-1145

Coral forests: Nested coexisting mangrove-coral habitats

Stewart, H.[1, 2, 3], Wright, J.[4], Carrigan, M.[5, 6], Altieri, A.[7], Kline, D.[8], Araújo, R.[4]
[1]University of the Virgin Islands, Center for Marine & Environmental Studies, St. Thomas, U.S. Virgin Islands
[2]Smithsonian Tropical Research Institute, Bocas Research Station, Panama City, Panama
[3]McGill University, Department of Biology, Montreal, Canada
[4]Rosenstiel School of Marine & Atmospheric Science University of Miami, Department of Marine Biology and Ecology, Miami, United States
[5]Biotork, Gainesville, United States
[6]Sante Fe College, Department of Natural Sciences, Gainesville, United States
[7]University of Florida, Department of Environmental Engineering Sciences, Gainesville, United States
[8]Smithsonian Tropical Research Institute, Panama City, Panama

hadar.stewart[at]gmail.com

Abstract

Mangroves and coral reefs are typically observed in adjacent assemblages with important ecological functions that emerge from their shared flow of resources and movement of animals. In the past two decades nested mangrove-coral assemblages (i.e., corals living within mangrove habitats) have increasingly been reported, particularly in the Caribbean. We define these nested assemblages as “coexisting mangrove-coral” (CMC) habitats and formalize a baseline understanding of these ecosystems through a review of the scientific literature to date. We identify 130 species of corals living within mangrove habitats across 12 locations spanning the Caribbean Sea, Red Sea, Indian Ocean, and South Pacific. We then provide the first description of a canopy CMC habitat located in Bocas del Toro, Panama. This canopy CMC habitat is one of the most coral rich CMC habitats reported in the world, with 34 species of corals growing on and/or among submerged red mangrove aerial roots. We provide a classification framework of CMC habitat categories based on physical setting and location of coral relative to the mangrove forest: (1) Lagoon, (2) Inlet, (3) Edge, and (4) Canopy. We then use GIS to model global distributions of coral reefs and mangroves with tidal amplitude limitations to suggest where additional CMC habitats may occur globally. Despite knowledge of the existence of CMC habitats for at least 90 years, these systems are largely overlooked, and little is known about their function. In a time where many ecosystems are at risk of disappearing, discovery and description of alternative habitats for species of critical concern are of utmost importance for their conservation and management.

Oral
A-1691

Newly discovered CO_2 vent supports a coral population persisting under high pCO_2 environments

Teixido, N.[1], Alliouane, S.[2], Carbonne, C.[2], Caroselli, E.[3], Comeau, S.[2], Copley, R.[4], Gattuso, J.-P.[2], Goffredo, S.[3], Mirasole, A.[5], Meynadier, M.[2], Palumbi, S. R.[6], Sheets, E.[7]
[1]Sorbonne University - Stazione Zoologica Anton Dohrn, Villefranche, France
[2]Sorbonne Université, CNRS, Laboratoire d'Océanographie de Villefranche, Villefranche-sur-mer, France
[3]University of Bologna, Bologna, Italy
[4]Developmental Biology Laboratory (LBDV)-Villefranche, Villefranche-sur-mer, France
[5]Stazione Zoologica A. Dohrn, Ischia-Naples, France
[6]Hopkins Marine Station, Stanford University, Pacific Grove, United States
[7]UC Santa Cruz Genomics Institute, Santa Cruz, United States

nuria.teixido[at]obs-vlfr.fr

Abstract

Natural volcanic CO_2 vents cause local acidification of seawater and are used as a proxy to represent future ocean acidification (OA) conditions. These high $p$$CO_2$ environments and their populations provide an unparalleled opportunity to assess the mechanisms of acclimatization and adaptation to climate variability and extremes. Here we investigate a newly discovered CO_2 vent system at the coast of Ischia (Italy) and how elevated seawater $p$$CO_2$ exposure influence trait-shifts on *Astroides calycularis*, an azooxanthellate scleractinian coral endemic to the Mediterranean, that naturally occurs in this acidified environment. *A. calycularis* is a long-lived coral, considered a warm-water species, with restricted gene flow and low dispersal capacities. This new CO_2 vent system recently discovered locally acidifies the seawater with gas comprising 92-95% CO_2 (no sulfur). We compare populations living near the vent to two reference areas hosting similar geomorphology but outside the influence of CO_2 venting. In this presentation, we summarize research into the mechanisms underlying the mechanisms of acclimatization and adaptation. We combine *in situ* population demographics, skeletal characteristics, computed tomography and transcriptomic approaches to assess changes in population abundance, skeletal characteristics, age and genomics of differentiation of *A. calycularis.* Unexpected shifts in skeletal and growth patterns were found. Colonies shifted to a skeletal phenotype characterized by encrusting morphology, smaller size, reduced coenosarc tissue, fewer polyps, and less porous and denser skeletons at low pH. Interestingly, while individual polyps calcified more and extended faster at low pH, whole colonies found at low pH site calcified and extended their skeleton at the same rate as did those at ambient pH sites. Transcriptomic data revealed strong genetic differentiation among local populations of this warm water species whose distribution range is currently expanding northward. Using RNA-seq, we are performing differential analysis of gene expression of corals between the CO2 vent site and ambient pH reference sites. This study aims to contribute to increase our understanding of how natural coral populations persist under high pCO_2 environments.

Oral
A-2020

Beyond marginality: Transcriptomic insights between marginal and extreme environments in Porites panamensis near hydrothermal activity

Trevino-Balandra, E.[1], Paz-García, D.[1], Flores-Lopez, V.[2], Fernández-Valverde, S. L.[3], Balart-Paéz, E. F.[1], Hellberg, M. E.[4]
[1]Northwestern Center of Biological Research (CIBNOR-Mexico), Fisheries ecology, La Paz, Baja California Sur, Mexico
[2]Cambridge University, Cambridge, United Kingdom
[3]Center for Research and Advanced Studies of National Polytechnic Institute (IPN), National Laboratory of Genomics for Biodiversity, Irapuato, Guanajuato, Mexico
[4]Louisiana State University, Department of Biological Sciences, Baton Rouge, LA, United States

etrevino[at]pg.cibnor.mx

Abstract

In the Anthropocene, coral reefs are in a state of severe degradation as a result of rising temperatures, ocean acidification and eutrophication, and are expected to get worse over the next 100 years. Some coral communities naturally inhabit marginal conditions similar to the climate scenarios predicted for the next century. Such is the case of the endemic coral *Porites panamenisis* in the eastern tropical Pacific. Recently, we have documented the presence of this coral near a hydrothermal field in a marginal region, defined by its high variable temperatures and pH . Our goal was to determine the genetic mechanisms that allowed this coral to persist in an extreme environment. To do this, we characterized corals from hydrothermal springs in the mid region of the Gulf of California in two conditions: control (23 ± 3 º C, pH = 8.1) and vent influenced (30±10 C, pH = 7.9). 32 cDNA libraries were sequenced, which yielded 960,000,000 total readings to incorporate into downstream analysis. More than 6000 genes were associated with antioxidant metabolism, ion transport, and immune response due hydrothermal activity and seasonal transition. 60% of the variation in gene expression was related to temperature, pH, as well as nitrates and sulphates concentrations. Our results suggest that the transcriptomic state of the coral P. panamensis in the Gulf of California is based on temperature, acidity and nutrient availability. This is the first evidence of how marginal species can shift their physiology to different stressor regiments in the ETP. Finally, future directions between molecular acclimatization and adaptation capabilities of corals (e.g. *P. panamensis*) should be considered to assess coral reef resilience to climate change.

Poster
A-1846

Latitudinal variation in thermotolerance of Porites lobata in the Red Sea

Barreto, M., Schmidt-Roach, S., Aranda, M.
King Abdullah University of Science and Technology, Red Sea Research Center, Thuwal, Saudi Arabia

marcelle.munizbarreto[at]kaust.edu.sa

Abstract

Spatial environmental heterogeneity creates different selective pressures that can lead to genetic variability and species adaptation. Due to its latitudinal temperature gradient and extreme temperature conditions, the Red Sea constitutes an ideal location to investigate local adaptation and acclimatization potential of corals to increased temperatures. This becomes particularly important in the context of global change and the rise of assisted gene flow (i.e. the managed movement of individuals of different populations within the species range) as a tool to accelerate coral adaptation to increasing temperatures. In this study, we investigated differences in the physiological response of the coral Porites lobata to translocation across five degrees latitude in the Red Sea to evaluate the potential of applying assisted gene flow to Red Sea reefs. Colonies from different thermal regimes (i.e. Duba in the North, Thuwal in the Central and Farasan Islands in the South Red Sea) were collected for a common garden experiment. Five colonies from each location were fragmented and deployed in situ in early summer, at the thermally intermediate location, Thuwal. Bleaching and survival were surveyed regularly. Results showed significantly higher bleaching in fragments from Duba, followed by 65% mortality. Even though no bleaching was observed in fragments from Farasan Islands, mortality rates of around 30% indicated that other environmental parameters besides temperature may influence coral health and survival. These results suggest that a management approach of Red Sea coral reefs based on assisted gene flow via translocation alone may not be efficient, due to local adaptation to environmental conditions other than temperature.

Poster
A-1588

Coral demographics of Qatar's offshore reefs

Lopez Padierna, M.[1], Goergen, E. A.[1], Range, P.[2], Al-Jamali, F.[1], Ben Hamadou, R.[1]
[1]Qatar University, College of Arts and Science, Department of Biological and Environmental Sciences, Doha, Qatar
[2]Qatar University, Environmental Science Center, Doha, Qatar

mauricio.lopez[at]qu.edu.qa

Abstract

The reefs of the Persian/Arabian Gulf (PAG) have been an object of study for many decades with the first reports in scientific literature surfacing in the early 1960s. However, most studies have focused on reefs that are relatively nearshore (less than 25km from land) with a few exceptions for locations with islands. The fate of these reefs has been widely regarded as bleak as the PAG has suffered immense anthropogenic stress from rapid population growth in recent decades. These stresses are further exacerbated by the extreme natural environment that exists in the Gulf. The shallow basin undergoes rapid annual temperature changes ranging from 16 ℃ in the winter to 35 ℃ during the summer and a salinity ranging between 36 to 43 psu.
Mass bleaching events have been recorded with increasing frequency and have altered the population structure of key species on coastal reefs. Given this scenario it is urgent to understand how the offshore reefs are responding to these stresses. Five sites around Qatar ranging in depths between 10-24 m have been selected as permanent monitoring sites with an average distance from shore of 50 km. These are the first systematic surveys conducted on these reefs, so describing the population structure for key species will allow to set a baseline for the current state of coral reefs in Qatar. Preliminary data show a range of coral cover from 2.2% at Sheraoh to 46.6% at Fasht East Halul, and densities from 2.6 colonies/m^2 to 37.4 colonies/m^2. The reefs are heavily dominated by *Dipsastraea*, *Platygyra* and encrusting *Psammocora*and *Pavona*. *Acropora downingi* was recorded at three of the five sites although in low numbers, and recent bleaching events reduced the numbers further. Although the nearshore reefs have faced severe declines if not local extirpations, these offshore reefs harbor some relatively healthy reefs that warrant further study.

Poster
A-1369

Diversity, ecology and genomic potential of bacteria associated with two hard coral species in the Red Sea

Raimundo, I., Delgadillo, N., Barno, A., Villela, H., Isotta Terraneo, T., Benzoni, F., Peixoto, R.
King Abdullah University of Science and Technology, Thuwal, Saudi Arabia

ines.goncalvesraimundo[at]kaust.edu.sa

Abstract

One of the key components promoting coral homeostasis is their association with microorganisms from different phylogenetic groups, including microalgae, bacteria, and viruses, which, together with the host, form the coral holobiont. Among coral-associated microbes, bacterial symbionts have drawn the attention of the scientific community because of their key roles in the host metabolism and health and their importance for understanding the ecological resilience of coral reef ecosystems. However, many questions remain regarding the roles of bacterial communities on coral physiology and distribution in different environments. In the Red Sea (RS), the large coral diversity and unique conditions combining high temperature and high salinity make this basin a suitable model environment for ecological surveys and studies about the future of coral reefs under climate change scenarios. In this study, we investigated the coral microbiome composition of two well-defined hard corals, *Coscinarea monile* and *Galaxea fascicularis*, which are species commonly found in shallow waters of the RS at depths ranging from 2 to 30 m. The sampling sites were located between Thuwal and Yanbu, in the central region of the Red Sea, Saudi Arabia. We collected healthy coral fragments from healthy corals from 16 sampling sites within inshore and offshore reefs, at depths of 5 and 15 meters. Total DNA was extracted from all the coral fragments and the 16S rRNA gene was sequenced to access the bacterial diversity and composition of the host. A detailed analysis will be conducted to unravel patterns of diversity, abundance and distribution of the associated microbial communities according to coral species, location, and depth, to increase the knowledge of RS coral-associated microbiomes and identify potential beneficial bacterial groups that can be further investigated as coral health promoters (probiotics).

Virtual
Oral
A-2156

MPAs and shallow-reefs thriving and maintaining reef structural complexity despite persistent climatic adversities – reef refugia for the Indian Ocean

Munbodhe, V.[1], McClanahan, T.[2], Muthiga, N.[3], Ranjeet, B.[4]
[1]University of Mauritius, Bioscience and Ocean Studies, Reduit, Mauritius
[2]Wildlife Conservation Society,, Coral Reef Conservation, Nairobi, Kenya
[3]Wildlife Conservation Society, Coral Reef Conservation, Nairobi, Kenya
[4]University of Mauritius, Department of Bioscience and Ocean Studies, Reduit, Kenya

vikash.munbodhe1[at]umail.uom.ac.mu

Abstract

Coral reefs have evolved with time and have adapted to cope with natural environmental changes, conversely to anthropogenic impacts (man-induced impacts). However, at the current rate of disproportionate reef degradation, it has been observed that over 30% of the global reefs are far from being structurally functional and under ongoing intensification of the stressors, by 2030, it is predicted that about 60% of the remaining corals may disappear. Like any of the reefs world-wide, Mauritius Island has not been spared to the impacts of prolonged climatic variability and anthropogenic activities. It has resulted in severe reef flattening with increased in rubbles, dead coral and algal covers leading to the loss of the 3-dimensional functional structure. This ecological study, therefore, was carried out at the 20 reefs around the island using 15 imaginary quadrats of 4m2 each for substrate cover and underwater photography for coral identification. The results showed that the mean coral cover in the legally Marine Protected Areas (6 MPAs) ranged between 55.7±3.8% and 38.0±1.9% as compared to the seven mid-lagoon Non-Protected Marine Areas (NPAs) which varied between 12.7±3.3% and 32.3±3.6%. Also, the live coral cover in the seven shallow-reefs NPAs shared values between 63.3±4.7% and 31.7±5.1% with the highest live coral coverage and highest coral diversity southwards of Mauritius. While, the last two decades have been detrimental to the coral reefs with major global coral demise, these results have revealed that the corals in the shallow reefs and MPAs have thrived through the frequent and prolonged severe marine heatwaves. The reefs in the MPAs and the shallow NPAs (Krushkal-Wallis $p<0.0001$) were found to be more resilient compared to the mid-lagoon areas. Also, the better performing reef habitat with relatively high coral cover and diversity in the MPAs and shallow reefs were indicative of thermal adaptation conversely to the mid-lagoon areas ($p<0.001$) which have shown signs of high vulnerability with lower coral cover and diversity in a macroalgal and rubble dominated benthos. This extended and intensive study firmly demonstrates that restricted and protected reefs have been and are thriving through the persistent climatic adversities by maintaining their reef structural complexity. Such marine biodiversity hotspot warrants in-depth molecular studies which may potentially serve as coral gene bank and shallow reef refugia for the Indian Ocean.

Virtual
Oral
A-1485

Unexpected coral cover and diversity in high wave regime environment at Sadranan Beach Southern Coast of Java Indonesia

Reza, A.
Universitas Gadjah Mada, Faculty of Biology, Laboratory of Ecology and Conservation, Yogyakarta, Indonesia

akbar.reza[at]ugm.ac.id

Abstract

Extremely low coral cover, small colonies, exposed during low tide, and a high degree of patchiness are the typical reef flat communities on the Southern coast of Java Island Indonesia. This community structure reflects the strong wave exposure as the structuring force caused by oceanic swell from the Indian Ocean with the wave energy ranging from 2000-4000 Joule. However, Sadranan Beach reef flat in Yogyakarta show a distinctive pattern since the formation of dead coral with algae provide a barrier structure similar to the reef crest, hence slowly attenuating the wave energy and forming a protected embayment that constantly flooded even during the low tide. The coral cover, lifeform, and species in this barrier structure and sheltered area were counted in a 20-meter transect parallel to the beach with fifteen replicates. The observer also records the corals within 0.5 m on either side to adapt with the coral clumped distribution. We also use the same method to investigate the reef flat community on adjacent beaches, including Drini, Sepanjang, Ngandong beach, to represent typical reef flats in the same area. The rough estimation of wave energy (Joule) was also measured on all the sampling sites by counting the mean wave frequency per minute and wave height. Our study in the sheltered area revealed an unexpected 27% of coral cover, six lifeforms including Acropora branching, coral branching, coral massive, coral foliose, and coral encrusting, seventeen species dominated by *Pocillopora* and *Favites* genus. In contrast, other sites show a typical reef flat in this area with 8-10% of coral cover, dominated by coral encrusting or coral massive, and eight coral species. Furthermore, the wave energy on the sheltered area in Sadranan Beach is 140 Joule, or 6-26-fold lower compared to other sites. The results highlight that the wave breaker in Sadranan beach provides protection, thus a more suitable habitat for coral larvae to settle and grow.

Session 6C - Mesophotic Coral Ecosystems: Lifeboats in the Challenging Future of Coral Reefs?

Conceptualized by: **Marc Slattery**[1], **Frederic Sinniger**[2], **Gal Eyal**[3], **Tyler Smith**[4], **Kimberly Puglise**[5], **Alejandra Hernandez**[6]

[1] University of Mississippi (Oxford, MS, USA)
[2] University of Ryukyus (Sesoko, Japan)
[3] The University of Queensland (Brisbane, Australia)
[4] University of the Virgin Islands (St. Thomas, U.S. Virgin Islands)
[5] NOAA National Ocean Service (Silver Spring, MD, USA)
[6] California Academy of Sciences (San Francisco, CA, USA)

Chaired by: **Marc Slattery**[1], **Tyler Smith**[4]

Oral
A-2241

Coral acclimation and migration to mesophotic depths

Bellworthy, J.[1, 2], Martinez, S.[3], Ferrier-Pagès, C.[3], Goodbody-Gringley, G.[4], Mass, T.[1, 5]
[1]University of Haifa, Department of Marine Biology, Haifa, Israel
[2]Interuniversity Institute of Marine Sciences, Eilat, Israel
[3]Centre Scientifique de Monaco, Monaco, Monaco
[4]Central Caribbean Marine Institute, Little Cayman Island, United Kingdom
[5]University of Haifa, Morris Kahn Marine Research Station, Sdot Yam, Israel

jhbellworthy[at]gmail.com

Abstract

Corals have depth dependent phenotypes. This is apparent for multiple coral species, across different locations, and in both adult and larval life stages. To what extent are depth dependent phenotypes fixed by population adaptation and how plastic are specific traits? Using the depth generalist coral *Stylophora pistillata* from the Red Sea, we performed a reciprocal translocation experiment of larvae from deep (40m) and shallow (5m) parent colonies. After settlement, symbiont photochemistry initially reflected the parental origin. However, within 35 days, acclimation to the new light environments was evident and photosymbionts performed similarly to non-translocated natives. Our data indicate the importance of symbiont photo-acclimation for recruit survival in novel environments. The importance of symbiont acclimation was further highlighted by our recent discovery of *Oculina patagonica* inhabiting mesophotic reefs along the Israeli Mediterranean coast having previously been present to a maximum depth of 10m. The physiology of shallow and mesophotic conspecifics was similar since shallow *O. patagonica* typically inhabit low light environments (caves and crevices) and have a facultative relationship with photosymbionts. Therefore, we suggest that this species was primed for life in deeper waters and that the existing phenotype and photophysiology aided rapid colonization of the mesophotic zone. This observation of coral migration from shallow to deep waters will be discussed in the context of the deep reef refugia hypothesis.

Oral
A-1067

The role of host pigments in coral photoacclimation on mesophotic reefs

Bollati, E.[1], Lyndby, N.[2], D'Angelo, C.[3], Kühl, M.[1], Wiedenmann, J.[3], Wangpraseurt, D.[4]
[1]University of Copenhagen, Department of Biology, Marine Biology Section, Helsingør, Denmark
[2]Ecole Polytechnique Fédérale de Lausanne, School of Architecture, Civil and Environmental Engineering, Lausanne, Switzerland
[3]University of Southampton, School of Ocean and Earth Science, Southampton, United Kingdom
[4]UC San Diego, Scripps Institution of Oceanography, San Diego, United States

elena.bollati[at]bio.ku.dk

Abstract

Many species of mesophotic corals produce colourful host pigments homologous to the Green Fluorescent Protein (GFP). It has long been proposed that these pigments facilitate photoacclimation of corals to mesophotic habitats by fine-tuning the internal light microclimate experienced by their symbionts. In particular, photoconvertible red fluorescent proteins (pcRFPs) are thought to enhance photosynthesis under mesophotic light conditions by converting abundant blue-green wavelengths into scarce orange-red ones. However, direct measurements demonstrating this mechanism are currently lacking. We have used scalar irradiance microsensors to investigate the intra-tissue spectral light environment of corals expressing pcRFPs at different stages of photoconversion, and quantified the contribution of fluorescence emission by these pigments. Our estimates suggest that, in shallow water, fluorescence emission by host pigments provides a very small contribution to the overall light spectrum inside the coral tissue. However, under a mesophotic spectrum, emission by pcRFPs can at least double the amount of orange-red photon available to the symbionts compared to the external environment. Our results provide the first direct quantification of the importance of pcRFPs in fine tuning the light microclimate of mesophotic corals, supporting a role of these pigments in photoacclimation.

Oral
A-1045

Hidden coral bleaching in the Indian Ocean

Diaz, C., Howell, K., Hosegood, P., Robinson, E., Stashchuk, N., Vlasenko, V., Attrill, M., Foster, N.
University of Plymouth, School of biological and marine sciences, Plymouth, United Kingdom

clara.diaz[at]plymouth.ac.uk

Abstract

The rapidly changing climate is a serious threat to coral reef communities, resulting in coral bleaching and mass mortality events. Mesophotic coral ecosystems (MCEs; found between 30-150 m depth) are thought to be buffered from the thermal stress experienced by shallow-water corals due to their depth and are hypothesised to act as refugia for shallow-water species. However, due to the difficulty of collecting data at depths beyond recreational SCUBA diving limits, limited studies have been undertaken to test this hypothesis to date. Here, we present data from the first extensive survey of MCEs in the Chagos Archipelago, located in the central Indian Ocean. This Archipelago is one of the World's largest Marine Protected Areas and it experiences very limited direct human impacts, largely due to its remote location and protected status. Using an ROV, we conducted video transects at multiple depths, from 15 m to 160 m, during two expeditions in November 2019 and March 2020. We observed extensive coral bleaching down to 100 m in the absence of shallow-water bleaching, due to a basin-scale depression of the thermocline driven by the Indian Ocean Dipole (IOD), the regional equivalent to ENSO. The IOD appears to be increasing in intensity due to climate change, suggesting that MCEs are not protected from increasing SSTs as previously assumed. Furthermore, bleaching was pronounced at locations where internal waves breaking over the slopes surrounding the atoll further deepened the influence of surface waters. Using a combination of biology, in-situ oceanographic observations and high-resolution numerical modelling, our study is the first description of coral bleaching from the shallow reef down to the lower mesophotic zone within the Indian Ocean, which has high implications for the “deep reef refugia hypothesis” and contributes to the conservation and management of these precious ecosystems.

Oral
A-1542

Genetic connectivity and algal symbiont communities of shallow and mesophotic Stephanocoenia intersepta populations in the Florida Keys

Eckert, R., Sturm, A., Carreiro, A., Klein, A., Voss, J.
Florida Atlantic University, Harbor Branch Oceanographic Institute, Fort Pierce, FL, United States

reckert2017[at]fau.edu

Abstract

Population genetic analyses can provide useful data on species' regional connectivity and diversity which can be leveraged to enhance conservation and restoration efforts. In this study, we quantified the genetic connectivity and diversity of *Stephanocoenia intersepta* corals from shallow (<30 m) to mesophotic (30–45 m) depths across Florida Keys National Marine Sanctuary. We generated a suite of >24,000 single nucleotide polymorphism (SNP) markers to identify genetic structuring of shallow and mesophotic *S. intersepta* populations. We estimated recent genetic migration rates and found that mesophotic populations provided larger proportions of recent immigrants compared to shallow populations, particularly in the Lower Keys and Tortugas Bank. Throughout the region, shallow populations exhibited lower heterozygosity, higher minor allele frequencies, and significantly higher levels of intrapopulation relatedness and inbreeding relative to mesophotic populations. Additionally, we compared Symbiodiniaceae communities among S. intersepta populations using the *ITS2* region and *SymPortal* analysis framework. We identified Symbiodiniaceae from the genera *Symbiodinium*, *Breviolum*, and *Cladocopium*. Symbiodiniaceae communities varied significantly across depth and demonstrated significant but limited correlation with host genotype. Together, these data demonstrate that despite population genetic structuring across depth, mesophotic populations may provide refuge potential for shallow populations moving forward and remain important contributors to the overall genetic diversity of this species throughout the region. This study highlights the importance of including mesophotic as well as shallow coral populations in population genetic analyses and provides information and data useful for future management and restoration efforts within the Florida Keys National Marine Sanctuary.

Oral
A-1383

A preliminary assessment of the diversity and community structure of the mesophotic coral ecosystems of the Chagos Archipelago, Indian Ocean

Foster, N., Diaz, C., Attrill, M., Howell, K.
University of Plymouth, Plymouth, United Kingdom

nicola.foster[at]plymouth.ac.uk

Abstract

Research on mesophotic coral ecosystems (MCEs) has grown exponentially in recent years; however, MCEs in the Indian Ocean remain relatively unexplored, with only 1% of global studies based in this region. The Chagos Archipelago is one of the World's largest Marine Protected Areas (640,000 km^2) and is comprised of a group of small islands and atolls located in the central Indian Ocean. The Archipelago is a relatively unperturbed ecosystem, due in large part to its protected status and remote location, with the nearest neighbouring territory approximately 500 km away. Research has been conducted on and around the islands of Chagos for many decades, with the shallow-reefs well documented. However, research diving is limited to a depth of 25 m on SCUBA and the deeper reefs beyond this depth remain relatively unexplored. Here, we present the first extensive surveys of MCEs in the Chagos Archipelago to a depth of 160 m. Using a sophisticated ROV, we conducted video transects at multiple depths, from shallow-water reefs (15 m) to the lower mesophotic zone (160 m). We present details on the variation in diversity and community structure of the benthic communities along this depth gradient and the environmental drivers of this distribution. We identify depth-generalist coral species that span the boundary between shallow reefs and the upper mesophotic zone, and which may potentially provide a biological connection between these depths. Our results indicate that some of the dominant reef-building species found on shallow reefs appear to be more depth specific, and few transcend down to mesophotic depths, which has implications for potential connectivity of key reef-building species. Our results also demonstrate that MCEs in the Chagos Archipelago are a unique ecosystem and deserve protection in their own right. Our study provides critical knowledge on the distribution and diversity of MCEs in the Indian Ocean and contributes to conservation and development of local management plans within the Archipelago.

Oral
A-1363

Phenotypic plasticity and physiological adaptation at early developmental stages for corals on shallow and mesophotic reefs in two northerly locations

Goodbody-Gringley, G.[1, 2], Neder, M.[3, 4], Nativ, H.[3], Scucchia, F.[3, 4], Mass, T.[3]
[1]Central Caribbean Marine Institute, Little Cayman Island, Cayman Islands
[2]Bermuda Institute of Ocean Sciences, St. Georges, Bermuda
[3]University of Haifa, Leon H Charney School of Marine Sciences, Haifa, Israel
[4]Interuniversity Institute of Marine Sciences, Eilat, Israel

ggoodbody[at]reefresearch.org

Abstract

Resilience of ecosystems under rapid environmental change relies, in part, on the capacity of organisms to adapt and/or acclimatize to new conditions. Several species that exist along a broad depth distribution have been shown to differ in morphology and reproductive ecology at different depths. These variations are often suggested to result from morphological plasticity in response to differing environmental conditions at depth, such as low light intensity. Variation can also result from selection, but the relative influence of acclimatization compared to adaptation on morphology and physiology remains unclear. In this study, we examined the early life history traits of two coral species, *Stylophora pistillata* in the Red Sea and *Porites astreoides* in Bermuda, between shallow (6-10 m) and mesophotic (40-45 m) reefs to elucidate the mechanisms that enable corals to thrive across broad vertical distributions. Larvae of each species were collected from corals at both depths in each location and reciprocal in situ settlement assays were performed across depths. Examinations of larval and primary polyp physiology and morphology indicate a plastic response to depth during early developmental stages, where larval features differed by parental depth, while primary polyp features differed by settlement depth. In situ settlement success and survival also indicate that larvae of both species can successfully recruit across depths, suggesting that both shallow and mesophotic coral populations contribute to overall reef resilience.

Oral
A-1778

Growth and physiology of the deepest photosymbiotic corals. What are the implications?

Kahng, S.[1], Martinez, S.[2], Wall, C.[3]
[1]University of Hawaii, Oceanography, Honolulu, United States
[2]Centre Scientifique de Monaco, Monaco, Monaco
[3]University of California- San Diego, La Jolla, United States

kahng[at]hawaii.edu

Abstract

The ecology of phototrophic corals in the lower photic zone remains poorly understood. Across the Indo-Pacific, the genus *Leptoseris* (family Agaricidae) appears to dominate the zooxanthellate coral community at the deepest depths. Published coral growth rates show that intra-species growth rates generally decrease as available light attenuates with depth. However, most data come from shallow water species (< 60 m). For many years, the only measured growth rates at deeper depths (*Leptoseris fragilis,* 90-120 m, Fricke et al. 1987) suggested that photosymbiotic corals grow very slowly at extreme depths supporting the dogma that zooxanthellate corals at these depths must be energy limited and rely heavily on heterotrophy. However, new data are emerging to alter this paradigm and provide insight into the physiology of deep-water specialists. Using reliable U-Th dating techniques, Kahng et al. (2020) measured growth rates (linear extension) of 8.0 to 24.6 mm yr^{-1} for four species of *Leptoseris* at 70-110 m in Hawaii. Given the modest growth rates of shallow-water agariciids and the exponential attenuation of downwelling light with depth, these growth rates are counter intuitive. While heterotrophy has long been assumed to play dominant role in symbiotic coral energetics in the lower photic zone, much of the supporting evidence from bulk $d^{13}C$ and $d^{15}N$ stable isotopic data are inherently confounded when critically reviewed. Recent advances in compound specific stable isotopic analyses have illuminated additional complexities in the heterogeneity of biomass composition, exchanges of C and N between host and algal symbionts, and taxon specific patterns. The physiology of the deepest *Leptoseris* spp. appears to be optimized for light harvesting and efficient use of calcium carbonate but not heterotrophic feeding. Their features include thin horizontal skeletons designed to maximize solar flux per unit area, light trapping septocostae, and a low density of polyps which completely lack tentacles for feeding. In the lower photic zone, characteristics which optimize photosynthetic and growth efficiencies directly conflicts with morphological features required for effective passive suspension feeding like those exhibited by sympatric azooxanthellate corals. Photosynthetic and growth efficiencies may be facilitated by increased exposure to higher concentrations of limiting inorganic nutrients and cooler temperatures at depth.

Oral
A-1017

Light-driven design: how coral architecture optimizes light capture for photosynthesis at shallow and mesophotic depths

Kramer, N.[1], Guan, J.[2], Chen, S.[3], Wangpraseurt, D.[3], Loya, Y.[1]
[1]Tel Aviv University, Tel Aviv, Israel
[2]University of California San Diego, Department of Electrical and Computer Engineering, San Diego, United States
[3]University of California San Diego, Department of Nanoengineering, San Diego, United States

nati.kramer[at]gmail.com

Abstract

The morphology and skeleton architecture of photosynthetic corals modulates the light capture and functioning of the coral-algal symbiosis on shallow-water corals. Since corals can thrive on mesophotic reefs under extreme light-limited conditions, we hypothesized that microskeletal coral features optimize light capture under low-light environments. Utilizing micro-computed tomography scanning, we conducted a novel comprehensive three-dimensional (3D) assessment of small-scale skeleton morphology of the depth-generalist coral *Stylophora pistillata* collected from shallow (4-5 m) and mesophotic (45-50 m) depths. We detected a high phenotypic diversity between depths, resulting in two distinct morphotypes, with calyx diameter, theca height, and corallite marginal spacing contributing to most of the variation between depths. To determine whether such depth-specific morphotypes affect coral light capture and photosynthesis on the corallite-scale, we developed 3D simulations of light propagation based on photosynthesis-irradiance parameters. We found that the mesophotic coral architecture provides a greater ability to trap solar energy and efficiently exploit the limited light conditions; while corals associated with shallow morphotypes dissipated excess light through self-shading microskeletal features. The results from the 3D light models demonstrate that morphological plasticity provide an optimized internal irradiance needed for the photosynthesis of photosymbionts, and suggest that morphology plays a key role in photoadaptation.

Oral
A-1010

Trophic Ecology of Corals and Sponges on Mesophotic Coral Reefs

Lesser, M.
University of New Hampshire, Molecular, Cellular and Biomedical Sciences, Durham, United States

mpl[at]unh.edu

Abstract

Mesophotic Coral Reef Ecosystems (MCEs) are unique communities whose development and persistence are a result of changes in irradiance and trophic resources, and are operationally defined as occurring from ~30-150 m. Several estimates suggest that the habitat available for the establishment and development of MCEs has been estimated at three to ten times the known areal extent of shallow coral reefs (<30 m), making the understanding of the structure and function of these ecosystems in the Anthropocene a scientific community imperative. Progress in understanding and testing the “deep-reef refugia hypothesis” and defining the depth zonation patterns of MCEs based on benthic community structure or abiotic factors. In fact, underwater irradiances have been shown to directly affect the relative abundance of dominant functional groups on MCEs such as corals, sponges and macrophytes. Additionally, a community break at 60 m has been shown to exist for many MCE ecosystems that is significantly correlated with changes in underwater irradiance. In fact, irradiance also facilitates changes in community structure by altering the trophic ecology and facilitating transitions from photoautotrophy to heterotrophy on MCEs. These transitions are further amplified by changes in the availability of trophic resources, especially in the lower mesophotic (>60 m) for specific community members such as sponges. Recent ecological theories postulated for shallow reef communities (i.e., sponge loop) have not been widely studied on MCEs, but under various climate change models decreases in primary productivity with increasing are predicted to occur on coral reefs with the potential for significant effects at mesophotic depths. Understanding the trophic ecology of corals and sponges as well as spatial patterns in underwater irradiances will help us to understand what shallow water processes, such as the “sponge-loop” operate at mesophotic depths and what resource utilization patterns (i.e., DOM versus POM) are important.

Oral
A-1789

Molecular and skeletal fingerprints of scleractinian coral biomineralization: From the sea surface to mesophotic depths

Mass, T.[1], Einbinder, S.[1], Martinez, S.[1], Scucchia, F.[1], Malik, A.[1], Nativ, H.[1], Tchernov, D.[1], Zaslanski, P.[2], Pokroy, B.[3], Stolarski, J.[4], Goodbody-Gringley, G.[5]
[1]University of Haifa, Marine Biology, Haifa, Israel
[2]Charité, Berlin, Germany, [3]Technion, Haifa, Israel
[4]Polish Academy of Sciences, Warsaw, Poland
[5]Central Caribbean Marine Institute, Little Cayman, Cayman Islands

tmass[at]univ.haifa.ac.il

Abstract

Reef-building corals, the major producers of biogenic calcium carbonate, form skeletons in a plethora of morphological forms. Here we studied skeletal modifications of *Stylophora pistillata* (clade 4) colonies that adapt to increasing depths with decreasing ambient light. The coral show characteristic transitions from spherical morphologies (shallow depths, 5 m deep) to flat and branching geometries (mesophotic depths, 60 m deep). Such changes are typically ascribed to the algal photosymbiont physiological feed- back with the coral that host them. We find specific fine-scale skeletal variability in accretion of structure at shallow- and mesophotic depth morphotypes that suggest underlying genomic regulation of biominer- alization pathways of the coral host. To explain this, we conducted comparative morphology-based analy- ses, including optical and electron microscopy, tomography and X-ray diffraction analysis coupled with a comprehensive transcriptomic analysis of *S. pistillata* . The samples originated from Gulf of Eilat in the Red Sea collected along a depth gradient from shallow to mesophotic depths (5 to 60 m). Additional samples were experimentally transplanted from 5 m to 60 m and from 60 m to 5 m. Interestingly, both morpho- logically and functionally, transplanted corals partly adapt by exhibiting typical depth-specific properties. In mesophotic depths, we find that the organic matrix fraction is enriched in the coralla, well match- ing the overrepresentation of transcripts encoding biomineralization “tool-kit" structural extracellularpro- teins that was observed. These results provide insights into the molecular mechanisms of calcification and skeletal adaptation that repeatedly allowed this coral group to adapt to a range of environments presumably with a rich geological past.

Oral
A-1465

Scleractinian coral assemblages on deeper fore-reef slopes: Lower mesophotic, oligophotic, …. or rariphotic?

Pichon, M.[1], Harii, S.[2], Muir, P.[3], Perez-Rosales, G.[4], Rouzé, H.[5], Sinniger, F.[6]
[1]Queensland Museum, Biodiversity and Geoscience, Townsville, Australia
[2]University of the Ryukyus, Sesoko Station. Tropical Biosphere Research Centre, Sesoko, Motobu, Japan
[3]Queensland Museum, Biodiversity and geoscience, Townsville, Australia
[4]PSL University EPHE-UPVD-CNRS. University of Perpignan, USR 3278 Criobe, Perpignan, France
[5]University of Guam, Marine Laboratory, Guam, United States
[6]University of the Ryukyus Okinawa, Sesoko Station. Tropical Biosphere Research Centre, Sesoko Motobu, Japan

michel.pichon[at]bigpond.com

Abstract

The recent interest in the study of Mesophotic Coral Ecosystems (MCEs) lies in the fact that the fore-reef slope environment has been associated with the Deep Reef Refugia Hypothesis (DRRH). Indeed, the DRRH suggests that MCEs might be able to play a role of refugium and be a source of replenishment for shallow coral reefs threatened by climate change and human disturbances. The vertical development of MCEs has been considered to cover the 30-150 m depth range of the fore-reef slope, but the lower bathymetric extent of the mesophotic area remains poorly known. At any rate, zonation on the lower slope is mostly controlled by light rather than depth, although the latter can be used locally as a proxy for light levels, and in a number of instances temperature which may show significant short terms variations (e.g, internal waves). Solar light penetration varies with the geography, optical water qualities, slope orientation and bathymetric profile. Here, we compare light penetration in different areas of the Indo-Pacific thus explaining the contrasting zonation of benthic assemblages observed in locations such as the Red Sea, the Great Barrier Reef, the Ryukyus and French Polynesia. Whereas the high levels of light irradiance drastically decrease from the surface to ca 40 m (zone where zooxanthellate scleractinians are dominant), they reach a very low and nearly stable level in the depth range 100-200 m. Recent studies on the lower part of the fore-reef slopes show that while zooxanthellate scleractinians are still present down to at least 172 m in the oceanic islands of the Indo-Pacific, with records of 38 and 16 species down to 100 m and 120 m respectively, they are no longer the dominant benthic group, and are replaced by sponges, azooxanthellate cnidaria (Stylasteridae and Scleractinia) and other low light adapted benthic groups, including algae and other anthozoans. Both environmental and biotic data suggest a significant departure from the situation considered to be typical of the shallower MCEs. One can therefore query the appropriateness of qualifying the benthic assemblages of the lower fore-reef slope as “mesophotic coral ecosystems”. A more appropriate terminology in accordance with recent knowledge, could be “lower mesophotic” or even introducing the term “oligophotic”, noting that “rariphotic” has been used specifically for fish assemblages in the Caribbean, rather than for the overriding physical factor determining benthic zonation.

Oral
A-1856

Diving deep in French Polynesia reveals new insights on the ecological importance of mesophotic coral ecosystems

Pérez-Rosales, G.[1], Rouzé, H.[1, 2], Pichon, M.[3], Bongaerts, P.[4], Torda, G.[5], Parravicini, V.[6], Hédouin, L.[6]
[1]CRIOBE - USR 3278 : PSL Université Paris: EPHE-CNRS-UPVD, Perpignan CEDEX, France
[2]Marine Laboratory, University of Guam, Guam, American Samoa
[3]Biodiversity Section, Queensland Museum,, Townsville, Australia
[4]California Academy of Sciences, San Francisco, United States
[5]ARC Centre of Excellence for Coral Reef Studies, James Cook University,, Townsville, Australia
[6]CRIOBE - USR 3278: PSDL Université Paris: EPHE-CNRS-UPVD, Perpignan CEDEX, France

gonzalo.prb[at]gmail.com

Abstract

Driven by their potential role as a refuge under climate change disturbances, mesophotic coral ecosystems (MCEs) have received growing attention from coral scientists in the Anthropocene. The DEEPHOPE project was launched in the broad geographical region of French Polynesia to explore these understudied ecosystems. Between others, the aims of this project were to: (1) reveal the distribution and community composition structure of MCEs in French Polynesia and (2) determine the environmental conditions of these unique ecosystems. Through a collaboration with “Under The Pole” and thanks to ~800 TRIMIX Rebreather dives down to 175 m over a 10-month period, we acquired a comprehensive genetic (>6,000 scleractinian coral specimens), taxonomic (>1,800 scleractinian coral specimens), ecological (>3,500 photo-quadrats) and environmental (e.g. light, temperature, bathymetry, CTD profiles and nutrients) repertoire database across a broad depth range (6-120 m) and scale (11 islands from 5 archipelagos [4,000 km2]). For the first time, we provided a detailed description of the MCEs of French Polynesia with some unexpected observations. Even at lower mesophotic depths, we observed high coral cover of nearly 30% at 120 m and up to 70% at 60 m at certain locations. Zooxanthellae coral species were observed to a maximum depth of 172 m, setting a new global depth record for scleractinian life. From photoquadrat analysis, genus diversity at mesophotic depths was higher than surface waters, with peaks of diversity at 40-60 m depth. Unexpectedly high 40-80% coral cover communities were found at mesophotic depths between 40 and 120 m. Additionally, surveys during the 2019 bleaching episode suggested evidence for the refuge potential of mesophotic environments, with coral bleaching and subsequent mortality decreasing with depth. Bleaching mortality went from 47% at 6 m to less than 5% at 20 m to non-existent after 40 m. Finally, environmental modelling was used to predict potential high coral cover communities along the depth gradient. Overall, the DEEPHOPE project has started uncovering the wealth and diversity of MCEs in French Polynesia. Given their potential role as thermal refuges, their high biodiversity, and their highly covered communities (i.e., increasing the fate of species and functions persistence after disturbances), we propose that, regardless of the reseeding potential, MCEs are likely to play a critical role in the overall resilience of the coral reef ecosystem.

Oral
A-1960

Taxonomy, biogeography, ecology, and conservation of recently discovered mesophotic fishes

Rocha, L.[1], Pinheiro, H.[2], MacDonald, C.[1], Shepherd, B.[1]
[1]California Academy of Sciences, San Francisco, United States
[2]Universidade de Sao Paulo, Sao Sebastiao, Brazil

lrocha[at]calacademy.org

Abstract

In the past 5-10 years several new species of fish have been added to the mesophotic fauna worldwide. This is likely a result of the increasing number of researchers exploring mesophotic coral ecosystems (MCEs) between 30 and 150m using a variety of methods, including technical rebreather diving, submarines, remotely operated vehicles, and baited remote underwater videos. In general, these fishes belong to families that are also found in shallow reefs (especially Serranidae and Pomacentridae), and a minority are in families more typically found at deeper depths (e.g.: Callanthiidae). Outside of the Caribbean, perhaps one of the families requiring the most taxonomic attention is Gobiidae, however, there are very few specialists in this group and dozens of species await description. Patterns of phylogenetic affinities are also varied: some groups, like the genus Chromis, are mostly composed of shallow species with mesophotic species distributed through the phylogeny, whereas others, like Pseudanthias, seem to be mostly mesophotic with a few species specializing to live in shallow reefs. Because these depths are still unsampled in most locations, biogeographic patterns are hard to infer, but some generalizations are emerging. The number of new records for every location our team visits is always higher than that of new species, indicating that species previously described from elsewhere are often more widely distributed than initially thought. Philippines mesophotic reefs had the highest regional species richness, whereas French Polynesia had the lowest, following the general west to east diversity gradient observed in shallow reefs. At smaller scales (reef), diversity seems remarkably similar across vast biogeographic regions. Along with the distinctiveness of its fauna, our team has consistently observed several human impacts reaching down to 150m. Plastic pollution (both coming from land and sea through fishing debris) is very common, and in most places, MCEs are not included in marine protected areas. Therefore, their uniqueness and lack of protection suggest these ecosystems should be a priority for conservation efforts worldwide.

Oral
A-1660

Chronic and acute disease impacts as a driver of mesophotic coral degradation in the US Virgin Islands

Smith, T.[1], Brandt, M.[1], Blondeau, J.[1, 2], Brandtneris, V.[1], Ennis, R.[1], Heidmann, S.[1], Kadison, E.[1], Nemeth, R.[1]
[1]University of the Virgin Islands, Center for Marine and Environmental Studies, Saint Thomas, U.S. Virgin Island
[2]National Oceanic and Atmospheric Administration, Miami, United States

tsmith[at]uvi.edu

Abstract

Mesophotic coral ecosystems have been posited as refugia from local and global stressors. This suggests populations of corals that are relatively stable compared to shallow water coral reefs. However, few long-term data sets exist to assess if mesophotic corals are recovering after disturbances or degrading in response to cumulative stressors. This study reassessed 31 sites chosen in a spatially stratified random design in the mesophotic Red Hind Marine Conservation District no-take reserve ~12km southwest of St. Thomas, US Virgin Islands (Smith et al. 2010). Over this period coral cover, primarily *Orbicella* spp., declined significantly from 26.8% ± 2.9 SE to19.3% ± 2.7, while macroalgal cover, primarily *Lobophora* spp., increased from 22.2% ± 1.7 to 41.1% ± 1.7 ($p<0.0001$ for both groups). Long-term annual monitoring at three mesophotic coral reefs within or immediately adjacent to the study area (30, 38, and 40m depth) also showed a decline of mean coral cover from 32.1% ± 2.3 SE to 27.2 ± 1.8 over this period. At long-term sites, the mean prevalence of
tissue eroding diseases consistent with a Caribbean white plague etiology was 2.3% ± 0.4 SE (n = 36 site observations), which was an order of magnitude higher than nearby shallow water reefs (mean prevalence = 0.2% ± 0.1 SE, n = 163 site observations). Peak white disease prevalence (10.0%) occurred in 2011 after regional heat stress in 2010, suggesting a potential lagged disease response to thermal stress. Our results suggest that these upper mesophotic star coral reefs are not recovering after acute disturbances because of a combination of chronic disease impacts that prevent recovery and increased disease impacts after thermal stress that increase degradation. Chronic disease may be tied to increasing macroalgal cover, possibly driven by declining herbivory caused by an invasive
predator, the Indo-Pacific lionfish.

Oral
A-1440

Genetic connectivity patterns among shallow and mesophotic Montastraea cavernosa coral populations in the Gulf of Mexico and western Caribbean

Sturm, A.[1], Eckert, R.[1], Carreiro, A.[1], Klein, A.[1], Studivan, M.[1, 2, 3], Dodge Farelli, D.[1], Simoes, N.[4, 5, 6], González-Díaz, P.[7], González Méndez, J.[7, 8], Voss, J.[1]
[1]Florida Atlantic University, Harbor Branch Oceanographic Institute, Fort Pierce, United States
[2]Cooperative Institute for Marine and Atmospheric Studies, University of Miami Rosenstiel School of Marine and Atmospheric Science, Miami, United States
[3]Atlantic Oceanographic and Meteorological Laboratory, National Oceanic and Atmospheric Administration, Miami, United States
[4]Unidad Multidisciplinaria de Docencia e Investigación–Sisal, Facultad de Ciencias, Universidad Nacional Autonoma de México, Sisal, Mexico
[5]International Chair for Coastal and Marine Studies, Harte Research Institute for Gulf of Mexico Studies, Texas A&M University-Corpus Christi, Corpus Christi, United States
[6]Laboratorio Nacional de Resiliencia Costera, Laboratorios Nacionales, Consejo Nacional de Ciencia y Tecnología, Sisal, Mexico
[7]Centro de Investigaciones Marinas, Universidad de La Habana, Havana, Cuba
[8]Centro Nacional de Áreas Protegidas, Havana, Cuba

asturm2017[at]fau.edu

Abstract

Despite the general decline of coral reef ecosystems across the tropical Western Atlantic, some reefs, including mesophotic reefs (30–150 m), are hypothesized to function as coral refugia due to their relative isolation from anthropogenic stressors. An understanding of the connectivity dynamics among these putative refugia and connected reefs is critical to developing effective management strategies to ensure the persistence and recovery of coral metapopulations. We conducted the widest-scale assessment of shallow (<30 m) and mesophotic (>30 m) regional connectivity dynamics of the depth-generalist coral species, *Montastraea cavernosa*. We collected >750 unique coral genets across the Northwest Gulf of Mexico (Flower Garden, Bright, and McGrail Banks), northern Florida Reef Tract, Florida Keys, Dry Tortugas, Pulley Ridge, Cuba, Southern Gulf of Mexico (Campeche Bank), and Belize. We generated a dataset of >5,000 SNP loci and quantified high-resolution genetic structure and connectivity among these populations on a regional scale. We identified multiple environmental variables that correlate to patterns of genetic differentiation with depth being the most significant. Ordination of genetic distance generally demonstrates a split between shallow and mesophotic populations. Shallow and mesophotic populations tend to show higher connectivity to distant populations within the same depth zone than to adjacent populations across depth zones. For example, despite a distance of >1,000 km genetic connectivity is higher between shallow populations in Belize and Florida than to their adjacent, mesophotic counterparts. Exceptions to this pattern include the Northwest Gulf of Mexico and the Florida Keys which exhibit relatively high levels of vertical genetic connectivity across depth zones. The location-based differences in vertical connectivity are likely a result of diverse oceanographic and environmental conditions that may also drive variation in the level of gene flow and depth-dependent selection. These results highlight the need to evaluate connectivity dynamics and refugia potential of mesophotic coral ecosystems and species on a population by population basis. Additionally, while management agreements have been developed among coral reef protected areas in the U.S. and Cuba, populations in Belize and Mexico also represent important *M. cavernosa* sources for U.S. populations and may warrant incorporation in future international management approaches.

Oral
A-2011

Differing lesion recovery of two reef-building Caribbean stony coral species from shallow water to mesophotic depths

Townsend, J.[1, 2], Brandt, M.[1], Mukherjee, S.[1], Medina, M.[3], Smith, T.[1]
[1]University of the Virgin Islands, Center for Marine and Environmental Studies, St. Thomas, United States
[2]National Science Foundation, Alexandria, United States
[3]Pennsylvania State University, Department of Biology, State College, United States

joetown94[at]gmail.com

Abstract

Following major stress events such as storms, bleaching events, or disease outbreaks, surviving corals must regenerate tissue in order to recover. We aimed to understand how this recovery changes from shallow to mesophotic depths, hypothesizing that deeper corals would regenerate more slowly and that this may limit resilience to acute stressors. Two species of reef building coral, *Orbicella franksi* (an intermediate-depth species) and *Agaricia lamarcki* (a depth-generalist), were tagged at selected sites across their overlapping depth range of 13 to 41m and directly monitored for recovery rate from experimentally generated lesions across time. Overall, recovery rates were distinct between species and across depths, with *O. franksi* recovery rates showing high variability and declining at depth, behaving significantly different from *A. lamarcki,* which maintained similar rates of recovery across the examined depth range. The consistent response of *A. lamarcki* suggests that it can attenuate its biology with changing light resources to maintain healing abilities in different environments. Recovery rates were additionally compared against environmental and biological covariates and it was found that only increased initial lesion size had a significant positive effect on tissue regeneration rates for *A. lamarcki*. Collectively, this suggests that some mesophotic coral reefs, despite having high coral cover, may be slower to recover from stress events if dominated by non-depth generalist species, such as *O. franksi*, resulting in increased vulnerability to repeated stress events.

Oral
A-2012

Mesophotic Coral Ecosystem Exploration and Characterization in the Gulf of Mexico, Florida, Cuba, and Mesoamerica

Voss, J. D.[1], Eckert, R. J.[1], Sturm, A. B.[1], Studivan, M. S.[1, 2, 3], Reed, J. K.[1], Farrington, S.[1, 4], Gonzalez Diaz, S. P.[5], Hickerson, E.[6], Schmahl, G. P.[6]
[1]Florida Atlantic University, Harbor Branch Oceanographic Institute, Fort Pierce, United States
[2]CIMAS University of Miami, Miami, United States
[3]NOAA AOML, Miami, United States
[4]NOAA Fisheries, Elk Grove, United States
[5]Universidad de La Habana, Centro de Investigaciones Marinas, Habana, Cuba
[6]NOAA Flower Garden Banks National Marine Sanctuary, Galveston, United States

jvoss2[at]fau.edu

Abstract

Mesophotic coral ecosystems (MCEs) at 30-150m depths are believed to be extensive in the Tropical Western Atlantic, but relatively little is known regarding their extent, distribution, and ecology. Through a collaborative and integrative approach combining multibeam mapping, remotely operated vehicle surveys, and technical SCUBA diving, the Cooperative Institute for Ocean Exploration, Research, and Technology (CIOERT) has explored and characterized MCEs in the Gulf of Mexico, South Florida, Belize, Mexico, and Cuba over the past decade. The goals of these studies were to 1) determine the extent and composition of mesophotic coral communities, 2) investigate genomic evidence of coral connectivity across depths and horizontal distance, 3) examine spatial and temporal variation in corals' gene expression and algal endosymbiont assemblages, and 4) develop models of larval connectivity dynamics among shallow and mesophotic coral reef populations. On a broad scale, populations of the depth-generalist coral *Montastraea cavernosa* demonstrate evidence of genetic connectivity across the entire GOM and NW Caribbean. Evidence of vertical connectivity among *M. cavernosa* populations was regionally variable; shallow and mesophotic populations in the NW GOM were panmictic, while populations from different depth zones were significantly distinct in Belize. The results of these studies and others indicate that mesophotic coral habitats in the GOM, Florida, Mesoamerica, and Cuba are more extensive, connected, and ecologically important than previously known, particularly with respect to supporting biologically diverse faunal assemblages. Through ongoing collaborative partnerships, this research has contributed to proposed and realized expansions of multiple marine protected areas that may improve metapopulation resilience among MCEs. Future investigations of MCE coral ecology, physiology, and evolution are needed to 1) understand the potential mechanisms and consequences of mesophotic corals' adaptations, 2) further evaluate the efficacy of MCE as refuges for coral species, and 3) develop effective management criteria and strategies for MCEs.

Poster
A-1293

Sponge fauna of euphotic and mesophotic bioconstructions along the southeastern Italian coast

Giménez, G.[1], Pierri, C.[1], Cardone, F.[2], Nonnis Marzano, C.[1], Mercurio, M.[1], Lisco, S.[3], Longo, C.[1]
[1]Università degli Studi di Bari Aldo Moro, Dipartimento di Biologia, Bari, Italy
[2]Stazione Zoologica Anton Dohrn, Dipartimento di Ecologia Marina Integrata, Napoli, Italy
[3]Università degli Studi di Bari Aldo Moro, Dipartimento di Scienze della Terra e Geoambientali, Bari, Italy

guadalupe.gimenez[at]uniba.it

Abstract

In the Mediterranean Sea, the main biogenic constructions are represented by the coralligenous outcrops, a carbonate bioherm derived from the activities of calcareous encrusting algae living in moderate light conditions. However, with the progressive decrease of light intensity diverse species of invertebrates, mainly scleractinians and bivalves, take on the role of main reef builders giving rise to what is known as mesophotic bioconstructions. Overall, both structures provide support for high habitat complexity and local biodiversity, but differ in their pattern of structuring species, leading to different morphologies and hosting a highly diversified benthic fauna. Of this fauna, sponges are significant components playing an important role in acting as habitat builders and eroders. To date, the available data on both the structuring and associated species of these bioconstructions is still fragmented. The present study aims to provide further information about whether mesophotic coral ecosystems represent distinct assemblages from those of upper photic communities by analyzing the taxonomic composition and distribution of the Porifera fauna of coralligenous and mesophotic bioconstructions in one study area of the Apulian Adriatic coast (SE Italy). Samples collection was carried out at two stations (25 m and 55 m depth) by SCUBA divers. For estimating the sponge covering values, underwater photographs (n=30) were taken at each station by SCUBA divers at shallow depths and by ROV at deep depths. A total of 85 taxa of Porifera were identified, 40 of which were exclusively found in the mesophotic coral reef, and 26 in the coralligenous. Only 19 were present in both bioconstructions. Sponge covering values were significantly different between stations ($p>0,05$) ranging from 16,3% to 23,5% for coralligenous and mesophotic bioconstructions, respectively. *Sarcotragus spinosulus* (6.4% ± 2.6), *Ircinia variabilis* (5% ± 2.3), and *Petrosia ficiformis* (4.6% ± 3.2) were the most represented species in the shallow station, while *Aplysina cavernicola* (2.8% ± 1.8), *S. foetidus* (1.8% ± 0.8), and *Haliclona mediterranea* (1.4% ± 0.7) were representatives for the deep one. The sponge community found in the present study highlights the uniqueness of the mesophotic bioconstruction and confirms how this habitat is different from that found in shallow depth.

Poster
A-1919

Mesophotic coral assemblages on offshore oil platforms: unexplored hotspots for coral conservation in the Arabian Gulf?

Range, P.[1], Riera, R.[2, 3], Torquato, F.[4], Omerspahic, M.[4], Almallah, S.[1], Bouwmeester, J.[5], Bach, S.[6], Reeves, C.[7], Al-Kaabi, N.[7], Rask Møller, P.[8], Ben-Hamadou, R.[4]
[1]Qatar University, Environmental Science Center, Doha, Qatar
[2]Universidad de Las Palmas de Gran Canaria, Grupo en Biodiversidad y Conservación (BIOCON), IU-ECOAQUA, Las Palmas de Gran Canaria, Spain
[3]Universidad Católica de la Santísima Concepción, Departamento de Ecología, Facultad de Ciencias, Concepción, Chile
[4]Qatar University, Dept. Biological and Environmental Sciences, Doha, Qatar
[5]Smithsonian Conservation Biology Institute, Hawaii Institute of Marine Biology, Kaneohe, United States
[6]Rambøll, Copenhagen, Denmark
[7]North Oil Company, Doha, Qatar
[8]University of Copenhagen, Natural History Museum of Denmark, Copenhagen, Denmark

prange[at]qu.edu.qa

Abstract

Offshore oil and gas platforms can provide adequate substratum for the settlement and recruitment of sessile marine invertebrates, as well as increase of habitat and food availability for fishes. Nevertheless, despite the fact that there are currently over 800 offshore oil and gas platforms in the Arabian Gulf, scarce information is available regarding the biological assemblages associated with these structures. We herein studied the previously unexplored biological assemblages that grow attached to the platform jackets in the Al Shaheen Oil field, in the north of the EEZ of Qatar. Results from
the analysis of ROV surveillance videos showed that age and depth are the main factors determining the distribution of sessile assemblages on these platforms. In contrast, no differences in community structure were found among the 9 platform locations studied, indicating a high level of connectivity within the oil field. At 30-60 m depth range, soft corals (Alcyonacea) and azooxanthellate scleractinian corals (Dendrophylliidae) dominated the communities. The abundance of both groups increased with depth and the hard corals also tended to be more abundant on older platforms (>10 years).
Coral reefs constitute the most diverse, complex and productive marine ecosystems in the Arabian Gulf, but widespread mass coral die-off has been reported during the last three decades. Corals are declining at such an alarming rate, particularly in shallow coastal habitats, that several species are now threatened with regional extinction. Further losses of coral communities seem unavoidable in this region, due to climatic changes and coastal development, both of which are unlikely to decrease in the near future. Our research has shown that offshore oil platforms can be considered as regional hotspots or refuges for coral conservation in the Arabian Gulf. The fact that azooxanthellate reef building corals are recruiting and growing on these oil platforms is highly significant, given that this type of corals had not previously been reported in Qatari waters. It further raises the question of whether their regional distribution extends beyond artificial substrates. Furthermore, it clearly illustrates the potential of this type of offshore infrastructure to support the establishment of functional reef ecosystems, suggesting that the conversion of decommissioned oil platforms into artificial reefs (i.e., Rigs to Reefs), may be a valid alternative in this region.

Poster
A-1636

Ecological Processes Structured by a Stress Gradient within the Mesophotic Zone

Slattery, M.[1], Lesser, M.[2]
[1]University of Mississippi, BioMolecular Sciences, Oxford, MS, United States
[2]University of New Hampshire, Durham, NH, United States

slattery[at]olemiss.edu

Abstract

Mesophotic Coral Ecosystems (MCEs) are deep fore-reef communities structured by strong gradients of down-welling solar irradiance and up-welling of nutrients supporting particulate organic carbon (POC) production, which has resulted in a functional shift from autotrophic to heterotrophic processes with increasing depth. In addition, MCEs are typically further offshore from land-based anthropogenic stressors and often below the depth limits of abiotic and biotic stressors. These gradients have resulted in a faunal break at 60m that separates an increasingly stressed upper mesophotic (~30-60m: increased predation and decreased POC) from a stable lower mesophotic (~60-150m: decreased predation and increased POC) community. To date, much of the ecological work on MCEs has focused on trophodynamics and predation with little attention to the structuring roles of competition and facilitation. Interestingly, the Stress-Gradient Hypothesis (SGH) predicts that competition will increase under stable environmental conditions, while facilitation will increase under stressful conditions. MCEs of the Caribbean Basin are characterized by a dense sponge community in the lower mesophotic zone where competition for space and/or food resources increase significantly, as predicted by the SGH. We took advantage of the natural experiment provided by the stressor gradient from the upper to lower mesophotic communities of the Bahamas and Cayman Islands to assess competition and facilitation in algae, corals, and sponges. Field surveys documented contact interactions between the aforementioned functional groups, and evidence for competition including overgrowth, tissue necrosis, and/or mortality. Tagged individuals were followed through time to assess competitive reversals, as well as facilitation of benthic diversity, density, and/or growth rates. Our data indicate that in general, the lower mesophotic is structured by competitive interactions while the upper mesophotic is structured by facilitation, as predicted by the SGH. However, there are taxa-specific differences relative to SGH predictions that reflect our limited understanding of MCEs.

Virtual
Oral
A-1984

Coral recruitment across depths and implications to coral reef resilience

Harii, S., Sitorus, E. D. S., Sinniger, F.
University of the Ryukyus, Tropical Biosphere Research Center, Okinawa, Japan

sharii[at]lab.u-ryukyu.ac.jp

Abstract

Climate change has increased the frequency and intensity of marine heatwaves, causing coral bleaching and changing shallow coral communities. The deep reef refugia hypothesis (DRRH) states that mesophotic coral ecosystems can act as refuges for shallow corals and sources of larvae to support the shallow reef recovery. However, their potential to act as refugia remains unclear, specifically regarding the possibility of supplying larvae. This study compares the coral recruitment patterns of shallow and upper mesophotic to explore the potential contribution of mesophotic corals to shallow reef recolonization (e.g., *Seriatopora*, a depth generalist species that disappeared from local shallow reefs). We deployed settlement tiles at three depths (10 m, 20 m, 40 m) before the expected coral spawning around Sesoko Island (Okinawa, Japan) and recovered them after the spawning season finished. All coral recruits on the tiles were observed, photographed, and collected for molecular identification. In addition, we assessed adult coral cover at each site using photo-quadrat images to characterize the adult coral community. Overall, the results showed that coral recruits were more abundant in shallow (10 m) than deeper reefs. The genera of recruits followed similar patterns as neighboring adult communities. This suggests that either coral larvae settle locally or local environmental conditions favor specific genera settlement and survival. Related to the DRRH, the absence of *Seriatopora* recruits at shallow depth mitigates the perspectives of a direct recolonization of the shallow reef from deep larvae. However, the finding of some identical genotypes at shallow and deep depths could indicate a limited potential for upper mesophotic coral to recruit directly to shallow reefs. This presentation will discuss these results and the implications of coral recruitment patterns at different depths for reef resilience.

Virtual
Oral
A-1808

MCEs in Okinawa: unique endangered ecosystems, lifeboats for coral reefs or both?

Sinniger, F.[1], Pichon, M.[2], Albelda, R. L.[1], Prasetia, R.[1], Rouzé, H.[3], Sitorus, E. D. S.[1], Thornton, B.[4, 5], Harii, S.[1]
[1]University of the Ryukyus, Tropical Biosphere Research Center, Motobu, Japan
[2]Queensland Museum, Biodiversity and Geoscience, Townsville, Australia
[3]University of Guam, Marine Laboratory, Guam, United States
[4]University of Southampton, Faculty of engineering and physical science, Southampton, United Kingdom
[5]University of Tokyo, Institute of Industrial Science, Tokyo, Japan

fredsinniger[at]gmail.com

Abstract

Mesophotic coral ecosystems (MCEs) have received a lot of attention following the Deep Reef Refuge Hypothesis (DRRH), which suggests that MCEs may serve as refuge for shallow corals in a global warming context. However, more mesophotic studies in deeper parts of MCEs have also shown that these ecosystems have some unique characteristics and should not only be considered through the DRRH. The depth range considered in the studies is likely a key factor affecting the perception of MCEs as refuges or as distinct ecosystems. In the Ryukyu Islands a few studies demonstrated the potential role of upper MCEs to act as refuge for at least some species. In order to understand the zonation of corals in northwestern Pacific MCEs and the potential role of MCEs as refuge, we first examined the results of an extensive coral biodiversity survey throughout the Ryukyu Islands down to 100 m depth. The coral distribution and diversity data were obtained using methods ranging from photoquadrats (0.5x0.5 m^2) to AUV mapping (30x30m^2) and morphological and molecular analyses of voucher specimens. With 49 genera and over 120 species, the mesophotic coral diversity observed in the region comes in second position between the GBR and the Red Sea. Most of the mesophotic species found in the Ryukyu Islands are also found at shallow depth, either in the same region or at different latitudes, yet some mesophotic preferential species could be clearly identified. Overall, the results show a gradual transition from shallow to deep coral communities, with a strong influence of the substratum characteristics and water turbidity. In general, the upper mesophotic zone is more suitable for the refuge hypothesis while deeper mesophotic depths tend to host mostly more unique communities. However, the upper mesophotic is also more prone to damage from strong storms and typhoons. The AUV data collected for three consecutive years at the same site provided an ideal visualization of upper mesophotic coral community dynamics. The coral cover underwent significant changes over the 3-year period with a large increase during a calm year, followed by strong disturbance (typhoon). Based on the results, we discuss whether the upper MCEs in the Ryukyu Islands can be considered as an extension of the shallow reefs and which specificities make MCEs at various depths unique. We further examine how the dynamics observed in the upper mesophotic communities affect the refuge potential of MCEs in the region.

Virtual
Oral
A-1615

Lighting-up the “Twilight Zone” as a potential larval source area of the needle coral, Seriatopora hystrix

Yasuda, N.[1], Takata, K.[2], Narita, Y.[3], Noguchi, N.[3], Nagai, S.[4], Kukuchi, T.[3], Sinniger, F.[5], Harii, S.[5]
[1]The University of Tokyo, Graduate School of Agricultural and Life Sciences, Bunkyo-ku, Japan
[2]The University of Tokyo, Graduate School of Agriculture and Life Sciences, Bunkyo-ku, Japan
[3]University of Miyazaki, Miyazaki, Japan
[4]National Research Institute of Fisheries, Fukuura, Japan
[5]University of the Ryukyus, Motobu, Japan

ninayausda[at]gmail.com

Abstract

Shallow water coral reefs in the world are now severely threatened by climate change and local anthropogenic stresses. In 1998 and 2016, most shallow Scleractinia corals bleached due to high seawater temperature and some coral species such as *Seriatopora hystrix* went locally extinct at some locations in Okinawa. *S. hystrix* is a brooding species releasing fully formed larvae that potentially disperse to other locations. Thus, recruitment of larvae from nearby populations is crucial for replenishing damaged/extinct populations of *S. hystrix*. In this context, healthy *S. hystrix* populations were reported after mass bleaching event at upper mesophotic depth (40 m depth) around Sesoko Island and Nagura Bay in Ishigaki Island. Such mesophotic coral ecosystems (MCEs) are the geographically nearest populations from the damaged shallow populations. The aim of this study is to elucidate if mesophotic habitat can supply larvae to shallow habitat for recovery or larvae can migrate from shallow habitat to mesophotic refugia via larval dispersal. In this study, we collected more than 700 *S. hystrix* samples from different depths (1 to 73 m) in the Ryukyu Islands. We used genome-wide SNPs obtained by MIG-seq to examine their genetic structure. STRUCTURE analysis indicated at least 3 major hidden lineages (named x, y, and z lineage) that are not correlated with depth or geographic distance along Ryukyu Islands. Almost all the individuals examined belong to either one of the different lineages with some intermediate genotypes between hidden lineages, implying current gene flow is limited among three different lineages. Further analysis of each lineage revealed there are two different lineages within each lineage. Overall, distribution of these two hidden lineages within each of the three lineages corresponded with depth, suggesting gene flow between deep and shallow populations are rather limited. However, one of the two linages in y lineage were found both deep and shallow water implying the possible genetic exchange between shallow and deep populations.

Virtual
Poster
A-1373

Are Okinawan deep corals threatened by the coral-killing sponges?

Albelda, R.[1], Sinniger, F.[2], Ise, Y.[2], Harii, S.[2]
[1]University of the Ryukyus, Marine and Environmental Sciences, Nishihara, Japan
[2]University of the Ryukyus, Tropical Biosphere Research Center, Sesoko Station, Motobu, Japan

albeldaritzellelima[at]gmail.com

Abstract

Mesophotic coral ecosystems (MCEs) are deep coral reefs at 30 to 150 m depth that may play a significant role in the recovery of degraded shallow reefs by providing a less disturbed environment and acting as larval source. Although deeper, MCEs are not fully protected from all threats. Sponges can become a potential threat to coral reefs as they are known to be strong spatial competitors of corals. In Okinawan MCEs, a number of hard corals including branching *Acropora* were seen covered by the coral-killing sponges *Chalinula nematifera* and *Terpios hoshinota* (Albelda & Sinniger, personal observation). Both species are encrusting sponges that are highly aggressive and fast-growing allowing them to overgrow live corals. They are both distributed throughout Indo-Pacific reefs, but rarely reported in MCEs. The lack of reef surveys makes it impossible to assess how much these sponges spread throughout the reef over time and whether or not these sponges currently pose a threat. The present study aims to understand how sponge prevalence relative to coral cover change in upper MCEs (40 m depth) and compare this with nearby shallow reefs (10 m and 20 m depths) off Sesoko Island in northern Okinawa, Japan. Sponge prevalence and coral cover were quantified using 50 x 50 cm photo-quadrats taken within the same reef areas during summer and winter in 2021 and 2022, respectively. Sponges were identified based on their overall appearance, spicule morphologies, and DNA analysis of the samples collected from shallow reefs and MCEs. Due to the image quality, only *C. nematifera* and *T. hoshinota* could be clearly observed in the photo-quadrats. Overall, sponge cover relative to coral cover was very low across all depths (<1%) in summer. Sponge in all depths was extremely patchy covering 0% to 2.6% of individual photo-quadrats. *C. nematifera* and *T. hoshinota* were observed in MCE and were mostly encrusting *Acropora tenella*, the dominant coral species in the area (>50%). On the other hand, only *C. nematifera* was observed in shallow reefs and was encrusting on *Platygyra*, *Pocillopora*, and branching *Porites* at 10 m and *Goniastrea* at 20 m depth. In this presentation, we will compare the changes in sponge cover between seasons and discuss the potential threat represented by the presence of these sponges in MCEs.

Virtual
Poster
A-1450

ROV assisted data collection to understand the status of Mesophotic Coral Ecosystems around Bonaire

Bartholomeus, R., Dogruer, G., Daniels, F., Meesters, E.
Wageningen Marine Research, Den Helder, Netherlands

rosanne.bartholomeus[at]wur.nl

Abstract

The coral reefs around Bonaire are among the richest, most resilient and least degraded in the Caribbean. Nevertheless, these reefs are threatened by local and global stressors. This study aims to identify the effect of local stressors to develop policy recommendations to increase the reef's resilience for global stressors. Locally, the coral reefs are negatively affected by increased surface runoff and pollution. Available information on what happens to coral reefs at greater depths, ranging from 30 to 100m, the so-called mesophotic reef ecosystems (MCEs), is scarce. Mesophotic reefs have gained more attention lately as it has been suggested that MCEs are spared from some local and global stressors. They are, for example, expected to survive bleaching events and suffer less from surface runoff. To what extent is this the case for Bonaire's mesophotic reefs, and how do they cope with a changing environment? Are they less disturbed than the shallower reefs, or do the mesophotic reefs function as a drain where pollution accumulates?

To obtain more knowledge on the cover of dominant benthic groups of MCEs and the vulnerability of MCEs for anthropogenic stressors, this study aims to answer the following question: To what extent can human impact explain differences in coral cover and biodiversity of mesophotic reefs?

Generally, there is little difference between photos taken by a ROV (Remotely Operated Vehicle) and by a diver. However, bottom time restricts the diver, while a ROV has unlimited bottom time. We deployed a ROV (QYSEA fifish V6 Pro) from a boat, equipped with a GoPro Hero 10 Black camera pointed vertically down to take pictures of the reef floor, as well as a gps locator (Waterlinked), which sends acoustic signals to a receiver which, in turn, is attached to the boat. Ten sites along the west coast of Bonaire were selected based on differences in human impact. We quantify and describe patterns in the abundance of corals, algae, and sponges with depth on mesophotic reefs around Bonaire, thereby providing insight into the condition of these unexplored areas of Bonaire’s coral reef. Finally, we compare the coral data with water quality parameters collected from the same study sites to better understand the impact of water quality on the deeper coral reef ecosystems.

Session 6D - Beyond the pristine - can evidence of well-functioning reefs in unexpected locations guide ecology in a period of rapid change?

Conceptualized by: **Stuart Sandin** [1], **Mark Vermeij**[2], **Jennifer Smith**[1], **Gareth Williams**[3]
[1] Scripps Institution of Oceanography (La Jolla, CA, USA)
[2] CARMABI / University of Amsterdam (Curacao / The Netherlands)
[3] Bangor University (Bangor, UK)

Poster
A-1834

Coral bleaching in turbid reefs of Northeast Borneo, Malaysia

Rosedy, A.[1], Waheed, Z.[1], Syed Hussein, M. A.[1], Sosdian, S.[2], Monteroso, D.[3], Johnson, K.[4], Santodomingo, N.[4]
[1]Borneo Marine Research Institute, Universiti Malaysia Sabah, Kota Kinabalu, Malaysia
[2]Cardiff University, School of Earth & Ocean Sciences, Cardiff, United Kingdom
[3]Darvel Bay Diving, Lahad Datu, Malaysia, [4]Natural History Museum, London, Department of Earth Sciences, London, United Kingdom

allia.rosedy[at]gmail.com

Abstract

Climate change means trouble for coral reefs worldwide. Future climate projections suggest bleaching events will become more frequent and severe, most likely at yearly basis by the end of this century. It is becoming more evident that the high diversity of the Coral Triangle is increasingly being threatened by the effects of this dramatic environmental change. However, recent studies have suggested that corals living in turbid environments are inherently more resilient in facing these threats. Therefore, our main goal was to test this hypothesis by assessing the response of corals to the 2020 bleaching event in two contrasting habitats in Darvel Bay (Sabah, Malaysian Borneo), the turbid reef of Sakar, and the clear-water reef of Blue Lagoon. High coral cover (33-62%) was observed on both reefs in 2019. Underwater dataloggers were collected and bleaching surveys conducted in July 2020, a few weeks after the Coral Reef Watch alert by NOAA, and immediately after the nationwide COVID-19 lockdown was lifted. Coral colonies were scored from video-transects of 100 m at 5 m and 10 m depth in both localities, with additional surveys at 15 m depth in Blue Lagoon. A total of 1488 coral colonies were evaluated for bleaching presence, percentage, and severity under a colour scale. Low levels of bleaching impact were observed in the high turbid locality, with 9% of bleached colonies at 5 m and 16% at 10 m. This was mainly affecting sparse, submassive colonies of *Goniopora*, with half of the colonies bleached. Foliose corals of *Leptoseris* and *Pavona* more common in this locality show low bleaching and if occurred, it was observed at the colony margins. Meanwhile, more bleaching occurred at the clear-water locality with 41% at 5 m, 54% at 10 m and 31% at 15 m, where acroporids and free-living mushroom corals of the genus *Fungia* were the most affected during this event. Interestingly, *Fungia* showed contrasting response to bleaching between the two localities, with only 5% of the colonies bleached in the turbid reef, in contrast to 35% bleached in the clear-water locality. These observations support the hypothesis of turbid reefs hosting resilient coral communities in the face of climate change.

Virtual
Oral
A-1235

Eight years of community structure monitoring through recreational citizen science at the “SS Thistlegorm” wreck (Red Sea)

Lee, C.[1], Caroselli, E.[1, 2], Machado Toffolo, M.[1, 2], Meschini, M.[1, 2], Mancuso, A.[1, 2], Marchini, C.[1], Pensa, F.[1], Branchini, S.[1], Goffredo, S.[1, 2]
[1]Marine Science Group, University of Bologna, Department of Biological, Geological and Environmental Sciences, Bologna, Italy
[2]Fano Marine Center, Inter-Institute Center for Research on Marine Biodiversity, Research, and Biotechnologies, Fano, Italy

chloe.lee[at]studio.unibo.it

Abstract

Large artificial coral reef communities, such as those thriving on sunken shipwrecks, tend to mirror those of nearby natural coral reefs and their long-term dynamics may help future reef resilience to environmental change. We examined the biodiversity of the world-renown SS “Thistlegorm” wreck in the northern Red Sea between 2007 through 2014, analyzing data collected during the recreational citizen science Red Sea monitoring project “Scuba Tourism for the Environment” (www.steproject.org). Date of the dive, maximum depth, average depth, temperature, dive time, hour of dive, and the possible sighting abundances of 72 target taxa, from sponges to mammals, were recorded by volunteer divers. Although yearly variations in biodiversity were significant, there was no clear temporal trend in community variation, and biodiversity remained high throughout the 8 years (71 of all 72 target taxa were sighted). Differences among years were visualized through a cluster analysis of yearly centroids, and the main taxa driving vearly variations were determined.

Virtual
Poster
A-2166

Predictive Regression Model: choosing the important variables of benthos and reef fishes for Brazilian oceanic islands monitoring

Monteiro-Leonel, A.[1], Sissini, M. N.[2], Cordeiro, C. A. M. M.[3], Mendes, T. C.[4], Ferreira, C. E. L.[4], Lotufo, T. M. C.[5]
[1]Universidade de São Paulo, Instituto Oceanográfico, São Paulo, Brazil
[2]Phycology Lab, Federal University of Santa Catarina,, Department of Botany, Florianópolis, SC,, Brazil
[3]Universidade Estadual do Norte Fluminense, Laboratorio de Ciencias Ambientais, Rio de Janeiro, Brazil
[4]Universidade Federal Fluminense, Departmento de Biologia Marinha, Niterói, RJ, Brazil
[5]Universidade de São Paulo, Instituto Oceanográfico, São Paulo, SP, Brazil

anamonteiroleonel[at]alumni.usp.br

Abstract

Atlantic tropical oceanic islands host unique reef habitats, with many endemic marine species. Assessing their conservation status is a complex task in term of logistics and baseline information, but also because each island has a distinct environmental setting. This work aims to analyze time series of benthic coverage and fish of reef ecosystems from four groups of Brazilian oceanic islands: Rocas Atoll (RC), Fernando de Noronha Archipelago (FN), São Pedro and São Paulo Archipelago (SP) and Trindade Island (TR). Shallow reefs of these islands have been sampled annually (2013 – 2019) using photo-quadrat transects for estimating the percentage cover of benthic organisms and by fish visual censuses for assessments of diversity, abundance, and biomass. The benthic cover of shallow reefs on Brazilian oceanic islands is dominated by macroalgae (23 to 41%) and epilithic algal matrix (25 to 36.9%), followed by crustose coralline algae (2.6 to 20.2%) and articulated calcareous algae (0.2 to 12.3%). Regarding reef fishes, a higher biomass was found on oceanic islands compared to other locations along the coast, but over the years of monitoring it has remained in a dynamic equilibrium, although showing signs that overfishing has changed the assemblage. Boosted regression trees were used to associate fish biomass with benthic cover, at the same depth ranges. BRT for each island showed that the most influential variables for fish biomass, in order, are: (i) stoloniferous, crustose coralline algae, and folious macroalgae in TR; (ii) stoloniferous macroalgae, articulated coralline algae, and filamentous in RC; (iii) folious, filamentous macroalgae and epilithic algae matrix in SP; (iv) scleractinian coral, epilithic algae matrix, and folious macroalgae in FN. We conclude that macroalgae in general and epilithic algae matrix and crustose coralline algae are the most important variables for total fish biomass in Brazilian oceanic islands, while Scleractinia corals were relevant only in FN.

Session 7A - Open Session: Scalable observations and technologies

Conceptualized and chaired by: **Arjun Chennu** [1], **Manuel Gonzalez Rivero** [2]

[1] Leibniz Centre for Tropical Marine Research (Bremen, Germany)

[2] Australian Institute of Marine Science (Townsville, Australia)

Oral
A-2067

Understanding Patterns of Hard Coral Demographics in Kenyan Reefs to inform restoration

Aboud, S., Gudka, M., Obura, D.
CORDIO East Africa, Mombasa, Kenya

saboud[at]cordioea.net

Abstract

Coral reefs are becoming increasingly vulnerable to a range of threats ranging from climate change to local disturbances. This has resulted in increased management, conservation, and restoration efforts to recover the reefs from degradation, as well as an assessment of the coral reef ecosystem's resilience. Recruits are important in the recovery process and critical for the persistence of coral reef ecosystems. Local coral community structure can be influenced by successful recruit settlement, survival, and growth.

This study examined the abundance and spatial pattern of coral recruits, in relation to adult and recruit community structures. This information would be useful in understanding the status of recruits as well as relating recruitment to the demographic structure of adults. The study would also look at changes in coral recruits over time, as well as identify sink and source recruitment sites. Understanding recruit community structure is also important for predicting how climate change may affect coral reef recovery.

The survey began in 2020 and has covered 33 coral reef sites along the Kenyan coast. We conducted in-situ counts for all sizes of corals in 23 selected genera using belt transects and sub-sampling of 1 m2 quadrat for small colonies. The surveys were only done during the North monsoon season.

Preliminary findings show the presence of 44 recruit genera, ranging from three at Marereni to thirty at Watamu Marine Reserve. Recruit densities ranged from 1.2± 1.5 (mean ± SD) at Likoni to 10.3 ± 8.4 recruit m-2 at Kisite Marine Park, with significant differences between some sites. The outer reef had the highest recruit density than the inner reef, but the differences were not statistically significant. There was a significant positive correlation between adults and recruits ($p < 0.001$).

The study will analyze spatial variation in recruits as well as the correlation between the recruit and adult coral abundance among genera. This may help to determine whether the reefs are self-sustaining and recommend further research to identify sink and source areas, recruit survival rates, and/or recruitment processes on the studied reefs.

Oral
A-1678

Quantifying spatial scaling properties of coral reef benthic communities across tropical seascapes

Ford, H.[1], Gove, J.[2], Healey, J.[3], Davies, A.[4], Graham, N.[5], Conklin, E.[6], Williams, G.[7]
[1]Bangor University, Ocean Sciences, Menai Bridge, United Kingdom
[2]NOAA, Honolulu, United States
[3]Bangor University, Bangor, United Kingdom
[4]University of Rhode Island, Rhode Island, United States
[5]Lancaster University, Lancaster, United Kingdom
[6]The Nature Conservancy, Honolulu, United States
[7]Bangor University, Menai Bridge,, United Kingdom

hv.ford[at]btinternet.com

Abstract

The issue of scale in ecology has historically been overlooked in study design. Observational scales in the marine realm can be constrained by traditional approaches, leading to a limited understanding of broader seascape patterns and processes. For the first time, we characterise the spatial structure (degree of departure from spatial randomness) of benthic communities and their physical drivers over multiple scales and geographies. Our first study used 6022 digital images, from sub-surface towed-diver surveys spanning ~140 linear km of reef, around five uninhabited tropical Pacific islands, to yield a spatially expansive and thematically resolved dataset. Around individual islands, benthic functional groups and coral morphologies displayed natural spatial clustering across the seascape, with individual groups dominating coastlines over km-scales. Among islands, some scales of clustering was consistent, particularly between islands close in proximity and size. Interestingly, at each island, the scales at which variables became spatially random were similar between benthic communities and two key physical drivers of benthic community structure on uninhabited coral reefs, wave energy and temperature. Our findings suggest such physical drivers not only limit or promote the abundance of various benthic competitors on coral reefs, but also play a role in controlling their spatial ecology across seascapes. We then looked at these spatial scaling patterns at a single island over time and following a mass coral bleaching event. We found that despite little change in coral cover leading up to the bleaching event, the spatial scaling properties of the benthic communities changed. The bleaching event caused a significant change in benthic community structure and gradients in functional group cover became less predictable based on concurrent gradients in environmental drivers. Our findings highlight the ability of mass coral bleaching events to fundamentally disrupt the spatial ecology of tropical coral reef benthic communities across scales.

Oral
A-1088

A new framework based on synchronised cameras to measure fish abundance

Magneville, C.[1], Brissaud, C.[1], Fleuré, V.[1], Loiseau, N.[1], Claverie, T.[1, 2], Villéger, S.[1]
[1]UMR MARBEC, Université de Montpellier, CNRS, Ifremer, IRD, Montpellier, France
[2]Centre Universitaire de Formation et de Recherche de Mayotte, Dembéni, France

camille.magneville[at]umontpellier.fr

Abstract

Knowledge of fish abundance in coastal ecosystems is crucial for assessing impact of human activities and of management policies as well as for unravelling the contribution of species to ecosystem processes. For the last decade, the assessment of fish abundance in coral reefs has been increasingly done using remote underwater videos which are logistically simpler to implement than Underwater Visual Census by divers and allow to keep permanent video records.
The abundance of a species on a video is estimated using the maximal number of individuals seen simultaneously (maxN). However, this very conservative metric underestimates markedly the actual abundance of populations made of numerous groups of mobile individuals, hence unlikely to all be recorded simultaneously on a single camera. We propose a novel methodological framework based on a network of synchronised remote underwater cameras. Several temporally synchronised cameras are dispersed across an habitat allowing to have a recording of all types of microhabitats. Linked with this approach we proposed a new metric called *Synchronised maxN* (SmaxN), which is an extension of the classical maxN. SmaxN accounts for each species for a “uniqueness interval”, during which we consider that individuals from a given species recorded by different cameras are different individuals. The computation of this time interval depends on species maximal locomotion speed and the distances between the cameras. SmaxN, is the maximum of all the maxN values computed on all time steps possible given the uniqueness interval over the video duration. To help users to compute the SmaxN metric for a given species and compare it to other count metrics, we coded a R package, SmaxN, available on Github.
We tested this framework on fringing reefs from Mayotte (Western Indian Ocean) in November 2020 with a network of 12 cameras that recorded for 2h over 3 periods . Estimates of abundance with the SMax metric were at least twice higher than estimates with maxN for five fish species with different traits (*Chaetodon auriga, Chaetodon trifasciatus, Gomphosus caeruleus, Parupeneus macronemus and Thalassoma hardwicke*). Our framework improves the estimation of fish abundance and could be applied to other video-based surveys such as Baited-Remote Underwater Cameras for pelagic predators or aerial surveys of megafauna.

Oral
A-1214

Novel tool for restoration: Unified coral sample registry to support cross-referencing across restoration programs

Moura, A., Winters, R. S.
Coral Restoration Foundation, Tavernier, United States

amelia[at]coralrestoration.org

Abstract

In the past decade, the field of coral reef restoration has experienced a proliferation of data detailing the source, genetics, and performance of coral strains used in research and restoration. Resource managers track the multitude of permits, species, restoration locations, and performance across multiple stakeholders while researchers generate large data sets and data pipelines detailing the genetic, genomic, and phenotypic variants of corals. Restoration practitioners, in turn, maintain records on fragment collection, genet performance, and outplanting location and survivorship. While each data set is important in its own right, collectively they can provide deeper insights into coral biology and better guide coral restoration endeavors – unfortunately, current data sets are siloed with limited ability to cross-mine information for deeper insights and hypothesis testing.

The newly launched Coral Sample Registry (CSR) is an online resource that establishes the first step in integrating diverse coral restoration data sets. Developed in collaboration with academia, management agencies, and restoration practitioners in South Florida, the CSR centralizes information on sample collection events by issuing a unique accession number to each entry. Accession numbers can then be incorporated into existing and future data structures. Each accession number is unique and corresponds to a specific collection event of coral sample tissue, whether for research, archiving, or restoration purposes. As such the accession number can serve as the key to unlock the diversity of information related to that sample's provenance and characteristics across any and all data structures that include the accession number field. The CSR is open-source and freely available to users, designed to be suitable for all coral species in all geographic regions. This resource is already being utilized by the Florida restoration community, with over 2,800 collection entries submitted thus far. Our goal is that this resource will continue to be adopted by researchers, restoration practitioners, and managers to efficiently track coral samples through all data structures and thus enable the unlocking of a broader array of insights.

Oral
A-1099

Exploring 3D modelling of radiative, heat and mass transfer in corals

Murthy, S.[1], Picioreanu, C.[2], Kühl, M.[1]
[1]Copenhagen University, Marine Biology section, Department of Biology, Helsingør, Denmark
[2]King Abdullah University of Science and Technology, Biological and Environmental Sciences and Engineering Division, Thuwal, Saudi Arabia

swathi.murthy[at]bio.ku.dk

Abstract

Corals are efficient biological collectors of solar radiation and consist of a thin tissue layer spread over a light scattering skeleton surface. They exhibit a vast diversity of structural forms to maximize photosynthesis of their dinoflagellate endosymbionts (Symbiodiniaceae), while simultaneously minimizing photodamage. This allows them to occupy both shallow reef platforms and crests with intense solar irradiance as well as mesophotic reefs with near to darkness illumination. We used finite element numerical modelling of radiative (Monte Carlo Simulation), heat and mass transfer in corals to explore the effects of various macroscale morphological forms of coral skeletons on their physico-chemical microenvironment. Unlike earlier 3D modeling attempts, we explored ways to include the optical, thermal and diffusion properties (on micro-scale) of stratified coral tissue and skeleton in our simulations. Such modelling was done on 3D scanned corals and assuming a laboratory aquarium set-up, with well-defined laminar flow conditions, further expanding on our earlier 2D modelling study of microenvironment on stratified coral tissue[1]. The modeling predicted the 3D distribution of light, temperature and dissolved oxygen concentration in the coral colony. The outcomes were supported with experimental microsensor measurements of light, temperature and O_2 at particular locations in the 3D coral structure. The results indicate that the morphology of the skeleton leads to hotspots of light and self-shadowed regions. This varies between different coral species, based on the degree of branching. The morphology of the coral also affects the water flow around it and, consequently, the diffusion boundary layer (DBL) and thermal boundary layer (TBL). A highly branched coral has more light shaded regions and thicker DBL (and TBL) than a massive coral under similar flow scenarios. These factors directly impact the temperature distribution and mass transfer of chemical species like O_2, pH and CO_2, and hence the coral microenvironment forming distinct microhabitats in a given coral species. Such fine scale ecological niche heterogeneity may affect the composition of both endosymbionts and microbiomes across the coral holobiont.

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Oral
A-2058

Tracking benthic change via large area imagery and virtual fieldwork

Petrovic, V.[1], Pedersen, N.[2], Edwards, C.[2], Runyan, H.[2], Amir, C.[3], Alcantar, E.[2], Zgliczynski, B.[2], Smith, J.[2], Sandin, S.[2], Kuester, F.[1]
[1]Qualcomm Institute, UC San Diego, La Jolla, United States
[2]Scripps Institution of Oceanography, La Jolla, United States
[3]National Oceanic and Atmospheric Administration, Pacific Islands Fisheries Science Center, Honolulu, United States

vid[at]ucsd.edu

Abstract

Tracking benthic change is a foundational element of coral reef studies. Change can be variously characterized and quantified--from binary transitions like recruitment and mortality events, to continuous areal measures like coral growth or tissue loss--and at various scales and granularities, from plot-wide statistics, down to individual organism-level measurements--with plot-scale, individual-level change measures serving as the fundamental measurements of demography and ecology, and as the quantitative building blocks for community projections. We consider the application of large-area imaging techniques to this task, and describe the development of Viscore, a software platform for facilitating the necessary workflows.
We first use the platform to assemble the collected imagery and derived products into coherent 4D site representations--generally comprising thousands of images and around a billion 3D points per 100m2 time snapshot--providing scientists with virtual access to the benthos via the collected evidence, and allowing measurements and analyses to be done interactively. The platform leverages derived products (such as camera pose estimates and pointcloud reconstructions) to provide spatiotemporal context for each image--as a projected view of the 'real' 4D benthos--and allows annotations to be transferred across different views, linking raw 2D images, 3D pointclouds, and derived 2(.5)D orthoprojected maps. This transferability affords flexibility with respect to how an analysis is done--per-image, over a 2D map, over pointclouds, or over derived meshes--and aids the long-term usefulness of analysis products, since they can be related to the raw imagery, and are automatically '3D-aware.'
These different views of the data (and underlying reality) present different opportunities for visualizing, annotating, and quantifying benthic change. We describe interactive workflows for aligning plot geometry and tracking organism identity and fate across time, 'painting' segmentations onto the 3D pointclouds, performing point-based Monte-Carlo projected area estimation using the original imagery, and assessing changes over time. We further discuss workflows for performing annotation tasks externally--such as ML-based 3D segmentation, 2D segmentation over exported maps, and image-based point classification--to accelerate data elaboration, and match the growing rate of data collection within our project.

Oral
A-1153

Altered predator and prey densities influence foraging behavior and vegetation patterns in mesocosm systems

Rago, Z.
Hawaii Institute of Marine Biology, Kaneohe, United States

zrago[at]hawaii.edu

Abstract

Coral reef halos are distinct vegetation patterns that have been documented throughout the tropics. Many have theorized about their underlying causes, yet very few experiments have attempted to disentangle these mechanisms. The most common hypothesis is that interactions between predators and herbivores lead to spatially-constrained herbivore foraging patterns, whereby grazing occurs most heavily immediately adjacent to patch reef predation refuges. This study aims to quantify the role that altered densities of predators and herbivores play in influencing how far herbivores are willing to graze from predation refuges (i.e., protective structures). To do so, twelve large mesocosm enclosures were deployed in Kāne'ohe Bay, O'ahu, Hawai'i . Mesocosms consisted of centralized protective structures only accessible to herbivores with outplanted cuttings of palatable algae (*Acanthophora spicifera*) attached at a range of distances from the central structure. Densities of predators (*Cephalopholis argus*, the peacock grouper) and herbivores (*Acanthurus triostegus*, the convict tang) varied independently by treatment. Measurements of *A. spicifera* were taken every day for the duration of the experiment. Our results demonstrate that densities of predators and herbivores are a driving force underlying spatial patterns and foraging strategies of herbivorous coral reef fishes. While other, un-tested mechanisms likely also contribute to coral reef halo formation, our study clearly shows that the landscape of fear created within habitats is a key component underlying these intriguing ecological patterns.

Oral
A-1805

Experiments in automation to expedite high-precision 2D/3D coral segmentation

Runyan, H.[1], Petrovic, V.[2], Edwards, C.[1], Pedersen, N.[1], Alcantar, E.[1], Kuester, F.[2], Sandin, S.[1]
[1]University of California San Diego, Scripps Institution of Oceanography, La Jolla, United States
[2]University of California San Diego, Qualcomm Institute, La Jolla, United States

hurunyan[at]ucsd.edu

Abstract

Technological developments have made it possible to, using only consumer electronics, recreate hundreds of m^2 of underwater landscapes in mm-resolution 3D models. This ability to "bring the reef back to the lab" promises to enable scientists to move beyond bulk measures such as coral cover to investigate specific drivers of complex community demographics across time and space. Our lab has embraced this methodology, collecting nearly 2000 plots from hundreds of locations across the world. This has become one of the largest repositories of data at our university, requiring substantial human and computational resources to store, transfer, and interpret. Semantically segmenting (defined as labeling per-pixel, per-genera) a single m^2 manually requires an average of one hour; at this rate, an expert working full time would need at least a century to map every organism in this database, and that number of years grows by much more than one with every new year of data we collect. A decade of field expeditions to a single Pacific atoll comprise ~20% of our stored data; orders of magnitude more would be required to provide coral researchers with the globally-comprehensive database we desire. In order to bring the time required to process reef models in line with how quickly they can be collected, we are investigating pipelines that incorporate both human experts and neural-network-driven automated tools to leverage as much of the information contained in raw survey images, 3D models, and 2D top-down large-area imaging as possible.

Oral
A-1071

Microbial fuel cells in coral reef sediments as indicator tools for organic carbon eutrophication

Thobor, B. M.[1], Schanz, F. R.[1], Kerzenmacher, S.[2,3], Wild, C.[1,3]
[1]University of Bremen, Marine Ecology, Bremen, Germany
[2]University of Bremen, Environmental Process Engineering, Bremen, Germany
[3]Center for Environmental Research and Sustainable Technology (UFT), Bremen, Germany

bmthobor[at]gmail.com

Abstract

Eutrophication with organic carbon (OC) can be harmful for corals and their reefs due to its stimulating effects on associated microbes. Mitigation measures require real-time monitoring of wastewater pulses close to coral reefs, where biogenic carbonate sands act as biocatalytic filters for OC. Microbial fuel cells (MFC) can generate sensitive electric signals through the microbial degradation of OC in sediments, but their application in coral reefs has not yet been tested. During a laboratory experiment, we thus investigated if MFCs, vertically deployed in coral reef sands, can be used as indicator tools for wastewater-induced eutrophication (i.e., two consecutive pulses of standardized wastewater at OC concentrations of 20, 40, or 60 mg C L^{-1} higher than controls). Results revealed a significant linear relationship between current density and OC concentration 12 h after the first OC pulse, but a decrease in precision for the second OC pulse 5 weeks later. All OC pulses (i.e., three concentrations with two pulses each) resulted in significant increases in the current density compared to baselines and controls (from < 0 up to 45 mA m^{-2}) for the following 2 to 5 weeks. This highlights the functionality of the MFC as a qualitative indicator tool for OC pulses even weeks after deployment. The reaction velocity of the MFC was fast (hours) compared to other indicators for water quality (e.g., bioindicators). The MFC successfully detected OC concentrations expected for wastewater effluents. Measurements can be automated for continuous monitoring, and no laboratory facilities are required (as for $\delta^{15}N$ or TOC analysis), making MFC sensors a suitable tool for remote locations. Overall, these findings emphasize the high potential of these low-cost (< 20 Euro per piece) MFCs as indicator tools for OC pulses in coral reef environments.

Poster
A-1654

Towards the analysis of coral skeletal density-banding using Deep Learning

Bertini, L.[1], Rutterford, A.[2], Hendy, E. J.[3], Johnson, K. G.[1], Summerfield, R.[3], Burghardt, T.[2]
[1]The Natural History Museum, Department of Earth Sciences, London, United Kingdo
[2]University of Bristol, Department of Computer Science, Bristol, United Kingdom
[3]University of Bristol, School of Earth Sciences, Bristol, United Kingdom

l.bertini[at]nhm.ac.uk

Abstract

X-ray micro-Computed Tomography (μCT) is increasingly used to record the skeletal growth banding in massive corals. However, the analysis of the high volume of 3D data generated is time-consuming, requiring expert annotation of 2D virtual slices followed by manual identification of low- and high-density band pairs to produce a chronological record and estimate linear extension rates along selected growth axes. Here we test an Artificial Intelligence (AI) approach using deep learning to reproduce the expert identification of annual density banding. A Convolutional Neural Network (CNN) was trained with μCT images and combined with manually labelled ground truths to learn the 2D topological features across μCT slices of different specimens of massive Porites sp. The CNN successfully predicted the position of density-band boundaries in images not used in training. Linear extension rates derived from CNN-based outputs and the traditional method were consistent. With more training sets including sufficient manual annotation, this technique has the potential to speed up density-banding analysis significantly. The resulting increased volume of coral growth data will allow more detailed assessments of population measures of both linear extension and calcification rates.The technique could rapidly move forward with the establishment of a collaborative platform where the coral research community shares expert-labelled μCT and X-ray images for the development of future AI applications. AI density-banding detection could then be used to improve our understanding of the variability in coral growth datasets and provide more precise information regarding the impacts of environmental fluctuations on coral growth, ensuring more detailed assessments of both coral health and reef carbonate budgets.

Poster
A-1873

Structural complexity patterns in time series of coral reef 3d models

Dagum, L. J.[1], Licuanan, W.[2], Soriano, M.[3], David, L.[1]
[1]The Marine Science Institute - University of the Philippines Diliman, Quezon City, Philippines
[2]De La Salle University, Manila, Philippines
[3]National Institute of Physics, University of the Philippines - Diliman, Quezon City, Philippines

ldagum[at]msi.upd.edu.ph

Abstract

Structural complexity components from time series 3D models revealed insights on reef health issues after a disturbance. A method was developed to quantify structural complexity from images captured by different cameras through time. Structure-from-motion photogrammetry was applied to images captured by different cameras through time creating 3D models of the reef. These models were scaled and aligned utilizing permanent structures on site as reference. Rugosity, viewshed, trough dimensions, shelter capacity, and coral morphology, which are descriptors of structural complexity, were quantified from the 3D model contours and orthomosaics. Automating these measurements and combining these quantities to represent structural complexity in coral reefs to aid in rapid assessments is this method’s novelty. The algorithm was developed and tested on 3D models of coral reefs from images taken within a span of ten years, including a bleaching event, in Lian, Batangas, Philippines. Time series trajectories showed high correlation among structural complexity components and reflected the reef's recovery after the disturbance. With this method, structural complexity components can be used to characterize the state of the reef and its trajectory over time, forecast reef recovery after disturbances such as typhoons or bleaching, proxy coral morphological cover and vice versa, and correlate with fish abundance for refuge potential.

Poster
A-1830

On the monitoring of coral reef ecosystems using novel laser-powered sensors

De Oliveira Filho, J., Trichili, A., Berumen, M., Ooi, B., Alouini, M.-S., Salama, K.
King Abdullah University of Science and Technology, Thuwal, Saudi Arabia

jose.deoliveirafilho[at]kaust.edu.sa

Abstract

Current technologies for marine life monitoring and scientific data collection involve the use of a variety of sensors that require continuous powering via batteries. Communication with those sensors is usually based on acoustic waves, which requires high power consumption. The battery of the underwater sensors can be recharged via solar panels. However, this is only possible in shallow seawater. Therefore, the frequent change of the sensors' batteries is needed. Such a process is challenging and yet expensive in a harsh underwater environment. In this context, we propose the use of lightwaves to recharge the batteries of remote underwater sensors while providing connectivity. We designed a variety of self-powered modules that harvest energy from light beams from visible laser sources or light-emitting diodes (LEDs), possibly emitting from a buoy, diver or remotely operated vehicle (ROV) via off-the-shelf solar detectors that are also used to decode information. In a first demonstration, we charge the battery of a submerged module equipped with temperature and turbidity sensors and transmit commands using a single laser. The temperature sensor is then used to monitor the variable temperature of a water tank. In a second demonstration, we report charging the super-capacitor of a sensing device that is equipped with a camera and a low-power laser for real-time video streaming.

Virtual
Oral
A-1564

Harnessing the power of Machine Learning to automate coral reef benthic transect image analysis

Conley, D.[1], Dempsy, A.[2], Chan, S.[3], Kline, D.[4], Mitchell, B.[1]
[1]University of California San Diego, Scripps Institution of Oceanography, La Jolla, United States
[2]Khaled bin Sultan Living Oceans Foundation, Annapolis, United States
[3]University of California San Diego, La Jolla, United States
[4]Smithsonian Institution, Panama, Panama

d1conley[at]ucsd.edu

Abstract

Machine learning has the potential to greatly benefit coral reef science and conservation by automating coral reef transect image analysis. Knowing the benthic cover and coral taxonomic composition of a reef is critical to understanding the health of a reef and monitoring how it changes over time, but the process of quantifying these details is a time-consuming and labor-intensive process. CoralNet, an open-source platform for automating the classification of benthic transect photos, has already been shown to be capable of estimating coral benthic cover and classifying corals to genus with an accuracy of up to 90% when compared to a coral expert. Recently we developed tools to allow input and output of data between CoralNet and Coral Point Count with excel (CPCe). CPCe is widely used within the coral ecology community for manually annotating coral reef photoquadrat images. Because CPCe is so widely used, there will be many groups around the world that currently have substantial collections of images already annotated using CPCe. These collections can serve as training libraries for the automated annotators in CoralNet allowing groups to automate the annotation of their backlogs and future expeditions. We are training CoralNet with annotated images from the Khaled bin Sultan Living Oceans Foundation's (KSLOF's) Global Reef Expedition mission to survey the reefs of Lau Province, Fiji in 2013.
We found that when approximately 46,500 annotations were used to train the CoralNet the AI machine was able to annotate novel images at approximately 90% accuracy for coral genus and for coral cover compared to a coral expert. This protocol for the automation of coral annotations has the potential to drastically increase the efficiency and output of coral ecologists by alleviating the bottleneck of having to manually annotate images from field expeditions, and potentially allow for more images to be collected in the field. The integration of CPCe into CoralNet will open the vast existing collections of CPCe annotations and allow them to be used as training sets for the annotation of existing and future coral images. This novel method has the potential to transform the field of coral monitoring worldwide. Details of CoralNet and associated tools to advance research are found at https://coralnet.ucsd.edu/.

Virtual
Oral
A-2160

Development of captive breeding methods for a peppermint shrimp Lysmata hochi: an insight towards conservation through marine ornamental aquaculture

Madhavan, M.[1], T. T. Ajith Kumar*, and Kuldeep Kumar Lal[1, 2]
[1]ICAR-National Bureau of Fish Genetic Resources, The Peninsular and Marine Fish Genetic Resources (PMFGR), Kochi, India
[2]Kerala University of Fisheries and Ocean Studies, Panangad - 682506, Kerala, KOCHI, India

manumadhavan060[at]gmail.com

Abstract

Peppermint shrimps *Lysmata* species is one of the commercially important species in the multibillion-dollar industry of marine aquarium trade, which is greatly exploited from the coral environment worldwide. Over 90% of the traded species are acquired from the wild, notably from fragile coral reefs regions. It is believed that the collection of wild marine ornamental species is responsible for 2% of global coral reef degradation. To control the wild collection and sustainable production of these species, the standardization of captive breeding protocol is required for these species through aquaculture. *Lysmata hochi* Baeza & Anker, 2008, is a colorful marine ornamental species that was recently reported from India at Lakshadweep islands. Still, the captive breeding technology of this species has not been reported yet. Hence, we investigated the standardization of the breeding protocol for *L. hochi,* introducing a novel captive-raised species into the aquarium trade. Handpicking methods were adopted to catch live *L. hochi* specimens from the intertidal zones of Agatti Island, Lakshadweep, India at a depth of 0.5-1 m. FRP tank with 500 L filtered seawater was used for broodstock development, breeding, and larviculture. After quarantine, the animals were introduced into the brooder development tank and fed with frozen *Artemia* and boiled clam thrice a day. To simulate the natural environment, live rocks and coral boulders were introduced for hiding and a 12 hours photoperiod was maintained with artificial lighting. Before stocking the larvae, tanks were conditioned with green microalgae, *Nannochloropsis salina,* and rotifer, *Brachionus plicatilis*, *which* showed greater fertility and each individual produced 800±150 larvae per release. The larval days were extended to 90-110 days, larval survival rate showed 40-45%, and juvenile survival showed 40%. Furthermore, the observation revealed that this species is a continuous spawner, with fecundity ranging between 900-950 oocytes. Overall, the findings are very encouraging, and successful scaling up will aid the promotion of marine ornamental aquaculture and help succeed in the development of the marine aquarium trade.

Virtual
Oral
A-2152

Scales of spatial variation of diversity ascidians assemblages in coral reefs of the southern Gulf of Mexico and Mexican Caribbean Sea

Palomino-Alvarez, L.[1], Guerra-Castro, E. J.[2, 3], Rocha M., R.[4], Simões, N.[5, 6, 7]
[1]Universidad Nacional Autónoma de México, Posgrado en Ciencias del Mar y Limnología, Ciudad de México, Mexico
[2]Universidad Nacional Autónoma de México, Departamento de Sistemas y Procesos Naturales, Escuela Nacional de Estudios Superiores Unidad Mérida, Yucatán, Mexico
[3]Laboratorio Nacional de Resiliencia Costera (LANRESC), Laboratorios Nacionales, CONACYT, Mérida, Mexico
[4]Universidade Federal do Paraná, Zoology Department, Curitiba, Brazil
[5]Universidad Nacional Autónoma de México, nidad Multidisciplinaria de Docencia e Investigación Sisal (UMDI-Sisal), Facultad de Ciencias, Yucatán, Mexico
[6]aboratorio Nacional de Resiliencia Costera (LANRESC), Laboratorios Nacionales, CONACYT,, Yucatán, Mexico
[7]Texas A and M University-Corpus Christi, Corpus Christi, International Chair for Coastal and Marine Studies, Harte Research Institute for Gulf of Mexico Studies, Texas, United States

lily.drgalvar91[at]gmail.com

Abstract

All ecosystems, including coral reefs, exhibit a range of species diversity and distribution patterns that can be explained as the result of environmental, biological, historical, anthropic, and stochastic processes. Although coral reefs are home to a significant portion of the planet's biodiversity, however, research trying to understand the distribution of species in these ecosystems has been insufficient and focused only on a portion of the biodiversity. Studies of metacommunities had already recognized that multiple processes can act simultaneously to generate variability in the composition of species and generate patterns of distribution and diversity at different spatial scales. Understanding and integrating the multiple scales where the processes that generate spatio-temporal variation of species occur is extremely important since it not only summarizes the evolutionary and ecological history of species, but also helps us to understand the functioning of ecosystems and identify the causes of ecosystem deterioration and thus inform more effective management actions. The aim of this research was to analyze the diversity of species (α, β, γ) of ascidian assemblages, and to associate the variation in the diversity with the driving processes in 13 coral reefs of the Gulf of Mexico and the Mexican Caribbean Sea. The present study recorded a total of 103 species of ascidians, 10 of which are new records for the Gulf of Mexico and 42 are new records for the Mexican Caribbean. The spatial distribution of the species showed that the reefs of the Bank of Campeche/Yucatan and the Mesoamerican Reef System have more than twice the diversity of the reefs of the Veracruz Reef System. The analysis of variation of the species composition detected that most variation occurred at a small spatial scale (sites and squares) in each coral system. Possible drivers of this variation are variability in settlement and recruitment, habitat availability and heterogeneity, biological interactions, and environmental stochasticity in the local disturbance.
Disentangling the relative importance of all those drivers has to be the object of future studies. There was also some variation in the medium-and large-scale (between reefs within coral systems and across systems) possibly forced by ocean currents, geomorphology, and size of the reef, in addition to the historical and geological features and age of the system.

Virtual
Oral
A-2181

Using satellite imagery and low-cost, towed underwater video for coral reef mapping and monitoring in Sri Lanka

Perera, N., Polwatta, S., Tanna, A.
Blue Resources Trust, Colombo, Sri Lanka

nishan[at]blueresources.org

Abstract

Coral reefs are being degraded at unprecedented rates due to direct anthropogenic impacts and climate change. Understanding coral reef distribution, condition and community composition is vital to developing better management. We attempted to map reefs within Kayankerni Marine Sanctuary, in eastern Sri Lanka using a simple towed video system for ground truthing coral assemblages and reef structure. Ground truthing was done using a Deep Blue Pro underwater drop camera towed from a boat and recording video of the substrate with latitude, longitude and time. Depth was recorded using a boat mounted Ray-marine Dragonfly echo sounder with video relay capability, and depth readings were corrected to account for tidal variation. Substrate and depth videos were synched, and still images were taken at specified intervals. Images were analyzed by substrate type based on dominant coral genera and growth forms. Substrate data was integrated into World View 3 satellite imagery corrected for atmospheric and water column scattering. Ground truthed sample points were taken as training samples for the Maximum Likelihood Supervised Classification (MLSC) for habitat classification. Analysis of video data and MLSC indicated a high level of accuracy ranging from 83% to 94% across the reef system. The Cohens Kappa statistic measures for interrater reliability was used to assess data accuracy and provided a high accuracy coefficient value of 0.81-0.93 across different sections of the reef system. Substrate cover across the mapped area was primarily sand (34.3%) interspersed with old coral rock and live coral. Most live coral areas (23.1%) had a mixed coral assemblage with some monospecific or single species dominated stands of branching *Acropora* (2.7%) and foliose *Montipora* (1.7). Habitat maps developed using remote sensing can be used for developing spatial plans, monitoring long term changes and documenting events such as mass coral bleaching. Using simple, low cost methods provide an ability to map large reef areas at relatively low costs, which is especially important in developing countries with limited resources for more advanced reef mapping.

Session 7B - How can autonomous data-driven robotics be used to improve cost effectiveness and spatial/temporal scaling of reef assessments?

Conceptualized by: **Josh Levy**[1], **Carlie Wiener**[2], **Phil McGillivary**[3], **Ved Chirayath**[4]
[1] University of Hawaii (Honolulu, HI, USA),
[2] Schmidt Ocean Institute (Palo Alto, CA, USA)
[3] US Coast Guard Pacific Area Science Liaison (Alameda, CA, USA)
[4] NASA Ames Research Lab (Moffett Field, CA, USA)

Chaired by: Alexandra Dempsey[1]
[1] Khaled bin Sultan Living Oceans Foundation (Annapolis, USA)

Oral
A-1664

Automated quantification of parrotfish grazing function using acoustic monitoring

Bruggemann, J. H.[1], Ducrettet, M.[1], Guilhaumon, F.[2], Cagnato, M.[3], Amy, M.[3], Guillerault, N.[3], Vigliola, L.[4], Elise, S.[1]
[1]Université de La Réunion, UMR ENTROPIE, Saint-Denis, Réunion
[2]Institut de Recherche pour le Développement, UMR ENTROPIE, Saint-Denis, Réunion
[3]Terres Australes et antarctiques Françaises, Saint-Pierre, Réunion
[4]Institut de Recherche pour le Développement, UMR ENTROPIE, Nouméa, New Caledonia

henrich.bruggemann[at]univ-reunion.fr

Abstract

Global change and human pressures increasingly push coral reefs into new configurations and challenge the continued delivery of ecosystem goods and services to humans. In response, management targets are shifting from the conservation of species towards safeguarding ecosystem functioning and resilience. Prioritizing conservation targets and evaluating the effectiveness of management interventions require assessments of ecosystem functioning at spatial and temporal scales that are challenging to attain using traditional monitoring methods. Parrotfish grazing provides critical ecosystem functions, particularly the removal of algal turfs, sediments and structural carbonates from dead coral substrates, processes that mediate benthic communities and favour coral recruitment. Here we present a method for automated classification of grazing bites of parrotfishes using acoustic monitoring and subsequently apply this method to quantify temporal and spatial variations in parrotfish grazing intensity. Sounds of grazing bites were initially labelled by inspecting simultaneous video and sound recordings from the Indian Ocean, permitting taxonomic identification of grazing parrotfishes. A set of sound templates was hence established. Training and validation datasets were then constituted by listening larger audio recordings and labelling every detected bite. Relying on spectrogram cross-correlation between templates and training dataset, template matching was used to iteratively select the optimal classification parameters. AUC criteria was employed to guide this selection, based on a trade-off between true positive and false positive rates.
Temporal variations in grazing intensity were analysed from 10 months continuous in situ sound recordings using a fixed hydrophone on the remote reef of Europa Island, western Indian Ocean. The potential of the tool to be used in other biogeographic contexts was examined based on its application at 14 sites around New Caledonia, western Pacific. Complementary to traditional methods, acoustic monitoring enables acquiring information on ecosystem functioning continuously, or at multiple sites within a short time span, at low cost and without human observer bias.

Oral
A-1207

An object detection model for global identification of reef halos using high-resolution satellite imagery

Franceschini, S.[1], Meier, A.[1], Suan, A.[1], Stokes, K.[1], Roy, S.[2], Madin, E.[1]
[1]University of Hawaii at Manoa, Hawaii Institute of Marine Biology, Kaneohe, United States
[2]Planet Labs, San Francisco, United States

simonefr[at]hawaii.edu

Abstract

Reef halos are circles of bare sand that surround patches of coral reef. Halo formation can, in large part, be the indirect result of healthy predator and herbivore populations. Herbivores graze closely to the safety of the reef imposed by predation risk potentially affecting the presence and size of the halo band.. Reef halos are readily visible in remotely sensed imagery and monitoring their presence and changes in size may offer clues as to how predator and herbivore populations are faring. However, manually identifying and measuring halos are slow and limit the spatial and temporal scales of studies. No tool yet exists to automatically identify reef halos and measure their size in order to speed up their identification and improve our ability to quantify their variability. Here, we present a Mask Region-Based Convolutional Neural Network (Mask R-CNN) aimed at identifying reef halo presence from very high-resolution satellite imagery (i.e., <4m pixel size). We selected different sites worldwide to train and validate an object detection model for more than 1,000 reef halos. We show that the Mask R-CNN algorithm can successfully detect reef halos with a high degree of accuracy, while measuring their width and area, thereby allowing faster and more accurate spatio-temporal monitoring of changes in halo size. This tool will aid in the global study and analysis of reef halos by speeding up our discovery of the ecological dynamics underlying their variability. Moreover, the integration of our object detection model into a readily-available, user-friendly mapping software will likely provide the foundation for others to apply this automated object detection method to other features thus supporting better marine conservation and management.

7B - How can autonomous data-driven robotics be used to improve cost effectiveness and spatial/temporal scaling of reef assessments?

Oral
A-1552

Rapid and Comprehensive Coral Reef Monitoring through Autonomous Underwater Vehicles and Semantic Mapping of the Reef Benthos

Jamieson, S.[1, 2], Becker, C.[1, 2], Apprill, A.[3], Mooney, A.[4], Girdhar, Y.[5]
[1]Woods Hole Oceanographic Institution, MIT-WHOI Joint Program in Oceanography/Applied Ocean Science and Engineering, Woods Hole, MA, United States
[2]Massachusetts Institute of Technology, Cambridge, MA, United States
[3]Woods Hole Oceanographic Institution, Marine Chemistry and Geochemistry, Woods Hole, MA, United States
[4]Woods Hole Oceanographic Institution, Biology, Woods Hole, MA, United States
[5]Woods Hole Oceanographic Institution, Applied Ocean Physics and Engineering, Woods Hole, MA, United States

sjamieson[at]whoi.edu

Abstract

Coral reef ecosystems worldwide are rapidly changing due to a host of natural and anthropogenic ecological pressures including climate change, disease outbreaks such as stony coral tissue loss disease, and invasive species. This motivates taking comprehensive inventories of reefs as soon and as often as possible, enabling early and continuous detection of new threats with the goal of aiding conservation and restoration efforts. However, the size and number of the world’s reefs makes it infeasible to monitor them at sufficient spatiotemporal resolutions via only diver-based surveys and manual analysis. To help overcome this challenge, we present a novel vision based semantic perception algorithm on an Autonomous Underwater Vehicle (AUV) platform, capable of automatically constructing, in realtime, 3D reef models and maps that depict a reef’s benthic composition.

The innovative robot system consists of an Autonomous Surface Vehicle (ASV) and one or more AUVs, designed by our lab. These vehicles are small enough to be packed in airline baggage, making it feasible for a small team to deploy them anywhere at low-cost. The ASV provides realtime AUV monitoring and enables the AUVs to localize themselves precisely so that they can repeat identical reef surveys. The forward and downward facing stereo-camera systems on each AUV enable them to conduct concurrent benthic mapping, fish surveys, biodiversity assessments, and coral disease surveys. The stereo-imagery is converted into 3D models, enabling accurate size estimation of fish and corals as well as 3D modeling of entire reefs.

A key feature of our system is the automatic discovery of the “topics” used to label each 0.5 m^2 (adjustable) grid cell of the benthos, which we show can be mapped to ecologically relevant categories such as “hard coral”, “soft coral”, and “seagrass”. It accomplishes this using a novel unsupervised spatiotemporal topic modeling algorithm we developed. We compare the benthic composition reports generated by this algorithm to those produced by scientist divers at the same reef sites around the US Virgin Islands. Furthermore, the algorithm can flag novel or unusual observations; we explore the potential of using this capability to identify coral diseases and bleaching without training data. We also explore how our robots can be used in scientist-in-the-loop approaches to guide targeted scientific analysis, and how they will be augmented to enable bio-acoustic biodiversity monitoring.

7B - How can autonomous data-driven robotics be used to improve cost effectiveness and spatial/temporal scaling of reef assessments?

Oral
A-1225

GLUBS - A Global Library of Underwater Biological Sound

Parsons, M.[1], Lin, T.-H.[2], Mooney, A.[3], Erbe, C.[4], Juanes, F.[5], Lammers, M.[6], Li, S.[7], Linke, S.[8], Looby, A.[9], Nedelec, S.[10], Van Opzeeland, I.[11], Radford, C.[12], Rice, A.[13], Sayigh, L.[14], Stanley, J.[15], Urban, E.[16], Di Iorio, L.[17]
[1]Australia Institute of Marine Science, Perth, Australia
[2]Biodiversity Research Center, Academia Sinica, Taipei,, Taiwan
[3]Woods Hole Oceanographic Institution, Woods Hole, United States
[4]Curtin University, Centre for Marine Science and Technology, Perth, Australia
[5]University of Victoria, Department of Biology, Victoria, Canada
[6]Hawaiian Islands Humpback Whale National Marine Sanctuary, Kihei, United States
[7]Chinese Academy of Sciences, Marine Mammal and Marine Bioacoustics Laboratory, Institute of Deep-sea Science and Engineering, Sanya, China
[8]Commonwealth Scientific and Industrial Research Organisation, Dutton Park, Australia
[9]University of Florida, Fisheries and Aquatic Sciences, Gainesville, United States
[10]University of Exeter, College of Life and Environmental Sciences, Hatherly Laboratories, Exeter, United Kingdom
[11]Alfred-Wegener-Institute Helmholtz-Zentrum for Polar and Marine Research, Ocean Acoustics Lab, Bremerhaven, Germany
[12]University of Auckland, Leigh Marine Laboratory, Warkworth, New Zealand
[13]Cornell University, K. Lisa Yang Center for Conservation Bioacoustics, Cornell Lab of Ornithology, Ithaca, United States
[14]Hampshire College, Amherst, United States
[15]University of Waikato, Coastal Marine Field Station, School of Science, Tauranga, New Zealand
[16]University of Delaware, Scientific Committee on Oceanic Research, Newark, United States
[17]Université de Perpignan Via Domitia, Centre de Formation et de Recherche sur les Environnements Méditerranéens,, Perpignan, France

m.parsons[at]aims.gov.au

Abstract

The underwater world is a cacophonous place, filled with biological, anthropogenic and geophysical sounds, from a multitude of sources. Monitoring the presence, abundance and characteristics of species-specific calls through time and space can assist in delineating spatio-temporal patterns in distribution and behaviours of source species, for management purposes. In addition, the acoustic characteristics of the soundscape (e.g., acoustic complexity, acoustics richness, biological sound levels) provide information on the local ecosystem type and condition. As underwater environments have changed in response to climate change and anthropogenic pressures (e.g., fishing, noise), and biodiversity is in decline worldwide, it is important to collate these sounds on a global scale, potentially before they disappear. A significant step towards achieving this is the development of a web-based, open-access platform that can provide a reference library of underwater biological sounds, a depository for audio data, an artificial intelligence database and training platform, species distribution maps based on sound, and a citizen science application. We will discuss some existing applications of these elements, previous calls for reference libraries and global data-sharing of acoustic data, the challenges to realising such a platform, and a conceptual framework of how the applications can come together, as a starting point to developing this integrated library.

Oral
A-1979

Using TagLab, a semi-automatic annotation tool for fast and accurate analysis of benthic species

Pavoni, G.[1], Corsini, M.[1], Pedersen, N.[2], Edwards, C.[2], Sandin, S.[2], Cignoni, P.[1]
[1]Visual Computing Lab, ISTI-CNR, Pisa, Italy
[2]Scripps Institution of Oceanography, UC San Diego, La Jolla, CA, United States

gaia.pavoni[at]isti.cnr.it

Abstract

Autonomous data-driven robotics for acquiring underwater data is making large-scale underwater imaging increasingly popular, and tools to efficiently process and understand demographic changes and spatial dynamics of coral reef communities are strongly needed. However, if we consider that even traditional acquisition techniques have resulted in the creation of thousands of orthorectified imagery, each capturing hundreds to thousands of coral colonies, we can easily forecast that handling such streams of acquired data is hard to be sustained. Further, the existing manual workflows used to generate highly accurate and precise segmentation for fine-scale colony mapping are time-intensive (~1 hour per m2), creating substantial bottlenecks to downstream analyses. While fully automated semantic segmentation can significantly reduce processing time, current solutions do not yet meet the level of accuracy attained by expert human operators. Further, to capture colony-specific growth, shrinkage, and death, there is a need to create automated and semi-automated tools to track individual corals through time. Here, we present our experience of using TagLab, a human-centric AI interactive open-source system for the semantic segmentation of benthic orthoimages. TagLab guides coral reef scientists through a step-by-step automatic recognition model tuning. First, it integrates two interactive segmentation CNNs that significantly reduce manual annotation times, facilitating the production of extensive training datasets. Second, it offers a pipeline for training automatic semantic segmentation models using custom dictionaries of labels. Finally, following a human-in-the-loop paradigm, it provides several tools for inferring and editing per-pixel predictions, allowing users to overcome the accuracy limitations of standard machine learning methods. TagLab supports the comparison of time-series surveys by automatizing demographic information extraction and offering tools for the automatic/supervised tracking of colonies. Additionally, TagLab has been designed to interact with GIS software and offers a highly customizable annotation experience. By reducing the time required for ecological post-processing of coral reef imagery, TagLab enables researchers to process increasingly large volumes of data without increasing the needed person time and ultimately facilitate a greater capacity to understand and predict future changes to coral reef ecosystems.

Oral
A-1208

Machine learning and UAS remote sensing: using novel technologies for rapid classification and monitoring of coral reefs structure

Suan, A., Franceschini, S., Madin, E.
University of Hawaii Manoa, Hawaii Institute of Marine Biology, Kaneohe, United States

aviv[at]hawaii.edu

Abstract

Coral reef ecosystems hold important biological, ecological, and economic value but are in widespread decline due to a combination of global and local stressors. Effective coral reef management hinges on efficient, affordable, and targeted monitoring. However, current in situ methods are expensive and have inherent weaknesses in terms of time, space, and scale. Here we showcase an integrated approach using aerial surveys from unmanned aircraft vehicles coupled with deep learning algorithms to monitor structural and compositional changes of patch reefs in Kāneʻohe Bay, Hawai'i. Orthophotographs of entire patch reefs were generated from survey data, with a mean ground sampling distance (GSD) of 2 cm. Using ArcGIS and Convolutional Neural Networks, the classification algorithm automates coral species annotation at the pixel level allowing for rapid assessment and high-fidelity mapping of substrate composition. Specifically, six key substrate types (*Porites compressa*, *Montipora capitata*, bleached coral, dead coral, algae, and sand) were classified on high resolution orthomosaics. Using in situ georeferenced transect sampling, we compared the ground truth data to the classification results for model accuracy validation. This approach will provide a powerful and efficient way of quickly assessing changes in reef extent and species composition in this region into the future, thus allowing for more rapid scientific and management responses when such events occur.

Poster
A-1866

An accurate and highly maneuverable autonomous visual survey platform for coral reef mapping

Gutnik, Y., Avni, A., Treibitz, T., Groper, M.
University of Haifa, The Hatter Department of Marine Technologies, Haifa, Israel

yevgenigutnik[at]gmail.com

Abstract

Visual surveys of the seafloor are extensively employed in underwater research and in particular in mapping of coral reefs. Moreover, recently developed methods allow the generation of accurate high resolution and color 3D reconstructions of the reefs. The underwater medium, however, presents significant challenges to imaging systems mainly due to the rapid light attenuation and high backscattering limit the altitude and the area covered by each image to a few meters. Consequently, in order to map large areas, a set of images along transects must be collected and stitched into photo mosaics. This method however requires an image set with sufficient overlap between adjacent images and homogeneous optical conditions.
Autonomous underwater vehicles (AUVs) are untethered and self-controlled vehicles. Their capability of freely maneuvering at low altitude above the seabed make them an effective tool for underwater mapping missions. However, achieving a stable and steady motion as required for visual mapping is challenging, in particular when operating a small AUV in the complex environment of coral reefs. To accomplish this, the AUV is required to possess a high degree of maneuverability and precise motion control.
In the present work we describe the adaptation of a small in size AUV (SPARUS II) into a vehicle capable of performing visual surveys in complex environment. In the frame of this work a special imaging payload was developed in house to fit the dimensions of the AUV. The payload consist a stereo camera pair in a compact pressure-resistant housing and two high-power LED strobes. The imaging system is able to acquire high resolution images with depth information at low light scenes from an altitude of about 2 meters above the seabed.
To facilitate stable and accurate motion along the imaging transects, the AUVs motion control was extended with two lateral thrusters. An intelligent thruster allocation method was implemented to optimally assign the required control forces to the new thruster configuration and minimize undesired motion, created by the AUV's coupled dynamics.
The AUV's path following controller was upgraded with sway motion control to provide accurate path following along the imaging transects in presence of currents.
The project resulted in an excellent underwater platform capable of performing autonomous visual surveys of coral reefs up to 200 meters depth.

Poster
A-1016

Autonomous real-time environmental data: an acoustic key to spatio-temporal assessments of reefs?

Steckenreuter, A.
Innovasea, Köln, Germany

andre.steckenreuter[at]innovasea.com

Abstract

Underwater acoustics are a well-established tool that have been used around the world for more than three decades to get an understanding of the spatio-temporal movements and associated behaviour of a wide range of aquatic animals. However, new emerging technologies in this sector are constantly being developed that allow for new research applications and designs. Two examples of these new technologies are (1) autonomous sensors that provide real-time data of environmental factors such as temperature, dissolved oxygen, salinity, turbidity, chlorophyll, etc. and (2) predation tags that can indicate if an aquatic organism has been ingested by a predator.
Applied real-time systems may consist of various underwater sensors, acoustic predation tags on aquatic animals, a surface hub that receives data from the sensors as well as from the tags, and a cloud-centric database. Data access is available via a mobile phone or laptop that provide real-time notifications when tagged animals are near receivers or of the current state of environmental variables. Additionally, the analyses of predation events on different trophic levels within the reef ecosystem may provide insights into its health and vulnerability in response to climate change and other (anthropogenic) pressures.
Such systems are now in use at several global installations, e.g. to monitor aquaculture systems or ecosystems where predator-prey relations are investigated. We propose that these real-time applications may play a key role in assessing and scaling the spatio-temporal regimes of reef systems in order to address timely conservation and management measures. Here, we will explore the evolution of underwater acoustics, how new sensors relaying data in real-time, and the new predation tag technology will help sustain our ocean ecosystems.

Virtual
Poster
A-1886

Submeter 3D ridge-to-reef classification using a WorldView-3 satellite stereoimagery

Collin, A.[1, 2], Andel, M.[3], Lecchini, D.[2, 4], Palola, P.[5], Wedding, L.[5]
[1]PSL University / EPHE, Coastal GeoEcological Lab, Dinard, France
[2]Labex CORAIL, Perpignan, France
[3]Maxar Foundation, Westminster, United States
[4]PSL University / EPHE, CRIOBE, Perpignan, France
[5]University of Oxford / School of Geography and the Environment, Seascape Ecology Lab, Oxford, United Kingdom

antoine.collin[at]ephe.sorbonne.fr

Abstract

Coral reef remote sensing has known significant advances over the last two decades by providing temperature, salinity, inherent optical properties at large scale, classifying geomorphic features at medium scale, and mapping bathymetry as well as benthic cover at fine scale. The latter scale enables the coral colony (unit of the reefscape) to be captured. Satellite remote sensing of clear and shallow waters outperforms diver-based surveys about the spatial extent and continuity.
Previously-criticized by its coarse grain, some satellite imagery can provide very high resolution (VHR) information below 0.5 m. In addition, the state-of-the-science multispectral WorldView-2 and -3 imageries leverage five visible and three near-infrared bands, allowing both bathymetry estimation and benthic classification to be improved. Despite the knowledge that the reef health depends on the oceanward drivers but also on the landward influence, a few VHR mapping studies have focused on the comprehensive picture of the ridge-to-reefscape spatial patterns. Nevertheless, the influence of
the watershed, intimately linked with its relief, is strongly lacking from common reefscape studies.
We propose here to build the first 3D habitat mapping of land-lagoon use and cover at VHR based on a stereoimagery. The steep Moorea Island (French Polynesia), provided with various reefs, is a prime candidate for this investigation. The topography is retrieved from the stereo-photogrammetry applied to panchromatic bands, calibrated by ground control points, and validated by topographic LiDAR data. The bathymetry is modelled using the ratio transform applied to the five visible WorldView-3 dataset, calibrated by open-source hydrographic soundings, and validated by bathymetric LiDAR (Light Detection and Ranging) data. VHR topobathymetry is then created as the by-products are spatially reconciled on the chart datum. The image classification, applied to the eight pansharpened bands, is run from ridge-to-reef (spanning forest, agriculture, urban, coral, algae and sediment classes), calibrated and validated by consumer-grade airborne drone imagery. We advocate that this 3D structural modelling of the landscape to seascape at VHR, based on a satellite steroimagery, will enable stakeholders to evaluate sustainable management scenarios with an integrated vision of ridge to reef connectivity.

Virtual Poster
A-2239

Developing a new technology for monitoring corals utilizing remote sensing and evolving advanced AI classification of coral

Fuji-ie, W.[1], Komatsu, T.[1], Yonezawa, Y.[1], Asada, N.[1], Lin, Y.[1], Kanyama, T.[2], Nakase, S.[3], Yamazaki, M.[3]
[1]KOKUSAI KOGYO CO., LTD., Tokyo, Japan
[2]Fisheries Infrastructure Development Center, Tokyo, Japan
[3]Ministry of Agriculture, Forestry and Fisheries, Tokyo, Japan

wataru_fujiie[at]kk-grp.jp

Abstract

Until recently, line surveying, complemented by spot surveying, was carried out by divers to observe and study the growth, death and decay of corals in the sea. Moreover, image-processing technologies using satellite images has been utilized to measure the area covered by corals at the largest scales, from several kilometers to tens of kilometers. However, for creating artificial reefs on a large scale of several hectares and continuously measuring their coral coverage with
high accuracy, diver surveying requires a great amount of effort and time, and detailed coral data cannot be obtained by the
interpretation of satellite imagery. Moreover, on remote islands such as frequent and duration is limited due the conditions of the sea and other factors - a method to measure the coral coverage in a short period of time is required. In response to this, we are engaging in aerial and underwater photography and filming the whole area of the coral reefs using drones and underwater video cameras, with the aim of evolving a sophisticated technology for measuring coral coverage. In terms
of work efficiency, both methods have greatly improved compared to the surveys done by divers. On the other hand in terms of data accuracy, it is a fact that drone aerial images, which show the topography of the coral reefs with high-resolution, including their complex forms and large undulate surfaces, allow the measurement of coral reef distribution with higher accuracy than those of satellite images. Additionally the high-resolution underwater photography taken by underwater
video allowed us to create orthoimages for each individual coral colonies, which can identify coral colonies. Therefore we also could have done utilizing these images for the deep learning method of the AI model, and classifying each object including coral colonies by dividing them into classes, and by applying the Instance Segmentation Method to extract each area of the objects. The overall accuracy of the classification of five categories, several corals and non-coral, was about 90% utilizing these methods. However, at present the classification accuracy of an individual coral colonies, such as Acropora and Porites, is low due to insufficient learning data on coral colonies. We will keep collecting more data by taking underwater photographs of coral reefs to increase the amount of learning data and improve the accuracy of coral classification.

Session 7C - How can new imaging-based tools help us better understand corals and other reef organisms?

Conceptualized by: **Philippe Laissue** [1], **Nils Rädecker** [2]
[1] University of Essex (Colchester, UK)
[2] École Polytechnique Fédérale de Lausanne (EPFL) (Lausanne, Switzerland)

Chaired by: **Nils Rädecker** [1], **Guoxin Cui** [2]
[1] École Polytechnique Fédérale de Lausanne (EPFL) (Lausanne, Switzerland)
[2] King Abdullah University of Science and Technology (Thuwal, Saudi Arabia)

Oral
A-1947

Quantifying skeletal extension rates of Montastrea annularis and Montastrea faveolata using large-area imagery on reef communities in Curacao

Alcantar, E.[1], Pedersen, N.[2], Edwards, C.[2], Petrovic, V.[3], Sandin, S.[2], Vermeij, M.[4]
[1]Institute for Biodiversity and Ecosystem Dynamics, University of Amsterdam, Amsterdam, Netherlands
[2]Scripps Institution of Oceanography, UC San Diego, La Jolla, United States
[3]California Institute for Telecommunications and Information Technology, UC San Diego, La Jolla, United States
[4]Caribbean Research and Management of Biodiversity, Willemstad, Curaçao

esme_alcantar[at]ymail.com

Abstract

Montastrea annularis and *Montastrea faveolate are* one of the most abundant and important reef-building corals in the Caribbean. Studies of *M. annularis* and *M. faveolata* skeletal extension rates offer insight into past, present, and future stress factors that affect coral cover. This skeletal growth rate has been successfully measured with procedures that involve either coring, capturing photo-transects, or inserting a stainless-steel nail. In coring, the extracted core is sliced and X-radiographed. Though accurate, this process results in damage to coral colonies. Photo-transects provide photos of suitable resolution with consistent area cover, 2 critical factors for observing changes over time. A third technique places a stainless-steel nail or pin on the main growth axis, acting as a growth monitor. In this study we measure average skeletal growth, geometric growth, and coral colony size by merging elements of previous methods into our powerful field-reconstruction imagery. Our innovative technology, *Viscore*, has allowed us to create 3-dimensional time-series for 9 sites, across 6 annual sampling intervals (2014-2020) from the island of Curacao. By combining thousands of photos to generate complex, large-area 3-D models, *Viscore* allows for creative freedom in data analysis. From our measurements, the average skeletal growth was consistent throughout each colony sample, as well as coral colony size, suggesting no significant colony-specific differences. The geometric growth showed a slight variation in rates, with a higher increase in horizontal growth compared to vertical growth, supporting the theory of corals striving for lager surface area. Modern image-based technology, like *Viscore,* has efficiently improved coral reef monitoring techniques and facilitated data quantifications, while achieving the same objectives as previous research techniques.

Oral
A-1421

Exploring artificial intelligence (AI) tools on coral photographic data from the Tara-Pacific Expedition

Clampitt, M.[1, 2], Milanesio, M.[3, 4], Tara Pacific Consortium[5], Tara Pacific Coordinators[5], McMinds, R.[1], Röttinger, E.[1, 2], Gilson, E.[1, 2]
[1]Université Côte d'Azur, CNRS, INSERM - Institute for Research on Cancer and Aging, Nice, France
[2]Université Côte d'Azur - Institut Fédératif de Recherche – Ressources Marines (IFR MARRES), Nice, France
[3]Université Côte Azur – Maison de la Modélisation, de la Simulation et des Interactions (MSI), Nice, France
[4]INRIA, Equipe Epione, Sophia Antipolis, France
[5]Fondation Tara Océan, Paris, France

megan.clampitt[at]univ-cotedazur.fr

Abstract

During the two and a half year-long Tara-Pacific expedition, the schooner Tara collected three coral genera, Pocillopora sp., Porites sp., and Millepora sp. across 32 island systems of the Pacific Ocean for a nearly exhaustive morpho-molecular inventory. The 11,000 photographs of the sampled colonies were analyzed in a semi-automated, randomized, and blind process, to extract information on each coral colony as well as its surrounding environment. The variables extracted were related to identification, algal contact, sediment contact, predation, presence of boring organisms, and health information such as coloration or presence of disease. These annotations were very time-consuming, taking approximately 4 months to complete. Currently, we are investigating the use of deep learning to create a preliminary monitoring tool capable of automating the annotations. For the classification of genera and coloration, we reached 80% accuracy on the validation set by exploiting transfer learning. We are currently working on the extension of this model to recognize and automatically label all other annotation categories, such as algal contact, sediment contact or predation.

Oral
A-1676

Optical Coherence Tomography (OCT) as a novel tool to study structural and optical properties of corals and other aquatic symbioses

Kuhl, M.[1], Lyndby, N.[2], Murthy, S.[1], Jacques, S.[3], Jaffe, J. S.[4], Wangpraseurt, D.[5]
[1]University of Copenhagen, Department of Biology, Helsingoer, Denmark
[2]EPFL, Laboratory for Biological Geochemistry, Lausanne, Switzerland
[3]University of Washington, Seattle, United States
[4]Scripps Institution of Oceanography, La Jolla, United States
[5]University of California San Diego, La Jolla, United States

mkuhl[at]bio.ku.dk

Abstract

Corals exhibit a great diversity in tissue plasticity and skeleton structure, which has strong implications for their solute exchange, light harvesting and radiative heating. Yet, it remains difficult to monitor coral tissue and skeleton structure non-invasively and dynamically on intact living corals. We have introduced the use of optical coherence tomography (OCT) as a novel tool in aquatic symbiosis research. OCT employs near-infrared radiation (NIR, typically at specific wavelengths >800 nm) to probe the distribution of directly backscattered photons at refractive index mismatches in coral tissue and skeleton. As NIR does not interact with coral function or behavior, it enables non-invasive monitoring in both dark and light conditions for prolonged observation of corals (and other symbioses like the upside-down jellyfish *Cassiopea*) e.g. in flow chambers, and it can be used in concert with other methods like microsensor analyses of light, temperature and chemical microenvironments. Furthermore, as OCT is mapping the distribution of scattered light it is possible to extract and map the underlying optical parameters such as the tissue or skeleton scattering coefficient to particular tissue/skeleton compartments.
In this presentation, we briefly introduce the principles of OCT imaging and then demonstrate how OCT can be used to i) identify particular structures in living corals and photosymbiotic jellyfish, ii) map coral movement such as tissue expansion and contraction, and iii) characterize the consequences of tissue plasticity for coral light propagation (e.g. by changing the distribution of GFP-like host pigments). Furthermore, such OCT data can also be used for detailed quantification of coral tissue surface area on live corals at high spatio-temporal resolution, and we demonstrate how this important normalization parameter in coral ecophysiology can change dynamically during experimental incubation.

Oral
A-1093

Developing a cloud-based pipeline for the automated creation, storage, and AI-driven analysis of large-scale coral restoration photomosaics

Neufeld, A., Moura, A., Winters, R. S.
Coral Restoration Foundation, Tavernier, United States

alex[at]coralrestoration.org

Abstract

Around the world, accelerating coral reef decline has spurred the rapid growth of coral restoration programs seeking to restore coral reefs by outplanting colonies onto degraded sites. While restoration programs have upscaled their workforces and their annual coral output, monitoring efforts that seek to assess the efficacy of this work have remained comparatively inefficient. Not only are standard in-water monitoring efforts time-intensive, but most traditional coral monitoring metrics fail to address key questions surrounding the efficacy of restoration efforts that have transitioned from individual-based to population-based approaches.

Coral Restoration Foundation (CRF) has developed and implemented a monitoring technique that relies on large-scale, high resolution reefscape imagery (orthomosaics) to digitally assess the impacts of 30,000+ annual coral outplants in the Florida Keys. However, even this approach to large-scale coral restoration monitoring has limitations. Namely, the creation of such large images often requires either a level of computing power that is impractical for standalone restoration organizations or such lengthy processing times on commercially available machines that the process is rendered inefficient. Furthermore, corals in the mosaics must still be recognized and measured by an expert evaluating the imagery. Thus, data acquisition has shifted from in-water to on-land but is still labor intensive and subject to the expertise of the evaluator.

To integrate solutions to both of these problems, CRF has created an all-in-one, online platform. This pipeline is capable of ingesting and storing raw imagery, stitching complete orthomosaics, and cataloging data according to user-defined metadata tags. This process, which uses virtual machines, significantly reduces the time needed to stitch orthomosaics, while also housing imagery and data in a secure cloud storage system. Additionally, we have developed artificial intelligence models that, are capable of accurately recognizing and measuring *Acropora spp.* individuals. These models can “analyze” the stitched orthomosaics as they are produced by the pipeline to automatically generate coral size and growth metrics for the identified corals.

Here, we present these described capabilities of the pipeline, as well as our plans for opening access to the platform to the broader coral monitoring community and for incorporating identification of different coral species to the pipeline’s processes.

Oral
A-1319

Combining structure motion (SfM) photogrammetric techniques with low-cost Hyperspectral imagers as a tool for assessing coral reef 'health'

Teague, J.[1], Megson-Smith, D.[1], Allen, M. J.[2], Day, J. C.[1], Scott, T. B.[1]
[1]University of Bristol, School of Physics, Bristol, United Kingdom
[2]University of Exeter, College of Life and Environmental Sciences, Exeter, United Kingdom

jt16874[at]bristol.ac.uk

Abstract

A significant marine impact of anthropogenic climate change has been the increasing prevalence of bleaching events on coral reefs. There is a pressing requirement for new monitoring techniques and methodologies to monitor these invaluable ecosystems. Non-destructive techniques which can gather higher definition information are hugely advantageous over the traditional in-situ, image-based techniques currently utilised.

Underwater Hyperspectral imaging (UHI) can reveal information about marine environments including but not limited to habitat mapping and monitoring. Hyperspectral imaging has the ability to detect minute colour changes in marine organisms such as corals and colour change metrics can be used to assess and monitor 'health'.

Due to the advances in new optical technologies, namely the development of linear variable filters (LVF) for hyperspectral applications, low-cost imagers can be developed at a fraction of the cost of traditional systems. Here we present a modified digital single lens reflex (DSLR) camera equipped with an LVF, capable of providing spectral data comparable to commercial imagers. With the cost of a commercial hyperspectral system varying from £25,000 to £120,000, LVF-DSLR imagers can be made for ~£5,000. The availability of low-cost imagers makes the technology more widely accessible for marine applications where previously the high financial cost as well as the inherent financial risk of submerging equipment was prohibitive.

Due to the reconstruction method utilised by the LVF-DSLR, 3D information is also recovered via structure from motion (SfM) photogrammetry from the dataset enabling for additional topological measurements of the marine ecosystem to be derived. From one dataset on a coral reef, the operator would be able to ascertain, from 3D data, the reef rugosity, species zonation/distribution as well as spectral data revealing pigment concentrations of corals and even fluorescence data (under UV light). These imagers can also supplement and verify (at high spatial resolution) hyperspectral measurements made by satellite/airborne systems which are capable of imaging large areas but only at relatively low spatial resolution. Where any imaging performed above the water's surface requires correction algorithms to account for the attenuation of light through the atmosphere and the water, by deploying an imager underwater the 'true' spectrum can be directly measured and this can be used to validate the correction algorithms

Oral
A-1135

Turning microplastics into microscopic lasers - Hyperspectral imaging of whispering gallery mode lasers to study microplastics in reef building corals

Titze, V. M.[1], Schubert, M.[1, 2], Gather, M. C.[1, 2]
[1]University of St. Andrews, School of Physics and Astronomy, St. Andrews, United Kingdom
[2]Humboldt Centre for Nano- and Biophotonics, University of Cologne, Cologne, Germany

vmt1[at]st-andrews.ac.uk

Abstract

The increasing abundance of microplastics in the oceans highlights the need for a better understanding of their effects on marine organisms like reef building corals. Microplastic particles may be mistaken for prey due to their comparable size and density, or prey may already contain microplastics. Studies of microplastic ingestion often rely on histology to characterize the distribution, position, and nature of ingested plastics. This is invasive and thus does not allow to track the long-term fate of microplastics in live animals, or to study how they continue to move through colonies, or even food chains.
Non-invasive, all-optical methods based on fluorescent microscopy are emerging as exciting alternatives to study coral anatomy and health. However, their potential to track and characterize individual ingested microplastics *in vivo* has not yet been exploited due to limitations including the number of individual microplastic particles that can be tracked, and the depth at which they can be followed. Here, we propose to mimic microplastics with fluorescent polymer beads that can act as microscopic lasers. We develop a hyperspectral confocal laser scanning microscope, which can optically pump the polymer beads to turn them into local, biointegrated sources of laser emission. Importantly, each bead has a unique emission spectrum, which can be used as an optical 'barcode,' allowing it to be re-identified among hundreds of others. This enables long-term tracking of individual plastic beads, which could be used to barcode different groups of plastics and to study transport of microplastics within corals. The emission spectra of our plastic lasers show a series of sharp peaks corresponding to "whispering gallery modes", and these depend on two key parameters: the size of the bead, and the optical properties of the environment. The former allows to determine the bead radius with nanometre precision, even when submerged in scattering media such as coral tissue. The latter allows their use as real-time remote micro- and nanoscale sensors. Through this sensing mechanism, changes in the coral tissue around an internalized plastic bead can be monitored. In the future, this might allow to study in a non-invasive manner how processes like tissue necrosis or calcification are involved in the integration of microplastics into the coral skeleton and could thus extend our understanding of the interaction between coral reefs and microplastics to new length- and timescales.

Oral
A-1826

Extracting Novel Ecological Information from Image-Based 3-Dimensional Models of Coral Reefs Before and After an Extreme Weathr Event

Yuval, M.[1, 2], Pearl, N.[1], Tchernov, D.[3], Loya, Y.[4], Bar-Massada, A.[5], Treibitz, T.[1]
[1]Viseaon Marine Imaging Lab, University of Haifa, Haifa, Israel
[2]Inter-University Institute for Marine Sciences in Eilat, Eilat, Israel
[3]Morris Kahn Marine Research Station, University of Haifa, Haifa, Israel
[4]School of Zoology, Tel Aviv University, Tel-Aviv, Israel, [5]Oranim Spatial Ecology Lab, University of Haifa, Haifa, Israel

mtnyvl[at]gmail.com

Abstract

Coral reefs are some of the most important ecosystems on the planet. Not only do they provide essential habitat for other reef organisms, but also shoreline protection, resources, and employment. Nevertheless, ecological systems are complex and open, deeming them extremely challenging to study across spatial and temporal scales. Accelerations in information technologies have facilitated the emergence of photogrammetry as a superior method for coral reef surveys and 3-Dimensional (3D) mapping, enabling the production of wide-scale photorealistic models in a cost effective manner. Although photogrammetry provides a unique opportunity to depict both the biological diversity and structural complexity of coral reefs, much work remains on extracting the ecological information concealed in the 3D models. Meaningful annotation and structural complexity analysis are the most important aspects of data-extraction. However, there are hardly any specific tools at the moment for these tasks. We have developed a methodology for 3D reef mapping that includes taxonomic classification as well as geometrical analysis of the full reef structure. Our dataset includes coral reef models from the Red-Sea, the Eastern-Caribbean, and the Eastern-Pacific regions, with repeated surveys in the Red-Sea following an extreme weather event. Structural complexity is one of the most important features of coral reefs because it is often related with biological diversity and ecosystem functions through positive feedback mechanisms. Our approach can serve as a proxy for reef-health, enabling us to ask questions such as what is the relation between biodiversity and structural complexity, and what are the consequences of an extreme weather event on coral reef structures? Altogether, we conduct high-resolution spatial and temporal comparisons that enhance our understanding of coral reef community-structure, resilience, and response to climate-change.

Poster
A-1578

Abundance variability of reef microborers communities in a slow-growing massive coral over the last 50 years: Innovative machine learning application

Alaguarda, D.[1], Tribollet, A.[1], Coulibaly, G.[2], Canesi, M.[2], Douville, E.[2], Simon, A.-C.[2], Agelou, M.[2], LeCornec, F.[1], Lelabousse, C.[3], Brajard, J.[4]
[1]Laboratoire LOCEAN-IPSL, Sorbonne Université-IRD-CNRS-MNHN, Paris, France
[2]Laboratoire LSCE-IPSL (CEA-CNRS-UVSQ), Université Paris-Saclay, Paris, France
[3]National Marine Park Authority of Mayotte, Pamandzi, French Southern Territories
[4]Nansen Environmental and Remote Sensing Center (NERSC), Jahnebakken, Bergen, Norway

diego.alaguarda[at]yahoo.fr

Abstract

Coral reefs are increasingly degraded due to global changes that affect both reef accretion and bioerosion processes. Among those latter processes, microbioerosion, also called biogenic dissolution which is mainly driven by the chlorophyte *Ostreobium* sp., plays a major role in reef carbonate budget. The dynamics of this process in dead reef carbonates under various environmental factors such as ocean acidification, hypersedimentation, and eutrophication begin to be relatively well understood over short term (month to year scale). In contrast, the long-term effects of environmental factors on microboring communities and their erosive activity remain poorly known, limiting predictions of coral reef fate by 2100. Massive coral colonies are great bio-carbonate archives recording environmental conditions over decades and are known to be colonized by microboring flora which can form eye visible green bands. Massive corals offer the opportunity to study the long-term effects of environmental changes on microboring communities and understand the possible implication of green bands in coral resilience. Here we studied microboring communities in a core of the massive coral*Diploastrea* sp. collected on the barrier reef of Mayotte and covering the last 50 years (1964-2018). The abundance of microborers galleries was estimated based on an innovative machine learning approach that we developed allowing the rapid analysis of hundreds of images obtained by scanning electronic microscopy taken along the coral core with an accuracy of 93%. Our results showed that a shift in microboring community composition occurred in 1985 with a community dominated by a mix of large and thin galleries before this breakpoint and a community mainly dominated by thin galleries after the breakpoint. We strongly suggest that this community shift resulted from a major marine heat wave around 1985, together with the rise of sea surface temperature (SST), positive SST anomalies (SSTA) and max instant wind speed, selecting the most adapted microboring species to those new environmental conditions. This shift had a major impact on the overall surface area colonized by microborers as it decreased by 91% over the last 50 years. Those trends are discussed here in the light of historical temperature change, temperature anomalies, precipitation rate, insolation period, max speed wind and coral growth variables to highlight the possible main drivers influencing microborer abundance in massive corals.

Poster
A-1573

Change in Coral Recruitment Densities Pre- and Post-Bleaching Event in Ant Atoll

Cacapit, A., Sandin, S.
University of California San Diego, Scripps Institution of Oceanography, San Diego, United States

acacapit[at]ucsd.edu

Abstract

Metrics for coral reef recovery have been investigated following disturbance events to consider potential pathways of recovery to baseline conditions. Percent coral cover is a common assessment tool used in many such studies, reporting just average benthic composition. However, such summary metrics do not offer explicit views of underlying mechanisms like regrowth and recruitment. Recruitment, the establishment of new individuals, provides existing reefs with gene flow from sexual reproduction. Genetic influx from these recruits may promote recovery both by increasing population size and by shifting community composition through introduction of different life histories from established corals that are undergoing current environmental stressors. Recruitment has typically been studied through experimental manipulation such as substrate preference through tiles, with limited in-situ studies. Emerging technologies now allow researchers to create digital surrogates of coral reefs from which detailed demographic information, including recruitment estimates, can be extracted through space and time. Here, we determined recruitment densities in silico at six sites across 2014, 2016, and 2018, spanning an extreme warm water and associated coral bleaching event in Ant Atoll. At each site, five $10m^2$ plots were randomly selected from the $100m^2$ orthoprojection. All recruits <5 cm in each plot were recorded and categorized into three major functional groups: branching, encrusting, and massive. Percent benthic cover was determined using 30 photo quadrats over two 25m transects at each site. Overall percent coral cover at Ant decreased during the following two time periods while CCA cover increased. Despite lower coral cover in years following the thermal event, we documented a dramatic increase in the densities of recruits, with the highest average of branching taxa like Acropora. These results show an increased proportional composition among these early life history individuals relative to adult coral cover composition from 2014.

Poster
A-1424

Using drone imagery to look at fish territories in the Red Sea

Campbell, C.
Kaust, Thuwal, Saudi Arabia

colleen.campbell[at]kaust.edu.sa

Abstract

Algae is very important to the health of the coral reef system. In the Red Sea there are over 500 species of algae, with many species beneficial to coral reef health. Many fish feed on algae and use it as breeding territories. The spread of some kinds of turf algae can be an indicator of a decline in coral health and early intervention could help save the reef before too much coral is lost.
Surgeonfish (Acanthuridae) are one of the species that use algae as a territory. They are medium-sized species ranging from approximately 9cm-38cm. Surgeonfish can be found at the top of the reef and are herbivorous using the algae as a feeding area. Looking at drone imagery we are able to see the boundaries of these territories giving insight into the size, shape, and other parameters that might make these areas hospitable for the fish to live.
Even though they are vital to the coral reef system, algae patches and fish territories are difficult to determine the extent with in situ surveys. Furthermore, monitoring using satellite images can be limited by both resolution and the near-total absorption of the Near Infrared (NIR) wavelengths by water. Drone imagery is an accessible way to monitor the size and change of algal growth and species interactions on a regular basis. This project combines drone imagery and field observations to examine the interaction between algae and fish territories on coral reefs in Saudi Arabia.

Poster
A-1466

Sedimentary characterisation of turbid-water reef environments using a novel Artificial Intelligence-based approach

Collins, T.[1, 2], Santodomingo, N.[2], Harrison, W.[3], Johnson, K.[2], Renema, W.[3], Rosedy, A.[4]
[1]Imperial College London, Department of Earth Science and Engineering, London, United Kingdom
[2]Natural History Museum, Department of Earth Sciences, London, United Kingdom
[3]Naturalis Biodiversity Centre, Leiden, Netherlands
[4]Borneo Marine Research Institute, Universiti Malaysia Sabah, Sabah, Malaysia

teigan.collins18[at]imperial.ac.uk

Abstract

Turbid-water environments have been recognised as potential refugia for corals, with the ability to provide long-term mitigation from unfavourable conditions. As globally important ecosystems, it is important to understand how resilient coral reefs may be to the threats of changing climate and oceans. Two contrasting reef settings in Darvel Bay, Malaysia, Blue Lagoon (clear-water) and Sakar North (turbid-water), were analysed for differences in their sediment compositions in samples collected at 10 m depth. Artificial Intelligence and machine learning were utilised to segment and classify grains from microscope camera imagery to analyse the proportions of grains. 7763 grains from 642 images were analysed in the AI development tool, where 7675 exceed 60% confidence in at least the coarsest label class. The greatest loss of confidence occurred between class 1 and class 2, in which 80.3% of grains could not be classified to a higher level. The segmentation task proves more successful than the classification task, which has lower accuracy and performance. However successful training of a working segmenter allows further classification projects to require less manual annotation. Regarding the environmental analyses, it was found that the clear-water reef sediments of Blue Lagoon were dominated by the autotrophs, coralline algae (38.35%) and symbiont-bearing foraminifera (30.64%), whereas heterotrophs such as molluscs were the dominant constituent of turbid-water reef sediments of Sakar North, accounting for 46.76%. Comparing user annotations of grains with output predictions of the AI model revealed the loss of bryozoan and coral grains in the sediment community when predictions were filtered to > 60% confidence. Different sediment size fractions within the same environment were tested in Blue Lagoon samples. There were no significant differences in composition, though there was a trend of higher abundance of foraminifera in the fraction 1.0 mm – 1.4 mm, whereas molluscs were more abundant in the 0.5 mm – 1.0 mm fraction. Further research should establish a more accurate classification model using a larger image dataset, with a focus on classes with ecological importance and high variability, e.g., foraminifera and molluscs, to further investigate trends in sediment composition in reef settings with varying environmental parameters and across different sediment size fractions.

Poster
A-1080

High-resolution visualization of the early settlement stages of Leptastrea purpurea reveals distinct bio-optical features

Fiegel, L. J.[1], Kellermann, M. Y.[1], Nietzer, S.[1], Petersen, L.-E.[1], Smykala, M. J.[1], Bickmeyer, U.[2], Schupp, P. J.[1, 3]
[1]University of Oldenburg, ICBM, Environmental Biochemistry, Wilhelmshaven, Germany
[2]Alfred Wegener Institute, Ecological Chemistry, Bremerhaven, Germany
[3]University of Oldenburg, HIFMB, Oldenburg, Germany

laura.fiegel[at]uni-oldenburg.de

Abstract

Sexually produced juvenile scleractinian corals play a key role in the adaptation process of coral reefs, as they are considered to possess an innate plasticity and thus are able to adjust to changing environmental parameters within a certain range. This advantage over their adult conspecifics could be crucial in the current climate crisis with estimated rising seawater temperatures. In recent years, some research groups made progress in understanding how to induce and control the complex settlement reaction of coral larvae by using isolated marine bacteria from crustose coralline algae (CCA) and their bioactive chemical compounds. However, to date there is still no detailed information on the recruit development after the initial settlement phase (first 48 hours) and high-resolution recordings of the larval transformation into fully developed juvenile corals are missing.

In this study, we investigated in detail the different stages and shifts during the early critical life phases of the brooding species *Leptastrea purpurea* to identify, categorize and evaluate the major steps of this complex transformation process. For that, we extended the monitoring time span up to 12 months and observed through bright field, fluorescence and confocal microscopy the distinct developmental patterns. While using different known (*i.e.,* cycloprodigiosin and CCA-chips) and yet unknown crude extract-based settlement cues, we aimed to describe the general developmental pathway of *L. purpurea*.

Our observations provoke the hypothesis that the ontogenetic shift of fluorescence patterns during larval settlement and recruit development might be connected to distinct functions in certain life stages of *L. purpurea* and likely in scleractinian corals in general. Since fluorescent proteins in corals have been reported to be associated to stress related reactions (*i.e.* antioxidants), our insights may enrich the current understanding of their role in early life stages and might help to further reveal their possibly multiple functions. In addition, our high-resolution picture series provides an early life stage template for breeding systems or field applications to instantly determine the growth state and health of a developing coral polyp.

Poster
A-1106

Tracking 3D size and shape changes in stony corals

Fundakowski, G.[1], Álvarez-Noriega, M.[2], Brambilla, V.[1], Edelaar, P.[3], Errington, A.[1], Fontoura, L.[4], Laland, K.[1], Madin, J.[5], Woods, R.[4], Zawada, K.[6], Dornelas, M.[1]
[1]University of St Andrews, Center for Biological Diversity, St Andrews, United Kingdom
[2]Monash University, School of Biological Sciences, Melbourne, Australia
[3]University Pablo de Olavide, Department of Molecular Biology and Biochemical Engineering, Sevilla, Spain
[4]Macquarie University, Department of Biological Sciences, Sydney, Australia
[5]University of Hawai'i at Mānoa, Hawai'i Institute of Marine Biology, Kāne'ohe, United States
[6]University of Technology Sydney, Centre for Compassionate Conservation, School of Life Sciences, Ultimo, Australia

gf64[at]st-andrews.ac.uk

Abstract

The 3D structure of corals is an important feature of coral reefs and is central to their ecological functioning. Understanding how this structure changes over time has implications for the reef communities the corals support, for the functions they provide (e.g. reef stabilization and habitat provision), and for understanding response to disturbance (e.g. bleaching and mechanical storm damage). Using colony-level photogrammetry, we build digital 3D reconstructions and extract nine morphological metrics that quantitatively describe the size (volume, surface area, and planar area) and shape (sphericity, convexity, fractal dimension, packing, and first moments of area and volume) of a coral colony. We follow these size and shape metrics over time to estimate growth rates, create phenotype development models, and quantify how morphological diversity arises on a reef. This presentation will illustrate a reproducible workflow using example colony time-series models from Lizard Island, Australia. We will discuss the morphological metrics and their ecological significance, and present results on the 3D growth and morphological development from an ongoing study.

Poster
A-1885

Hyperspectral monitoring of deep-water coral reefs exposed to drill cuttings

Hansen, I. M.[1], Baussant, T.[2], Bergsagel, Ø.[1], Mogstad, A. A.[3], Nilssen, I.[4], Frost, T. K.[4]
[1]Ecotone, Trondheim, Norway
[2]NORCE, Stavanger, Norway
[3]NTNU, Trondheim, Norway
[4]Equinor, Trondheim, Norway

ingrid[at]ecotone.com

Abstract

The reef building cold water coral Desmophyllum pertusum comprises an ecosystem with several ecological functions as they offer a three-dimensional habitat for other species. The vertical distribution ranges from tens to thousands of meters depth. It has a widespread geographic distribution and can be found at subsea oil and gas fields off the continental shelves.

During a sub-sea drilling event, drill cuttings may be deposited on the seafloor. Drill cuttings consists of solid ground rock from the drilling hole broken into smaller particles together with added fluids. There are concerns regarding the local environmental impacts of drill cuttings on habitats such as coral reefs. Hence, there is a need for thorough habitat mapping prior to and after a sub-sea drilling event in order to identify possible effects. However, field monitoring of corals is challenging due to great depths and a lack of integrative index to evaluate the in-situ coral condition.

An underwater hyperspectral imager utilizes high spectral resolution of the visible light reflected from objects on the seafloor for identification, mapping and monitoring. The reflectance spectrum of organisms is known as their optical signatures. The technology features a line camera and spectrograph integrated into a pressure housing installed on a ROV or other underwater vehicle with external light sources.

Time-lapse cameras are installed at specific locations, auto-recording the object of interest at frequent intervals over the course of time. Using specialized software, health end points such as polyp activity can be evaluated.

In this study, Desmophyllum pertusum corals are photographed using underwater hyperspectral imager and time-lapse camera in the lab. This is done prior to and after exposure to drill cuttings from a drilling operation. The work feature in-situ assessment at an offshore drilling location and laboratory studies. The spatial distribution of corals is reported together with changes in color, apperance and optical signatures.

We propose that this recent advantage in imaging technique can be an effective, objective and reliable tool for tomorrow's large scale monitoring of deep-water coral habitats located at drill sites.

Poster
A-1596

Occurrence and Distribution of Soft Corals of Northern Mozambique – Taxonomy, Habitat, and Threats

Nassongole, B.[1], Silva, I.[1], Ferreira, E.[2], Sola, E.[3], Malawene, B.[4], Santana, P.[4], Amoda, C.[4], Buhl-Mortensen, L.[5]
[1]Universidade Lúrio, Marine Ecology, Pemba, Mozambique
[2]Universidade Aveiro, Biology, Aveiro, Portugal
[3]Wildlife Conservation Society-Mozambique, Maputo, Mozambique
[4]Instituto Nacional de Investigação Pesqueira, Maputo, Mozambique
[5]Institute of Marine Research in Norway, Marine research in developing countries, Bergen, Norway

bibiananassongole1[at]gmail.com

Abstract

In the Western Indian Ocean (WIO) there is limited research on soft coral, and, as a result, coral fauna is among the least known. This study aims to determine distributions of soft coral species along the coast of northern Mozambique and identify key environmental factors shaping community structures and ultimately document the seabed habitats (substrate, fauna, and flora) in relation to the exposure to and effects of environmental contaminants. Data were collected on the research vessel Dr. Fridtjof Nansen in 2018 in the northern part of Mozambique between the Pemba Bay (13 ° S) and the border with Tanzania (10 ° 30´S), covering a large part of the Rovuma Basin. Images (videos and photos) were captured using a high-resolution camera equipped on the ROV (Remotely Operated Vehicle) coupled to VAMS (Video-assisted multi sampler). 37 stations were carried out, at depths ranging from 25 to 2000 m, based on the development plans for the oil and gas sector in the Rovuma Basin, and five stations were located in gas exploration wells. We found 56 species of soft corals at 31 stations. The results show that Tungue Bay (in the gas field) and Lazarus Bank are the sites with the highest diversity while the Pemba region is less diverse. A deep station located in gas exploration wells also showed low diversity. On the other hand, coastal sites with higher temperatures showed higher species richness. The ascending hierarchical ranking, with environmental variables, identified seven main groups of affinity between samples. This result is supported by the principal component analysis, which shows 7 groups, distributed on the basis of environmental variables. In which depth, temperature, and mud are the most important variables. Richness was influenced by factors such as depth and temperature, whereby deeper sites showed lower richness. The species that most contribute to the dissimilarity between the groups are *Cespitularia sp. Sarcophytum sp. Lobophytum sp. Lemnalia sp.* and *Xenia sp.*

Poster
A-1285

The PAMERA: A wide scale view of photosynthetic efficiency

van der Geer, A.[1], Baer, J.[1], Hatay, M.[2], Rohwer, F.[1]
[1]San Diego State University, Biology, San Diego, United States
[2]San Diego State University, San Diego, United States

aevander[at]ucsc.edu

Abstract

The vast building potential of tropical coral reefs hinges on the productive symbiosis between the coral animal and it's endosymbiotic zooxanthellae. As the sugars produced through the endosymbiont's photosynthetic pathways constitute a major source of carbon for coral polyps, evaluation of the effectiveness of the zooxanthellae's photosynthetic pathways can provide useful insight into the health and success of the coral animal. Changes in the symbiont's photosynthetic output can also be used to indicate early signs of nonlethal stress in corals. Assessment of photosynthetic efficiency (PSE) by pulse amplitude modulated (PAM) fluorometry is a non-invasive and commonly used measurement for evaluating the physiological robustness of zooxanthellae, and, by proxy, coral health. The most commonly utilized tool to obtain this metric in situ is the diving PAM, which remains limited in its utility in that measurements consist of many small points across a coral head and do not provide a visual representation of PSE. Here we describe a new tool for the assessment of PSE in situ which provides an image-based readout of changes in PSE across an entire coral head. The PAM underwater imaging system, or PAMERA, is a fully-submersible reef monitoring system, which utilizes the principles of PAM fluorometry to provide an image-based map of PSE across a photosynthetic organism or benthic community. Field tests on a reef offshore of CARMABI Research Station in Curacao demonstrate that the PAMERA can (1) capture the Chla fluorescence signature as well as other fluorescent pigments (GFP, OFP), (2) isolate differing intensities of Chla fluorescence within a single image; and (3) obtain the Fv/Fm ratio on a per pixel basis across the area of interest. These results indicate that the PAMERA can serve as an effective imaging system to visualize differences in PSE across three-dimensional space and may be used for assessing PSE health in corals and other photosynthetic organisms in situ on a larger scale than existing metrics can provide.

Virtual Oral
A-2227

Humans versus Machines: A Comparison of Manual and Automated Analysis in Benthic Communities Monitoring Surveys

Alves Méga de Andrade, M.[1], Mendes Cordeiro, C. A. M.[2]
[1]Universidade Federal do Rio de Janeiro, Rio de Janeiro, Brazil
[2]Universidade Estadual do Norte Fluminense Darcy Ribeiro, Campos dos Goytacazes, Brazil

marinaamegaa[at]gmail.com

Abstract

Tropical reefs are one of the most important ecosystems on the planet but they are threatened by local and global impacts. In order to understand these ecosystem functioning in response to impacts, long-term research is needed. Image-based surveys are advantageous as they allow quick collection and data storage. However, identifying and annotating organisms manually is a slow and tedious process and creates a bottleneck between image collection and analysis. Furthermore, human annotators are subjective and inconsistent. Automatic annotators are advantageous because they reduce the time and subjectivity of annotations, but there are few studies comparing the performance of both annotation methodologies. Image quality can also influence annotations, but too little is known about which parameters influence the most. Thus, the general aim of this work was to verify how much the automated analysis tool, more specifically CoralNet, helps in the classification of organisms in reef benthic cover images. This study is a pioneer in evaluating how image quality affects annotations. Initially, images pre-annotated by an expert were used to training and evaluate the performance of manual and automated annotators. Performance was measured by agreement with previous annotations using Cohen's Kappa. Secondly, image quality was qualitatively measured and related to the annotator's performances in which image, using analysis of variance (ANOVA). Manual and automatic annotators showed similar performance for most labels and morphofunctional groups, indicating the efficiency of the computer in the annotations. Best performance was observed for corals, leathery macroalgae and filamentous macroalgae and the most confusion were in turf, crustose coralline algae and Dictyota spp. Both annotators were influenced by image quality parameters in the same way, and the most representative imperfections were not the most influential. The main influencing parameters were suspension, parallax error, sun glint and overexposure, which can be mitigated with camera adjustments, diver experience and use of fixed support linked to the quadrat. These results indicate that the automatic annotation tool is comparable to the manual annotator in benthic image annotations and is able to efficiently detect changes in reef communities.

Session 7D - Scaling up: what lessons can we learn across larger scales for understanding coral reefs?

Conceptualized by: **Emma Kennedy** [1], **Chris Roelfsema**[1], **Sarah Hamylton**[2], **Stuart Phinn**[1], **Greg Asner** [3]
[1] University of Queensland (Brisbane, Australia)
[2] University of Wollongong (New South Wales, Australia)
[3] Arizona State University (Tempe AZ and Hilo HI, USA)

Chaired by: Manuel Gonzalez Rivero [1]
[1] Australian Institute of Marine Science (Townsville, Australia)

Oral
A-2101

A synopsis of fine scale habitat complexity across the main Hawaiian Islands

Asbury, M.[1], Couch, C.[2], Oliver, T.[3], Madin, J.[1]
[1]Hawaii Institute of Marine Biology, University of Hawaii, Kaneohe, United States
[2]Cooperative Institute for Marine and Atmospheric Research, NOAA/Pacific Islands Fisheries Science Center, Honolulu, United States
[3]National Oceanic and Atmospheric Administration, Pacific Islands Fisheries Science Center, Honolulu, United States

masbury[at]hawaii.edu

Abstract

Habitat complexity plays a fundamental role in determining the composition and functioning of ecosystems worldwide. Despite this importance, few studies have quantified how habitat complexity varies across large spatial scales. In this study, we used Structure-from-Motion photogrammetry to assess the structural complexity of 300 reef sites spanning the main Hawaiian Islands (approximately 4 degrees of latitude), with depths ranging from 1 to 30 m, in order to quantify broad-scale patterns in habitat structural complexity. We used a recently described geometric theory to create a synoptic view of how three surface descriptors—rugosity, fractal dimension, and height range—trend with island age, depth, and wave exposure. Our results reveal unexplored, fine-scale spatial associations between reef geometry and environmental and historical variables at different scales. Identifying how different features interact to produce or correlate with reef structural complexity will lead to a better understanding and prediction of biodiversity gradients and recovery potential.

Oral
A-1248

Predicting fine-scale climate on tropical coral reefs

Bos, J., Pinsky, M.
Rutgers University, Ecology and Evolution, New Brunswick, United States

jaelyn.bos[at]rutgers.edu

Abstract

Increasing global temperatures constitute an existential risk for tropical corals, most of which exist near their upper thermal limits. However, actual temperatures experienced by individual corals vary both between regions and within reefs, and fine-scale microclimates within reefs can correspond to differences in thermal tolerance between even conspecific corals. Despite the ecological importance of fine-scale variability in reef temperature, remotely sensed temperature is rarely resolved to sub-kilometer level. Here, we use remotely sensed products from NASA and the Allen Coral Atlas to predict *in situ* temperatures on coral reefs at the scale of tens of meters. We fit our model using records from 318 temperature loggers across the Indo-Pacific and Caribbean. Using sea surface temperature, distance to shore, and remotely sensed depth and reef geomorphology, we are able to predict maximum monthly mean temperatures *in situ* to within 1 degree Celsius. The majority of our predictions fall within half a degree Celsius of the true max monthly mean. We project this model across coral reefs in the Caribbean Sea, South Pacific Ocean, and Western Indian Ocean to assess prevalence of microclimates and spatial thermal heterogeneity across regions. By accurately modeling microclimates across coral reefs, we can also predict where coral populations might exhibit elevated heat tolerance, leading to better understanding of the adaptive capacity of coral reefs.

Oral
A-2061

Mapping neighbourhoods: spatial distribution of Scleractinian corals on a reef

Dornelas, M. A.
University of St Andrews, St Andrews, United Kingdom

maadd[at]st-andrews.ac.uk

Abstract

Understanding the spatial distribution of organisms is a key goal of ecology. Major biodiversity models make two assumptions about spatial distributions: that individual species are spatially clustered, and that the distributions of different species are independent. These assumptions are common across all models that aim to predict the global distribution of biodiversity. However, there is remarkably poor empirical knowledge to support these assumptions. Moreover, to our knowledge these patterns have never been quantified on reef corals, the niche constructors of the most diverse marine ecosystem on the planet. We used AUV collected imagery to build 3D topographic maps of a 7500 m^2 of a reef at Lizard Island, Great Barrier Reef. These models were annotated with the species identities and locations of over 11,000 coral colonies, identified *in situ* by divers, to resolve the spatial distribution of the 120 species in the surveyed area. We analysed these spatial distributions and quantified intra and inter specific clustering. We show that across a range of scales, all but the rarest species are spatially clustered with conspecifics, a finding that is consistent with model assumptions. However, neighbouring species are remarkably diverse, and we find evidence for interspecific clustering rather than independent distribution of different species. This finding contradicts the second assumption of biodiversity models, and indicates that models should be refined to include interspecific clustering.

Oral
A-1020

Can the Allen Coral Atlas indicate adaptive capacity of coral reefs?

Fox, H.[1], Green, R.[1], Rivera-Sosa, A.[1], Gleason, A.[2], Purkis, S.[3], Randazzo Eisemann, A.[1, 4], Rivera, A.[5], Colton, M.[1]
[1]Coral Reef Alliance, Conservation Science, Oakland, United States
[2]University of Miami, Physics, Coral Gables, United States
[3]University of Miami, Marine Geosciences, Miami, United States
[4]Universidad Nacional Autónoma de México (UNAM), PIESACOM, UMDI-Sisal, Facultad de Ciencias, Sisal, Mexico
[5]Coral Reef Alliance, Mesoamerican Region, Tegucigalpa, Honduras

hfox[at]coral.org

Abstract

Scientific evidence is mounting to indicate that corals can adapt to the effects of climate change if emissions are brought under control and corals have sufficiently high genetic variability. In addition, marine practitioners have highlighted a critical need for guidance on how to integrate climate resilience into MPA design and management. However, methods to identify proxies for adaptive capacity at scales that can inform conservation efforts and match local management systems do not currently exist. The emergence of the Allen Coral Atlas, a new mapping initiative, provides high-resolution maps of shallow water (<10-15 m) geomorphic reef zones, benthic habitats, and bathymetry that can be used for reef conservation and planning. We explore the extent to which habitat complexity, as detected by the Atlas, can inform adaptive capacity. Beta-diversity is a common index used to assess environmental heterogeneity within natural systems, indicating the change in species/habitat composition across a landscape. We calculated beta-diversity from benthic and geomorphic classes and also examined other remotely-sensed data sources that provide potential key indicators of resilience, e.g. depth, slope, aspect, and connectivity, to model how these indicators are linked to ecological metrics related to reef resilience and adaptive potential. To assess correlations between the Atlas beta-diversity metrics and thermal diversity, we measured diversity and habitat structure in the field, and we also installed in-situ temperature monitors (TidBits and real-time Aqualink smart buoys) in the Bay Islands of Honduras. If, as we hypothesize, the Atlas can identify locations of greater habitat and thermal diversity, these metrics can be scaled up and used to better incorporate the principles of adaptive capacity and reef resilience into marine spatial planning processes.

Oral
A-2182

Global conservation potential in coral reef halos: Consistency over space, time, and ecosystems worldwide

Madin, E.[1], Precoda, K.[2], Roelfsema, C.[3], Suan, A.[2]
[1]Hawai'i Institute of Marine Biology, Kane'ohe, United States
[2]University of Hawaiʻi, Hawaiʻi Institute of Marine Biology, Kāneʻohe, United States
[3]The University of Queensland, Remote Sensing Research Centre, School of Earth & Environmental Sciences, Brisbane, Australia

emadin[at]hawaii.edu

Abstract

Halos around coral reefs are landscape-scale patterns arising from multi-species interactions that collectively structure reefscapes over many thousands of kms2. First described in the 1960s, halos are known from a handful of locations and continue to captivate scientists. What remains unknown is how globally widespread, persistent, and dynamic halos are. We examined satellite imagery of reefs globally, coupled with in-situ field observations, to show that halos are a globally-ubiquitous, persistent, yet dynamic ecological phenomenon spanning vastly different systems. We further document the previously-undescribed presence of halos outside of the tropics surrounding seagrass ‘reefs’, and highlight the temporal scales over which coral reef halos change, merge, and persist. Specifically, we show that halos can change in size over relatively short temporal scales of months, despite persisting over decades. In doing so, we document patterns suggesting that additional biophysical mechanisms than previously assumed may shape halos. Understanding the full suite of mechanisms governing halo formation and maintenance may enable us to use them as proxies for species interactions. Given halos’ global extent, their role in affecting sedimentary carbon storage, and their relationship with marine reserve existence and maturity, they may ultimately serve as globally-relevant indicators of coral reef ecosystem functioning and health.

Oral
A-1205

Synergizing Remote Technologies to Assess the Association Between a Predator Community and Coral Reef Halo Presence

Meier, A., Franceschini, S., Suan, A., Madin, E.
University of Hawaii at Manoa, Hawaii Institute of Marine Biology, Kaneohe, United States

ameier3[at]hawaii.edu

Abstract

Coral reefs are in precipitous decline despite being a critical resource for 8% of humanity. Coral reef monitoring and conservation on a global scale is challenged by their patchy and dispersed nature. Coral reef halos – rings of sand around reefs – are created and maintained through complex interactions between fishers, marine predators (i.e., sharks), and fish. Despite recent research suggesting that coral reef halos exist because of herbivore fear of predation, causing fish to forage near the reefs, few studies have explored the relationship between predator presence and the persistence of coral reef halos. Modern satellites, offering fine-scale resolution with global coverage, now allow us to observe halos pan-tropically. Synthesizing remotely sensed imagery of patch reefs from Planet Inc. and BRUV collected predator population data from the Global FinPrint project we tested the association between predator presence and coral reef halos at a global scale. Our results describe the correlation between shark communities and halo presence. By clarifying the connection between predators and coral reef halos, our study explores the potential of using a global, landscape-level phenomenon as a remotely sensed proxy for shark community health. The frequent, global coverage of satellites enables us to provide the data marine managers need to protect and adaptively manage these important ecosystems.

Oral
A-1298

High-Resolution Habitat and Bathymetry Maps for 65,000 km^2 of Earth's Remotest Coral Reefs

Purkis, S.[1], Gleason, A.[1], Bakker, A.[1], Dempsey, A.[2], Carlton, R.[2], Faisal, M.[2]
[1]University of Miami, RSMAS, Miami, United States
[2]Khaled bin Sultan Living Oceans Foundation, Annapolis, United States

spurkis[at]rsmas.miami.edu

Abstract

With compelling evidence that half the world's coral reefs have been lost over the last four decades, there is urgent motivation to understand where reefs are located and their health. Without such basic baseline information, it is challenging to mount a response to the reef crisis on the global scale at which it is occurring. To combat this lack of baseline data, the Khaled bin Sultan Living Oceans Foundation embarked on a ten-year survey of a broad selection of Earth's remotest reef sites – the Global Reef Expedition. Our presentation focuses on one output of this expedition, which are meter-resolution seafloor habitat and bathymetry maps developed from DigitalGlobe satellite imagery and calibrated by field observations. Distributed on an equatorial transect across 11 countries, these maps cover 65,000 sq. km of shallow-water reef-dominated habitat. The study represents an order of magnitude greater area than has been mapped previously at high resolution. We present a workflow demonstrating that DigitalGlobe imagery can be processed to useful products for reef conservation at regional to global-scale. We further emphasize that the performance of our mapping workflow does not deteriorate with increasing size of the site mapped. Whereas our workflow can produce regional-scale benthic habitat maps for the morphologically diverse reefs of the Pacific and Indian oceans, as well as the more depauperate reefs of the Atlantic, accuracies are substantially higher for the former than the latter. It is our hope that the map products delivered to the community by the Living Oceans Foundation will be utilized for conservation and act to catalyze new initiatives to chart the status of coral reefs globally.

Oral
A-1833

Digitizing the coral reef with dense taxonomic maps through machine learning of underwater spectral images

Schürholz, D.[1], Chennu, A.[2]
[1]Max Planck Institute for Marine Microbiology, Microsensor Group, Bremen, Germany
[2]Leibniz Centre for Tropical Marine Research, Data Science and Technology, Bremen, Germany

dschuerh[at]mpi-bremen.de

Abstract

Existing coral reef survey methods struggle to accurately capture the taxonomic detail within the complex spatial structure of benthic communities. Thematic detail and flexibility within densely labelled habitat maps are required to meet the information needs of different experts, as well as to communicate uncertainty and provide validation data for global mapping efforts. We propose a workflow to leverage underwater hyperspectral transects and two machine learning algorithms to produce dense habitat maps of 1150 m^2 of reefs across a Caribbean island coastline. Our multi-method workflow leaves no pixel behind assigning them one of 43 labels, comprised by taxonomic family, genus or species labels for biotic components such as corals, algae, sponges, and non-taxonomic labels for substrates such as sediment, turf algae and cyanobacterial mats. Despite the thematic detail our produced habitat maps were highly accurate (87% Fbeta) and were predicted with little human expert effort (2% pixels). Our composition and configuration assessment of the 400+ million pixels from 23 classified transects showed high consistency. The dense habitat maps reveal the inadequacies of point sampling methods to accurately describe reef benthic communities, revealing that under certain settings even high numbers (>1000) of sparse sampling points fail to accurately describe (<5% error) benthic communities. Digitizing the reef habitat structure with unprecedented detail and scale enables/invites novel analyses of pattern and scale in coral reef ecology.

Oral
A-1970

“Scaling up” solutions for reef remediation and restoration in the Biosphere 2 Ocean mesocosm

Thompson, D.[1], Cole, J.[2], Morgan, K.[1], Killam, D.[1], Roach, T.[3], Santoro, E.[4], Duhaime, M.[2], King, S.[1], Peixoto, R.[4], Watkins, J.[2], Trzybinski, J.[1], Hackett, J.[1], Muller, E.[5], Sullivan, C.[6], Sandin, S.[6], Crocker, L.[1], Grambihler, R.[1]
[1]University of Arizona, Tucson, United States
[2]University of Michigan, Ann Arbor, United States
[3]Hawai‘i Institute of Marine Biology, Manoa, United States
[4]King Abdullah University of Science and Technology, Thuwal, Saudi Arabia
[5]Mote Marine Laboratory, Sarasota, United States
[6]Scripps Institution of Oceanography, San Diego, United States

thompsod[at]email.arizona.edu

Abstract

The coral reef community has identified a range of potential interventions that can improve reef restoration outcomes, but they urgently need to be tested before they are applied on natural reefs. However, the nature of critical scale- and feedback-dependent processes requires experimentation with fine environmental control and high-resolution (spatial & temporal) measurements across ecosystem scales. Despite this critical need, existing data represent a disconnected mix of controlled small-scale and complex large-scale studies in natural systems (where stressors are compounded).

The 2.6-million-liter Biosphere 2 Ocean (B2O) mesocosm provides a unique opportunity to rigorously test and “scale up” innovative techniques for reef restoration and interventions for resilience (e.g., stress hardening, probiotic and phage therapy). We present an overview of an international collaborative project that brings decades of observational and experimental studies to action, leveraging the B2O mesocosm to develop viable solutions for (re)building resilient reefs. With state-of-the-art life support and engineering upgrades, we can simulate future environmental conditions, capture intrinsic processes, study novel species interactions, and test how environmental conditions impact reef health, calcification and biomineralization processes (all at ecosystem scale).

The B2O also presents a unique opportunity to investigate recovery processes and explore solutions for rebuilding degraded coral reefs. Here we present results from the “bioremediation” phase of the project, during which we closely monitored the environmental and biogeochemical conditions of the B2O algae-dominated state, isolated beneficial microorganisms for probiotic experiments, and monitored the symbiont health and feeding behavior of *Tridacna derasa*. Our results provide new insights into the spatial and temporal scales across which key parameters cycle on a degraded reef, the utility of giant clams as biomonitors, and the role of the reef microbiome in regulating biogeochemical cycling and reef health. We also show additional evidence for the utility of nitrogen isotopes for tracking reef health, as the sediments accumulating in the B2O benthos show a marked decline in $\delta^{15}N$ across the phase shift from coral to algal dominated reef since the 1990s. We end with an outline of the coral reef restoration experiments, and a call to the ICRS community for proposals to further leverage this unique opportunity.

Oral
A-1669

Building a Colombian interdisciplinary network for coral reef characterization using modern technologies

Zapata Ramírez, P. A.[1], Vasquez, R.[1], Zuluaga, C.[1], Osorio, A. F.[2], Urdaneta, S.[3], Fitzsimmons, C.[4], Quintero, J.[5], Cano, M.[6]
[1]Universidad Pontificia Bolivariana, School of Engineering, Medellin, Colombia
[2]Universidad Nacional de Colombia, Facultad de Minas, Medellin, Colombia
[3]Geomares S.A.S, Cartagena, Colombia
[4]Newcastle University, School of Marine Science and Technology, Newcastle, United Kingdom
[5]Centro de Investigaciones Oceanográficas e Hidrográficas del Caribe CIOH, Cartagena, Colombia
[6]Parques Nacionales Naturales de Colombia, Bogotá, Colombia, (paula.zapataramirez[at]upb.edu.co)

Abstract

One of the goals of the National Politics of the Ocean and the Coastal Spaces (in Spanish PNOEC)" of Colombia (2016-2030), is "to use the resources of the country in its oceanic and coastal spaces, under the principles of sustainable development, inter-institutional and inter-sectoral work and respect for international maritime regulation, considering the need to progress in processes of protection of the marine environment"; achieving this goal requires advances in the development of science and technology, and strengthening education programs. Coral reefs are among the most important
ecosystems providing services within the coastal and insular regions of Colombia. This work addresses the construction of an interdisciplinary (academia - government - industry) network to conduct research and innovation to measure, map, model and monitor Colombian reefs. The network includes two academic institutions, two governmental institutions and one marine surveying industry partner.
Additionally, the network includes an international partner, Newcastle University. Projects executed by the network are related to the use and application of satellite images, remotely piloted aircraft systems, multi-beam and backscatter bathymetry data, oceanographic measurements, remotely operated vehicles, video/image acquisition and advanced processing techniques. Specifically, artificial intelligence applications and cloud computing are generating models to analyse reef dynamics. Here we report the results of the produced maps at multiple scales, resolutions and multi temporal
acquisition dates along with a combination of a suite of geomorphometric (e.g.: flat and sloping zones, crests, depressions and breaks of slope) and textural analytical techniques to map specific types of seafloor morphologies and compositions in the studied reefs. The use of such technologies is helping the country in the production of high-resolution cartographical data pivotal to informed management decisions. Furthermore, the projects are being designed with an inherent emphasis on modern methods that can be also relevant for addressing challenges related to marine spatial planning processes and marine protected areas design and monitoring. Obtained data are being shared for the benefit of local communities and stakeholder's engagement in a manner that opens up science to broader society, promoting outreach activities and educational tools that can help current challenges faced by the Colombian reefs.

Poster
A-2029

Scaling Up Coral Demography: Measuring Coral Vital Rates Using Repeated Photomosaics

Rodriguez, C.[1, 2], Logan, C.[2], Couch, C.[3, 4], Sandin, S.[5], Madin, J.[6], Wulstein, D.[6], Oliver, T.[4]
[1]Moss Landing Marine Laboratories, Moss Landing, United States
[2]California State University Monterey Bay, Marine Science, Seaside, United States
[3]Cooperative Institute for Marine and Atmospheric Research, Honolulu, United States
[4]NOAA, Pacific Islands Fisheries Science Center, Honolulu, United States
[5]Scripps Institution of Oceanography, La Jolla, United States
[6]Hawaii Institute of Marine Biology, Kaneohe, United States

crodriguez[at]mlml.calstate.edu

Abstract

Developing models that document changes in coral communities following thermal stress events and project trends in reef recovery is crucial in identifying resilient reefs. Traditional approaches to generating the coral vital rates necessary for demographic modeling are time consuming and field intensive; however, by leveraging Structure from Motion photogrammetry, we can accurately track populations over time at a large spatial scale. In this study, we assessed the population dynamics of the dominant coral species across the Hawaiian archipelago and determined the effect that thermal stress events have on coral populations. The annual growth, survival and recruitment of 3,852 coral colonies (5,636 unique colony-level transitions) for 3 genera was recorded at 15 sites spanning the Hawaiian archipelago across 14 intervals from 2013 to 2019, including 3 bleaching events. These data were used to parameterize integral projection models to determine the impact of thermal stress on population growth. Degree Heating Week output from the NOAA Coral Reef Watch daily global 5km satellite was used to estimate thermal conditions at each site by calculating temperature stress severity (the mean of all maximum thermal anomalies) and frequency (number of thermal stress events per 10 years). Across all taxa, population growth rates (λ) varied spatiotemporally, but most sites exhibited a declining population growth rate ($\lambda < 1$). While increased severity and frequency of thermal stress events negatively impacted the population growth rate of massive *Porites* corals, there was no signal of this effect on encrusting *Montipora* corals. We demonstrate that despite variations in the responses observed among taxa, there is an overall expected population decline across the Hawaiian archipelago. While coral population growth rates are higher following bleaching events, signifying recovery, the projected increase in both the severity and frequency of thermal anomalies may overwhelm corals' ability to recover and threaten coral population persistence.

Virtual
Oral
A-2019

Spatiotemporal Investigation of Reef Resistance to the 2014-2017 Bleaching Events in the Pacific Ocean

Neuhausler, R.[1], Scarmuzza, J.[1], Eakin, C. M.[2], Larsen, L.[1]
[1]University of California, Berkeley, Berkeley, United States
[2]NOAA Center for Weather and Climate Prediction (NCWCP), College Park, United States

rneuhausler[at]berkeley.edu

Abstract

The 2014-2017 coral bleaching event, triggered by rises in temperature, saw reductions of coral cover worldwide. Across the Pacific ocean, local coral losses were frequently as high as 50%, such as in regions in the Great Barrier Reef. While temperature and past bleaching temperature thresholds were able to predict a large amount of the bleaching that was observed, discrepancies exist; some areas with high temperature increases did not bleach, while others with lower temperatures did. With the goal of teasing out spatial determinants of bleaching additional to temperature, we explore the socioenvironmental systems surrounding Pacific coral reefs that exhibited these discrepancies. To reduce potential confoundedness and omitted variable bias, we conduct an ocean-wide analysis and include a multitude of variables, including both those whose influence has been seen to weaken coral as well as factors that have not yet been considered at this scale. Our data sources include, but are not limited to, Landsat-7, Hansen's Global Forest Change v1.8, WorldPop, CHIRPS, and existing local surveys. Due to the scope of this project, specifically the wide spread of data sources and potential gaps, our first step has been the development of a data pipeline. Our solution is fully open source, utilizing apache nifi for the processing pipeline and conda environments for reproducibility. Preliminary results from a subset of islands suggest improved prediction capabilities when including factors such as proxies for sediment plumes. Further outcomes of this analysis may illuminate best management practices for building or preserving reef resistance to temperature induced bleaching.

Virtual
Oral
A-1387

The Allen Coral Atlas: Updates, innovations, and analysis of global coral reef mapping

Roelfsema, C.[1, 2], Lyons, M.[1, 2], Markey, K.[1, 2], Say, C.[1, 2], Kovacs, E.[1, 2], Kennedy, E.[1, 3], Phinn, S.[1, 2], Murray, N.[1, 4], Fox, H.[2, 5], Bambic, B.[2, 6], Gerstner, P.[2, 6], Skone, M.[2, 6], Asner, G.[2, 6]
[1]University of Queensland, School of Earth and Environmental Sciences, Brisbane, Australia
[2]Allen Coral Atlas Partnership, Tempe, United States
[3]Australian Institute of Marine Science, Townsville, Australia
[4]James Cook University, Townsville, Australia
[5]Coral Reef Alliance, Oakland, CA, United States
[6]Arizona State University, Center for Global Discovery and Conservation Science, Tempe, United States

c.roelfsema[at]uq.edu.au

Abstract

Reliable and informative maps of coral reef habitat not only capture the visible wonder of our planet but can extend our scientific capability to understand reefs. In 2021 the first globally consistent, high thematic and spatial resolution geomorphic and benthic maps with complete coverage of shallow coral reefs were made accessible through the Allen Coral Atlas. The Allen Coral Atlas maps increase the ability to understand the composition of our reefs, design marine protected areas, model ecosystems in space and time and support field site selection.
A short overview of the habitat mapping process will be provided, followed by improvements on the 2021 process, example of usage by the community, creation of new reef extent, and analysis of some of our findings.

The mapping process includes: a) input data: over 2 million satellite scenes, physical properties (depth, slope, waves) and over 500 reference field data sets received from the community and expert knowledge, b) a classification scheme, c) an machine learning and object based editing routine to create the maps and d) validation routine.

We then present improvements of the 2021 global habitat maps, utilising both technical innovations to the mapping process, as well as integration of local and global expert feedback.These improved geomorphic maps in combination with machine learning process were then used to create on update reef extent layer, which includes areas of the reef slopes, flats, crest, and lagoon for which the bottom is visible in the used satellite image mosaics.

We discuss some of the challenges encountered and how to use and when not to use the maps. Followed by an analysis of our updated estimates of the global distribution of coral reef habitats, including implications for how this might impact conservation and management.

The new version of the habitat maps will be accessible and freely downloadable by the end of 2022 from www.allencoralatlas.org.

Session 7E - What are the genetic and cellular mechanisms underlying cnidarian-dinoflagellate symbiosis and its breakdown during bleaching?

Conceptualized and chaired by: **Phillip A. Cleves** [1], **Katie Barott**[2]
[1] Stanford University (San Francisco, CA, USA)
[2] University of Pennsylvania (Philadelphia, PA, USA)

Oral
A-1941

The characterisation of the phosphatidylinositol signalling pathway in the cnidarian-dinoflagellate symbiosis.

Ashley, I.[1], Gorman, L.[1], Rosset, S.[1], Oakley, C.[1], Grossman, A.[2], Suggett, D.[3], Weis, V.[4], Davy, S.[1]
[1]Victoria University of Wellington, Wellington, New Zealand
[2]California Institute of Science and Technology, Pasadena, United States
[3]University of Technology Sydney, Sydney, Australia
[4]Oregon State University, Department of Integrative Biology, Corvallis, United States

imogen.ashley[at]vuw.ac.nz

Abstract

The molecular functioning of the cnidarian-dinoflagellate symbiosis is still largely unknown. In particular, we know very little of the cell signalling involved in symbiosis regulation. One cell signalling pathway reported to be differentially regulated in Symbiodiniaceae in the symbiotic state is the phosphatidylinositol (PI) signalling pathway. Moreover, cross-kingdom manipulation of this pathway is implicated in mediating other host-microbe interactions. The PI pathway functions in the intracellular transduction of diverse stimuli by the biosynthesis of phosphoinositides, regulating vital cellular responses such as apoptosis, cell growth, and inflammation. The central mediators of the PI pathway are a variety of specific PI kinases and phosphatases which respectively phosphorylate and dephosphorylate phosphoinositides. Here, we carried out a complete bioinformatic analysis of all enzymes involved in the PI pathway across Symbiodiniaceae and other dinoflagellates, as well as symbiotic and non-symbiotic cnidarians. We identified proteins of interest across publicly available genomic and transcriptomic resources for target species through sequence homology using consensus sequences of key functional domains. The diversity of identified PI kinases and phosphatases was further assessed by phylogenetic analysis. The cnidarian PI pathway showed a high level of conservation to higher metazoans, both in the complexity of the pathway and in the domain structures of individual enzymes. Conversely, the complexity of the PI pathway was greatly reduced in Symbiodiniaceae, much like their sister taxon Apicomplexa, and the domain organisation of PI kinases and phosphatases was highly divergent. Additionally, proteins able to bind to PI kinases and phosphatases were identified in target organisms to predict the downstream functionality of the pathway within both symbiotic partners. This bioinformatic characterisation of the PI pathway in Cnidaria and Symbiodiniaceae will be used to conduct a targeted analysis of the activity of the PI pathway in the model cnidarian Aiptasia using phosphoproteomics to elucidate the role of this cell signalling pathway in the establishment and maintenance of the cnidarian-dinoflagellate symbiosis. Understanding such specific molecular processes in the symbiosis is vital in understanding how the cnidarian-dinoflagellate symbiosis is regulated and is required for the advancement of novel tools in the conservation of coral reefs.

Oral
A-1618

Using Transcriptomics and Reverse Genetics to Understand Mechanisms of Cnidarian-dinoflagellate Bleaching

Cleves, P.[1], Tinoco, A.[1], Krediet, C.[2], Renicke, C.[3], Bay, L.[4], Pringle, J.[3]
[1]Carnegie Institution for Science, Baltimore, MD, United States
[2]Eckerd College, St. Petersburg, Florida, United States
[3]Stanford University, Stanford, CA, United States
[4]Australian Institute of Marine Science, Townsville, Australia

pacleves[at]gmail.com

Abstract

The symbiosis between corals and dinoflagellate algae is essential to the energetic requirements of coral-reef ecosystems. However, coral reefs are in danger due to elevated ocean temperatures and other stresses that lead to the breakdown of this symbiosis and coral "bleaching". Despite the importance of coral reefs, the molecular basis of how corals maintain a healthy symbiosis and avoid bleaching is poorly understood, in part because of the lack of a tractable genetic model system. The small anemone *Aiptasia* is symbiotic with algal strains like those in reef-building corals but has many experimental advantages, making it an attractive laboratory model for cnidarian symbiosis. To explore the transcriptional basis of heat-induced bleaching, we used RNAseq to identify genes that are differentially expressed during a time course of heat stress of symbiotic and aposymbiotic Aiptasia strains. We observed a strong upregulation of hundreds of genes at times long before bleaching begins in symbiotic anemones. The putative promoters of these early stress-response genes are enriched for binding sites for the NFkB and HSF1 transcription factors, suggesting that many of these genes share core transcriptional control. The overall expression patterns were similar between the symbiotic and aposymbiotic anemones, indicating that many of the expression changes are not specific to the presence of the algae. Nonetheless, reducing HSF1 activity with a pharmacological inhibitor resulted in more severe bleaching, suggesting that this symbiont-independent stress response is protective against bleaching.

Genetic tools are needed to allow rigorous functional testing of the roles of candidate genes in symbiosis and bleaching. Recently, we have developed methods for knocking down and overexpressing genes of interest in Aiptasia. Meanwhile, we have successfully used the CRISPR/Cas9 technology to create genetic changes in embryos of the coral *Acropora millepora*. We used this technology to knock out HSF1 and demonstrated its role in coral heat tolerance. Through the establishment of both gain-of-function and loss-of-function methods in both Aiptasia and corals, it will be possible to exploit the year-round spawning of Aiptasia to perform initial tests of gene function in cnidarian-algal symbiosis and then further test the discoveries made using similar technologies in corals.

We thank the Simons and Gordon and Betty Moore Foundations for support.

Oral
A-1900

Intrinsically High Capacity of Animal Cells From a Symbiotic Cnidarian to Deal With Pro-Oxidative Conditions

Cotinat, P.[1], Fricano, C.[1], Toullec, G.[2], Röttinger, E.[1], Barnay-Verdier, S.[1], Furla, P.[1]
[1]Institute for Research on Cancer and Aging, Nice (IRCAN), Nice, France
[2]Laboratory for Biological Geochemistry, School of Architecture, Civil and Environmental Engineering, Lausanne, Switzerland

pauline.cotinat[at]gmail.com

Abstract

The cnidarian-dinoflagellate symbiosis is a mutualistic intracellular association based on the photosynthetic activity of the endosymbiont. This relationship involves significant constraints and requires co-evolution processes, such as an extensive capacity of the holobiont to counteract pro-oxidative conditions induced by hyperoxia generated during photosynthesis. In this study, we analyzed the capacity of Anemonia viridis cells to deal with pro-oxidative conditions by in vivo and in vitro approaches. Whole specimens and animal primary cell cultures were submitted to 200 and 500 µM of H2O2 during 7 days. Then, we monitored global health parameters (symbiotic state, viability, and cell growth) and stress biomarkers (global antioxidant capacity, oxidative protein damages, and protein ubiquitination). In animal primary cell cultures, the intracellular reactive oxygen species (ROS) levels were also evaluated under H2O2 treatments. At the whole organism scale, both H2O2 concentrations didn't affect the survival and animal tissues exhibited a high resistance to H2O2 treatments. Moreover, no bleaching has been observed, even at high H2O2 concentration and after long exposure (7 days). Although, the community has suggested the role of ROS as the cause of bleaching, our results indicating the absence of bleaching under high H2O2 concentration may exculpate this specific ROS from being involved in the molecular processes inducing bleaching. However, counterintuitively, the symbiont compartment appeared sensitive to an H2O2 burst as it displayed oxidative protein damages, despite an enhancement of antioxidant capacity. The in vitro assays allowed highlighting an intrinsic high capacity of isolated animal cells to deal with prooxidative conditions, although we observed differences on tolerance between H2O2 treatments. The 200 µM H2O2 concentration appeared to correspond to the tolerance threshold of animal cells. Indeed, no disequilibrium on redox state was observed and only a cell growth decrease was measured. Contrarily, the 500 µM H2O2 concentration induced a stress state, characterized by a cell viability decrease from 1 day and a drastic cell growth arrest after 7 days leading to an uncomplete recovery after treatment. In conclusion, this study highlights the overall high capacity of cnidarian cells to cope with H2O2 and opens new perspective to investigate the molecular mechanisms involved in this peculiar resistance.

Oral
A-1129

Frenemies - Nutrient competition is the general mechanism underlying the cnidarian-Symbiodiniaceae symbiosis

Cui, G.[1], Mi, J.[2], Moret, A.[1], Hung, S.-H.[1], Al-Babili, S.[2], **Aranda, M.**[1]
[1]King Abdullah University of Science and Technology, Red Sea Research Center, Thuwal, Saudi Arabia
[2]King Abdullah University of Science and Technology, Center for Desert Agriculture, Thuwal, Saudi Arabia

manuel.aranda[at]kaust.edu.sa

Abstract

The symbiotic relationship between marine invertebrates and dinoflagellates in the family Symbiodiniaceae is arguably the most common eukaryote-eukaryote endosymbiosis in our oceans and fundamental to coral reef ecosystems. This symbiotic relationship has evolved convergently across a broad range of marine phyla, including sponges, cnidarians, platyhelminthes and mollusks. Among these, cnidarians likely evolved the largest diversity in Symbiodiniaceae symbioses, with two out of the four cnidarian subphyla, Anthozoa and Scyphozoa, having evolved symbiotic species since their evolutionary divergence >700 Mya. The repeated evolution of these relationships suggests that a common mechanism might exist that regulates the interactions between hosts and symbionts. Based on previous studies we propose a simple metabolic model in which hosts limit nitrogen availability to the symbionts by using the photosynthesis derived sugar to assimilate waste ammonium via the GS/GOGAT cycle and subsequent amino acid biosynthesis. Here, we tested this model in three distantly related cnidarians that evolved Symbiodiniaceae symbioses independently, the reef-building coral *Stylophora pistillata*, the upside down jellyfish *Cassiopea andromeda*, and the sea anemone Ex*aiptasia diaphana*. Using nutrient supplementation experiments we confirm our model in all three species and show that symbiont density is regulated based on the availability of glucose and ammonium. Provision of glucose led to a significant reduction of symbiont densities in all three species while ammonium resulted in significant increases in *S. pistillata* and *E. diaphana*, and an increasing trend in *C. andromeda*. Metabolomic analyses using ultrahigh-performance liquid chromatography-high resolution mass spectrometry of nutrient supplementation experiments with ^{13}C glucose and ^{15}N ammonium further confirmed the proposed metabolic pathways. All three species showed high incorporation of ^{13}C and ^{15}N in downstream metabolites of the GS/GOOGAT cycle and serine and glycine biosynthesis pathways, which confirms that the hosts use the glucose provided to assimilate ammonium. Based on our results we show that the proposed metabolic model and molecular pathways form the universal mechanism underlying these symbiotic relationships in Cnidaria. Importantly, our results further reveal that these symbioses are based on competition rather than cooperation, which has important implications for our understanding of these relationships.

Oral
A-1877

Mechanisms of symbiont-produced lipid exchange powering animal-algal symbiosis

Hambleton, E.
University of Vienna, Centre for Microbiology and Environmental Systems Science, Division of Microbial Ecology, Vienna, Austria

elizabeth.hambleton[at]gmail.com

Abstract

Among the outstanding questions in cnidarian cell biology are the molecular mechanisms of nutrient transfer from the Symbiodiniaceae algal symbionts to the host. Besides sugars and amino acids, the uptake of sterols is essential for sterol-auxotroph cnidarians. In an earlier study, using a combination of phylogenetics, lipidomics, biochemistry, immunofluorescence, pharmacology, and quantitative PCR in the model anemone *Aiptasia*, we observed both symbiont- and host-driven patterns of sterol transfer, revealing plasticity of sterol use and functional substitution. That work suggested that sterol transfer is mediated by symbiosis-specific, non-canonical NPC2 sterol transporters, which are adapted to the highly acidic symbiosome environment. Symbiodiniaceae algae also colonize diverse marine invertebrates including acoel flatworms, sponges, and mollusks; although ecologically important and valuable for evolutionary comparisons, these remain molecularly poorly characterized. In my newly established group, our research questions are: how do these different host organisms interact on the cellular level with the same intracellular algal symbiont? What are their underlying molecular mechanisms, particularly metabolic exchange? Are sterol lipids a recurring currency in these mutualisms? I'll present new data and outline our plans to use single-cell transcriptomics, metabolomics/lipidomics, MALDI-MS metabolic imaging, and functional experimentation in established and new model systems comprising cnidarians and other marine invertebrates. Ultimately, we aim to understand globally widespread and evolutionarily important animal-algal symbioses and their response to environmental change.

Oral
A-1102

Interactions between symbiosis, innate immunity, and nutrition in cnidarians

Ingersoll, M. V., Desai, N., Davies, S., Gilmore, T.
Boston University, Biology, Boston, United States

mingers[at]bu.edu

Abstract

Coral reefs are under immediate threat from multiple environmental stressors, and understanding the molecular mechanisms governing the establishment, maintenance, and loss of symbiosis is key to successful restoration efforts. The mutualistic symbiosis between certain cnidarian species and photosynthetic algae of the family Symbiodiniaceae modulates the host's immune and stress responses under various conditions. Here, I present work investigating the role of the innate immune system protein Nuclear Factor kB (NF-kB) as an indicator of symbiosis and stress response programming under different nutrition stimuli and host-algal partnerships. We demonstrate that starvation of the facultatively symbiotic sea anemone *Exaiptasia pallida* (Aiptasia) leads to increased NF-kB protein levels and DNA-binding activity, but reduced expression of gene pathways involved in innate immune and stress response processes, regardless of symbiotic state. We further demonstrate that this regulation of the immune response is contingent upon specific host-symbiont pairings across multiple life stages of Aiptasia and two coral species. To further investigate the relationship between symbiosis and nutrition, we analyzed the photosynthetic efficiency (Fv/Fm) of symbiotic Aiptasia starved for over one month. We show that Fv/Fm decreases during starvation, indicating that starvation may be a stimulus for bleaching. Finally, we performed single-cell RNA sequencing (scRNA-seq) on aposymbiotic and symbiotic branches of the facultatively symbiotic coral *Oculina arbuscula.* These results reveal distinct transcriptional patterns in a subset of the 18 projected cell subtypes. Future scRNA-seq of facultative corals across stress conditions will reveal cellular-scale dynamics of gene expression and will illuminate the way symbiosis maintenance and loss affect gene expression across different cell types. Overall, this research suggests a regulatory role of the cnidarian immune system under certain stressors and implies that symbiotic cnidarians have two pathways for immune regulation – one to control symbiosis and one to defend against pathogen infection. The latter system may be downregulated when resources are limited.

7E - What are the genetic and cellular mechanisms underlying cnidarian-dinoflagellate symbiosis and its breakdown during bleaching?

Oral
A-1793

Molecular pathways in coral acclimatization to heat stress

Majerova, E., Carey, F., Drury, C.
University of Hawai'i, Hawai'i Institute of Marine Biology, Kaneohe, HI, United States

majerova[at]hawaii.edu

Abstract

Many plant and animal species are known to withstand sudden stress conditions much better after being previously exposed to them. With this thought, we investigated whether and how a short-term exposure of a stony coral *Pocillopora acuta* to sublethal temperatures influences its resistance to acute severe hyperthermal stress. We focused on analyzing the early molecular and cellular response in preconditioned vs. non-preconditioned corals with emphasis on oxidative stress defense and programmed cell death pathways. Using fluorescence confocal microscopy, we measured the bleaching rate by comparing host and symbiont cell-derived autofluorescent signals and we confirmed that a relatively short 3-day preconditioning makes corals more resilient to impending acute thermal stress. During such stress, non-preconditioned corals accumulate markers of oxidative DNA damage while preconditioned corals avoid it through enhanced activity of antioxidants maintaining the reducing cellular environment. Moreover, we showed that the more thermal resilient phenotype is driven by modulations in early phase of the programmed cell death pathway. We found several differentially expressed genes that correlated with the observed phenotype. To go beyond correlation, we developed methods of reverse genetics, such as siRNA-mediated gene knockdown, which allowed us to identify several pathways directly involved in coral bleaching and thermal acclimatization.

Our results get us closer to understanding the mechanisms of coral-algal symbiosis maintenance, which is indispensable for recognizing resilient traits in corals that have the best chance to survive in the changing world.

Oral
A-1015

The role of heterotrophy in the host-symbiont interactions of Stylophora pistillata

Martinez, S., Grover, R., Ferrier Pages, C.
Centre Scientifique de Monaco, Monaco, Monaco

stephane.martinez[at]gmail.com

Abstract

Mixotrophic corals can acquire their food through the heterotrophic feeding of the host and through symbiont autotrophy. It has been suggested that autotrophy dominates in shallow waters where irradiance is high, whereas heterotrophy increases along a depth gradient. To test these trophic changes, we applied amino acid compound-specific isotope analysis (AA-CSIA) to the coral *Stylophora pistillata*, either sampled along a depth gradient or grown under controlled feeding conditions in the laboratory. This coral is the perfect model as it has a broad range of depth and can be observed from the bright shallow reef (5m) to the mesophotic zone (70m). Despite the different light regimes it experiences, AA-CSIA revealed that *S. pistillata* maintained the same proportion of heterotrophy (35%) in its diet at all depths. Since the photosynthetic rates at shallower depths are higher, the predation rate of *S. pistillata* should also be higher to maintain the same contribution of heterotrophy to its total diet. Further controlled experiments on the coral heterotrophy pointed to a complex interaction between the host and its symbionts. Contrary to our expectations, heterotrophy was mainly traced through the δ^{15}N-AAs of the symbionts, suggesting that the latter directly profit from host heterotrophy. On top of that, there are indications for a direct transfer of amino acids to the symbionts, highlighting the mixotrophic status of the symbionts and suggesting that the host directly feeds the symbionts when prey is available. Our conclusions were validated using stable isotope probing (SIP) with labeled *A. salina* nauplii. These works reveal the importance of the coral symbiont interaction in assimilating heterotrophic acquired food.

Oral
A-1939

Dissecting the molecular basis of recognition between Symbiodiniaceae and cnidarians

Tortorelli, G.[1], Davy, S. K.[2], van Oppen, M. J. H.[3, 4], McFadden, G. I.[3]
[1]Hawai'i Institute of Marine Biology, Kāne'ohe, United States
[2]Victoria University of Wellington, School of Biological Sciences, Wellington, New Zealand
[3]University of Melbourne, School of BioSciences, Melbourne, Australia
[4]Australian Institute of Marine Science, Townsville, Australia

giadatortorelli[at]gmail.com

Abstract

Mutualistic interactions between reef-building corals and photosynthetic dinoflagellates in the family Symbiodiniaceae are the foundation of coral reefs. The establishment of this association resembles a microbial infection, where symbionts' glycoproteins (pathogen-associated molecular patterns, PAMPs) recognize host lectins (pattern recognition receptors, PRRs) to allow symbiosis. The interaction between PAMPs and PRRs is broadly species-specific, but little is known about the mechanisms underpinning this specificity in the coral-algal symbiosis. To explore this recognition process, we first created a matrix of symbiotic compatibilities between a wide range of Symbiodiniaceae and three genotypes of *Exaiptasia pallida*—a model organism for the cnidarian-dinoflagellate symbiosis. This permitted the selection of Symbiodiniaceae types with various level of affinity to the cnidarian host: *Breviolum minutum* (the homologous type); *Cladocopium goreaui* (a heterologous compatible type); and *Fugacium kawagutii* (a heterologous incompatible type). Inspired by medical and plant science, we used lectin array technology, monosaccharides component analysis, confocal microscopy of specific lectin conjugates and proteomics to biochemically characterize the surface glycoproteins of these three different Symbiodiniaceae species. The cell surface polysaccharide composition of *B. minutum* was found to be more similar to *C. goreaui* than *F. kawagutii*, which agrees with the affinity profiles of these algae for *E. pallida*. These findings provided a list of surface molecular candidates likely to be involved in symbiotic recognition. Hence, we strategically masked the glycans of interest with specific lectins, and used our matrix of host-symbiont compatibilities to dissect the involvement of these surface molecules in the onset of the cnidarian-algal mutualism. Observations of the effect of these cell surface manipulations highlighted the critical role played by the glycan ligands D-galactose, L-fucose, D-xylose and D-galacturonic acid on the uptake of Symbiodiniaceae during the first stages of symbiosis establishment with *E. pallida*. Understanding the lock-and-key mechanism used by cnidarians to recruit suitable symbionts sheds light on the fundamental molecular principles that underpin the symbiosis that powers coral reefs.

Poster
A-1104

Oxidative stress response pathways in larvae and juveniles of Pocillopora acuta.

Munk, N., Majerová, E., Drury, C.
Hawai'i Institute of Marine Biology, Coral Resilience Lab, Kāne'ohe, United States

ninahm[at]hawaii.edu

Abstract

At the molecular level, bleaching may be characterized by the accumulation of reactive oxygen species (ROS) due to overexcitement of the algal photosynthetic apparatus and subsequent expulsion of symbionts from coral tissue. This oxidative stress has been identified as a common consequence of elevated temperatures and UV light, leading to higher enzymatic activity in adult corals and symbiotic coral larvae. Higher enzymatic activity in response to stress suggests the deployment of an antioxidant defense system. Here, we investigated the role of ROS in cellular damage and function of the antioxidant defense system in symbiotic larvae and juveniles of the important Hawaiian reef building coral, *Pocillopora acuta*. *P. acuta* larvae from multiple maternal genotypes (n = 6-8) were exposed to experimental heat stress (32 ℃) and examined for ROS production (via confocal microscopy), DNA damage, and enzymatic activity (catalase, glutathione reductase, superoxide dismutase). This experiment was repeated with juvenile *P. acuta* to make comparisons across life history stages. We observed differential levels of ROS production and antioxidant activity in multiple enzymatic pathways indicating a genotypic effect on the molecular defense system in response to heat stress. As temperature maximums are concurrent with major coral spawning events, climate change threatens reproduction, a fundamental process driving the ecological persistence of coral reefs. Oxidative stress pathways may also have implications for coral restoration approaches using early life history stages to restore reefs (i.e., selective breeding, larval preconditioning, larval seeding).

Poster
A-1569

Elucidating cellular mechanisms of symbiont proliferation in cnidarian-Symbiodiniaceae symbiosis by using Breviolum mutants

Xiang, T.[1], Jinkerson, R.[2]
[1]University of North Carolina, Department of Biological Sciences, Charlotte, NC, United States
[2]University of California, Department of Chemical and Environmental Engineering, Riverside, CA, United States

robert.jinkerson[at]ucr.edu

Abstract

Many cnidarians rely on endosymbiotic algae in the family Symbiodiniaceae to provide them with photosynthate to meet their nutrient and energy needs. During symbiosis establishment in juvenile animals, symbionts must proliferate to populate the whole animal. A similar process occurs when symbionts re-populate an animal after a bleaching event. Despite the importance of symbiont proliferation in cnidarian-Symbiodiniaceae symbiosis, mechanistically this process is poorly understood. Recently we have isolated *Breviolum minutum* mutants that are visually distinct from wild type when imaged *in hospite* with bright-field microscopy. Mutant and wild type populations co-infected into the sea anemone Aiptasia can be easily tracked during proliferation. Data from these experiments was used to generate models of Symbiodiniaceae proliferation in Aiptasia that are revealing new insights into how symbionts proliferate in cnidarian hosts. These mutants can serve as new tools for microscopy-based approaches for evaluation of a wide variety of aspects of cnidarian-Symbiodiniaceae biology.

Session 7F - What can molecular approaches contribute to determining sublethal stressor effects on coral reefs and evaluating the effectiveness of management interventions?

Conceptualized by: **Robert Richmond**[1], **Kaho Tisthammer**[2], **Narrissa Spies**[3]
[1] University of Hawaii at Manoa (Honolulu, HI, USA)
[2] San Francisco State University (San Francisco, CA, USA)
[3] Pacific Islands Fish and Wildlife Office (Honolulu, HI, USA)

Chaired by: **Robert Richmond**[1]

7F - What can molecular approaches contribute to determining sublethal stressor effects on coral reefs and evaluating the effectiveness of management interventions?

Oral
A-1187

Peeling back the layers of coral holobiont multi-omics data

Bhattacharya, D.[1], Williams, A.[1, 2], Shumaker, A.[1, 3], Stephens, T.[1]
[1]Rutgers University, Department of Biochemistry and Microbiology, Rutgers University, United States
[2]Rutgers University, Microbial Biology Graduate Program, New Brunswixk, United States
[3]Rutgers University, Microbial Biology Graduate Program, Rutgers University, United States

debash.bhattacharya[at]gmail.com

Abstract

The integration of multiple 'omics' datasets provides a promising avenue for answering many important and challenging questions in biology, in particular those relating to complex ecological systems such as coral reefs. Multi-omics was, however, developed using data from model organisms which have significant existing prior knowledge. These resources allow omics data relationships to be meaningfully interpreted. The question remains whether multi-omics can be effectively applied to non-model organisms, such as coral holobionts, which house an assemblage of microbial partners and inhabit species-rich and changing marine environments. Here, we explored, in the emerging rice coral model, *Montipora capitata*, how transcriptomic, proteomic, metabolomic, and microbiome amplicon datasets interact across the coral holobiont and how well their overall patterns correlate with lab-induced thermal stress. We show that transcriptomic and proteomic data broadly capture the stress response of the coral, whereas the metabolome and microbiome datasets show patterns that likely reflect stochastic and homeostatic processes, potentially driven by changes in the local environment of the samples. Metabolites from the microbiome are present in the metabolomics data, producing a strong connection between microbiome composition and coral metabolomic data. These results provide important practical and conceptual frameworks through which researchers, beyond the coral field, can interpret multi-omics data generated from non-model systems, particularly those with intricate biotic interactions among microbial partners.

Oral
A-1327

Proteomics as a tool for accurately assessing specific stressor effects on corals and determining the effectiveness of management interventions

Richmond, R.[1], Nunn, B.[2], Tisthammer, K.[3]
[1]University of Hawaii at Manoa, Kewalo Marine Laboratory, Pacific Biosciences Research Center, Honolulu, United States
[2]University of Washington, Department of Genome Sciences, Seattle, United States
[3]University of California at Davis, Department of Environmental Toxicology, Davis, United States

richmond[at]hawaii.edu

Abstract

Protein expression has long been used in human medicine to help diagnose and determine options for treating health problems. Recent advances in coral genomics and transcriptomics have enabled the use of proteomic-based diagnoses to be applied to assessing and addressing the impacts of multiple stressors on corals and coral reefs. Liquid Chromatography – Mass Spectrometry (LC-MS) can be used to identify thousands of proteins expressed by corals qualitatively and quantitatively using small (1 cm) coral plugs or branches, sampled in a non-destructive manner. Both the Kyoto Encyclopedia of Genes and Genomes (KEGG) and Gene Ontology (GO) databases can be queried using the proteomic and genomic data to determine 1) the key stressors affecting corals along with their relative contributions to reduced function and, 2) how corals respond to management interventions over relevant time periods of days, weeks and months. Our proteomic data evaluated alongside genomic data have demonstrated that different genotypes of a species exhibit differential sensitives and responses to specific categories of stressors, such as toxicants, reduced oxygen, sedimentation and elevated temperatures. The results of these differential responses on reefs is adaptation and selection within coral populations distributed across stressor gradients such as watershed discharges resulting from land-based sources of pollution. Samples from coral reef sites across the Pacific Islands including Yap, Palau, Saipan, Maui and Oahu demonstrate the value of protein expression data in assessing exposure and responses to a variety of different stressors. The application of proteomics can help resource managers focus on the most relevant stressors at particular sites, determine threshold levels of stress that affect key biological processes such as gamete production supporting reproductive success, and guide efforts at selective breeding for coral restoration, to improve outcomes.

Poster
A-1560

Effects of Tungsten on the Hawaiian Corals Pocillopora damicornis and Porites lobata

Schelvis, M., Wilkins, K., Richmond, R.
University of Hawaii at Manoa, Kewalo Marine Laboratory, Honolulu, United States

madelief[at]hawaii.edu

Abstract

Corals form the basis of some of the most biodiverse and valuable ecosystems on Earth and are among the most vulnerable to anthropogenic stressors. Tungsten is a heavy metal found in increasing quantities in marine environments due to its industrial and military uses, including missile testing at the Reagan Test Site, Kwajalein Atoll, Republic of the Marshall Islands. This study aims to assess the effects of tungsten on the health and survival of two scleractinian corals commonly found in the Kwajalein lagoon: *Pocillopora damicornis* and *Porites lobata*. Colonies of each species were collected in Hawai'i, fragmented, and exposed to the following ecologically relevant concentrations of tungsten in filtered seawater along with a control of only filtered seawater: 100 ppb, 1 ppm, 10 ppm, and 100 ppm, each with five replicates. Each species underwent short-term (72-hour) and long-term (30-day) ecotoxicology assays followed by 30-day recovery periods and were monitored daily for mortality and health. Coral color was measured pre- and post-exposure, weekly, and post-recovery using the Hawaiian Ko'a color card. Tissue thickness and coverage were measured post-exposure and post-recovery. Post-exposure protein samples were taken and analyzed using liquid chromatography-mass spectrometry for changes in protein expression as indicators of sublethal stress. Changes in color, tissue thickness, and tissue coverage between treatments and over time did not significantly indicate acute toxicity. Sublethal responses were observed in some corals, including bleaching and tissue loss. Protein expression showed sublethal effects on metabolism with greater sensitivity in *P. damicornis* than *P. lobata*. These metabolic effects will likely result in reduced reproductive success over time. Overall, the results of this study indicate that tungsten is not acutely toxic to the representative corals over the concentrations tested and that following tungsten exposure corals can recover from associated sublethal stress over time.

7F - What can molecular approaches contribute to determining sublethal stressor effects on coral reefs and evaluating the effectiveness of management interventions?

Virtual
Oral
A-1580

Using molecular tools to evaluate the effects of brodifacoum cereal bait pellets on lobe coral Porites lobata

Barkman, A.[1], Tisthammer, K.[2], Richmond, R.[3]
[1]University of Hawaii at Manoa, Honolulu, United States
[2]San Francisco State University, San Fransisco, United States
[3]University of Hawaii at Manoa, Kewalo Marine Laboratory, Honolulu, United States

abarkman[at]hawaii.edu

Abstract

Rodent eradication efforts often involve the use of cereal bait pellets containing the anticoagulant pesticide brodifacoum. Pellet application occurs exclusively on land, however pellets inevitably enter the ocean surrounding islands. Very few laboratory studies have been conducted using brodifacoum cereal bait pellets, and little is known about the effects of the cereal bait pellets on non-target organism, such as corals. *Porites lobata* nubbins were exposed to 1 ppb, 10 ppb, and 100 ppb brodifacoum in cereal bait pellet solutions. Additionally, corals were exposed to paired inert cereal bait pellet solutions for three days. Dissolved oxygen and pH levels dropped in both pellet treatments with increasing concentrations. LC-MS/MS analysis and PAM fluorometry were used to examine sublethal signs of stress. Protein analysis revealed gene ontology enrichment in the citrate metabolic process in corals exposed to 10 ppb and 100 ppb brodifacoum in cereal bait pellet solutions. Phosphoenolpyruvate carboxykinase [GTP] mitochondria (PEPCK-M) and Heat shock protein 90 were significantly upregulated in corals exposed to 100 ppb brodifacoum in cereal bait pellet solutions compared to the control. There was no upregulation of tradition detoxification biomarkers. Photosynthetic efficiency was reduced in corals in the highest treatment of both pellet types. Results indicate that brodifacoum pellet exposure may cause metabolic changes in corals. Managers considering the use of cereal bait pellets on tropical islands to eradicate invasive rodents should consider the risks associated with the accidental introduction of pellets to nearshore environments. Bait applications should be carefully executed as to avoid excessive runoff, and to avoid peaks in coral reproductive periods.

Virtual Oral
A-2243

Using molecular biological tools in conjunction with predictive modeling approaches to gauge reef coral health in an era of changing global climate

Mayfield, A. B., Enochs, I., Kolodziej, G., Aguilar, C., Jankulak, M., Manzello, D.
National Oceanic and Atmospheric Administration, Miami, United States

andersonblairmayfield[at]gmail.com

Abstract

Coral reefs the world over are now threatened by anthropogenic activity to such an extent that pristine reefs no longer exist; this lack of "control" corals has thwarted efforts aimed at developing diagnostic tools since corals and the in hospite dinoflagellate populations that reside within their gastrodermal cells constitutively exhibit cellular hallmarks of a stress response. Given that 1) gene expression levels do not correlate with concentrations of their respective proteins in scleractinians or their endosymbionts and 2) absolute levels of individual biomarkers are not reflective of a coral colony's degree of stress, it may be more informative to instead compare cellular behavior between markedly resilient and stress-susceptible corals over space and time in a manner that would both aid in elucidating the physiological basis of stress tolerance and permit the delineation of relative levels of colony health through mapping coral resilience onto molecular biology. To this end, the responses of both thermo-tolerant and thermo-sensitive corals (Orbicella faveolata) were compared in a series of field and laboratory experiments aimed at understanding the sub-cellular means by which homeostasis is maintained under marginal environmental conditions. Conspecific colonies at both thermo-sensitive offshore and thermo-tolerant inshore sites of the Florida Keys were then sampled seasonally, and predictions as to their bleaching likelihood were made upon comparing their protein profiles to those of corals from the high-temperature challenge experiments via similarity analysis combined with partial least squares- and artificial intelligence-based predictive modeling. By tracking proteomic signatures over time and across a gradient of environmental stress tolerance, this effort sought to establish a coral actuarial framework whereby bleaching risk could be proactively forecasted on a triage-enabling timescale.

Virtual
Poster
A-1575

The Effects of Tungsten on Coral Gamete Fertilization and Larval Success

Wilkins, K., Schelvis, M., Richmond, R.
Kewalo Marine Laboratory, Honolulu, United States

keikow2[at]hawaii.edu

Abstract

Coral reefs are highly complex and valuable ecosystems which are also among the most threatened on Earth from both global and local level stressors. Among these stressors, tungsten from the construction of missiles is of concern at the Reagan Test Site (Kwajalein Atoll, Republic of the Marshall Islands). No studies to date have explored how tungsten may affect successful coral reef fertilization or larval success. In our study, we exposed larvae of two common species of corals, *Pocillopora damicornis* and *Montipora capitata*, to four concentrations of tungsten (100 ppb, 1 ppm, 10 ppm and 100 ppm) along with a control. *P. damicornis* parent corals and larvae were exposed to tungsten of the same concentrations. To better assess how tungsten may have affected the reproductive mechanisms of the parent corals, *P. damicornis* were also analyzed using liquid chromatography-mass spectrometry for changes in protein expression. For *M. capitata*, gamete bundles were collected and exposed to the same tungsten concentrations to determine fertilization success. For both *P. damicornis* and *M. capitata*, larvae were exposed to tungsten for 30 days and monitored for development and mortality. High fertilization rates for *M. capitata* were seen in all tungsten treatments. Larval survival for both species did not differ significantly between tungsten treatments. Surprisingly, the highest concentration of tungsten (100 ppm) resulted in the highest larval settlement rates for both species potentially as an adaptive stress response. Although larval survival did not show a significant relationship with tungsten, protein expression data collected from parent corals yielded tungsten effects on metabolism which could reduce reproductive success. Comparison of traditional laboratory assays with protein expression analysis allowed for a more complete picture of the effects of tungsten on coral reproduction.

Session 7G - What can we learn about the biology of coral reef organisms from ‘omics-based analyses?

Conceptualized by: **David Miller** [1], **Ira Cooke**[1], **Chris Voolstra**[2], **Iliana Baums** [3]
[1] James Cook University (Townsville, Australia)
[2] University of Konstanz (Konstanz, Germany)
[3] Pennsylvania State University (Pennsylvania, PA, USA)

Chaired by: **Chris Voolstra**[2], **Iliana Baums** [3]

Oral
A-1762

Do facultative coral hosts buffer their symbionts in response to thermal extremes?

Aichelman, H.[1], Wuitchik, D.[1], Huzar, A.[1], Atherton, K.[2], Kriefall, N.[1], Davies, S.[1]
[1]Boston University, Biology, Boston, United States
[2]Boston University, Bioinformatics, Boston, United States

hannahaichelman[at]gmail.com

Abstract

Increasing temperatures are compromising the symbiotic relationship between coral hosts and their algal symbionts. Physiologically, both symbiotic partners exhibit a variety of stress responses; however, evidence suggests that host transcriptomes respond more strongly to stress compared to their symbionts. This lack of transcriptional response by algae raises the question: are coral hosts regulating their symbiont’s environment to buffer environmental stress? Understanding each symbiotic partner’s stress response in tropical reef-building corals is challenging because symbiosis is obligate, and therefore a bleached (i.e., aposymbiotic) host’s response is inherently coupled with severe stress. We capitalized on the facultative symbiosis between the coral *Oculina arbuscula* and its algal symbiont *Breviolum psygmophilum* to characterize the transcriptomic responses of the symbiont in and out of symbiosis, and compare these responses with the coral host’s response. First, we focus on understanding the response of the symbiont and host in symbiosis. To accomplish this, symbiotic fragments of *O. arbuscula* were exposed to three temperature treatments: 1) control (18°C constant), 2) heat stress (18 to 32°C increase over 15 days), and 3) cold stress (18 to 6°C decrease over 15 days. Next, we determined how symbiosis modulates the symbiont’s response to thermal extremes, and replicated the above experimental design but with *B. psygmophilum* cultured from *O. arbuscula.* At the end of both experiments, samples were flash-frozen and prepared for whole-genome gene expression profiling using TagSeq. When comparing gene expression profiles of *B. psygmophilum* symbionts in and out of symbiosis, we found that there were many more genes differentially expressed in response to thermal extremes in culture relative to in symbiosis and gene expression plasticity was greater for *B. psygmophilum* in culture compared to in symbiosis. Additionally, when in symbiosis, there were more differentially expressed orthologs in the host compared to the symbiont. Thus far, these two experiments support our host buffering hypothesis. While analyses are ongoing, it is clear that testing these questions in facultatively symbiotic corals and their cultured symbionts across thermal extremes will enrich our understanding of the molecular mechanisms underlying symbiosis maintenance and loss in corals.

Oral
A-1803

Identifying heat stress correlated metabolites in reef building corals using polar LCMS based metabolomics

Chiles, E.[1], Bhattacharya, D.[2], Su, X.[3]
[1]Rutgers University, Graduate Program in Microbial Biology, Molecular Biology and Biochemistry, Cancer Institute of New Jersey Metabolomics Shared Resource, New Brunswick, United States
[2]Rutgers University, Molecular Biology and Biochemistry, New Brunswick, NJ, United States
[3]Rutgers University, Department of Medicine, New Brunswick, United States

enchiles[at]cinj.rutgers.edu

Abstract

Coral reefs are under threat globally due to anthropogenic climate change. Understanding the relationship between the coral holobiont, the animal host and its algal and bacterial symbionts, is essential for conservation efforts. Previously we used LCMS based metabolomics and statistical analysis tools to reveal metabolomic features correlated with prolonged heat stress. Features showing increased levels with prolonged heat stress were annotated based on accurate mass, retention time, and the MS^2 spectra match to chemically synthesized pure standards. We validated several dipeptides that are significantly enriched during heat stress. This data raises questions regarding the origin of dipeptide enrichment and nitrogen metabolism in the holobiont.

We designed a controlled time course experiment using nubbins from three species of coral, the heat tolerant *Montipora capitata* & *Porites compressa* and the heat sensitive *Pocillopora acuta*, all of which are endemic to the Hawaiian reef in Kaneohe Bay, Oahu. Samples were transplanted to tanks with water-flow directly from the bay and subjected to either ambient or high temperatures, i.e., 26°C or 31°C, for 15 days. Samples were collected at regular intervals for stable isotope enrichment using 100µM $^{15}NH_3$ for 18 hours before targeted and untargeted LCMS analysis under both positive and negative polarities. The ^{15}N enrichment was determined using AccuCor natural abundance corrector.

Isotopic tracer incorporation was observed in dipeptides. In contrast to observed results from other primary metabolites, dipeptides are significantly enriched following incubation. Averaged isotopic enrichment per nitrogen atom is 16.3% ± 4.1% (mean ± SD). This was consistent among all coral species suggesting there is a high turnover of dipeptide pools. Statistically significant intra-group isotopic enrichment was not observed. The disparity in the labeling incorporations among amino acids and dipeptides, suggests there are distinct biosynthetic mechanisms mediating amino acid and dipeptide production. These preliminary data show there is direct nitrogen incorporation into dipeptide production unobserved in other metabolite classes. This suggests that nitrogen assimilation in the coral holobiont is compartmentalized, with rapid assimilation and quick dipeptide turnover occurring in one region of the holobiont and slow turnover of other nitrogen containing metabolites in another region. Work exploring nitrogen assimilation is ongoing.

Oral
A-1256

Gene expression analysis of triploid and diploid cauliflower coral (Pocillopora acuta) reveals signals of natural selection on polyploid lineages

Chille, E.[1], Misri, D.[1], Stephens, T.[1], Strand, E.[2], Putnam, H.[2], Bhattacharya, D.[1]
[1]Rutgers University, Department of Biochemistry and Microbiology, New Brunswick, United States
[2]University of Rhode Island, Department of Biological Sciences, Kingston, United States

echille124[at]gmail.com

Abstract

In corals, polyploidy can act as an important source of intraspecific variation that drives natural selection. Previous work in Kāneʻohe Bay, Hawaiʻi showed that out of 119 *Pocillopora acuta* samples collected, approximately 60% belonged to two triploid clades, whereas 40% clustered into a diploid clade. We identified differences in gene expression profile between these triploid and diploid lineages. Gene expression profiles of the triploid individuals correlated more strongly by clade than by ploidy, therefore, we conducted pairwise comparisons between the two triploid clades (T1 and T2) and the diploid clade (D). We find that the triploid clades share a large number of differentially expressed genes, however there is an equally large number that are differentially expressed between the two triploid groups. These results provide support for two polyploidization events in Kāneʻohe Bay *P. acuta* populations, and show that clade membership is a better predictor of gene expression than ploidy alone. Differences in gene expression between the two triploid groups may be the result of differential transcriptional regulation. Shared differentially expressed genes among triploids, when compared to the diploid group, may indicate biological processes impacted by triploidy. Gene ontology enrichment analysis was done to identify functionally important gene expression differences within and between ploidy groups. This approach showed that protein phosphorylation and signal transduction are upregulated in triploids, whereas gene silencing by RNA, spermatogenesis, and protein glycosylation are among the processes downregulated in these lineages. The gene ontology results also show that genes associated with protein modification mechanisms and developmental signaling pathways, including wnt and notch, are differentially expressed between the two triploid *P. acuta* clades in Kāneʻohe Bay and may be signals of divergent selection between them. These preliminary results highlight how polyploidy can drive intraspecific variation in corals, and is the first step in understanding how large-scale genome growth reflects the forces of natural selection acting under increasing anthropogenic stress and climate change.

Oral
A-1980

Patterns of Somatic Mutation Accumulation in Acropora palmata

Conn, T., Baums, I.
The Pennsylvania State University, University Park, United States

tlc458[at]psu.edu

Abstract

The accumulation of somatic mutations during the lifetime of an organism is traditionally seen as a detriment because mutations increase the potential for cancer and contribute to senescence. However, in clonal organisms such as corals, this intra-organismal genetic variation can be a source of potential adaptive variation. This is because the modular organization can insulate the genet from deleterious mutations in some modules while allowing beneficial mutations to rise to high frequency in others. Here, we study the extent of somatic genetic variation across a branch of a large colony of *Acropora palmata* estimated to be at least 150 years old in Curacao. 28 samples of tissue were collected approximately every 10 cm along one branch from the base to the tips of a single colony of *Acropora palmata.* These samples were then genotyped using the Applied Biosystems Axiom Coral Genotyping Array – 550962. Somatic mutations can be difficult to distinguish from technical errors and thus we used restriction fragment length polymorphisms to verify putative somatic mutations. After stringent filtering, 252 somatic mutations were identified out of 19,696 single nucleotide polymorphisms. Of these mutations, 237 (94.0%) led to a gain of heterozygosity mutations and 15 (6.0%) led to a loss of heterozygosity. Somatic mutations did not accumulate linearly from base to tips of the sampled branch and thus the phylogeny of somatic mutations found at the tips is not representative of their geographic distance. This data was then replicated using whole genome sequencing to a depth of 80x. Instead, the pedigree of polyps based on the inheritance pattern of these somatic mutations is more complicated. Analysis of the ancestral genotype of these polyps and sub-clonal structure along the colony will provide an insight into the growth process of coral colonies and how potentially beneficial mutations may rise to high frequency in parts of a colony. Such a detailed picture is needed to build a framework for understanding the impact of module-level selection on adaptive genetic variation in coral populations and to assess the potential contribution of asexual evolution in clonal organisms.

Oral
A-1140

A sea anemone cell atlas illuminates the molecular mechanisms underlying Darwin’s paradox

Cui, G.[1], Konciute, M.[1], Ling, L.[2], Esau, L.[1], Raina, J.-B.[3], Han, B.[1], Salazar, O.[1], Persnell, J.[4], Rädecker, N.[1, 5, 6], Zhong, H.[1], Menzies, J.[1], Cleves, P.[7], Liew, Y. J.[1], Krediet, C.[8], Lapacek, V.[4], Cziesielski, M.[1], Guagliardo, P.[9], Bougoure, J.[9], Pernice, M.[3], Hirt, H.[1], Voolstra, C.[1, 5], Weis, V.[4], Pringle, J.[2], Aranda, M.[1]
[1]King Abdullah University of Science and Technology, Thuwal, Saudi Arabia
[2]Stanford University School of Medicine, Stanford, United States
[3]University of Technology Sydney, Ultimo, Australia
[4]Oregon State University, Corvallis, United States
[5]University of Konstanz, Konstanz, Germany
[6]École Polytechnique Fédérale de Lausanne, Lausanne, Switzerland
[7]Carnegie Institution for Science, Baltimore, United States
[8]Eckerd College, St. Petersburg, United States
[9]The University of Western Australia, Perth, Australia

guoxin.cui[at]kaust.edu.sa

Abstract

Symbiotic cnidarians, such as corals and anemones, build one of the world's most productive and biodiverse ecosystems, coral reefs, in one of the most nutrient-poor environments. This "Oasis-in-the-desert" phenomenon, also known as Darwin's Paradox, has been highly debated for the past 200 years. Many studies have tried to solve this mystery by investigating potential hidden nutrient sources of reef ecosystems. The proposed answers include cavity-dwelling sponges, small cryptobenthic reef fishes, and chronic ocean upwelling. However, the fundamental question of how exactly symbiotic cnidarians manage to thrive in these environments still remains unanswered. Solving this so-called paradox requires deciphering the molecular bases of the high nutrient efficiency of cnidarian-dinoflagellate holobionts. Using the sea anemone Aiptasia, we show that symbiosis induces changes in the expression and localization of essential ammonium and glucose transporters in the host to direct and control nutrient fluxes in support of symbiosis and nutrient efficiency. Specifically, we find that the host relocates ammonium transporters to provide symbionts with essential nitrogen and to increase its own capacity to recycle and take up ammonium from the surrounding seawater. We further show that the photosynthesis-derived sugar provided by the symbionts is distributed throughout all tissues to allow assimilation of waste ammonium via the GS/GOGAT cycle and subsequent amino-acid biosynthesis. By combining tissue- and cell-specific gene and isotope profiling with molecular characterization of critical transporters, we illuminate the molecular mechanisms through which symbiosis allows these organisms to become highly nitrogen efficient and to build the largest living structures on earth in oligotrophic environments. Our findings provide a central piece to the puzzle of Darwin's Paradox and pave the way for a better understanding of cnidarian-dinoflagellate photosymbiosis.

Oral
A-1234

Oxidative stress and protein changes: Understanding cellular response mechanism in Scleractinian coral Acropora digitifera

Jaafar, S. N., Maznan, N. A., Chun Hong, T.
Universiti Malaysia Terengganu, Faculty of Science and Marine Environment, Kuala Nerus, Malaysia

tahirah[at]umt.edu.my

Abstract

Coral reefs are vulnerable to numerous stressors and these stressors could lead to oxidative stress in coral. Prolonged exposure to stressors may cause coral reef degradation, thus it is crucial to understand the cellular mechanism involved in coral behind this situation. In this study, the activity of antioxidant enzymes glutathione S-transferase (GST) and catalase (CAT) in Scleractinian coral *Acropora digitifera* were investigated in order to understand their variations with respect to different sampling sites and sampling times. The result demonstrated variation in GST activities with highest level in May ($P<0.05$) and in contrast, no significance difference in CAT activities between different sampling months and sites ($P>0.05$). In addition, the coral samples collected in Pantai Pasir Cina showed highest antioxidant activities for both enzymes suggesting coral in this location are exposed to higher level of oxidative stress. Furthermore, oxidative stress producing reactive oxygen species (ROS) is able to affect proteins in coral, therefore, protein analysis through sodium dodecyl sulfate-polyacrylamide gel electrophoresis (SDS-PAGE) was used for the separation of proteins and following SDS-PAGE electrophoresis, six protein bands; three from May samples (~24-70 kDa) and three form July samples (~32-43 kDa) were selected for further sequencing by liquid chromatography-tandem mass spectrometry (LC-MS/MS). A total of 2330 proteins were identified and sorted based on molecular and biological function to select the protein of interest. Identified proteins focused on proteins that associated with the response of coral to stressors, cell signalling, apoptosis, metabolism, cytoskeleton, immune system and transport. These results highlight key differences in proteins of interest that shows promising candidates for biomarkers that involved mainly in oxidative stress response (heat shock cognate 71 kDa protein, peroxiredoxin-4, pyruvate kinase, retinal dehydrogenase, protein disulphide isomerase, carbonyl reductase), apoptosis (calreticulin, cytochrome c oxidase) as well as immune-related proteins (mannose-binding lectin, ferritin). These present findings provide an insight on the response of *A.digitifera* to environmental stressors and potential implications for future marker to use for early warning of oxidative stress in coral.

Oral
A-1760

From lists to function - Spatial proteomics as a tool to map the protein cellular landscape of Symbiodiniaceae

Krueger, T.[1], Barylyuk, K.[1], Lilley, K.[1], Knowles, H.[1], Atatüre, M.[2], Sweet, M.[3], Waller, R.[1]
[1]University of Cambridge, Department of Biochemistry, Cambridge, United Kingdom
[2]University of Cambridge, Department of Physics, Cambridge, United Kingdom
[3]University of Derby, School of Built and Natural Environment, Derby, United Kingdom

tk556[at]cam.ac.uk

Abstract

Identifying the subcellular localization of proteins is an essential pre-requisite for understanding the functions of proteins and for establishing cellular maps of protein activity. Spatial proteomics, based on cell fractionation and mass spectrometry, has enabled the creation of global cellular proteome maps of thousands of proteins and resolved the compositional architecture of cells to the level of subcellular compartments and even molecular complexes. Symbiotic dinoflagellates of the family Symbiodiniaceae are of exceptional importance to the health and productivity of coral reefs. Using LOPIT (Location of Organelle Proteins by Isotopic Tagging) spatial proteome mapping, we will provide a comprehensive, high-resolution view of the cellular proteomic architecture of a symbiotic member of this family. LOPIT data is based on mass spectrometric assessment of specific protein abundance profiles across subcellular fractions collected from a density gradient. We will demonstrate its applicability and present a spatial proteomics dataset for a cultured Symbiodiniaceae strain. Considering the particular adaptations in cellular morphology and pathway activity as the cell transitions from its motile, free-living life style into a vegetative, nitrogen-limited state when engaged in symbiosis, comparative LOPIT will provide a detailed view on the symbiosis-induced plasticity of cellular protein architecture.

Oral
A-1411

Calcium homeostasis disruption initiates rapid growth after micro-fragmentation in the scleractinian coral Porites lobata

Lock, C.[1], Bentlage, B.[2], Raymundo, L.[2]
[1]University of Guam, Mangilao, United States
[2]University of Guam, Mangilao, Guam

clockdive[at]gmail.com

Abstract

Coral reefs are ecosystems under increasing threat from global climate change. Coral restoration is a tool for preserving biological and ecological function of coral reefs by mitigating coral loss and maintaining the structural integrity and complexity of reefs. To generate the necessary stock for coral restoration, larger coral colonies are usually fragmented to generate smaller specimens for outplanting, taking advantage of the high regenerative ability of corals. In this study, we utilized RNA-seq technology to understand the physiological responses of *Porites lobata* colonies to physical fragmentation and outplanting, which have thus far not been characterized. Our results demonstrate that P. lobata fragments undergoing physical injury recover through two distinct phases: rapid wound regeneration of the cut margins, followed by a slower growth phase that cements the colony to the substrate. Our study found *rapid* physiological responses to acute physical injury and outplanting in the coral host that involved significantly increased energy production, calcium homeostasis disruption, and ER stress leading to increased antioxidant expression and rates of protein turnover. Our results suggest that phosphoinositide-mediated acute calcium homeostasis disruption stimulates wound recovery processes in response to physical injury. Contrary to other coral transcriptomic experiments, symbiont gene expression revealed extremely low gene differences in response to fragmentation, growth, and outplanting. These results provide insight into the physiological mechanisms that allow for rapid wound healing and stabilization in response to physical injury in corals.

Oral
A-1098

Rhodobacteraceae dominate the microbiome and metabolism of corals infected with white syndrome

Mohamed, A.[1], Ochsenkühn, M.[1], Abrego, D.[2], Amin, S. A.[1]
[1]New York University Abu Dhabi, Biology, Abu Dhabi, United Arab Emirates
[2]Southern Cross University, National Marine Science Centre, Lismore, Australia

are6747[at]nyu.edu

Abstract

Corals living in extreme conditions represent a unique opportunity to study coral populations experiencing end-of-century temperatures such as those of the southern Persian/Arabian Gulf (PAG). PAG corals are exposed to large fluctuating sea surface temperatures (reaching 11°C in the Winter and exceeding 36°C in the Summer). These conditions exceed the survival limits of most corals on the planet, leading to more frequent episodes of bleaching events and temperature-driven disease outbreaks, including the infectious disease white syndrome (WS). Here, we generated shotgun metagenomic data from colonies of the coral *Acropora downingi* from the PAG to investigate structural and functional changes in the coral microbiome associated with disease manifestations. Corals were sampled at both WS lesion and adjacent lesion sites in WS-affected colonies along with healthy colonies as control. Diversity and richness indices were significantly higher in the lesion and adjacent lesion sites compared to healthy colonies. The microbial consortium differed significantly between the three groups, with enrichment in Rhodobacteraceae and Synechococcaceae at WS lesion and adjacent lesion sites compared to controls. Local and systemic (colony-wide) responses of the coral microbiome were evident in the microbial composition of adjacent lesion samples, which were intermediate between lesion and healthy samples. This observation parallels previously-reported local and systemic gene expression responses of the coral host during WS manifestation, suggesting a synchronized response of the coral holobiont to the disease. To understand the potential functional roles of these bacterial assemblages, we assembled 11 high-quality metagenomic-assembled genomes (MAGs) from the WS-affected colonies, three of which belonged to Rhodobacteraceae (MAG2, MAG6, and MAG7). Using functional annotations of the Rhodobacteraceae MAGs and metabolomics collected simultaneously with metagenomic sampling, we uncover the role this family of bacteria plays in disease manifestation. These microbial species and molecules could further be used as WS bio-markers to better understand and predict WS etiologies, which remain elusive.

Oral
A-1864

New high-quality genomes and full-length transcripts of Aiptasia to benefit the coral community

Nagarajan, A. P., Salazar, O. R., Lastra, M. A.
King Abdullah University of Science and Technology, Red Sea Research Center, Thuwal, Saudi Arabia

arun.nagarajan[at]kaust.edu.sa

Abstract

The sea anemone Aiptasia (Exaiptasia pallida) is widely used as a model organism to understand several nuances of coral symbiosis. In this work, we sequenced the genomes of three clonal Aiptasia lineages including H2 from Hawaii, RS from the Red Sea, as well as the previously sequenced CC7 strain from North Carolina using a combination of PacBio and 10X Genomics sequencing. The genome assemblies show overall high N50 values (3.7 Mb for H2, 3.2 Mb for RS and 1.9 Mb for CC7) and >93% completeness (BUSCO).
To further increase the quality of these resources, we performed PacBio Iso-Seq to sequence full-length isoforms. We obtained 15,470 unique full-length transcripts (FLT) of which, 1,570 full-length non-redundant transcripts (FLT-nr) were used as a training set for gene prediction (AUGUSTUS) along with existing RNA-seq data. We define a transcript as FLT-nr, that contains a single 5' and 3' UTRs over its entire length, at least three exons and a protein sequence alignment coverage >40% against its homolog from the Swiss-Prot database.
These new genome assemblies and FLT dataset will be an excellent resource for the community in several aspects. The high-quality assemblies will facilitate comparative genome analyses within and across species to identify gene clusters, analyze regulatory regions, and highlight the genetic factors underlying traits of interest, such as thermal tolerance plasticity. While, the identification of expressed isoforms will further serve as a valuable asset to study basic gene regulatory events (e.g., splicing) and the difference in isoform-specific expression within Aiptasia.

Oral
A-1704

Multi-omic gene expression under thermal stress in three symbiont genera: identifying the core bleaching response

Oakley, C. A.[1], Nitschke, M.[1, 2], Camp, E.[3], Kahlke, T.[3], Ros, M.[3], Leggat, B.[4], Davy, S.[1], Suggett, D.[3]
[1]Victoria University of Wellington, School of Biological Sciences, Wellington, New Zealand
[2]Australian Institute of Marine Science, Townsville, Australia
[3]University of Technology Sydney, Climate Change Cluster, Sydney, Australia
[4]University of Newcastle, School of Environmental and Life Sciences, Newcastle, Australia

clint.oakley[at]vuw.ac.nz

Abstract

The links between elevated temperatures, coral bleaching, and impaired physiology of the dinoflagellate symbionts of corals, family Symbiodiniaceae, are well-established. To understand the diversity of coral symbiont responses to thermal stress, the identification of thermally induced changes in gene expression is critical. Transcript-based gene expression studies, however, have noted that gene expression in dinoflagellates does not appear to be well correlated to transcription rates, potentially owing to the many distinct features of dinoflagellate DNA packaging, transcription factors, and translational machinery. We used a combination of transcriptomic and proteomic analyses to investigate the effects of thermal stress on cultured isolates of three Symbiodiniaceae species: *Breviolum sp.*, *Cladocopium goreaui*, and *Durusdinium trenchii*. For both analyses, samples were taken from cultures kept at 25 °C or exposed to 32 °C for two or seven days. RNASeq-based gene models were constructed, quantified, and the resulting sequences for each species used as search databases for data-dependent mass spectrometry-based proteomics with label-free quantification. Over 3,500 protein/mRNA pairs were identified from each species. As expected, the three species varied in their physiological and gene expression responses to thermal stress. The number and degree of changes in transcript and protein abundances were correlated with the physiological responses. Gene enrichment analysis was performed to identify the processes and components most affected by elevated temperatures. The correlations between transcript counts and protein abundances under steady-state and stressed conditions were also analysed to inform our understanding of dinoflagellate gene expression mechanisms and future experimental design. This combined omics approach allowed us to determine: 1) the photosynthetic and cellular changes induced by thermal stress, 2) differences in the tolerance to thermal stress and associated mechanisms in different genera, and 3) whether a “core” thermal stress response is shared amongst Symbiodiniaceae.

Oral
A-1194

Metagenomic analysis of bacterial microbiomes associated with SCTLD lesions from Montastraea cavernosa

Rubin, E.[1], Ushijima, B.[2, 3], Abey, G.[3], Hase, C.[4], Paul, V.[3], Meyer, J.[1]
[1]University of Florida, Department of Soil and Water Sciences, Gainesville, FL, United States
[2]University of North Carolina, Department of Biology & Marine Biology, Wilmington, NC, United States
[3]Smithsonian Marine Station, Ft. Pierce, FL, United States
[4]Oregon State University, Corvallis, OR, United States

ewelinarubin[at]ufl.edu

Abstract

Stony coral tissue loss disease (SCTLD) is leading to extensive coral losses on reefs in Florida and the Caribbean. The direct causes or etiological agents of the SCTLD have not been identified, but the abundance of multiple bacterial taxa has been shown to increase in coral tissue lesions compared to healthy coral tissue. To provide an insight into the bacterial role in the SCTLD infection process and disease progression, we conducted a set of SCTLD-transmission experiments followed by metagenomic shotgun sequencing of DNA extracted from healthy, diseased, and newly infected coral tissue. The 16S rRNA gene abundance profiling revealed enrichment of four major bacteria groups: Clostridia, Bacteroidetes, Alpha- and Deltaproteobacteria in SCTLD lesions in comparison to healthy coral tissue. The metagenomic analysis led to the assembly of 52 bacterial MAGs (metagenomic assembled genomes, >60% completeness and <10% contamination), which were functionally annotated and examined for the possible presence of bacterial toxin and extracellular enzymes homologs as well as description of their secretion systems, biofilm formation, and chemotaxis and flagellar assembly related proteins. The present description of bacterial virulence factors in SCTLD lesions will lead to better understanding of bacterial role in coral tissue degradation and digestion during SCTLD progression and provide molecular targets for the development of SCTLD treatment and genetic functional investigations.

Oral
A-1460

The coral Acropora loripes genome reveals an alternative pathway for cysteine biosynthesis in animals

Salazar, O. R.[1, 2], Prasanna N., A.[1, 2], Cui, G.[1, 2], Bay, L. K.[3, 4], van Oppen, M. J. H.[3, 5], Webster, N. S.[3, 6, 7], Aranda, M.[1, 2]
[1]King Abdullah University of Science and Technology, Marine Science Program, Biological and Environmental Sciences and Engineering Division, Thuwal, Saudi Arabia
[2]King Abdullah University of Science and Technology, Red Sea Research Center, Thuwal, Saudi Arabia
[3]Australian Institute of Marine Science, Townsville, Australia
[4]AIMS[at]JCU, Division of Research & Innovation James Cook University, Townsville, Australia
[5]University of Melbourne, School of BioSciences, Melbourne, Australia
[6]Australian Centre for Ecogenomics, University of Queensland, Brisbane, Australia
[7]Australian Antarctic Division, Department of Agriculture, Water and the Environment, Kingston, Australia

octavio.salazarmoya[at]kaust.edu.sa

Abstract

The metabolic capabilities of animals have been derived from well-studied model organisms and are generally considered to be well understood. In animals, cysteine is an important amino acid thought to be exclusively synthesized through the transsulfuration pathway. Mutations in the cystathionine β-synthase (*CBS*) gene, a key enzyme for cysteine biosynthesis, lead to homocystinuria in humans, resulting in cardiovascular disease, optic lens dislocation, psychiatric disorders, and skeletal abnormalities. Corals of the genus *Acropora* have lost CBS and it was proposed that *Acropora* relies on the symbiosis with dinoflagellates of the Symbiodiniaceae family for the acquisition of cysteine. Cysteine is required for the production of glutathione, an important and crucial antioxidant for the response to reactive oxygen species generated by the symbiont under heat stress. It was, therefore, proposed that the reliance on symbiont derived cysteine may contribute to the increased susceptibility of *Acropora* species to thermal bleaching compared to many other coral genera. Through the sequencing and analysis of the genome of *Acropora loripes*, we identify the existence of an alternative pathway for cysteine biosynthesis in animals. We demonstrate that these coral proteins are functional and synthesize cysteine *in vivo*, exhibiting previously unrecognized metabolic capabilities of animals. Furthermore, it shows that corals of the genus *Acropora* have the required machinery for cysteine biosynthesis and might thus not depend on symbiosis with Symbiodiniaceae algae for its acquisition. Interestingly, this pathway is present in most animals but absent in mammals, arthropods, and nematodes, precisely the groups where most of the animal model organisms belong to. This highlights the risks of generalizing findings from model organisms and exemplifies how much knowledge there is to gain through the study of corals and marine organisms.

Oral
A-2050

Spatiotemporal variability of coral virus communities in Moorea French Polynesia with comparison of 5 high-throughput metagenomic preparation methods

Schmeltzer, E.[1], Gaulke, C.[2], Thurber, A.[1], Correa, A.[3], Sharpton, T.[1], Vega Thurber, R.[1]
[1]Oregon State University, Microbiology, Corvallis, United States
[2]University of Illinois Urbana-Champaign, Pathobiology, Champaign, United States
[3]Rice University, Houston, United States

schmelte[at]oregonstate.edu

Abstract

Viruses are the most abundant biological entities in the ocean, and 10x more abundant on reef-building coral surfaces than in the surrounding seawater. While correlations between viral load and coral decline have been previously documented, it is unknown how coral physiology correlates with viral infection and pathogenicity in the face of environmental disturbances. Additionally, the diversity and function of coral viruses as part of the coral holobiont may shed light on the mechanisms that contribute to spatiotemporal trends in coral bleaching and disease. Evaluating trends in viral diversity and function in such underexplored systems is best accomplished through the use of metagenomics; however, current approaches are expensive and labor-intensive. While an increasing number of commercial methods for preparing metagenomes are now available, we have little insight into differences in the quality and cost-effectiveness of these resources. Thus we evaluated 5 preparation methods for metagenomic sequencing using coral, soil, and fecal DNA samples. The abundance profiles generated by all methods strongly correlated with the known taxonomic composition of a microbial community DNA standard (r=0.94-0.97). As a result we found that more cost-effective methods may meet similar sequencing goals of the coral -omics community. Using these new metagenomic approaches we then assessed the viral relative abundance and diversity on an island-wide spatiotemporal scale in Mo'orea, French Polynesia, from coral tissues spanning three coral host species, three reef types, and varying levels of nutrient enrichment from 21 sites. Approximately 120 metagenomic samples were sequenced for genome assembly and gene annotation in order to gain insight on differences in regional bacterial and viral diversity, abundance, and function. We used the relative viral taxonomic abundance and diversity in conjunction with current and historical nutrient data from the Mo'orea Coral Reef LTER to determine which environmental variables may contribute to viral production in different coral species and across various reef types under typical conditions, as well as during an extreme thermal anomaly. We found that site, island region, and host were the strongest explanatory variables for significant differences in microbial composition and function. We will continue to analyze these data to determine linkages between the microbiome and virome of these corals and reef health around the island.

Oral
A-1324

Global Search: Elucidating signatures of thermal tolerance for conservation of coral reefs using short-term standardized heat stress assays (CBASS)

Voolstra, C. R.[1], Barshis, D. J.[2], Valenzuela, J. J.[3], Baliga, N.[3], Bay, L.[4], Baums, I. B.[5]
[1]University of Konstanz, Department of Biology, Konstanz, Germany
[2]Old Dominion University, Department of Biological Sciences, Norfolk, VA, United States
[3]Institute for Systems Biology, Seattle, WA, United States
[4]Australian Institute of Marine Science, Townsville, Australia
[5]The Pennsylvania State University, Department of Biology, University Park, Germany

chris.voolstra[at]gmail.com

Abstract

A global approach to elucidate thermal tolerance signatures has not yet been attempted due to the complexity of running standardized thermal stress experiments across a large number of sites, species, and regions within a timeframe that is amenable to direct cross-comparison. Short-term heat stress experiments allow for such global investigations. Here we present first results from the “Global Search” project funded by the Paul G. Allen Family Foundation that uses the Coral Bleaching Automated Stress System (CBASS) to (1) identify coral populations that are thermally tolerant across the Caribbean, Pacific, Great Barrier Reef, and Arabian Seas and (2) investigate their genomic underpinnings and elucidate conserved signatures of heat tolerance across all major holobiont compartments. Based on a proof-of-principle pilot study, we show that our approach can resolve thermal tolerance differences in holobionts across the Red Sea, accompanied by contrasting molecular response patterns that can be used as a starting point for the development of resilience biomarkers. We highlight the high reproducibility of the CBASS platform, making it possible to compare thermal tolerance differences between colonies in the same reef and our efforts to build an open access global database to support action on conservation and restoration efforts at local, regional, and global scales.

Poster
A-1744

Inside out: Transcriptome assembly and differential gene expression during polyp bailout in Pocillopora acuta

Gösser, F.[1], Raulf, A.[2], Mosig, A.[2], Tollrian, R.[1], Schweinsberg, M.[1]
[1]Ruhr University Bochum, Department of Animal Ecology, Evolution and Biodiversity, Bochum, Germany
[2]Ruhr University Bochum, Department of Bioninformatics, Bochum, Germany

fabian.goesser[at]rub.de

Abstract

Coral reefs around the world are increasingly facing acute environmental changes. Marine heatwaves place particularly severe stress on corals and can lead to high coral mortality. Due to their sessile lifestyles and inability to avoid periods of stress simply by relocating, corals have developed various strategies to overcome these challenges. However, a stress response called polyp bailout, which might allow corals to survive detrimental conditions, is underrepresented in scientific studies. During polyp bailout, the colonial integrity of the coral is broken down. The coenosarc dissolves, and individual polyps withdraw from the colony and can be relocated by water flow. To investigate the signaling pathways of polyp bailout in *Pocillopora acuta* under heat stress, we performed stress experiments and tested differential gene expression using RNAseq and a qPCR assay. In addition, polyp bailout was induced by hypersalinity conditions comparing gene expression between the two stressors to identify stressor-independent signals and pathways active during polyp bailout. Both stressors induced polyp bailout and vital polyps could be collected. Activation of microbe-associated molecular pattern receptors and downstream signaling pathways of the innate immune system was detected. Growth factors and genes active during Wnt signaling, may contribute to wound healing, regeneration, and proliferation. In addition, upregulation of matrix metalloproteinases and the fibroblast growth factor signaling pathway are most likely responsible for extracellular matrix remodeling as well as the detachment process of polyps from the calcium skeleton during polyp bailout. A qPCR assay confirmed our results, and the genes of vital polyps from our heat stress experiment showed a trend toward normalization of gene expression after polyp bailout. These results provide new insights into the signaling cascades that lead to the observed physiological responses during polyp bailout. The stressor-independent nature of certain signaling pathways suggests that polyp bailout is a general response of corals to acute stress. Immune system signaling during polyp bailout may indicate the involvement of microbe-associated partners in triggering the polyp bailout response. However, further research is needed to better understand this specialized stress response, its application in model systems, and the potential ecological implications of polyp bailout in stressed coral reefs.

Poster
A-1909

Biomarkers of stress in coral reef ecosystems

Quinlan, Z.[1], Koester, I.[1], Petras, D.[2, 3, 4], Sparagon, W.[5], Comstock, J.[6], Carlson, C.[6], Dorrestein, P.[3], Haas, A.[7], Aluwihare, L.[1], Nelson, C.[5], Wegley Kelly, L.[1]
[1]Scripps Institution of Oceanography, San Diego, United States
[2]University of Tuebingen, Controlling Microbes to Fight Infections Cluster of Excellence, Tuebingen, Germany
[3]University of California San Diego, Skaggs of Pharmacy and Pharmaceutical Sciences, San Diego, United States
[4]University of California San Diego, Collaborative Mass Spectrometry Innovation Center, San Diego, United States
[5]University of Hawai'i at Manoa, Department of Oceanography and Sea Grant College Program, Center for Microbial Oceanography Research and Education, Honolulu, United States
[6]University of California Santa Barbara, Department of Ecology, Evolution, and Marine Biology, Santa Barabara, United States
[7]NIOZ Royal Netherlends Institute for Sea Research and Utrecht University, Department of Maribe Microbiology and Biogeochemistry, Den Burg, Netherlands

zquinlan[at]gmail.com

Abstract

Corals and other marine primary producers exude a portion of their fixed carbon budget into the surrounding water column. In addition to photosynthate, this exometabolite pool includes compounds biosynthesized by the coral animal (e.g., secondary metabolites) as it responds to the metabolism of a suite of symbionts. Corals release classes of organic compounds that are chemically distinct from all other marine producers, providing a novel application for monitoring physiological indicators of coral stress in experimental settings and in the environment. High resolution untargeted mass spectrometry is allowing us to characterize the coral holobiont responses to stress through the analysis of shifts in exometabolomes. This characterization is vital as corals face higher levels of stress as a result of increasing abiotic stressors and climate change. Moreover, understanding how coral specific exometabolites shift under environmental stress will be crucial in the development of methods for early diagnosis of coral stress. To begin understanding these dynamics, we experimentally monitored the production of exometabolites by three species of coral (Acropora sp., Pocillopora verrucosa, and Porites rus) in Mo’orea, French Polynesia, under ambient (28˚C) and elevated temperatures (31˚C). We evaluated the compositional changes of these metabolites over five days as these corals bleached. We measured concentrations of dissolved organic carbon, fluorescent dissolved organic matter and characterized the exometabolites using liquid chromatography tandem mass spectrometry (LC-MS/MS). We also monitored the change in the bacterioplankton community over the extent of the experiment to determine how the selected communities shift in response to stress-metabolites. Our study advances the identification of biomarkers of stress released by corals during heat stress and how these stress-metabolites drive changes in the microbial community on reefs. Continued studies using metabolomics to investigate compositional shifts of the exometabolomes under different stressors will allow for better assessments of reef health and better understandings of how these stressors can lead to phase shifts.

Poster
A-1625

Lipid profile of coral adapted to ambient temperature relating to the physiological function

Tang, C. H.[1, 2], Lin, C.-Y.[3], Wang, W.-H.[2]
[1]National Museum of Marine Biology and Aquarium, Pingtung, Taiwan
[2]National Sun Yat-sen University, Department of Marine Biotechnology and Resources, Kaohsiung, Taiwan
[3]National Taiwan University, Institute of Environmental and Occupational Health Sciences, Taipei City, Taiwan

chtang[at]nmmba.gov.tw

Abstract

Thermal stress leading to mass scleractinian coral bleaching and mortality discloses a high susceptibility to temperature change with the coral. Membrane lipids constitute the basic structural element to create a cell a dynamic structure according to the circumstance. The lipid profile of coral responded to a difference in ambient temperature could be a specific biomarker as well as give an insight into the mechanism of thermal effect. Glycerophosphocholine profiling of the coral Seriatopora caliendrum responded to different ambient temperature (26.5–29.5°C) for 2–8 days was therefore performed using a lipidomic methodology. A quantitative model for a thermal sensation of coral was developed by correlating the lipid variations with the incubated temperature. Interestingly, variations in the lipid profile were also modeled well based on the activity of carbonic anhydrase in coral. Based on the physicochemical properties, the changed lipids logically indicated accommodation to the thermal perturbation of cellular membrane dynamics in coral. This implicates a basic action model of thermal stress influencing coral physiology, such as carbonic anhydrase activity.

Poster
A-1422

Genetic resources and coral biodiversity of seamount in West Pacific

Woo, S., Jo, Y.
Korea Institute of Ocean Science and Technology, Busan, South Korea

cwoo[at]kiost.ac.kr

Abstract

Seamounts are relatively small sub-marine volcanoes that develop adjacent to mid-oceanic ridges, on the oceanic crust and also in extensional forearc basins along the island arcs. Since seamounts are volcanic and host active hydrothermal convective systems, seamounts have a significant effect on element cycles involving sea water and its dynamic interaction with the ocean crust. They may also have a significant influence on global ocean circulation patterns because their presence induces much greater mixing than is measured in areas with smooth bottom topography. Seamounts have a great effect on circulation patterns and currents, which in turn have very important effects on seamount biota. In general, seamounts host very diverse and abundant faunas, with important effects on oceanic biology. In this study, we explored seamounts in West Pacific, approximately 400km northeast from Guam, using ROV(remotely operated vehicle) and RV *Onnuri* to investigate the deep-sea fauna and biodiversity around the seamounts and aimed construction of the ecological map and discovery of biological resources, particularly from cnidarian. First of all, we purposed sampling of deep-sea coral species among the cnidarian and extracted its RNA and DNA. We constructed transcriptomic assemblage of 3 deep sea corals (Rohdanirdogorgia. Sp., Chrysogorgia stellata, Calyptrophora lyla) after de novo RNA sequencing to investigate further gene expressions in abiotic extreme environment and also to discover differentially expressed genes comparing between deep-sea environment and shallow water species or cold water and trophic coral species.

Session 7H - Where are coral reefs now and where are they headed: The status of coral reefs of the world in 2020

Conceptualized by: **David Souter** [1], **David Obura**[2], **Serge Planes**[3], **Supin Wongbusarakum**[4]
[1] Australian Institute of Marine Science (Townsville, Australia)
[2] CORDIO East Africa (Mombasa, Kenya)
[3] CRIOBE (Moorea, French Polynesia)
[4] NOAA Pacific Island Fisheries Science Center (Honolulu, HI, USA)

Chaired by: **David Obura**[2]

Oral
A-1798

ReefCloud – integrated solutions for coral reef monitoring

Gonzalez-Rivero, M.[1], Kennedy, E.[2], Wyatt, M.[1], Vercelloni, J.[3], Olsudong, D.[4], Karanassos, C.[4], Amir, H.[5], Nand, Y.[6], Johnson, J.[7], Mangubhai, S.[8], Kininmonth, S.[9], Sykes, H.[10], Golbuu, Y.[4], Crossman, D.[1], Logan, M.[1], Jupiter, S.[6], Rengiil, G.[4], Mengersen, K.[3], Souter, D.[1]
[1]Australian Institute of Marine Science, Perth, Australia
[2]Australian Institute of Marine Science, Townsville, Australia
[3]Queensland University of Technology, Brisbane, Australia
[4]Palau International Coral Reef Center, Koror, Palau
[5]Maldives Marine Research Institute, Male, Maldives
[6]Wildlife Conservation Society, Suva, Fiji
[7]C2O Pacific, Carins, Australia
[8]Talanoa Consulting Fiji, Suva, Fiji
[9]University of the South Pacific, Suva, Fiji
[10]Marine Ecology Consulting, Suva, Fiji

m.gonzalezrivero[at]aims.gov.au

Abstract

Coral reefs are under threat, and the rate of ecosystem degradation often surpasses the speed of knowledge generation to support evidence-based management. Despite the considerable efforts to monitor coral reefs, limited resources, differences in capacity, remoteness and inconsistencies in methodologies weaken the bridge between scientific advice and management decision-making. For more than a decade, images ('photo quadrats') have been widely adopted as a technology for rapid assessments of reef condition. More recently, applications of big-data science, more specifically artificial intelligence, have rapidly evolved in coral reef ecology. Although loosely connected, the evolution of these technologies now provides plausible opportunities for fast-tracking measurements of coral reef condition across large geographies. Here, we introduce a new and open-access tool, ReefCloud, as a holistic approach towards integrating, synthesising, reporting and communicating coral reef monitoring using advances in automated image analysis and statistical modelling. Our results demonstrate that the amalgamation of technologies can help coral reef monitoring by 1) alleviating resource limitations; 2) increasing efficiency; 3) preventing inconsistencies; 4) producing timely reports, and 5) integrating monitoring efforts. We show that automated image analysis can replicate expert observations from photo quadrats with 85-95% confidence to produce accurate estimations of benthic composition (3% mean error), at a rate that is 700-fold faster than manual assessment. Statistical models implemented in ReefCloud enable the integration of disparate data while accounting for differences in methodologies and inherent uncertainties. By making these technologies widely accessible with easy user engagement, ReefCloud generates robust, meaningful, and visual syntheses from complex datasets. In partnership with the Global Coral Reef Monitoring Network (GCRMN) and Pacific institutions, we will report results from a pilot implementation in Fiji, Palau, and Australia. The results will demonstrate a rapid, robust, and user-friendly approach to facilitate a deeper and more comprehensive understanding of the condition and trends of coral reefs. This information will be used to promote effective communication and efficient, adaptive, and transparent conservation actions; thus, creating a pathway for the next generation of global and regional syntheses reports for the GCRMN.

Oral
A-1572

Vulnerability to collapse of coral reef ecosystems in the Western Indian Ocean

Obura, D.[1, 2], Gudka, M.[1], Samoilys, M.[1, 3], Osuka, K.[1], Mbugua, J.[1], Keith, D.[4], Porter, S.[5], Roche, R.[6], van Hooidonk, R.[7, 8], Ahamada, S.[9], Araman, A.[10], Karisa, J.[11], Komakoma, J.[12], Madi, M.[13], Ravinia, I.[14], Razafindrainibe, H.[15], Yahya, S.[16], Zivane, F.[17]
[1]CORDIO East Africa, Mombasa, Kenya
[2]IUCN Coral Specialist Group, Mombasa, Kenya
[3]IUCN Grouper and Wrasse Specialist Group, Mombasa, Kenya
[4]University of New South Wales, Sydney, Australia
[5]Oceanographic Research Institute, Durban, South Africa
[6]Bangor University, Bangor, United Kingdom
[7]Cooperative Institute for Marine and Atmospheric Studies, Rosenstiel School of Marine and Atmospheric Science, Miami, United States
[8]NOAA Atlantic Oceanographic and Meteorological Laboratory, Miami, United States
[9]AIDE, Moroni, Comoros
[10]Administração Nacional das Áreas de Conservação (ANAC), Maputo, Mozambique
[11]Kenya Marine and Fisheries Research Institute, Mombasa, Kenya
[12]Marine Parks and Reserves Unit, Dar es Salaam, Tanzania
[13]Moheli Marine Park, Nioumachoua, Comoros
[14]Seychelles National Parks Authority, Victoria, Seychelles
[15]Centre National de Recherches Océanographiques (CNRO), Nosy Be, Madagascar
[16]Institute of Marine Science (IMS), Zanzibar, Tanzania
[17]National Institute of Fisheries Research, Maputo, Mozambique

dobura[at]cordioea.net

Abstract

Ecosystems worldwide are under increasing threat. We applied a standardized method for assessing the risk of ecosystem col- lapse, the International Union for Conservation of Nature (IUCN) Red List of Ecosystems, to coral reefs in the Western Indian Ocean (WIO), covering 11,919 km2 of reef (~5% of the global total). Our approach combined indicators of change in historic ecosystem extent, ecosystem functioning (hard corals, fleshy algae, herbivores and piscivores) and projected sea temperature warming. We show that WIO coral reefs are vulnerable to collapse at the regional level, while in 11 nested ecoregions they range from critically endangered (islands, driven by future warming) to vulnerable (continental coast and northern Seychelles, driven principally by fishing pressure). Responses to avoid coral reef collapse must include ecosystem-based management of reefs and adjacent systems combined with mitigating and adapting to climate change. Our approach can be replicated across coral reefs globally to help countries and other actors meet conservation and sustainability targets set under multiple global conven- tions—including the Convention on Biological Diversity's post-2020 global biodiversity framework and the United Nations' Sustainable Development Goals.

Oral
A-2069

Updating the extinction risk of corals in 2020

Obura, D.[1], **Cabada-Blanco, F.**[2], Pearce-Kelly, P.[3], Pettersson, E.[1], Polidoro, B.[4]
[1]CORDIO East Africa, Mombasa, Kenya
[2]University of Portsmouth, School of Biological Sciences, Southamptom, United Kingdom
[3]Zoological Society of London, London, United Kingdom
[4]Arizona State University, Arizona, United States

francoise.cabada-blanco[at]port.ac.uk

Abstract

Coral reefs hold a flagship role in the awareness and communication of the beauty and biodiversity that marine ecosystems harbour. Sadly, they also are a flagship for the magnifying threats human activities impose on nature, and the bleak fate of the natural world in the Anthropocene. In 2008, 1/3 of reef-building corals were assessed as threatened with extinction using the International Union for the Conservation of Nature's (IUCN) Red List of Threatened Species (RLS). Corals show the steepest decline in status (nearly 20%) among major taxonomic groups assessed on the RLS. As ecosystem engineers, the decline of reef-building coral species jeopardises ecosystem function of coral reefs, reliant biodiversity and ecosystem services they provide in the more than 100 countries that harbour them. Their flagship role thus combines both awe and vulnerability, raising their importance in influencing decisions at all levels, from the local, where they are found, to global.

The extinction risk status of corals is being updated, to inform global commitments for the decade 2020-2030. Updated datasets on coral species distributions, estimates of species and coral cover decline, trends in major threats, and projections of major threats (particularly thermal) in coming decades are being prepared on an online repository (using Github and R), to support a team of 120 assessors working remotely in taxonomic teams. Extinction risk for each coral species will be assessed against all five IUCN Red List Criteria, reviewed within and across teams to assure consistency, and by independent reviewers, prior to submission to IUCN for final review, acceptance and publication. The online tools developed will be applicable to red listing of any species groups, reducing the cost and logistics of red listing, and increasing the affordability, practicality and ability of the process to deal with large numbers of species. This will accelerate red listing assessments in coming decades.

The capstone result will be released in a plenary policy event at the International Coral Reef Symposium (ICRS). This scientific presentation will focus on the primary findings and key trends affecting reef corals, the approach and tools developed and used, key variances among species, taxonomic groups and geographies in the results obtained, and a summary of the costs, feasibility and applicability of this approach for other taxa.

Oral
A-1776

A model of population growth in massive Porites across the Pacific

Pedersen, N.[1], Edwards, C.[1], Petrovic, V.[2], Runyan, H.[1], Zglizcynski, B.[1], Smith, J.[1], Planes, S.[3], Sandin, S.[1]
[1]UC San Diego, Scripps Institution of Oceanography, La Jolla, United States
[2]UC San Diego, Department of Computer Science and Engineering, La Jolla, United States
[3]EPHE-UPVD-CNRS, USR 3278 CRIOBE, PSL Universite Paris, Papetoai, French Polynesia

nepeders[at]ucsd.edu

Abstract

Despite global reports on the decline of coral reefs, long term monitoring data as reported in the recent GCRMN report, “Status and Trends of Corals of the Pacific”, suggest stable coral coverage across the Pacific over the past three decades. While overall coral cover has revealed no significant change, there is evidence for a shift in community composition driven in part by an increase in coverage of the genus *Porites.* We use demographic tools to assess patterns of growth for dominant space-filling *Porites* from across the Pacific, and use size-based modeling to predict potential longer-term population trajectories. We focus on four common species of *Porites* – *P. lobata, P. lutea, P. arnaudi*, and *P. evermanni* – all of which exhibit similar traits of stress-tolerance and massive-like morphologies. We collected large-area imagery (i.e., composite ‘photomosaics’ of 100m^2 areas) from up to 30 islands across the Pacific, with imagery repeated at annual to four-year intervals, with sampling ranging from 2012 to 2019. The goal was to quantify vital rates of thousands of *Porites* colonies in multiple dimensions (change in colony maximum radius, planar area of live tissue, and surface area of live tissue) across locations spanning a range of oceanic primary productivity. While the mean growth rate was similar across locations, the variability of growth rates showed a negative relationship with availability of heterotrophic food resources. Based upon these vital rates, we built a size-based population model of massive morphotypes of *Porites* to better understand the demographic pathways through which populations of *Porites* have steadily increased over the past few decades. Across sites the idealized model (based upon unconstrained growth to predicted ‘equilibrial’ size structure, without disturbances) suggests that average colony size of *Porites* will continue to increase for 5-30 years, depending upon oceanographic context. We explore the importance of colony fission and fusion as demographic processes, which are revealed to be critical drivers of the maintenance and expansion of *Porites* populations across the Pacific.

Oral
A-1977

Red Sea reefs in Sudan revisited - long-term monitoring sites reveal both, continuity and change

Reinicke, G. B.[1], Abdelhamid, S.[2], Claus, R.[1], Ivkic, A.[3], Höhn, J.[4], Grenzdörffer, G.[5], Zuschin, M.[3]
[1]German Oceanographic Museum, Marine Sciences, Stralsund, Germany
[2]University of Rostock, Marine Sciences, Rostock, Germany
[3]University of Vienna, Department of Palaeontology, Vienna, Austria
[4]Coralaxy GmbH, Bentwisch, Germany
[5]University of Rostock, Geodesie and Geoinformatics, Rostock, Germany

goetz.reinicke[at]meeresmuseum.de

Abstract

Coral reefs off the coast of the Republic of the Sudan are still considered to be among the most pristine reefs in the central Red Sea region. The complex coastal fringing reefs, offshore banks and shoals extending from Dungonab Bay in the north to Sanganeb atoll in the south were inscribed on the UNESCO World Heritage List in 2017. Due to their remote position and limited access, monitoring of the status of the reefs has been erratic. Here we present the results of repeated photoquadrat surveys on Sanganeb that were first surveyed in 1980.
A trip to the region in 2019 revisited a number of monitoring locations in the area. Current data was analyzed using photogrammetric and computer vision techniques. Analogous and digital evaluation of photographic and video records of photoquadrats revealed general continuity of the overall community structures and patterns. However, while some locations were difficult to recover, observations revealed certain development (growth), and change was detected with regard to substrate composition, scleractinian and soft coral living coverage, as well as in the accompanying fauna. The contribution relates new observations to environmental conditions and earlier data available over 39 years.

Poster
A-1590

Baseline assessment of coral reef health status along the Sudanese Red Sea coast

Abaker, K. Y. I.[1], Elamin, S. M.[2], Nash, K. L.[3], Kleiven, A. R.[4], Moland, E.[4]
[1]Red Sea University, Faculty Of Marine Sciences and fisheries, Port Sudan, Sudan
[2]Red Sea University, Faculty of Marine Science and Fisheries, Port Sudan, Sudan
[3]University of Tasmania, Centre for Marine Socioecology, Hobart, Australia
[4]Norwegian Institute of Marine Research (IMR), His, Norway

khadijasea[at]yahoo.com

Abstract

Coral reefs are subject to an increasing array of anthropogenic impacts, including climate change. A challenge faced by researchers is understanding how these impacts will affect coral reefs in the future. Thus, there is an increasing interest in studying reefs located in marginal areas or those already exposed to high water temperatures, such as the Red Sea. This Study was conducted as a Masters project with the objective to assess the health status of coral reefs in the Sudanese Red Sea coast, aiming to establish baseline data for future studies, evaluate the status of these coral reefs using and quantify the presence and prevalence of coral bleaching. Coral reef communities were assessed by extracting data from benthic transects recorded by diver operated video (DOV) during surveys conducted as part of the Norwegian funded UNIDO project "Building institutional capacities for the sustainable management of the marine fishery in the Red Sea State" (2015 – 2017). The reef check sampling protocol was adapted to the 2016 and 2017 surveys, from 43 sites covering reefs from north to south of Sudanese Red Sea coast. Ta assess diversity we calculated Shannon's, Evenness and Richness indices. The available data indicated differences in coral cover and diversity between sites. Average hard coral cover was 38.01 % and the average of soft coral cover was 6.04 %. The average percentage of live cover for two years was 43.9%. The benthic surveys revealed 40 genera of hermatypic corals belonging to 15 families. Shannon's diversity index, Evenness index and Richness index were 1.71, 1.73 and 8.83, respectively. The bleaching index varied according to sites, and ranged from category: no bleaching (0), partially bleaching (1), white (2), bleaching and partly dead (3), and recently dead (4), with scores 58.5, 8, 19.5, 8, and 6 %, respectively. A Chi-square test indicated no significant difference between 2016 and 2017 for live cover and bleaching. At the time of study, the health status of the coral reefs assessed are not seriously threatened by cumulative human impact. This study constitutes an important source of information in an ongoing effort to build a conservation and management regime for Sudan's unique coral reef ecosystem.

Poster
A-1191

13 years Reef Check reef monitoring at Red Sea Diving Safari, Egypt

Moldzio, S.
Reef Check, Braunschweig, Germany

stephan.moldzio[at]reefcheck.de

Abstract

Standardized and comparable data on the condition of coral reefs worldwide are an essential basis for counteracting the decline of reefs.
This poster presents a local reef monitoring program, launched by Red Sea Diving Safari (RSDS) and Reef Check team scientist Stephan Moldzio in 2009.
Annual Eco Diver courses and Reef Check surveys are being conducted to monitor the condition of the main dive sites. During the 4-day course, participants learn and practice the Reef Check (RC) methodology on land as well as under water and practice the identification of various indicator organisms. After the course, five RC surveys are conducted annually on different reefs. In addition to the newly certified course participants, RC Eco Divers from previous years also join on a regular basis.
The determined data is submitted to the RC headquarters and are being included in the international database https://www.reefcheck.org/global-reef-tracker/ , which to date contains 14,657 survey data records of 5,445 reefs in 101 countries and territories (as of february 2022). The data is publicly available and will be used for scientific publications, including the latest global report of the GCRMN "*Status of coral reefs of the world 2020*".
RSDS has been a pioneer in eco-tourism for 30 years and invites its guests to participate in various workshops, reef checks, research activities and environmental activities, or to experience Egyptian nature and culture at first hand on excursions with the local Bedouins.
The house reefs are actively protected, which is reflected in the abundance of corals and fish in general, so that many regular guests return.
With its comprehensive environmental concept, RSDS is emphatically committed to the protection of reefs and mangroves, recycling management, resource efficiency and the gradual switch to renewable energies and cooperates with various environmental organizations, the Egyptian national parks and other initiatives.
We believe this is a best practice example of sustainable ecotourism that protects the reefs and natural resources, collects data on the condition of the reefs, raises awareness, supports the local population and culture, and provides a sustainable source of income for the local population.

Virtual
Oral
A-2111

Decadal changes on reef fish assemblages in the West Philippine Sea, Philippines

Arceo, H.[1], Cabasan, J.[2], Nanola Jr., C.[3], Alino, P.[2]
[1]University of the Philippines Cebu, Cebu City, Philippines
[2]Marine Science Institute, University of the Philippines Diliman, Quezon City, Philippines
[3]University of the Philippines Mindanao, Davao City, Philippines

hoarceo[at]up.edu.ph

Abstract

Reef fish diversity in the West Philippine Sea ranks second among the six marine biogeographic regions in the Philippines. Linked with this ecological significance is its important contribution to food security and to the livelihood of coastal communities across the archipelago. However, excessive extraction and unsustainable fishing practices within the region persist, affecting the overall reef health condition, including a decline in fish standing stocks. This study determined the temporal trends and present condition of reef fish assemblages in the West Philippine Sea. Data on reef fish community structure obtained from underwater fish visual surveys conducted from 1991-2019 were binned into three decades (i.e. 1991-2000, 2001-2010, 2011-2019) and then compared across time. A total of 615 transects were analyzed, encompassing the northern-, southern-, and eastern-most reef sites of the region. Results showed that both mean species richness and mean density displayed declining trends over the last three decades. The families with huge decline in density were Siganidae and Serranidae, both commercially important fish families. On the other hand, mean fish biomass showed a relatively stable condition, although this varied across sites. For instance, in the Kalayaan Island Group (KIG) which is part of the Spratly Islands, fish biomass has been reduced from 102.6 mt km-2 to 32.7 mt km-2 while increasing trends were observed in Occidental Mindoro largely due to the long-term protection of marine reserves in the area. The potential influences of environmental conditions (e.g. sea surface temperature) and anthropogenic factors (e.g. fishing density, coastal development) on the observed patterns were explored. Findings of this study are concordant with global trends of serious decline in fish stocks. Proper and sustainable management interventions are urgently needed in the region, especially since illegal and unregulated fishing practices remain unabated in the West Philippine Sea.

Oral
A-2053

Collaborative monitoring of Hawai‘i coral reefs to understand status and trends and inform sustainable development goals

Donovan, M.[1], Counsell, C.[2], Donahue, M.[3], Lecky, J.[4, 5], Conklin, E.[6], Hawaii Monitoring and Reporting Collaborative, H.[1, 3, 5, 6, 7, 8]
[1]Arizona State University, Center for Global Discovery and Conservation Science, Tempe, United States
[2]Fairfield University, Fairfield, United States
[3]University of Hawaii at Manoa, Hawaii Institute of Marine Biology, Kaneohe, United States
[4]Azura Consulting, Garland, United States
[5]NOAA Pacific Island Fisheries Science Center, Ecosystem Science Division, Honolulu, United States
[6]The Nature Conservancy, Hawaii Marine Program, Honolulu, United States
[7]Hawaii Division of Aquatic Resources, Honolulu, United States
[8]US National Park Service, Assessment and Monitoring Program, Kona, United States

marydonovan[at]ucsb.edu

Abstract

The effective management of marine resources depends on measurements of current conditions, prioritization of areas most likely to benefit from management, and the documentation of change after management actions are taken. Each of these steps are key to efforts by the State of Hawai‘i, USA, to address a sustainable development goal established in 2016 to ‘effectively manage 30% of Hawai‘i’s nearshore by 2030’. To inform these management efforts, the Hawaii Monitoring and Reporting Collaborative (HIMARC) was formed as an integrated group of stakeholders to build a comprehensive, data-informed foundation for the assessment of Hawai‘i’s marine resources in support of successful management. We have synthesized existing fish and benthic data from 7 long-term monitoring programs into an integrated database and established rigorous quality control procedures. To date, the database includes over 11,000 benthic surveys and 15,000 fish surveys from which we have developed a suite of ecological indicators to measure the current status and future trends of nearshore ecosystems in Hawai‘i. We modeled these indicators with spatially explicit hierarchical Bayesian models that include the biophysical context and human impacts at each survey location to estimate management potential for a given place. Our results reveal high variability in the past status of nearshore coral reefs across Hawai‘i and projected responsiveness of different locations to management action: some locales are more likely to benefit from fisheries management and others from improved management of land-based pollution. We will discuss these results in the context of stakeholder collaboration to promote data-informed management, which has amplified the use of monitoring in decision making.

Virtual
Oral
A-1487

Quantifying the state of the coral reef ecosystem in relation to biophysical indicators in the Saba National Marine Park, Dutch Caribbean

Homes, W.
Leibniz Institute for Tropical Marine Sciences, Social Sciences, Bremen, Germany

wiebke.homes[at]leibniz-zmt.de

Abstract

Coral reefs are experiencing large scale degradation. Motivated by the need for regular data monitoring and for quantification of the state and change of benthic and pelagic organisms, the Global Coral Reef Monitoring Network protocol was executed on 18 dive sites in fished and unfished areas around the island of Saba in the Saba National Marine Park (SNMP) in the Dutch Caribbean from March to May 2019. Pictures of the benthos were taken and analysed with the Coral Point Count Excel extension software and fish biomass was calculated through the Bayesian length-weight-relationship. Although considerably below the Caribbean-wide average, coral cover around the island seems to be slowly recovering from past diseases and hurricane events. Coral species richness positively correlates with reef fish density and Serranidae species richness. As in other parts of the Caribbean, macroalgae in the SNMP are rapidly spreading and increasingly compete for space with habitat-providing gorgonians, sponges and other benthic organisms. In contrast to expectations, fish density and biomass continue to increase, even in zones where fishing is allowed. This might be explained by the higher availability of macroalgae that serve as food for various herbivorous fish species, which in turn are, amongst others, the prey of predatory fish and those higher up in the trophic cascade. However, with the exception of the commercially important fish family Lutjanidae all key fish species have declined in average size in recent years. Another finding is the increase of coral diseases. The results indicate the need for further species-specific research in order to identify the factors that are causing the degradation of the reefs in the SNMP. A better understanding of the interactions, ecological roles and functions of benthic and fish communities is therefore essential for the protection of reefs, that are of high value to Saba. The results of this study contribute to the adaptive management of the Saba Conservation Foundation that manages the SNMP.

Oral
A-1109

Democratising coral reef data to improve global insights into reef health

Kennedy, E.[1], Gonzalez-Rivero, M.[1], Evans-Illidge, L.[1], Depczynski, M.[2], Forester, M.[1], Muir, B.[1], Ivey, J.[1], Bardi Jawi Rangers, B. J.[3], Nand, Y.[4], Miller, K.[5], O'Flaherty, C.[6], Hughes, A.[7], Mangubhai, S.[8], Jupiter, S.[4], Darling, E.[9]
[1]Australian Institute of Marine Science, Townsville, Australia
[2]Australian Institute of Marine Science, Perth, Australia
[3]Bardi Jawi Rangers, Kimberley region, Australia
[4]Wildlife Conservation Society, Suva, Fiji
[5]Vatuvara Foundation, Northern Lau Island Group, Fiji
[6]Kokomo Island, Kadavu, Fiji
[7]Wildlife Conservation Society, Munda, Solomon Islands
[8]Talanoa Consulting, Suva, Fiji
[9]Wildlife Conservation Society, New York, United States

e.kennedy[at]aims.gov.au

Abstract

Coral reef condition is changing rapidly across the planet, driven by a range of intensifying climate-related and local environmental stressors. Despite technological leaps in our ability to map and monitor reef habitat using satellites, our global tracking of benthic community composition (as a proxy for reef health status) remains reliant upon compiling in-water observations made by snorkelers and divers. Temporal and spatial inconsistencies in field data collection along with barriers to integration and data sharing, limit our collective understanding of regional-to-global reef health trends. This talk will explore how the *Australian Institute of Marine Science* (AIMS) and the *Wildlife Conservation Society* (WCS) are working with Pacific Island resource managers to address barriers to monitoring, through sharing home-grown digital technologies that are helping to: 1) expand participation in data collection activities, 2) support better collaboration across organisations, and 3) ease integration and synthesis of information to speed up delivery of accurate reporting and insights. Platforms like *ReefCloud* and *MERMAID* (a Marine Ecological Research Management Aid) aim to promote a more inclusive approach to monitoring, sharing digital tools that allow non-conventional data providers such as community groups, Indigenous scientists (e.g., Northern Australian Marine Monitoring Alliance NAMMA Project), the tourism industry and citizen scientists to benefit from technological advancements in data processing. The contributions of observations from local monitoring groups can complement those from research organisations and government agencies, and cloud-based computing can support rapid integration and delivery of data to key reporting organisations. Given that people will remain central to in-water observations of coral community change, reducing barriers to participation in global monitoring, reporting, and aggregating to global trends will be fundamental to improving insights through more efficient sharing and greater coverage and frequency of in-water observations. Extracting and sharing important information on benthic community composition through digital technologies are helping expand participation – and therefore geographic coverage, consistency, and reliability – of reef health changes.

Session 7J - How can innovative techniques to investigate calcification shed light into the past, present, future of coral reef organisms? / How do new insights into biomineralization help us understand reef calcification response to global climate change?

Conceptualized by: **Alexander Venn**[1], **Sylvie Tambutté**[1], **Anton Eisenhauer**[2], **Virginie Chamard**[3], **Ed Hathorne**[4], **Fiorella Prada**[5], **Stefano Goffredo**[5], **Tali Mass**[6], **Jeana Drake**[7]

[1] Centre Scientifique de Monaco (Monaco)
[2] GEOMAR (Kiel, Germany)
[3] Institut Fresnel (Marseille, France)
[4] GEOMAR (Kiel, Germany)
[5] University of Bologna (Bologna, Italy)
[6] University of Haifa (Haifa, Israel)
[7] University of California Los Angeles (Los Angeles, CA, USA)

Chaired by: **Alexander Venn**[1], **Sylvie Tambutté**[1], **Ed Hathorne**[4], **Tali Mass**[6]

Oral
A-1083

Moonlight cycles mediate the architecture of the coral skeleton

Martinez Rugerio, I.[1, 2], Enriquez, S.[2], Carricart-Ganivet, J. P.[2], Iglesias-Prieto, R.[1]
[1]The Pennsylvania State University, Biology, University Park, United States
[2]Universidad Nacional Autonoma de Mexico, Unidad Academica de Sistemas Arrecifales, Puerto Morelos, Mexico

izamtz06[at]gmail.com

Abstract

The morphology of the skeleton is essential to the functional biology of scleractinian corals. The growth and shape of the coral skeleton are determined by the amount of calcium carbonate produced and how it is deposited in the skeleton (skeletal architecture). The skeletal architecture is a feature that results from the size and arrangement of the structural components of the skeleton, however, mechanisms underlying the control of this feature remain unclear. Dissepiments -horizontal $CaCO_3$ sheets supporting the living polyp-play a key role in the upward growth of the colony. The process by which coral polyps form new dissepiments has been strongly correlated with a moonlight cue, but there is no experimental evidence to support this association. Here, we conducted a controlled laboratory experiment on Orbicella faveolata to test if dissepiment formation is induced directly by changes in a moonlight stimulus. Coral fragments were exposed for 6 months to two night-time light regimes; a control group under moonlight cycles of 29.7 days, and a treatment group in the absence of moonlight exposure. Control and treatment groups were exposed to equal diurnal light regimes, according to previously assessed light levels required to induce maximum calcification rates. Illumination was supplied by a custom-made LED system, designed to simulate sunlight/moonlight variation of natural light cycles. Throughout the experiment, controls and treatments presented similar phenotypes, described by fluorescence in hospite, photosynthetic, and respiration rates. Skeletal analyses revealed a significant change in skeleton architecture between control and treatment groups, but no differences in calcification rates were observed. Control fragments showed well-defined monthly formed dissepiments, higher skeletal extension, and lower bulk density. Treatments did not form new dissepiments, presented a reduced skeletal extension with higher bulk density, resulting in an almost non-porous skeleton. Coral skeletal extension was strongly correlated with the number of dissepiments formed. Overall, our study presents the first experimental evidence that dissepiment formation and skeletal architecture are mediated by a moonlight stimulus, and it suggests that moonlight is among the drivers of morphological changes in the coral skeleton of this species. This highlights the importance of light-driven mechanisms, still unrevealed, supporting the diversity of coral skeletal morphology.

Oral
A-1686

Seawater conditions differentially affect calcification in two species of Scleractinian corals, Stylophora pistillata and Galaxea fascicularis

Osinga, R., Wijgerde, T.
Wageningen University, Animal Sciences, Marine Animal Ecology, Wageningen, Netherlands

ronald.osinga[at]wur.nl

Abstract

Calcification in scleractinian corals is affected by several factors including irradiance (Light-Enhanced-Calcification), oxygen, pH, Dissolved Inorganic Carbon (DIC) and the availability of food. In a series of laboratory experiments, we investigated the sensitivity of calcification to these factors in two coral species with different characteristics: the branching coral *Stylophora pistillata*, a species known to be rather resistant against ocean acidification, and the boulder shaped coral *Galaxea fascicularis*, which has been reported to be more sensitive to ocean acidification.
Incubations with these two corals under different pH values (8.1 versus 7.5) confirmed a disparity in sensitivity to pH between these species. Whereas light calcification was not significantly affected by pH in *S. pistillata*, light calcification in *G. fascicularis* ceased completely at a pH of 7.5. The addition of planktonic food also caused a complete shutdown of dark calcification in *G. fascicularis*, even in the presence of additional oxygen (150% supersaturation), which was found to promote dark calcification in this species under unfed conditions. We hypothesize that carbon dioxide production through the digestion of the food caused the internal pH in *G. fascicularis* to drop substantially. In *S. pistillata*, dark calcification was not inhibited by heterotrophic feeding. This species is apparently better capable to remove protons from the site of calcification than *G. fascicularis*. In fact, dark calcification in *S. pistillata* was even stimulated by feeding when the alkalinity of the ambient seawater was doubled from a normal seawater value of 2.4 meq to 4.8 meq. Similar as in *G. fascicularis*, addition of oxygen (150% supersaturation) also stimulated dark calcification in *S. pistillata*. The combination of food addition, oxygen supersaturation and a doubled alkalinity resulted in a dark calcification rate that was equal to the saturated light calcification rate in this species.
These findings shed light on the mechanism by which light enhances calcification. Photosynthesis simultaneously produces oxygen, rises the internal pH through the uptake of carbon dioxide and provides metabolic energy to support the ATP-consuming calcification process. These three effects enhance calcification in an additive manner and can be mimicked in darkness by adding oxygen and food and by stabilizing the internal pH though increasing the alkalinity of the ambient seawater.

Oral
A-1750

Do massive Porites mirror the heavy metal concentration in the ambient seawater? - A culture study

Schmidt, S.[1], **Hathorne, E.**[1], Schönfeld, J.[1], Gosnell, K.[1], Garbe-Schönberg, D.[2]
[1]GEOMAR Helmholtz Centre for Ocean Research Kiel, Kiel, Germany
[2]CAU Kiel University, Institute of Geosciences, Kiel, Germany

ehathorne[at]geomar.de

Abstract

Coral reefs house an extraordinary biodiversity and provide fish, a tourist attraction and natural shoreline protection and are therefore vitally important for society. Anthropogenic influences like ship traffic, agriculture, urban runoff or mining have increased the level of dissolved heavy metals in some tropical near-shore environments threatening reef ecosystems. Monitoring of the ecosystem status by using chemical tracers in sessile organisms has become increasingly important for reef risk assessment and environmental management. The skeleton of stony corals like *Porites* species provide a high-resolution geochemical archive for the recent and historical heavy metal concentration in ambient seawater, yet there are little calibration data directly comparing metal concentrations in water and coral skeletons. To address this, culturing experiments exposing *Porites lobata* and *Porites lichen* colonies to a mixture of dissolved chromium (Cr), manganese (Mn), nickel (Ni), zinc (Zn), silver (Ag), cadmium (Cd), mercury (Hg) and lead (Pb) over a wide concentration range have been performed. Water samples were taken frequently to monitor expected changes in the heavy metal concentration due to adsorption. The concentrations of some metals declined as anticipated but stabilised a few days after the input of the high metal stock solution. Laser ablation ICP-MS measurements of the coral aragonite revealed metal concentrations that were positively correlated with Cr, Mn, Ni, Zn, Ag, Cd and Pb concentrations in the culturing medium. Cu and Sn showed no variance as the variation in the concentration of these metals in the experimental seawater was minimal. Hg did not exhibit any clear trend, even though the Hg concentration in seawater varied by a factor > 5 between phases. The calibrations and calculated partition coefficients for some metals enable a reconstruction of the heavy metal concentration in seawater for ecosystem monitoring and potentially century long records revealing baseline values before large-scale human disturbance.

Oral
A-1538

Coral proteomic responses, calcifying fluid pH and symbiont health give insights into adaptive physiology and calcification under ocean acidification

Stuhr, M.[1], Cameron, L. P.[2], Reymond, C. E.[1, 3], Kollipara, L.[4], de Beer, D.[5], Sickmann, A.[6], Westphal, H.[7, 8, 9], Ries, J.[10]
[1]Leibniz Centre for Tropical Marine Research (ZMT), Biogeochemistry and Geology, Bremen, Germany
[2]Northeastern University, Department of Marine and Environmental Sciences, Boston, United States
[3]China University of Geoscience, Wuhan, China
[4]Leibniz-Insitut für Analytische Wissenschaften (ISAS), Bioanalytics, Dortmund, Germany
[5]Max Planck Institute for Marine Microbiology (MPI), Bremen, Germany
[6]Leibniz-Insitut für Analytische Wissenschaften (ISAS), Dortmund, Germany
[7]King Abdullah University of Science and Technology (KAUST), Thuwal, Saudi Arabia
[8]Leibniz Centre for Tropical Marine Research (ZMT), Bremen, Germany
[9]Bremen University, Bremen, Germany
[10]Northeastern University, Boston, United States

marleen.stuhr[at]leibniz-zmt.de

Abstract

Numerous effects of increasing anthropogenic CO_2 emissions threaten reef-building organisms. Modern proteomics approaches provide relevant data to gain insights into the underlying response mechanisms of corals to ocean acidification to aid our understanding of acclimatization processes in reef-builders. *Stylophora pistillata* and *Pocillopora* crossed with elevated temperature for two months. Calcification rates, calcifying fluid pH, and colour score were measured and linked to proteomic changes detected via LC-MS/MS. With rising $p\mathrm{CO_2}$, calcification rate and photosymbiont abundance increased in both species, while they consistently elevated their calcifying fluid pH. At elevated temperature, this effect was impaired and the coral could not maintain substantially positive calcification rates under any pH treatment. However, species-specific effects were evident, which is seen in the divergent proteomic responses of each species. In *S. pistillata,* most of the proteomic responses were only induced by the highest $p\mathrm{CO_2}$ level, while most *P. damicornis* proteins showed a distinct response to moderate $p\mathrm{CO_2}$ increases. Increased ocean acidification led in both corals to an enrichment of proteins involved in cytoskeleton development and function, cell signalling and ion channel regulation, while ribosomal constituents responsible for translation and biosynthesis were depleted. Remarkably, *S. pistillata* was less susceptible to acidified conditions even under thermal stress, which predominantly induced upregulations in the coral proteome. Our study identified linkages between photosymbiont density, regulation of calcifying fluid pH, and calcification rate. It supports the assertion that tropical corals can cope with ocean acidification by fertilizing photosynthesis, elevating the calcifying fluid pH, and intensifying particular pathways and cellular functions, but only in the absence of temperature increases. We further demonstrate how comparing patterns in proteome regulation with the organisms' physiological conditions and proton regulation can reveal meaningful insights into their response to changing ocean conditions.

Oral
A-1164

Proton gradients across the coral calcifying cells under ocean acidification

Venn, A., Tambutté, E., Tambutté, S.
Centre Scientifique de Monaco, Marine Biology, Monaco, Monaco

avenn[at]centrescientifique.mc

Abstract

Understanding the vulnerability and resilience of corals to ocean acidification requires knowledge of the physiology driving calcification. Current models of calcification propose that the initial steps occur in the calcifying “calicoblastic” cells, after which amorphous calcium carbonate precursors are released into the extracellular calcifying medium (ECM) where the coral skeleton forms by a combination of particle attachment and ion-by-ion growth. pH regulation of the ECM by the calcifying cells is critical to this process because it promotes elevated calcium carbonate mineral saturation states in the ECM that favour skeletal growth. Although it is now well-established that corals regulate pH in the ECM, very little is known about the underlying cellular mechanisms and their response to OA. Here, working with the model coral *S. pistillata*, we used *in vivo* tissue imaging and pH sensitive dyes to characterise the proton gradient across the calcifying epithelium from its apical side in the ECM to its basal side facing the mesoglea. Our results reveal functional polarity of this cell layer in terms of its pH regulation. Furthermore, by analysing corals in light and darkness, we gained insight into how the transepithelial pH gradient is modulated by the corals’ photosymbiosis with dinoflagellate algae. Finally, we analysed the proton gradient across the calicoblastic epithelium under conditions of experimental ocean acidification. Our study shows that coral calcifying cells face a greater pH regulatory challenge under acidification than previously anticipated.

Poster
A-1126

Potential sources of pH variability in the coelenteron, implication for coral calcification

Crovetto, L., Sevilgen, D., Venn, A., Tambutté, S., Tambutté, E.
Centre Scientifique de Monaco, Physiology / Biochemistry, Monaco, Monaco

lcrovetto17[at]gmail.com

Abstract

Coral reefs, the largest bioconstruction on Earth, are formed by calcium carbonate skeletons of corals. This process is commonly named calcification and leads to the formation of a composite structure, the biomineral, comprising an organic and a mineral fraction ($CaCO_3$ in the form of aragonite). It takes place in a specific compartment of the coral, namely the extracellular calcifying medium (ECM) which is a semi-enclosed compartment located between the calicoblastic epithelium and the skeleton. The ECM presents a specific chemical environment to promote calcification where pH plays an important role in mineral formation. The ECM isn't directly in contact with the surrounding seawater because of the presence of several tissue layers and an internal cavity, the coelenteron. In the polyp, seawater enters the coelenteron through the mouth and its composition is modified notably due to the presence of dinoflagellate-containing cells which modify its pH due to their photosynthetic activity. We performed pH measurements in the coelenteron by using microelectrodes with the help of a motorized micromanipulator and a computer control. We set up a reliable experimental protocol for the fabrication and use of microelectrodes in order to measure pH in the coelenteron of corals. We measured coelenteron pH in both brown (high density of dinoflagellates) and white polyps (low density of dinoflagellates) in order to determine the effect of photosynthesis on pH. pH values recorded in brown polyps are higher than in white polyps. This raises the question of the role of variable pH in the coelenteron of different polyps and its implication regarding calcification for gradients between the coelenteron and the ECM.

7J - How can innovative techniques to investigate calcification shed light into the past, present, future of coral reef organisms? / How do new insights into biomineralization help us understand reef calcification response to global climate change?

Virtual
Oral
A-1312

A contribution to the understanding of coral calcification by a submersible torsion microbalance that enables measurements to be made in real time.

Sandeman, I.[1], Creary Ford, M.[2]
[1]Trent University, Biology, Peterborough, Canada
[2]University of the West Indies (Kingston), Centre for Marine Sciences, Kingston, Jamaica

isandeman[at]trentu.ca

Abstract

An underwater torsion microbalance was used to monitor, in real time, weight gain of small live pieces from the edges of thin plates of the scleratinian coral *Agaricia agaricites* in gently stirred, temperature controlled seawater in a closed chamber in which temperature, light and pH were controlled. Total Alkalinity was measured before and during experiments to give calcium uptake rates and pH was monitored continuously. Calcification by live coral was linear and not always synchronous with or equal in magnitude to calcium uptake. At 28°C and under low illumination (15 µmol photons/m^2/s) mean calcification rate (n=9) was 0.75 µmol/hr/cm^2, mean Ca^{2+} uptake rate was 0.47 µmol/hr/cm^2. Changes of pH of the medium are double the value expected from the uptake of calcium alone plus dark and light respiration and indicate that protons, derived from calcification, are exchanged during calcium uptake to maintain electroneutrality. This indicates an intracellular route for calcium to the site of calcification. Freshly water-piked coral, from which live tissue had been removed, had high non-linear calcification rates in regular and calcium free seawater. Calcium is not taken up from the medium, indicating that the calcium required for calcification is already present on the skeleton, probably in the thin layer of organic matrix secreted daily. Under low illumination calcification decreased by about 10% for a pH reduction of 0.1 in the medium and a closer correlation of calcification rate with [H+] than either pH or saturation state, Ω, was found. This, together with the proton exchange adds weight to the Proton Flux explanation for reduced calcification rates with ocean acidification. Under higher illumination (200 µmol photons/m^2/s) both calcification and calcium uptake increase and the rate of pH reduction of the medium in the coelenteron due to proton release from calcium uptake and calcification would be balanced by pH increase resulting from additional uptake of CO_2 for photosynthesis. This may provide a mechanism for pH upregulation in the coelenteron.

Session 8A - Open Session: Human relations to reefs

Conceptualized by: **Sebastian Ferse**[1], **Christina Hicks**[2], **Marleen Schutter** [2], **Colette Wabnitz** [3]
[1] Leibniz Center for Tropical Marine Research (Bremen, Germany)
[2] Lancaster University (Lancaster, UK)
[3] University of British Columbia (Vancouver, CAN)

Chaired by: **Sebastian Ferse**[1], Carin Jantzen[2]
[1] Leibniz Center for Tropical Marine Research (Bremen, Germany)
[2] SECORE International (Bremen, Germany)

Oral
A-1683

Red and green loops help uncover missing feedbacks in a coral reef social–ecological system

Dajka, J.-C.[1], Woodhead, A. J.[2], Norström, A. V.[2], Graham, N. A. J.[3], Riechers, M.[4], Nyström, M.[2]
[1]Helmholtz-Institute for Functional Marine Biodiversity, Oldenburg, Germany
[2]Stockholm Resilience Centre, Stockholm, Sweden
[3]Lancaster Environment Centre, Lancaster, United Kingdom
[4]Leuphana University, Lüneburg, Germany

jan-claas.dajka[at]hifmb.de

Abstract

People use their local ecosystem and there are often signals about how this use affects ecosystem health. Capturing, interpreting, and responding to signals that indicate changes in ecosystems is key for their sustainable management. These signal-response chains are called “feedbacks”. Breaks in signal-response chains, “missing feedbacks”, will allow ecosystem health to degrade until a point when abrupt ecological surprises may occur. In our study, we demonstrate how we can uncover missing feedbacks using the red loop-green loop (RL-GL) concept and how we may restore the feedbacks. The RL-GL concept classifies how people depend on their local ecosystems along a spectrum of two fundamentally different dynamics. One end of the spectrum is with weak local ecosystem ties and strong ties with external systems (red loop), the other with strong local ecosystem ties and weak ties with external systems (green loop).
Both dynamics are theoretically sustainable – but when either end of the RL-GL spectrum follows unsustainable dynamics, for instance through over-consumption of resources, they are classified as red or green traps. We classified the dynamics between Jamaican people and their coral reefs for eight different periods through Jamaican history from first human settlement (roughly the year 600) until now. The dynamics between Jamaican people and reefs have moved between all four RL-GL states: green loop, green trap, red loop, and red trap.
Through this, we were able to pinpoint where feedbacks between Jamaican people and reefs were missing and which aspects were responsible for this. One of the main aspects that masked the connection between Jamaican people and reefs appeared to be seafood exports.

We therefore proposed that the Jamaican system could attempt to gradually move away from seafood exports and get Jamaica back to more sustainable green-loop dynamics between the people and reefs. Our study is the first to apply the RL-GL concept to a coral reef system and we advocate for its practicality in uncovering missing feedbacks and in gaining an understanding of past, present, and future sustainability that can be of use in other systems.

Oral
A-1489

Towards a better understanding of small-scale fishing decisions and their social and ecological consequences in Pemba Bay, Mozambique

Heckendorn, K.[1], Aswani, S.[1], Sauer, W.[1], Bernard, A.[2], daSilva, I.[3]
[1]Rhodes University, Ichthyology and Fisheries Science, Grahamstown, South Africa
[2]SAIAB, Grahamstown, South Africa
[3]Universidade Lurio, Zoology, Pemba, Mozambique

kheckendorn[at]gmail.com

Abstract

This study asks: how to best understand fishers' attitudes and behaviors in Pemba Bay and what are the resulting social and ecological states of the fishery. Human behavioral plasticity and occasional rapid cultural evolution allow human behaviors to adapt faster than most other species, making them the target of most resource management interventions. Most fisheries management assumes behaviors are motivated by profit maximization. This study investigates this assumption by comparing the compatibility of fisher attitudes and behaviors with rational actor theory (RAT), focusing on profit maximization, and other theories including prospect theory (PT) and theory of planned behavior (TPB). It investigates the state of the social and ecological systems and makes recommendations to improve the fishery. The hypotheses are: fishers are heterogeneous and therefore no single behavioral theory explains all decision making and RAT is not most compatible; fishing in Pemba is a chosen profession and therefore fishers are as well-off as non-fishers and catch reliability and/or profitability affects their wellbeing; marine biomass, individual size, and functional diversity are lower in Pemba Bay than other sites due to high fishing pressure, and direct removal of species by fishing has a dominant effect. This study used fisher interviews, catch data, and in-water samples analyzed using multinomial and Bayesian statistics to address these hypotheses. It finds that no single behavioral theory is consistent will all fishers' attitudes and behaviors, and TPB, and behavioral control, is the most consistent with interview responses. Catch data shows PT is more consistent than RAT. In the social system, fishers using most methods are as materially well-off as non-fishers, but have lower subjective wellbeing. Catch reliability or profitability does not affect material or subjective wellbeing. In the ecosystem, Pemba has lower biomass and individual sizes than other sites with less fishing, but not lower functional diversity and the differences in biomass and size are not directly affected by fishing catch. Together these data indicate that the Pemba fishery is in decline based on social and ecological characteristics. The importance of behavioral control in understanding fishing decisions indicates that any interventions to mitigate problems in the fishery need to work with fishers to increase empowerment and allow experimentation to find locally relevant solutions to problems.

Oral
A-1138

Fisheries' dynamics around a restored reef: a case study from Hatamin island (Seraya Besar, Indonesia)

Jacob-Lozano, F.[1], Toderasc, R.[1], Murdini, J.[1, 2], Amiel, A.[3, 4, 5], Colognoli, M.[1], Sutarjana, I. M.[2], Detournay, O.[1]
[1]Coral Guardian, Lyon, France
[2]Waka Eling Semeton, Bali, Indonesia
[3]Université Côte d'Azur, CNRS, INSERM - Institute for Research on Cancer and Aging in Nice - IRCAN, Nice, France
[4]Université Côte d'Azur – Institut Fédératif de Recherche : Ressources Marines (IFR MARRES), Nice, France
[5]Kahi Kai non-profit–One Ocean, Eze, France

f.jacob[at]coralguardian.org

Abstract

Coral reefs' rapid degradation threatens the livelihoods of millions of people around the world. Coral restoration is one of the strategies to accelerate the recovery of coral ecosystems and to maintain ecosystem services. Local fisheries' monitoring near restoration areas can give an integrative insight into the socio-economic dimension of restoration projects, and to their impact on local communities' livelihoods. Around Hatamin island (East Nusa Tenggara, Indonesia), blast-fishing had destroyed the reef and threatened local fisheries and livelihoods. In 2015 a coral restoration and protection project started in the area, thanks to the close collaboration between the Seraya Besar village, the local government, and the NGOs Coral Guardian and Waka Eling Semeton. The project's monitoring program included a fisheries' survey to describe not only the fishing location, catch quantity and diversity, but also the fisheries' revenues of a focus group of fishermen from the village of Seraya Besar. For the first time in this conservation effort, after the first 4 years of data collection (beginning of 2016-end of 2019), the present research addresses the question "how have fisheries evolved at Seraya Besar 4 years after the beginning of the coral restoration project at Hatamin island?". Data trends of fishing locations, fish catch (Kg/ fishing day, Kg and number of individuals per species) and fisheries-derived incomes were compared through non parametric tests (Wilcoxon signed-rank tests), following the data structure. The results show that the zone around the restoration area gained importance as a fishing location, passing on average from 2% of fishing days in 2016 to 27% in 2019. Interestingly, compared to 2016, in 2019 an increase in the fish catch abundance and weight around Hatamin, as well as an increase with a factor of 4 in the mean catch per unit of effort (Kg/fishing day) were observed. Regarding catch diversity, for the first time in 2019 individuals of Serranidae and Scombridae taxa were reported around the restoration area. Finally, an increase in fishermen's incomes, and in their fish consumption have also been highlighted, suggesting that target species are more available for fishermen in the area, therefore supporting a better livelihoods. Our current study contributes to the understanding of the benefits a protected and restored ecosystem can bring not only to the reef community but also to the socio-economic livelihoods of the local fishermen.

Oral
A-1338

Behavioral Spillovers and Public Goods Conservation

Rojas, C.[1], Cinner, J.[2], Gelcich, S.[3]
[1]Universidad Catolica de Temuco, Temuco, Chile
[2]ARC Centre of Excellence for Coral Reef Studies, Townsville, Australia
[3]Pontificia Universidad Catolica de Chile, Santiago, Chile

cristian.rojasu[at]gmail.com

Abstract

The provision of public goods, such as voluntary enforcement efforts, can be critical for the protection, conservation, and management of natural resources such as coral reefs and fisheries. However, the degree to which context can influence people's contributions to the public good is poorly understood. We used sequential games in an economic 'lab in the field' experimental setting with Papua New Guinea's coral reef fishing communities to explore whether behavior in two particular contexts (market and trust) spill over public goods' contributions. Behavioral spillovers occur when behavior in one context influences, or is transferred to, behavior in another context. Our results indicate that there is spillover, but surprisingly this occurs from specific roles assumed within the context rather than the broader context itself. Specifically, we show receivers in the trust game have significantly lower public good contributions relative to a control group. The existence of behavioral spillovers into public goods can render conservation initiatives that rely on contributions ineffective, or even damaging, if they crowd out intrinsic behavior or social norms. Understanding the potential biases different context (e.g. markets created by market-based instruments or trust relied upon by community-based mechanism) can create, is necessary for the implementation of effective and efficient conservation initiatives aimed to protect natural resources in general and coral reefs in particular.

Poster
A-1488

To the environmental analysis and beyond: a critical overview and possibilities of in situ analysis of coral reef health

Gastoldi, L.[1], Cioffi, A.[2], Raucci, A.[2], Miglione, A.[2], Cinti, S.[2, 3]
[1]Università Politecnica delle Marche, Life and Environmental Science, Ancona, Italy
[2]University of Naples Federico II, Department of Pharmacy, Naples, Italy
[3]University of Napoli Federico II, BAT Center - Interuniversity Center for Studies on Bioinspired Agro-Environmental Technology, Naples, Italy

lucia.gastoldi[at]gmail.com

Abstract

Nowadays, pollution and temperature alterations, due to, above all, increase in CO_2 emissions, cause important ecosystems' variations.
Coral reefs are considered one of the most endangered ecosystems and an important indicator of how fast our planet is changing. Indeed, their reactions to environmental variations are fast detachable within a few years' time range, especially since temperature alterations and water column acidification cause the reef's equilibria breakdown. Because of their natural and economical importance, analytical methods for evaluating their health status and improving their protection are highly required. Several techniques based on different approaches are nowadays applied to coral reefs' research, mostly represented by remote surveys, morphological observations, detection of associated fauna, and laboratory-bound approaches.
Only lately, some physiological *in situ* techniques have been developed and have been added to the canonical *in situ* reefs' evaluation and status description. To underline this aspect, we performed a literature review based on available techniques based on *in situ* monitoring from the published peer-reviewed scientific literature. We included works evaluating 1) the **morphology** of the reef based both on human operators and remote sensing approach, 2) the **physicochemical characterization** of the reef, and, more important for this work, 3) the **physiological evaluation** of the reef health status based on underwater measurements of metabolic rates of both coral individuals and coral communities. We wanted to underline those approaches that allow obtaining statistically analyzable data without performing experiments in the laboratory. We include the idea of (bio)sensors applied as a reef *in situ* technique since, as reported, offer plenty of potential application for *in situ* monitoring of the most diverse chemical species (metals, toxic ions, biocides), including those relevant for physiological evaluation (i.e., metabolites), and they allow to perform measurements easily, quickly, and low-cost. In addition, some preliminary applications towards monitoring aquatic and sea-related matrices are shown, including salinity and toxic metals evaluation at portable strips.
Portable and decentralized analytical devices represent the advance to interpret ecological data from *in situ* surveys and, furthermore, to add some physiological data that will represent the resilience of the organisms influenced by climate change.

Virtual
Oral
A-2145

Strengthening coral reef management through citizen science: a local community case in the Mexican Caribbean

González-Posada, A., Pérez-Cervantes, E., Molina-Hernández, A., Mendoza-Quiroz, S., Soto, M., Estrada-Saldívar, N.
Brigada Comunitaria, Parque Nacional Arrecife de Puerto Morelos, CONANP, Puerto Morelos, Mexico,

albagpmf[at]gmail.com

Abstract

The Stony Coral Tissue Loss Disease (SCTLD) is an unprecedented deadly disease affecting numerous reef-building corals. In the Mexican Caribbean, the disease was first reported in Puerto Morelos during the summer of 2018. By spring 2019, it had spread along Quintana Roo's entire coastline. The local community quickly joined the efforts made by Academia, NGOs, and the Marine Protected Areas (MPA) managers, and created local citizen science brigades to coordinate and monitor the impacts of the disease. These brigades were formed in the MPAs of Tulum, Cozumel, and Puerto Morelos. Here we present the achievements of a brigade formed by six female members from the community of Puerto Morelos. The brigade was financed by Puerto Morelos MPA and had four main objectives: 1) to monitor four sites' SCTLD prevalence and track the disease progression on specific colonies, 2) to monitor water quality, 3) to help enforcement and communicate about MPA's best practices, 4) to strengthen capacities of brigades members and community peers. In all four sites, water quality presented cause for concern as Enterococcus spp. levels were above legislated limits, which may be linked to disease spread. We also found a decrease in the prevalence of SCTLD in 2020 compared to 2019, which suggests that the worst damage happened during the outbreak of 2018 and has been decreasing since then. The numerous in-land and in-water watch guards undertaken by the brigade members have helped identify several incidents and violations to the MPA management program. With those reports, park rangers were able to take appropriate measures hence strengthening enforcement. Training courses were given to 94 people from different backgrounds. These results have been widely presented to the Puerto Morelos MPA's authorities, fishers, tour operators, and the general public showing the relevance of citizen science and how it can help to make informed decisions as well as raise awareness. This brigade model has also been implemented in other coastal towns of Quintana Roo. As a result, it has increased scientific knowledge of SCTLD, improved enforcement, strengthened the link between MPA management and the community, encouraged best practices, and built local capacity. The commitment of these brigades not only empowers its members to learn and preserve reef systems but also inspires the community to take active responsibilities into environmental awareness.

Virtual
Oral
A-2121

Coastal communities in the time of a pandemic – Tracing the impacts on fisheries, tourism, and the communities that depend on coral reefs

Holmes, K. E.[1], Yulianto, I.[1], Lestari, W. P.[1], Suciati, L.[1], Agusriadi, A.[1, 2], Arisa, A. A.[3], Darmono, O. P.[4], Haryanta, S.[5], Mardiah, U.[1], Muhardy, A.[3], Prasetia, R.[1], Prihatinningsih, P.[5], Rafandi, M. T.[6], Ripianto, R.[7], Ruchimat, T.[1], Rusmiati, S.[8], Sudarman, S.[9], Syamsuri, F.[2], Utami, A.[6]
[1]Wildlife Conservation Society - Indonesia, Bogor, Indonesia
[2]Takebonerate National Park, Selayar, Indonesia
[3]Wildlife Conservation Society - Indonesia, Banda Aceh, Indonesia
[4]Wildlife Conservation Society - Indonesia, Manado, Indonesia
[5]Karimunjawa National Park, Semarang, Indonesia
[6]Wildlife Conservation Society - Indonesia, Mataram, Indonesia
[7]Wildlife Conservation Society - Indonesia, Karimunjawa, Indonesia
[8]Wildlife Conservation Society - Indonesia, Ternate, Indonesia
[9]Wildlife Conservation Society - Indonesia, Takabonerate, Indonesia

katherine.holmes[at]gmail.com

Abstract

The Covid-19 crisis and the efforts to contain its spread had near-immediate effects on tourism and fisheries sectors globally as well as throughout Indonesia, where coral reef-dependent capture fisheries and marine tourism support a wide range of livelihoods. We are in a unique position to track impacts on Indonesia's coastal communities since we have long-standing collaborations with communities from across six provinces. Since May 2020, we have been reaching out regularly to 265 key informants from 46 villages with socio-economic surveys. Respondents have been contacted using mobile phones and given short, one-on-one interviews following protocols that ensure informed consent and confidentiality. In order to reduce survey fatigue, weekly surveys shifted to every other week in September and, later, to monthly. Since areas of the country ranged widely in their degrees of isolation and infection spread, they experienced different government-imposed restrictions on travel and other services; this resulted in coastal communities throughout Indonesia experiencing a wide range of restrictions and, therefore, impacts. As with many other fisheries-dependent countries, unsurprisingly, there were near-immediate drops in prices for fish species typically destined for export due to the collapse of international trade. However, scales of those drops, the impacts on communities, and the recovery trajectories have varied based on a range of geographic and governance characteristics. The impacts have been more severe for communities that are heavily reliant on tourism, both international and domestic. Since tourism dropped to nearly zero at the crisis' outset, tourism-related enterprises had few options other than to close with workers shifting to other income-earning options. We expect tourism recovery will differ significantly across the archipelago due to variabilities in travel restrictions and local government responses to the pandemic. National tourism resumed first, with a long delay before international tourism can become fully operational. We present time-series and assess the impacts of the pandemic for both of these reef-dependent sectors using generalized additive models. Implications for management and conservation of coral reefs in Indonesia within the new context will also be discussed.

Virtual
Oral
A-2168

Do MPAs benefit fishers?: a study of food security status of fishers residing in the Birds' Head Seascape MPAs of Papua, Indonesia

Pakiding, F.[1], Salosso, K. E.[1], Matualage, D.[1], Anggriyani, I. R.[1], Lisangan, M. K.[1], Lindongi, L.[1], Suawa, E. K.[1], Glew, L.[2]
[1]University of Papua, Manokwari, Indonesia
[2]Sequoia Climate Fund, Irvine, United States

f.pakiding[at]unipa.ac.id

Abstract

The Bird's Head Seascape of West Papua is located in the heart of the Coral Triangle and contains some of the highest marine biodiversity places in the world. To secure effective long-term management of these marine resources, ensure food security, sustain economic benefits, and conserve biodiversity, about 5 million hectares have been protected through establishing and managing Marine Protected Areas (MPAs) by 2021. MPAs are an integral component of local, national, and international strategies for biodiversity conservation, but their impacts on human well-being remain contested. Advocates tout MPAs as win-win strategies for conservation and poverty alleviation, while opponents argue that MPAs place the welfare of fish above the well-being of impoverished fishing communities. To inform this debate, we are monitoring the social impacts of six MPAs in the Bird's Head Seascape (BHS). In this study, we particularly examine the food security status of fishers' families living in the MPAs area and factors affecting their food security with a survey between 2017 and 2020. Using an adapted version of the U.S. Household Food Security Survey Module to assess household food security status, we surveyed more than 1100 fisher households. Food secure households represented 57-82 percent of each study site. In addition, around 17-37 percent of households had occasional problems providing meals for their families, while less than 10 percent experienced hunger within the last 12 months. In general, there is no significant difference in food security status between families who fish for income or fish for food. Likewise, those who have other sources of income appear to have food security status that is not significantly different from those who depend on fishing as their primary source of income. However, those who sell their catch more often have better food security status than those who trade less frequently. Therefore, ensuring market access is one of the keys to improving the food security conditions of fishers living in the Bird's Head. In addition to providing insights for site-level adaptive management, the variability in the food security among fishers and among MPA sites in the BHS highlights the need for a more niche approach to manage MPA in order to deliver benefit to broaden community.

Virtual
Oral
A-2164

Carrying capacity for snorkelers visiting Indonesia's Karimunjawa National Park

Rimayanti, R.[1], Sulisyati, R.[2], Rohman, E. A.[2], Tarigan, S. A.[1], Ripanto, R.[1], Jamaludin, J.[1], Muttaqin, E.[1], Muhidin, M.[1], Pardede, S. T.[1], Kartawijaya, T.[1], Holmes, K. E.[1]
[1]Wildlife Conservation Society - Indonesia Program, Bogor, Indonesia
[2]Karimunjawa National Park Authority, Semarang, Indonesia

rrimayanti[at]wcs.org

Abstract

Karimunjawa National Park is one of nine marine national parks in Indonesia. The park is a popular tourism destination due to its white sandy beaches, undisturbed coral reefs, and island scenery. Like all national parks, Karimunjawa has been managed through a system that divides the area into different zones based on their purposes and protections including Marine Tourism Zones. The number of visits to the park has surged from 39,224 people in 2011 to a peak of 188,301 people in 2016, a nearly five-fold increase in just six years. This is attributed, in part, to improved transportation allowing people from the capital region to easily reach the islands. High visitation has become a threat to Karimunjawa's marine environment, especially to its coral reef ecosystem, the foundation of the tourism itself. Despite existing communication approaches that encourage best snorkeling practices, tourists to the park still often cause direct, physical damage to its reefs. We collected extensive survey data at sites across ten of Karimunjawa's Marine Tourism Zones in 2016 and 2020 and used these data to assess snorkeling impacts since this is the primary marine activity of tourists who visit the park. Comparison between survey data in 2016, when tourism activity was active, and in mid-2020, during the Covid-19 pandemic when tourism activity had been halted for five months, revealed fewer damaged coral colonies in 2020 (90 colonies) than in 2016 (242 colonies) across the same snorkeling sites. Carrying capacity of each site was calculated using Real Carrying Capacity (RCC) formulae. Across multiple snorkeling sites, the number of allowable snorkelers based on RCC ranges from 5 to 476 people/day. The locations can be ranked from the lowest carrying capacity off of western Tengah Island to the highest off of Menjangan Besar Island. A sustainable tourism plan had been legalized under the Karimunjawa National Park Authority policy after the carrying capacity study being disseminated. One component of this plan includes a system to evenly distribute tourists across sites in the park. The plan has been implemented since October 2021 and tourism patrol are done regularly to date. Recommendation of the next steps are collaborating with other stakeholders to promote sustainable tourism, further strengthening the knowledge and communication skills of tourism operators, conducting campaigns for sustainable tourism, and assessing and improving waste management.

Virtual
Oral
A-2143

Participation and patrols promote sustainable fisheries in the Mesoamerican Reef Region.

Rivera, A.[1], San Martín - Chicas, J.[2], Myton, J.[2]
[1]The Coral Reef Alliance, West End, Honduras
[2]Coral Reef Alliance, West End, Honduras

antonellarivera.p[at]gmail.com

Abstract

Caribbean reef fisheries are highly diverse ecologically, socially and economically. However, management and conservation efforts often rely on a conventional top-down approach, which fails to incorporate a fishery's diversity into its framework. Here we present a case study of Los Micos Lagoon, a coastal lagoon responsible for seeding fish biomass in sites with some of the highest live coral cover in the Mesoamerican Region, the Tela Bay (Honduras) reefs. Through an adaptive co-management approach, local stakeholders sequentially implemented different strategies to improve fish biomass: (1) Temporal fishing bans, (2) Increased enforcement and (3) Locally-adapted Territorial Use Rights for Fishing (TURFs). We used both fishery-dependent (dockside landings monitoring) and independent (scientific fishing surveys) sampling to test the impact of the different management strategies from 2017 to 2019. Fish biomass increased only 10% after the implementation of the temporal ban, but biomass increased 171% when the temporal bans were paired with enforcement patrols. Furthermore, when the TURFs were added, fish biomass increased by 689%. This increase in fish biomass was also reflected in a doubling of profits when TURFs were incorporated into the management system. The Los Micos Lagoon case study demonstrates that in complex socioecological systems, such as coral reef fisheries, it is important to include local stakeholders in the management process to tailor management strategies to their needs; complex problems require participatory solutions.

Session 8B - How can social sciences contribute to equal exchanges between different ways of thinking and doing coral protection and rehabilitation?

Conceptualized by: **Annet Pauwelussen**[1], **Aída Sofía Rivera Sotelo**[2]
[1] Wageningen University (Wageningen, The Netherlands)
[2] University of California, Davis (Davis, CA, USA)

Chaired by: **Sebastian Ferse**[1], Carin Jantzen[2]
[1] Leibniz Center for Tropical Marine Research (Bremen, Germany)
[2] SECORE International (Bremen, Germany)

Oral
A-2204

What does it mean to say coral reefs have value?

Jones, E.
University of Exeter, Exeter, United Kingdom

erj205[at]exeter.ac.uk

Abstract

Coral reefs are often described in terms of their considerable value. Understanding, defining and clearly articulating this value has never been more important – especially in communicating across the widely differing disciplines and disparate societal groups working together on coral conservation and rehabilitation. Coral scientists offer interesting and useful subjects for examining coral value, given that those with the greatest understanding of coral systems are often best placed to judge their value. This is, in part, for the simple reason that valuing something requires knowledge of it.

This paper therefore uses an examination of the coral science literature to address the question ‘how do coral scientists think about the value of coral reefs?’. I analyse some of the key forms of value running through the coral science literature: notably economic, scientific, ecological, and affective value. I then analyse the different roles these forms play. In the process I connect these notions of value to their conceptual foundations, drawing links from coral science into philosophy, ecology and the social sciences and projecting their significance towards the practical Implications for coral conservation.

The purpose of this investigation is to provide the basis for a more in-depth empirical and philosophical examination of the roles of key forms of value in coral science, conservation and rehabilitation (for example, in spurring and shaping strategies to regenerate coral). As such, I present the results of a preliminary investigation focused on the forms of value visible in the literature, both to stimulate discussion and elicit participation from coral scientists and those working to protect coral. The paper therefore forms an important precursor to a larger and more comprehensive PhD project studying coral value.

8B - How can social sciences contribute to equal exchanges between different ways of thinking and doing coral protection and rehabilitation?

Oral
A-1295

The Lady Musgrave Reef as a model, an artistic perspective

Maitz, P.
kli.ac.at, An Insitute for the advanced study of natural complex systems, Konrad Lorenz Insitute for Evolution and Cognition Research, Klosterneuburg, Austria

office[at]petramaitz.com

Abstract

The Lady Musgrave Reef project has to do with the comparison of a natural ecosystems, such as a coral reef, and human work as an integrative social system. The Reef developed as an artwork since 2001, assigning work to people who could crochet the corals. Such people were recruited through ads in the paper and paid for their work. The aim for this endeavour was to increase consciousness for a shrinking natural beauty (the reefs) in our oceans.
How can a coral reef provide a philosophical platform for discussions of evolution and how can it be a model of complexity concerns?
The Art-Project/Installation ‘Lady Musgrave Reef‘ is exhibited in Museums:
The different corals crocheted by people build a big simulation of a natural reef.
Coral reefs form the largest eco-social unit of species and diverse forms of life. They live from one another and together in an alternating cycle with their environment, an extraordinary example of epigenetic transformations in microbiological terms.
The Lady Musgrave Reef is a network of different levels of information, we can say that the whole enterprise works in the spirit of, and on the principle of, participation of many.
This project enables the understanding of how mankind can intervene in protecting reefs on a level of culture in art/science.
The scientific vocabulary is quoted and integrated into an artistic program.
The Lady Musgrave Reef is an epistemic model. Lady Musgrave Reef produces a picture of growth in the organic/living sense as a “positive mould” or positive shape. In cooperation between marine-biology on the one hand and the social aspect of job-creating measures in poor economic times on the other hand, the art project Lady Musgrave Reef emerged from a collection of countless crocheted corals.
The Lady Musgrave Reef works as a knowledge and transfer oeuvre in the art and science
sector. The Lady Musgrave Reef Foundation was incorporated by Petra Maitz in Vienna 2001.
The connection of needlework, science (marine biology) and art and the way in which disciplines have already interconnected, becomes apparent.

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Oral
A-2209

Art for Impact and Restoration, changing public perception to marine restoration

Thomas, S.
University of Florida, Apollo Beach, United States

shelby.thomas.21[at]ufl.edu

Abstract

The Ocean Rescue Alliance (ORA) is a marine conservation and restoration nonprofit organization that implements innovative techniques to restore our marine environments. ORA creates artistic and memorial reefs that are designed to increase fish biodiversity, enhance coral restoration, and provide a unique diving location. Our ability to connect people to the ocean is
more important now than ever before. Through the use of artistic and memorial reefs ORA aims to change the publics' relationship with the ocean and our coral reefs. Having a family member or family reef in the ocean can make a more intimate connection which may alter peoples' daily activities. Diving into a world full of life provides a more enjoyable experience when visiting a loved
one. Art gives us the ability to connect people and cultures, designing unique dive sites which draw tourism, aiding in natural reef relief. Culturally impactful reefs connect and engage our local communities, creating a social responsibility to conserve and protect our reefs. Each memorial and sculpture are fixed with a habitat base which incorporates micro and macro habitat to
benefit fish biodiversity. In addition every module has Coral Loks, a device that enhances coral out planting, embedded to provide an opportunity to out plant coral. ORA is committed to coral restoration and has partnered with other organizations to expand research with the Coral Lok device, out planting coral on natural and artificial reefs. ORA targets a community approach to sustainable restoration through incorporating art and memorials, our goal is to strengthen societies relationship to marine conservation. Our citizen science and coral rangers program engages our local communities and youth in marine conservation, coral restoration, and reef monitoring efforts. Through habitat creation, restoration, research, and education ORA seeks to conserve our marine ecosystems aiding in saving our oceans one reef at a time.

8B - How can social sciences contribute to equal exchanges between different ways of thinking and doing coral protection and rehabilitation?

Virtual
Oral
A-1965

Progress in facilitating genuine reef research partnerships with Australian Traditional Owners

Muir, B.[1], Evans-Illidge, L.[2], Forester, M. T.[2], Depczynski, M.[2], Ivey, J.[2], Pfitzner, R.[2], Souter, D.[2]
[1]AIMS, Research Services, Townsville, Australia
[2]Australian Institute of Marine Science, Research Services, Townsville, Australia

b.muir[at]aims.gov.au

Abstract

For millennia, Traditional Owners have held inherent rights, interests and knowledge of Australian reefs. The Australian Institute of Marine Science (AIMS) is implementing an institutional research governance model to respect and uphold these rights and interests to achieve genuine research partnerships with Traditional Owners [1, 2]. We present progress in implementing this approach since the presentation provided to ICRS 2021. Our focus on processes to seek and obtain Free Prior Informed Consent upholds Lore and positions Traditional Owners as decision makers on their sea Country. This approach supports aspirations within the United Nations Declaration on the Rights of Indigenous Peoples [3], which are not yet embraced in the regulatory framework in Australia. Indigenous interest in coral reef sea Country is especially significant in Australia given continuous occupation of coastal areas at least since the time of the last glacial maximum when areas such as the Great Barrier Reef were a vast inhabited coastal plain [4].

Case studies of Traditional Owner partnerships in reef restoration science and reef monitoring will be presented, along with new initiatives in meaningful training and capacity building. The AIMS approach has influenced others involved in reef science and management in Australia including across the Reef Restoration and Adaptation Program. Besides celebrating significant success, this ‘warts and all’ presentation will also describe the challenges and lessons learnt along the way.

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Session 9A - Open Session: Global and local impacts

Conceptualized by: **Christian Wild**[1], **Christian Voolstra**[2]
[1] University of Bremen (Bremen, Germany)
[2] University of Konstanz (Konstanz, Germany)

Chaired by: **Christian Wild**[1], **Christian Voolstra**[2], **Selma Mezger**[1], **Svea Vollstedt**[1]

Oral
A-1444

Artificial Light at Night (ALAN) alternating corals physiology lifestyle

Ayalon, I.[1], Avisar, D.[2], Levy, O.[3]
[1]The Interuniversity Institute Of Eilat, Eilat, Israel
[2]Tel Aviv University, 3Porter School of the Environment and Earth Sciences, Faculty of Exact Sciences, Tel Aviv University, 39040, Israel, Tel Aviv University, Israel
[3]Bar-Ilan University, Faculty of Life Sciences, Ramat Gan, Israel

inbalaya[at]gmail.com

Abstract

In the current age of the Anthropocene, coral reefs have become increasingly vulnerable to environmental stress, such as extreme weather events and climate change, as well as anthropogenic impacts, such as urban development and degrading habitats. Due to human settlement, coastal habitats have become some of those most vulnerable to light pollution, which may shift the daily and monthly rhythm of organisms. As human populations grow and lighting technologies improve, artificial light at night (ALAN) gradually alters natural cycles of light and dark that have been consistent over long periods of geological and evolutionary time. While considerable ecological implications of artificial light have been identified in both terrestrial and aquatic habitats, knowledge about the physiological, behavioral and biological effects of light pollution is vague. Here I would like to present the biological processes including physiology parameters impact coral reefs under light pollution. We show that ALAN can lead to coral stress including elevation of Reactive Oxygen Species, a decline in the photosynthesis performances and also shifting the corals gametogenesis cycles, symbiosis, reproduction timing and metabolism.

Oral
A-1154

Global trends of echinoid mass mortalities – insights from Echinocardium from the Eastern Mediterranean Sea

Benaim, G. A.[1], **Schmidt, L.-M.**[1, 2], Kroh, A.[3], Bronstein, O.[1]
[1]Tel Aviv University, School of Zoology and The Steinhardt Museum of Natural History, Tel Aviv, Israel
[2]The Interuniversity Institute for Marine Science in Eilat, Eilat, Israel
[3]Natural History Museum Vienna, Department of Geology & Palaeontology, Vienna, Austria

lisamaria.schmidt[at]gmx.net

Abstract

Mass mortality events (MMEs) have been occurring since the dawn of time. However, in contrast to terrestrial events, most marine MMEs remain undetected due to the inaccessibility of most marine environments. One of the most notorious marine MMEs is the population collapse of *Diadema antillarum* in the Caribbean during the early ’80s which triggered a catastrophic phase shift in local benthic communities – from which the region never fully recovered.
Here we summarize 314 studies of echinoid MMEs dating back to 1888 and include citizen-science reports, social media and newspaper articles. We formulate five potential mechanisms driving echinoid MMEs and calculate their relative abundance. We then provide the first reports of echinoid MMEs in the Eastern Mediterranean, compiling *in situ* observations, molecular, morphological and environmental data, to illustrate a decade-long history of ongoing localized MMEs in the region. We found five main mechanisms driving echinoid MMEs: 1) catastrophic events (25%), 2) algal blooms (9.6%), 3) pathogenic activity (16.9%), 4) temperature and tides (39%) and 5) human activity (9.6%). Along the Israeli coastline, four MMEs of irregular echinoids of the genus *Echinocardium* are reported between 2011 and 2020. Using the Israeli MMEs as a case study to scrutinize the abovementioned mechanisms, we analysed skeletal remains collected during one of the MMEs as well as meteorological and remote-sensed environmental data (Chlorophyll *a*, sea surface temperatures, and precipitation) collected during the weeks prior to the MMEs. While none of the environmental parameters alone could be identified as the sole contributor of the Israeli MMEs, the mortality events were always recorded near the outlet of polluted rivers or adjacent to major power stations – suggesting pollution from human activity as the main source of these mortalities. Observations from the warm Eastern Mediterranean may predict the future of the western parts of the Mediterranean as global warming accelerates and human activity intensifies.

Oral
A-1562

Assessment of nutrient enrichment effects on stony coral tissue loss disease progression and microbial communities in Montastraea cavernosa corals

Carreiro, A.[1], Eckert, R.[1], Shilling, E.[1], Klein, A.[1], Combs, I.[2], Voss, J.[1]
[1]Florida Atlantic University-Harbor Branch Oceanographic Center, Fort Pierce, United States
[2]Elizabeth Moore International Center for Coral Reef Research and Restoration-Mote Marine Laboratory, Summerland Key, United States

acarreiro2019[at]fau.edu

Abstract

Florida's Coral Reef is presently facing a multi-year outbreak of a coral disease described as stony coral tissue loss disease (SCTLD), which has affected at least 24 species of scleractinian corals. This disease was first described off the coast of Florida in 2014 and has since spread across the entirety of Florida's Coral Reef and throughout multiple reefs across the Caribbean. Potential anthropogenic and environmental drivers of SCTLD progression and severity are still poorly understood. For other stony coral diseases, including black band and yellow band disease, severity is exacerbated by the introduction of excess nutrients, meaning that efforts to improve water quality could help mitigate disease outbreaks. Additionally, nutrient enrichment within the water column can disrupt coral microbiomes which may facilitate pathogenesis and coral mortality. This project aims to determine if elevated nutrient levels contribute to the progression of SCTLD on local reefs in Southeast Florida. To evaluate the potential effects of elevated nutrients on SCTLD progression and coinciding fluctuations in the corals' microbial communities, this study simulated urban and agriculture runoff near coral colonies by experimentally increasing nutrient levels using 30g of Osmocote™ slow-release fertilizer. Fifteen healthy and thirty SCTLD-affected *Montastraea cavernosa* coral colonies were tagged and divided into three treatment groups: 1) apparently healthy, 2) SCTLD-affected controls, and 3) SCTLD-affected experimental colonies amended with fertilizer. Coral tissue loss was tracked over time using structure-from-motion photogrammetry, and control colonies were compared to nutrient amended experimental colonies to understand the effects of nutrient enrichment on SCTLD progression rates. Tissue punches were collected from coral colonies before nutrient exposure, during exposure, and after the nutrient amendments were removed to examine the effects of nutrient enrichment on microbial community dynamics. From these samples, 16S amplicon sequencing was used to assess differences in diversity and abundance of microbial taxa between treatment groups, time, and disease status. This information may be used to link specific microbial taxa or consortia to SCTLD and environmental stressors such as nutrient enrichment. The results of this study can inform water quality management guidelines to help reduce the severity of SCTLD on coral reefs.

Oral
A-1710

Global coral reef diversity forecasts for warmer, more acidic seas

Couce, E., Cowburn, B., Clare, D., Bluemel, J.
Cefas (Centre for Environment, Fisheries and Aquaculture), Lowestoft, United Kingdom

ecouce[at]gmail.com

Abstract

Coral reefs are set to undergo significant changes and ecosystem shifts over the coming decades as seas become warmer and more acidic. We investigate the environmental tolerances of over 650 Scleractinian coral species to identify short- and medium-term "winners" and "losers" and predict how coral species composition is likely to evolve in different regions around the world. Using the species distribution model Maximum Entropy (MaxEnt), we analyse the environmental requirements of each coral species based on their current ranges, and predict changes to their distributions under future warming and acidification, accounting for connectivity between reef sites driven by oceanic currents. We develop global forecasts for the evolution of coral community structure and reef diversity (coral species richness) over the next half century under two different emission scenarios: SSP 1-2.5 (approximately 2 degree warming, the target of the Paris Agreement) and SSP 5-8.5 (high warming, business-as-usual scenario). We find that environmental conditions in many reefs will become unsuitable within 50 years for the majority of species currently present, particularly in the Great Barrier Reef, Coral Sea, Coral Triangle, Western Indian Ocean and Caribbean. However, regional diversity could largely be maintained by achieving Paris Agreement goals, highlighting the critical importance of mitigating climate change to avoid potentially massive extinctions of coral species.

Oral
A-1884

First records of hydrocoral mass mortality in the southwestern Atlantic: heat waves as a major threat to turbid zone coral refugia.

Duarte, G.[1], Dias Müller Villela, H.[2], Deocleciano, M.[3], Silva, D.[1], Barno, A.[2], Cardoso, P.[2], Leite Spindola Vilela, C.[1], Rosado, P.[2], Simões Martins, C.[1], Alejandra Chacón, M.[1], P. Santoro, E.[2], Blasquez, D.[1], Szpilman, M.[4], A. Rocha, L.[5], Sweet, M.[6], Silva Peixoto, R.[2]
[1]Universidade Federal do Rio de Janeiro, Instituto de Microbiologia Paulo de Góes, Rio de Janeiro, Brazil
[2]King Abdullah University of Science and Technology, Red Sea Research Center, Thuwal, Saudi Arabia
[3]AquaRio - Aquário Marinho do Rio de Janeiro, Rio de Janeiro, Brazil
[4]Instituto Aquario Marinho do Rio de Janeiro - IMAM, AquaRio, Rio de Janeiro, Brazil
[5]California Academy of Sciences, San Francisco, United States
[6]University of Derby, Environmental Sustainability Research Centre, Derby, United Kingdom

gust.duarte[at]gmail.com

Abstract

Coral reefs provide shelter and habitat for a third of all marine organisms, protect the coast from erosion and are a primary source of protein for over 500 million people. However, they are threatened by climate change on a global scale resulting in bleaching events being widely reported and reef health declining in many areas. The reefs off the east coast of Brazil have only seen relatively low levels of mortality (5-10%) since the first recorded bleaching event in 1995. However, between Feb and May 2019, the reefs suffered catastrophic decline in coral cover, in particular the hydrocoral *Millepora alcicornis* due to bleaching and disease, a result of exposure to >19°C degree heating weeks. *M. alcicornis* inhabits the high flow reef-crest areas of the reefs, and is one of the three major reef-building corals in the Brazilian Eastern Cost Reefs. Almost 90% mortality of *M. alcicornis* was observed at Pedra do Silva, and 83.49% (± 9.04%) mortality at Virada de Fora: both of which are situated in a co-managed federal marine protected area. One further site surveyed (Coroa Vermelha) had slightly lower mortality rates of 43.32% (± 11.99%). However, this site was 70 km north of the other two and was exposed to lower (yet still extreme levels) of DHW (10°C-week). The more thermotolerant corals (such as Mussidae) also showed bleaching, however this was reduced further with 'only' 50% of colonies bleaching with and circa 8% mortality. To conclude, the mass die off witnessed in 2019 on these Brazilian reefs is unprecedented. As *M. alcicornis* grows relatively slowly (2,4 cm/year), recovery will likely take decades, indicating the need for restoration efforts in this area as a priority.

Oral
A-1144

Coral metabolomes exhibit contamination by anthropogenic products and show potential as tools for prescriptive management

Greene, A.[1, 2], Leggatt, W.[3], Moriarty, T.[3], Ainsworth, T. D.[4], Nijagal, B.[5], Falinski, K.[1, 6], Sogin, E. M.[7], Caldwell, J. M.[2, 8], Heron, S. F.[9], Donahue, M. J.[1, 2]
[1]University of Hawaiʻi at Mānoa, Honolulu, United States
[2]Hawaiʻi Institute of Marine Biology, Kāneʻohe, United States
[3]University of Newcastle, Ourimbah, Australia
[4]University of New South Wales, Sydney, Australia
[5]Metabolomics Australia, Bio21 Molecular Science and Biotechnology Institute, Parkville, Australia
[6]The Nature Conservancy, Honolulu, United States
[7]University of California, Merced, Merced, United States
[8]Princeton University, Princeton, United States
[9]James Cook University, Townsville, United States

austinlg[at]hawaii.edu

Abstract

In this study, we demonstrate the utility of untargeted metabolomics at large scales to highlight site-specific patterns in land-based pollution and other impacts to coral reefs. Current impact assessments, particularly those targeting land-based pollution, rely on point sampling of water quality. These water samples are a snapshot of the water on the reef and may be taken some distance from exposed corals and; therefore, they may not reflect the pollutants in direct contact with or accumulated by the coral holobiont. Using high-resolution mass spectrometry, we identify a variety of micropollutants present in the coral metabolome and cluster sites according to the metabolome and associate patterns with reef condition, local land use, and submarine groundwater discharge. We show that hallmark contaminants of concern abundant in Hawaiian corals are absent from corals sampled in the more remote Southern Line Islands and suggest that metabolomic contamination represents a widespread sub-lethal impact to corals along developed coastlines. These results demonstrate the coral metabolome as a highly sensitive indicator of land-based pollution to support prescriptive management and bring into focus the extent of anthropogenic contamination occurring on coral reefs.

Oral
A-1968

Experimental reef communities persist under mitigated future ocean acidification and warming

Jury, C.[1], Bahr, K.[2], Barba, E.[1], Brainard, R.[3], Cros, A.[4], Dobson, K.[5], Graham, A.[1], McLachlan, R.[6], Nelson, C.[7], Price, J.[5], Rocha de Souza, M.[1], Shizuru, L.[1], Smith, C.[8], Sparagon, W.[7], Squair, C.[8], Timmers, M.[9], Tran, T.[10], Vicente, J.[1], Webb, M.[1], Yamase, N.[11], Grottoli, A.[5], Toonen, R.[1]
[1]Hawai'i Institute of Marine Biology, Kāneʻohe, United States
[2]Department of Life Sciences, Texas A&M University – Corpus Christi, Corpus Christi, TX 78412, USA, Corpus Christi, United States
[3]Red Sea Research Center, King Abdullah University of Science and Technology, Thuwal, Saudi Arabia, Thuwal, Saudi Arabia
[4]Woods Hole Oceanographic Institution, Woods Hole, MA 02543, USA, Woods Hole, United States
[5]School of Earth Sciences, The Ohio State University, Columbus, OH 43210, USA, Columbus, United States
[6]Oregon State University, Corvallis, U.S. Outlying Islands
[7]Daniel K. Inouye Center for Microbial Oceanography: Research and Education, Department of Oceanography and Sea Grant College Program, School of Ocean and Earth Science and Technology, University of Hawaiʻi at Mānoa, Honolulu, HI 96822, USA, Honolulu, United States
[8]School of Life Sciences, College of Natural Sciences, University of Hawaiʻi at Mānoa, Honolulu, HI 96822, USA, Honolulu, United States
[9]Pacific Islands Fisheries Science Center, National Oceanic and Atmospheric Administration, Honolulu, HI 96818, USA, Honolulu, United States
[10]School of Ocean and Earth Science and Technology, University of Hawaiʻi at Mānoa, Honolulu HI 96822, USA, Honolulu, United States
[11]Marine Biology Graduate Program, College of Natural Sciences and School of Ocean and Earth Science and Technology, University of Hawaiʻi at Mānoa, Honolulu HI 96822, USA, Honolulu, United States

jurycp[at]hawaii.edu

Abstract

Coral reefs are among the most sensitive ecosystems affected by ocean acidification and warming, and are predicted to shift from net accreting calcifier-dominated systems to net eroding algal-dominated systems over the coming decades. Here we present a long-term experimental study examining the responses of entire mesocosm coral reef communities to acidification (-0.2 pH units), warming (+2 °C), and combined future ocean (-0.2 pH, +2 °C) treatments. We show that under future ocean conditions, net calcification rates declined yet remained positive, corals showed reduced abundance yet were not extirpated, and community composition shifted while species richness was maintained. Our results suggest that under Paris Climate Agreement targets, coral reefs could persist in an altered functional state rather than collapse.

Oral
A-1229

Compensatory dynamics regulate mesopredatory coral reef fish community stability under global change.

Karkarey, R., Maire, E., Keith, S.
Lancaster University, Lancaster Environment Centre, Lancaster, United Kingdom

r.karkarey1[at]lancaster.ac.uk

Abstract

Unravelling the drivers of diversity–stability relationships is an urgent issue under global change, since stable communities are less prone to extinctions and invasions, providing more reliable ecosystem services. Community stability (i.e., the temporal stability of community abundance or biomass) can be achieved by higher species diversity (portfolio effect), higher asynchrony across species populations (compensatory dynamics), or higher abundance of species (selection effect). However, the relative importance of these mechanisms and the interplay between different biotic (community structure) and abiotic drivers is controversial and not widely studied across many trophic groups and ecosystems. On coral reefs, mesopredators play important roles in ecological and evolutionary dynamics through consumptive and non-consumptive effects and support extensive fisheries, such that fluctuations in their abundances can have important implications for reef ecosystems and people.

To examine global patterns and drivers of mesopredator community stability (temporal stability of aggregate community abundance), we used structural equation modelling to analyse 182 time series datasets of coral reef fish (SCORE-REEFs project) from four biogeographic regions (Western Atlantic Ocean, Western Indian Ocean, Central Indo-Pacific Ocean and Central Pacific regions) sampled between 2010 - 2020.

We found that compensatory dynamics, rather than portfolio, or selection effects were the dominant mechanism of mesopredator stability across reefs. Overall, functional redundancy (i.e., low distinctiveness of functional traits), strongly increased asynchrony, suggesting that interspecies competition likely plays a strong role in stabilizing mesopredators. SST- anomalies destabilised mesopredators by thinning species and functional richness and lowering asynchronous dynamics consistent with the environmental filtering hypothesis. Fishing pressure stabilised mesopredators by removing rare traits (e.g. large body size) and increasing asynchronous dynamics consistent with the mesopredator release hypothesis. Our findings highlight the crucial role of community composition, biotic interactions and compensatory dynamics in regulating mesopredator community stability that need to be managed under global change.

Oral
A-2217

Turning rubble to reef: Quantifying rubble mobilisation and binding dynamics to assess recovery potential of disturbed reefs

Kenyon, T.[1], Doropoulos, C.[2], Dove, S.[1], Webb, G. E.[1], Harris, D.[1], Newman, S.[3], Mumby, P. J.[1]
[1]University of Queensland, Brisbane, Australia, [2]Commonwealth Scientific and Industrial Research Organisation, Brisbane, Australia, [3]Banyan Tree Marine Lab, North Male' Atoll, Maldives, (tania.kenyon[at]uqconnect.edu.au)

Abstract
Production of rubble on coral reefs is increasing due to more frequent and severe disturbance events, including mass coral bleaching, cyclones and blast fishing. Recovery of rubble-dominated reefs is constrained by physical and biological
processes, particularly rubble mobilisation and binding. Rubble that has been naturally stabilised by rubble-binding organisms can provide a solid substrate for coral recruitment. Conversely, the hydrodynamic mobilisation of unstable rubble can inhibit binding while also increasing mortality of recruits or fragments in the rubble by scouring or smothering, potentially limiting recovery and fixing the system in a rubble-dominated state. Using observational and experimental work on highly degraded reefs in the Maldives, we characterise (i) rubble mobilisation, (ii) binding dynamics, and (iii) impacts of mobilisation on recruitment. We investigated (i) hydrodynamic thresholds required to overturn rubble of different sizes and morphologies; (ii) community composition and binding rates in natural rubble beds and experimentally stabilised rubble; and (iii) the response of coral fragments to experimental scouring, a proxy for rubble mobilisation impact. At least 50% of rubble was overturned when bottom orbital velocities reached a threshold of ~0.3 m/s, and this threshold decreased as rubble size and complexity decreased. In natural rubble beds, 20% of rubble was bound, but when rubble was experimentally stabilised, this increased to 70% after 6 months. Binding was more likely in reef slope than lagoon environments, and the most prevalent binders in both natural and stabilised scenarios were sponges. In the scour experiment, we found that increasing scour frequency caused sublethal effects including reduced tissue growth and pigmentation, and increased partial mortality, even in robust species (Porites rus). Thus, rubble beds that experience threshold mobilisation velocities more than every 6 months will not bind well, with subsequent impacts on recruit survival that would vary among reefs depending on environmental factors including bathymetry and hydrodynamics. Predicting the natural stabilisation and recovery potential of degraded, rubble-dominated areas is imperative given the current trajectory of coral reefs from live to dead substrates. Degraded reefs with poor recovery potential could be prioritised for management strategies that include implementation of assisted rubble stabilisation.

Oral
A-1641

Projecting coral responses to intensifying marine heatwaves under ocean acidification

Klein, S.[1], Geraldi, N.[1], Anton, A.[1], Schmidt-Roach, S.[2], Ziegler, M.[2, 3], Cziesielski, M.[2], Martin, C.[1], Rädecker, N.[2], Frölicher, T.[4, 5], Mumby, P.[6], Pandolfi, J.[7], Suggett, D.[8], Voolstra, C.[2, 9], Aranda, M.[2], Duarte, C.[1]
[1]King Abdullah University of Science and Technology (KAUST), Red Sea Research Center and Computational Bioscience Center, Thuwal, Saudi Arabia
[2]King Abdullah University of Science and Technology (KAUST), Red Sea Research Center, Thuwal, Saudi Arabia
[3]Justus Liebig University, Department of Animal Ecology & Systematics, Giessen, Germany
[4]University of Bern, Climate and Environmental Physics, Physics Institute, Bern, Switzerland
[5]University of Bern, Oeschger Centre for Climate Change Research, Bern, Switzerland
[6]The University of Queensland, Marine Spatial Ecology Lab, School of Biological Sciences, Brisbane, Australia
[7]The University of Queensland, Australian Research Council Centre of Excellence for Coral Reef Studies, School of Biological Sciences, Brisbane, Australia
[8]University of Technology Sydney, Climate Change Cluster, Faculty of Science, Sydney, Australia
[9]University of Konstanz, Department of Biology, Konstanz, Germany

shannon.klein[at]kaust.edu.sa

Abstract

Over this century, coral reefs will run the gauntlet of climate change, as marine heatwaves (MHWs) become more intense and frequent, and ocean acidification (OA) progresses. However, we still lack a quantitative assessment of how, and to what degree, OA will moderate the responses of corals to MHWs as they intensify throughout this century. Here, we first projected future MHW intensities for tropical regions under three future greenhouse gas emissions scenario (representative concentration pathways, RCP2.6, RCP4.5 and RCP8.5) for the near-term (2021–2040), mid-century (2041–2060) and late-century (2081–2100). We then combined these MHW intensity projections with a global data set of 1,788 experiments to assess coral attribute performance and survival under the three emissions scenarios for the near-term, mid-century and late-century in the presence and absence of OA. Although warming and OA had predominately additive impacts on the coral responses, the contribution of OA in affecting most coral attributes was minor relative to the dominant role of intensifying MHWs. However, the addition of OA led to greater decreases in photosynthesis and survival under intermediate and unrestricted emissions scenario for the mid- and late-century than if intensifying MHWs were considered as the only driver. These results show that role of OA in modulating coral responses to intensifying MHWs depended on the focal coral attribute and extremity of the scenario examined. Specifically, intensifying MHWs and OA will cause increasing instances of coral bleaching and substantial declines in coral productivity, calcification and survival within the next two decades under the low and intermediate emissions scenario. These projections suggest that corals must rapidly adapt or acclimatize to projected ocean conditions to persist, which is far more likely under a low emissions scenario and with increasing efforts to manage reefs to enhance resilience.

Oral
A-1052

Light limitation and coral mortality in urbanised reef communities due to sea-level rise

Law, M. T.[1, 2], Huang, D.[1, 3]
[1]National University of Singapore, Department of Biological Sciences, Singapore, Singapore
[2]Nanyang Technological University, Earth Observatory of Singapore, Singapore, Singapore
[3]National University of Singapore, Tropical Marine Science Institute, Singapore, Singapore

e0724744[at]u.nus.edu

Abstract

Sea-level rise (SLR) is predicted to elevate the depth of seawater above coral reefs, reducing the amount of light available to the benthic environment and impacting the survival and growth of corals especially on turbid coral reefs. However, knowledge on how SLR will impact coral reefs in urbanised areas remains limited. For example, there are few projections of coral mortality on the deepest parts of turbid reefs, whether coral growth will continue to keep pace above light thresholds as SLR progresses through the end of the century, and whether mortality rate would vary by location and local conditions. Here, we predict the outcomes of corals inhabiting the turbid reefs of Singapore in 2050 and 2100 by classifying their depth distributions and analysing their mortality rates against the projected rates of SLR. Our results reveal a strong, positive relationship between the loss of deeper corals and rising sea levels. Higher rates of SLR will result in greater mortality in 2100, even when accounting for continuous coral linear extension. Our findings suggest that sea-level rise poses an immediate threat to the survival of corals on turbid reefs, impacting their ability to cope with climate change especially under the most extreme circumstances.

Oral
A-1368

Impacts of desalination brine waste on a hard coral: new insights and future perspectives

Marques, J.[1, 2], Adler, O.[2], Gafni, A.[2], Levy, O.[3], Bar Zeev, E.[2]
[1]The Interuniversity Institute for Marine Sciences in Eilat, Eilat, Israel
[2]Ben Gurion University of the Negev/Zuckerberg Institute for Water Research, Midreshet Ben Gurion, Israel
[3]Bar Ilan University, Ramat Gan, Israel

jmarques.oceano[at]gmail.com

Abstract

Coral reefs often occur in coastal areas of many arid and semi-arid countries. These nations often face severe water scarcity and rely on desalination for freshwater production. Desalination plants may pose a risk to the marine environment as brine waste that include few central chemicals (e.g., antiscalants) is discharged back into the sea. Antiscalants (AS), comprised by polyphosphonates or polymer-based materials, are used to enhance the efficiency of freshwater production. Although widely used, little is known on the ecotoxicological effects of ASs on keystone organisms such as corals. Recently, we have tested the impacts of polyphosphonate-based and polymer-based ASs presence on the coral *Montipora capricornis*. We explored the effect of ASs (0.025 ml AS/L) on bacteria production and abundance, microalgae abundance, photosynthesis performance, chlorophyll a content, coral host protein content, antioxidant capacity and lipid oxidative damage after exposing the corals for up to two weeks. After two weeks of exposure, corals from both ASs presented severe tissue damage (30.1% and 41.4% of fragment for polymer and phosphonate treatment, respectively), lower photosynthetic efficiency, and higher bacteria abundance (43.5% and 18.6% increase for polymer and phosphonate, respectively). We assume that the biological responses found in corals exposed to phosphonate lead to an oxidative stress condition. Corals from this treatment upregulated their non-enzymatic antioxidants by the end of the second week, where we found the peak of total antioxidant capacity (45% increase) and decreased microalgae abundance (-20%). More detailing is necessary to reduce the knowledge gaps on the impacts of desalination effluents on corals, and future perspectives include testing different desalination-related stressors on a range of soft and hard coral species. Our results so far shed new insights on the effects of brine waste on the physiology and vitality of hard corals. To minimize the damage of desalination effluents on corals, we suggest to avoid using phosphorus-based AS. And for the establishment of monitoring programs, in addition to the classic endpoints for coral`s health (e.g. photobiology and microalgae abundance), we suggest monitoring early-warning biomarkers such as oxidative stress parameters. Water scarcity is a global issue, so it is imperative to investigate the best approaches to monitor and mitigate impacts of desalination technologies on marine ecosystems.

Oral
A-1107

Combined effects of heavy fuel oil and UV radiation across multiple life stages of coral

Nordborg, M.[1, 2, 3], Brinkman, D.[3], Agustí, S.[4], Negri, A.[1, 3]
[1]AIMS[at]JCU, Townsville, Australia
[2]James Cook University, College of Science & Engineering, Townsville, Australia
[3]Australian Institute of Marine Science, Townsville, Australia
[4]King Abdullah University of Science & Technology, Red Sea Research Centre, Thuwal, Saudi Arabia

mikaela.nordborg[at]my.jcu.edu.au

Abstract

Petroleum oils can severely impact marine ecosystems, especially in regions frequently receiving high amounts of ultraviolet radiation (UV) such as tropical coral reefs. UV can more than double the toxicity of dissolved petroleum hydrocarbons and contributes to preventing critical life stage transitions at very low concentrations. While some data on the sensitivity of coral gametes, larvae and adults to petroleum hydrocarbons are available, differences in methodology, pollutant, species and life stage studied prevents direct comparisons of the relative effects identified among studies. Additionally, only a handful of previous studies have included UV co-exposure, despite its influence on toxicity and prevalence on shallow-water reefs. Here, we present a unique comparison of the effects of dissolved heavy fuel oil (HFO) components on gametes, developing embryos, planula larvae, newly settled recruits, 2-month old juveniles and propagated adults of the coral *Acropora millepora.* The toxicity of HFO was tested through chronic exposures of each life stage in the presence and absence of UV. The general and phototoxic effects of HFO were assessed using both lethal and sublethal endpoints, as appropriate for each life stage tested. The sensitivity of life stages varied substantially, with impacts observed for multiple life stages at dissolved concentrations lower than, or similar to, those previously reported from the field following accidental spills and generic protective concentrations applied in risk assessments. Additionally, the results demonstrate that several coral life stages are more sensitive to oil exposure than previously studied taxa from other habitats. The study highlights the importance of tropical environmental conditions as co-factors when studying petroleum toxicity to coral reef organisms and confirms that UV, when ecologically relevant, should be included in experimental designs and risk assessments to ensure the potential impacts of petroleum hydrocarbons are not underestimated.

Oral
A-1723

Biological changes in open-ocean and their influence on the coral reef.

Stambler, N.
Stambler, Kiriat Ono, Israel

drnogas[at]gmail.com

Abstract

The climate change is mainly increase in temperature and CO_2 acidification of the ocean. The temperature changes leaders major changes in stratification of the ocean and as such leder to variation in nutrients concentration. In one scenario decreasing in nutrients concentration will limit the phytoplankton growth which is already a limiting factor at the oligotrophic water surrounding the coral reefs and by that will decreased the zooplankton biomass and the food supplied to the coral reef.
Another scenario is because of the increased in temperature, and nutrient from dust, there will bloom of phytoplankton including toxic algae, e.g. harmful algae bloom, (HAB) and /or bloom of macroalgae. In both case due to competition with the corals as example on light the coral reef even if can survive the bleaching due to the temperature increase or will develop in the mesophotic reef but will suffer from lower light.
Eruption of Mount Pinatubo in the Philippines (1991) led to deeper mixing in the Gulf of Eilat, overgrowing of macroalgae g fringing reefs in Eilat, Israel, Gulf of Aqaba and corals death. Changes in the open ocean will detriment the future of our corals reef.

Oral
A-1659

Meta-analysis reveals additive impacts of deoxygenation and acidification on marine biota - but does this apply to coral reefs?

Steckbauer, A., Klein, S. G., Duarte, C. M.
King Abdullah University of Science and Technology (KAUST), Red Sea Research Center (RSRC) & Computational Bioscience Research Center (CBRC), Thuwal, Saudi Arabia

alexandra.steckbauer[at]kaust.edu.sa

Abstract

Deoxygenation in coastal and open-ocean ecosystems rarely exists in isolation but occurs concomitantly with acidification. Within coastal marine ecosystems, deoxygenation and acidification commonly co-occur when biological respiration outweighs primary productivity to consume O2 and produce CO2. However, the severity and duration of these events can vary widely depending upon numerous physical and biological processes, making it difficult to predict ecosystem-wide consequences. Here, we first combine meta-data of experimental assessments to investigate the potential interactive impacts of deoxygenation and acidification on a broad range of marine taxa. We characterize the differing degrees of deoxygenation and acidification tested in our dataset using a ratio between the partial pressure of oxygen and carbon dioxide (pO2/pCO2) to assess how biological processes change under an extensive, yet diverse range of pO2 and pCO2 conditions. The dataset comprised 375 experimental comparisons and revealed predominantly additive but variable effects (91.7% additive; 6.0% synergistic; and 2.3% antagonistic) of the dual stressors, yielding negative impacts across almost all responses examined. Our data indicate that the pO2/pCO2 - ratio offers a simplified metric to characterize the extremity of the concurrent stressors and shows that more severe impacts occurred when ratios represented more extreme deoxygenation and acidification conditions. Importantly, our analysis highlights the need to assess the concurrent impacts of deoxygenation and acidification on marine taxa and that assessments considering the impact of O2 depletion alone will likely underestimate the impacts of deoxygenation events and their ecosystem wide consequences. Finally, we identify a crucial gap of knowledge for tropical regions and taxonomic groups such as calcifying cnidarians and other reef taxa. These regions and taxa may be particularly vulnerable owing to the increasing instances of deoxygenation events being reported for the tropics and the vulnerability of tropical taxa to rising temperatures, which may result in compounding impacts.

Oral
A-1640

eDNA as a new coral reef monitoring tool: Genetic detection of larvae and post-settlement individuals of Crown-of-Thorns seastar outbreaks

Uthicke, S., Patel, F., Gomez Cabrera, M., Doyle, J.
Australian Institute of Marine Science, Townsville, Australia

suthicke[at]aims.gov.au

Abstract

Coral predation by Crown-of-Thorns Seastars (CoTS) is a major contributor to the coral reef crises in the Indo-Pacific Region, with the 4th wave of outbreaks on the Great Barrier Reef (GBR) now well under way. New monitoring tools are needed to allow early detection, because early outbreak stages are difficult to detect using scuba or manta tow surveys. Early outbreak detection would allow early intervention, but also improve understanding of the initiation zone of the outbreaks. Environmental DNA (eDNA) approaches are now widely used for detection of introduced pest species in terrestrial and freshwater environments. Uptake of these methods in the marine environment has been slower, possibly due to the perceived lower chance of positive outcomes due to vast water volumes and higher flow environments. We have developed eDNA methods that allow us to a) identify and quantify CoTS larvae in the plankton and b) detect the presence of post settlement CoTS using 'free eDNA' from water samples. Our CoTS larvae work has been supported by tourism operators and CoTS culling teams and we have > 7000 plankton samples collected over the last eight years. This dataset can now be employed to i) investigate small scale temporal variability during the summer season to obtain details about spawning time of CoTS, ii) look at large scale inter-annual differences in larvae distribution and spread, and iii) obtain cues about the relationship between CoTS larvae and water quality ('nutrient hypothesis of outbreaks'). To detect post-settlement individuals, we collected replicate (> 10 per reef location) 2.5L water samples and filtered through a 1 mm mixed cellulose ester filter. Employing digital droplet PCR (ddPCR), we developed a highly sensitive assay which can detect < 10 target gene copies per ddPCR reaction (equivalent to ~100 copies per 2.5L sample). We found a significant relationship with CoTS eDNA concentration and CoTS densities from several reefs on the GBR. We demonstrated that CoTS densities below those classified as 'outbreak levels' can be detected using occupancy modelling of eDNA presence absence data. We propose to integrate larval and post-settlement e-DNA monitoring into a large-scale CoTS monitoring program for early outbreak detection and to assist with CoTS control.

Oral
A-1604

Spatiotemporal environmental drivers of stony coral tissue loss disease (SCTLD) in an endemic region.

Walker, B.[1], Williams, G.[2], Aeby, G.[3], Maynard, J.[4], Whitall, D.[5], **Sharkey, R.**[1]
[1]Nova Southeastern University, Halmos College of Arts and Sciences, Dania Beach, FL, United States
[2]Bangor University, School of Ocean Sciences, Bangor, United Kingdom
[3]Smithsonian Marine Station, Fort Pierce, FL, United States
[4]SymbioSeas, Carolina Beach, NC, United States
[5]NOAA NCCOS, Silver Spring, MD, United States

rsharkey[at]nova.edu

Abstract

Spatiotemporal patterns of coral diseases on reefs are often driven by a complex array of environmental, anthropogenic and host-specific factors that affect pathogen virulence and host susceptibility. Identifying disease drivers is key to designing effective local mitigation strategies, prioritizing disease intervention resources, and identifying areas suitable for reef restoration. Since its 2014 emergence in Florida, stony coral tissue loss disease (SCTLD) has decimated coral populations, and it currently persists in the endemic region on intermediately susceptible species. Monthly monitoring of Orbicella faveolata colonies showed that disease incidence varies temporally, with total infections highest during warmer, wetter months, and spatially between conspecifics at different sites. Effective disease interventions that halt lesion progression have provided the unique opportunity to explore spatiotemporal patterns of SCTLD incidence. Spatial and temporal statistical models were created to investigate the relationship of monthly SCTLD incidence on 51 large coral colonies (> 2 m diameter) to various abiotic environmental drivers (e.g., depth, seawater temperature, nutrient concentrations) and human drivers (e.g., density of septic tanks, outflow from the Inlet Contributing Areas (ICA), and distance to offshore outfall locations) over 20 months.
Three predictors explained 52.7% of the spatial variation in total lesions per colony: septic tanks within 21 km (35.1%), percent live coral (11.2%), and water depth (6.4%). Higher SCTLD incidence were associated with areas containing >7000 septic tanks within 21 km, on colonies with <60% live tissue, and in shallower depths. One predictor explained 49.7% of the temporal variation in new lesions: higher flow rates from ICAs over previous 7 days (especially >140 m3/second). These results suggest a significant link between SCTLD and flows from the inlets and nearby areas with more septic tanks.
It is possible that inlet water contains the disease, or that decreased water quality is exacerbating corals that already have the disease. Investigations underway to include an additional 14 months of data to these models and investigate the relationship of monthly water quality data collected on the reef with inlet flow will be presented.

Poster
A-1287

Impacts of reduced human activity due to COVID-19 on reef fish populations in the Cayman Islands

Goodbody-Gringley, G., Weber, S., **Chequer, A.**
Central Caribbean Marine Institute, Little Cayman, Cayman Islands

achequer[at]reefresearch.org

Abstract

In the Cayman Islands, the oceans were quiet for nearly two years due to the lockdown and closed borders resulting from the COVID-19 pandemic. This dramatic shift in human behaviour provided a unique opportunity to study how fish populations react when human activities are minimized, and the oceans are relatively 'quiet'. In July 2020, when lockdown restrictions were initially eased, we began a series of in situ fish population surveys repeated every other month to estimate fish density, biomass, and diversity at 4 sites in and around George Town Harbour, which is the main shipping port in Grand Cayman and the central point of cruise and in-water tourism activity. Fish density and biomass were found to have significant positive correlations with increasing time since lockdown. Likewise, species richness increased significantly over time, however diversity indices did not change. Herbivorous species, particularly parrotfish, were also found to significantly increase in density and biomass, which was largely driven by increases in juvenile and initial stage individuals, suggesting that recovery is related to recruitment. Overall, these results indicate that reduced human activities associated with COVID-19 restrictions had a positive impact on fish populations and suggest that fish communities maintain the capacity to rebound when disturbance is removed. However, continued increases in abundances through the end of the study indicate that full recovery may take several months to years. Consideration of human activities and their impacts to the marine environment, therefore, must be incorporated into strategic development plans as borders re-open and post-COVID tourism activities resume.

Poster
A-1374

Compensatory dynamics regulate mesopredatory coral reef fish community stability under global change

Karkarey, R.[1], Maire, E.[2], Keith, S.[2]
[1]Lancaster university, Lancaster Environmental Centre, Lancaster, United Kingdom
[2]Lancaster University, Lancaster Environment Centre, Lancaster, United Kingdom

ruchakarkarey[at]gmail.com

Abstract

The accelerating pace of human-driven pressures, including climate change, is compromising ecosystem functioning and stability. Although biodiversity promotes stability, unravelling the drivers of diversity–stability relationships is an urgent challenge since stable communities are less prone to extinctions and invasions, providing more reliable ecosystem services. Community stability (i.e., the temporal stability of community abundance or biomass) can be achieved by higher species diversity (portfolio effect), higher asynchrony across species populations (compensatory dynamics), or higher abundance of species (selection effect). However, the relative importance of these mechanisms on stability and the interplay between different biotic (community structure) and abiotic drivers is controversial and not widely studied across many trophic groups and ecosystems. On coral reefs, mesopredators play important roles in ecological and evolutionary dynamics through consumptive and non-consumptive effects and support extensive fisheries, such that fluctuations in their abundances can have important implications for reef ecosystems and people.
To examine global patterns and drivers of mesopredator community stability (temporal stability of aggregate community abundance), we analysed 182 time series datasets of coral reef fish (SCORE-REEFs project) from four biogeographic regions: Western Atlantic Ocean, Western Indian Ocean, Central Indo-Pacific Ocean and Central Pacific regions, sampled between 2010 - 2020,
We found that compensatory dynamics, rather than the portfolio or selection effects were the dominant mechanism of stability across reefs. Overall, functional redundancy (i.e., low distinctiveness of functional traits), strongly increased asynchrony, suggesting that interspecies competition likely plays a strong role in stabilizing mesopredators. SST- anomalies destabilised mesopredators by thinning species and functional richness and lowering asynchronous dynamics consistent with the environmental filtering hypothesis. Fishing pressure stabilised mesopredators by removing rare traits (e.g. large body size) and increasing asynchronous dynamics consistent with the mesopredator release hypothesis. Our findings highlight the crucial role of community composition, biotic interactions and compensatory dynamics in regulating mesopredator community stability that need to be managed under global change.

Poster
A-1974

Testing the mode of transmission of Stony Coral Tissue Loss Disease in the U.S Virgin Islands

Mills, M.[1, 2], PhD Marilyn Brandt's Coral Reef Health Lab[2]
[1]Texas A&M University, Center for Marine and Environmental Studies, College Station, United States
[2]University of the Virgin Islands, Center for Marine and Environmental Studies, St. Thomas, U.S. Virgin Islands

makeda_mills[at]aim.com

Abstract

The Caribbean is known as one of the two global centers of biodiversity in the world. Corals aid largely in maintaining this diversity by providing a variety of food, shelter and protection for marine life. A disease with matching characteristics to stony coral tissue loss disease (SCTLD) was discovered in the U.S Virgin Islands in early 2019. This disease has been found to drastically increase the mortality rate of stony corals. With the emergence of the disease in the US Virgin Islands came opportunities to test potential mechanisms of transmission. The purpose of this study was to determine whether or not the disease is transmissible through the movement of water. Seawater was sampled from above healthy corals at unaffected sites and above diseased corals at affected sites. Similarly, mucus samples were collected from apparently healthy *Colpophyllia natans* corals at unaffected sites and from the disease lesion margin of diseased *C. natans* corals at affected sites. In the laboratory, healthy fragments of the highly susceptible species *C. natans* were then exposed to one of four (4) treatments: 1) “diseased” water, 2) control “healthy” water, 3) diseased mucus, or 4) healthy mucus. Corals were then monitored for the appearance of disease lesions for ten days. Results were inconclusive of whether reef water surrounding diseased corals and diseased coral mucus were potential mediums for transmission of SCTLD. Identifying potential mechanisms of disease transmission is essential in development of methods for control and prediction of disease spread but requires further research.

Poster
A-1193

Using DNA metabarcoding to survey the presence of nonindigenous species in natural and artificial habitats in the Red Sea

Shchepanik, H.[1], Carvalho, S.[1], Aylagas, E.[2], Berumen, M. L.[1]
[1]King Abdullah University of Science and Technology, Thuwal, Saudi Arabia
[2]The Red Sea Development Company, Riyahd, Saudi Arabia

hailey.shchepanik[at]kaust.edu.sa

Abstract

Globalization has increased marine transportation and subsequent translocation of marine organisms within and between biogeographical regions. Marine transport is the principal vector for spreading nonindigenous species (NIS) in the marine environment, which may establish at ports and become invasive. Once established, marine NIS can adversely affect the structure and functioning of nearby natural ecosystems, such as coral reefs. Globally representative and comparable data regarding the monitoring of introduced and invasive species is scarce, particularly within the Red Sea, a major shipping corridor. This highlights the importance of establishing a robust and rapid baseline monitoring system to assess native biodiversity and facilitate early detection of NIS. Recently, there has been increasing use of DNA-based molecular techniques in biosecurity applications as a cost-effective and accurate alternative to the morphological taxonomic identification of NIS. Yet, these techniques require further validation in the context of routine port surveillance and biogeographical comparisons. Here, we apply DNA metabarcoding (targeting a 313 bp fragment of the cytochrome c oxidase subunit I (COI) gene and a 450 bp fragment of the nuclear small-subunit ribosomal RNA (18S rRNA) gene), to investigate biofouling and eDNA communities in Red Sea shipping ports, marinas, and coral reefs. This study deployed short-term settlement tiles and collected eDNA water samples at 1–2 m depth at two natural reef sites and two artificial sites. Short-term tiles were deployed seasonally (i.e., winter and summer) for one week. Long-term tiles were deployed for 1, 3, and 6 months at one artificial site. Both spatial and temporal patterns are compared between sites to identify differences in community composition and relative occurrence of NIS in coral reef and anthropogenically disturbed environments. The baseline biodiversity information derived from this study will help build the capacity to distinguish spatiotemporal patterns in pioneering community composition and seasonal recruitment and may assist in improved monitoring and management strategies.

Virtual
Oral
A-1597

Unintended benefits of COVID 19 restrictions on coastal marine water quality in southern Grenada: Implications for coral reef health

Francis, D.[1], Matthew-Bernard, M.[2], Walcott, T.[2], Fields, P.[3], **Nimrod, S.**[1]
[1]St. Georges University, Biology, Ecology and Conservation, St. George's, Grenada
[2]St. Georges University, Microbiology, St. George's, Grenada, [3]Windward Islands Research and Education Foundation, St. George's, Grenada

snimrod[at]sgu.edu

Abstract

Restrictions implemented to reduce the spread of the COVID 19 virus has modified human activities in Grenada and the world over. Such large-scale restraints present a unique opportunity to assess and document the effects that changes in human activities may have on coastal marine water quality in Grenada. Moreover, eutrophication in coastal waters have long been attributed to increase in human activities in Grenada, yet data to support this remains lacking. Given the potential negative impact excess nutrients can have on coral reef ecosystems, this study measured mean concentrations of dissolved nitrogen-ammonia and phosphorous in water samples at four sites in True Blue Bay, Grenada during June 2021. The results revealed that there were no significant differences in mean concentrations of dissolved nitrogen-ammonia (P = 0.44) and phosphorous (P = 0.06) among the four sites. However, the mean concentrations measured at the individual sites were above the acceptable ambient water quality limits for ammonia (>9.8μm/l) and phosphorus (>2.48 (μg P/l). Nitrogen-ammonia data for two of the sites (True Blue Bay West and True Blue Bay Middle) were compared with data gathered in 2019 prior to the COVID 19 restrictions and 2020 when the COVID 19 restrictions were implemented. Despite also being above the acceptable limits, the mean concentrations of ammonia at the two sites displayed a significant downward trend for each year. The data suggests that the changes in human activities associated with COVID 19 restrictions appear to have contributed to the reductions in dissolved nutrients entering coastal waters in Grenada. Additionally, the results suggest that local domestic population during the COVID 19 restrictions and their activities appears to have a considerably reduced negative impact on nearshore coastal water quality as compared to pre-COVID 19 populations and their activities. Such reductions in dissolved nutrients in the coastal waters if sustained could potentially reduce algae abundance and positively impact nearshore coral reefs.

Virtual
Oral
A-2122

The abundance of an invasive soft coral is strongly related to the decrease in native diversity in Southwestern Atlantic

Lolis, L.[1], Miranda, R.[2], Barros, F.[3]
[1]Universidade Federal da Bahia, Laboratório de Ecologia Bentônica, Instituto de Biologia, INCT In-Tree, Salvador, Brazil
[2]Universidade Federal de Alagoas, Instituto de Ciências Biológicas e da Saúde, Maceió, Brazil
[3]Universidade Federal da Bahia, Laboratório de Ecologia Bentônica, Instituto de Biologia, CIENAM and INCT In-Tree, Salvador, Brazil

lucas.lolis[at]gmail.com

Abstract

Coastal reefs are under increasing pressure from multiple impacts, including invasive species. Recently, several Alcyonacea from Indo-Pacific has invaded Atlantic Ocean reefs threatening native communities. Here, we investigated the effects of *Sarcothelia* sp. invasion on Southwestern Atlantic reefs, hypothesizing a negative relationship between invader abundance and native benthic diversity. We compared the community structures at one invaded with two nearby non-invaded areas. Benthic species cover was estimated (i.e., turf algae, macroalgae, ascidians, sponges, zoantharians, soft corals, hard corals, hydrocorals, and crustose algae) taking 20 photo quadrats on four transects at each area. The four transects at the invaded site were distributed to capture an abundance gradient of *Sarcothelia* sp., with the following mean coverage percentages: Transect I: <5%; II: 12.24%; III: 18.57%; IV: 27.9%. The community structure at the invaded site was dissimilar from the non-invaded sites mainly due to the dominance of *Zoanthus* sp. and *Neospongodes atlantica* in the non-invaded and invaded areas, respectively. We found evidence of *Sarcothelia* sp. impact on species richness. In the invaded area, the lowest species number (11) occurred in the transect with the highest invader cover, while the transect with the lowest *Sarcothelia* sp. cover presented 26 species. Finally, we found evidence that invaded sites were more homogeneous (i.e. less variability in species composition). The specific mechanisms responsible for the observed patterns are yet to be tested. Nevertheless, the presence of novel functional traits in the community, such as growth form and allelochemicals, are important mechanisms to be investigated. We suggest a strong competition between exotic and native octocorals because there was an inverse abundance pattern between them (*Sarcothelia* sp. vs *N. atlantica*). Our study presented strong evidence of the negative impacts of invasive species on diversity and reinforces the concern about the establishment of non-native soft-corals in marine environments.

Virtual
Oral
A-2151

Environmental drivers of coral health in coastal and oceanic reefs in Southwestern tropical Atlantic

Pacheco, M. C., Bleuel, J., Vieira, E. A., Longo, G. O.
Universidade Federal do Rio Grande do Norte, Natal, Brazil

mcarolaop[at]gmail.com

Abstract

The increase in frequency and severity of coral bleaching due to climate change threatens reefs worldwide. In the South Atlantic Ocean, corals seem to be more resistant and resilient to thermal stresses, which could be explained by their adaptation to marginal conditions found in many different Brazilian reefs (e.g. high turbidity, nutrient content). Assessing the variation in the health condition of these corals and how they relate to natural environmental conditions can help us understand local and global drivers that influence coral health, and how the environment can shape resistance and resilience under climate change. For about two years we monitored the health condition of colonies of the reef-building corals Siderastrea stellata, which is dominant in tropical Brazilian shallow reefs (~3m), and Montastraea cavernosa, dominant in deeper reefs (~20-30m). We used 3D models created by photogrammetry to evaluate and measure the percentage of health indicators (bleaching, paleness, disease, algae overgrowth, and healthy color) in each colony. We compared corals from coastal sites (Rio Grande do Norte state) and oceanic sites (Fernando de Noronha) in NE Brazil. We compiled satellite data on Marine Heat Waves (MHW) and light attenuation coefficient (KD) and associated their variation with coral health. We found that environmental drivers of coral health were different between coastal and oceanic reefs, with turbidity being more relevant and favoring a healthier condition of corals on coastal shallow reefs in turbid periods. On oceanic shallow reefs, where corals are under naturally more transparent waters, coral health was subjected to a greater influence of local dynamics. The coral S. stellata, in shallow and less stable reefs, showed greater health condition variation than M. cavernosa in deeper and more environmentally stable reefs. The healthy area in colonies of both species decreased in response to marine heatwaves, which was the main driver causing coral health condition fluctuation. These results may indicate that Brazilian corals are well adapted to local adverse conditions (high turbidity) but are also able to recover after thermal stress events, a global threat.

Virtual
Oral
A-2147

Sclerochronological characteristics of the reef-building coral Orbicella faveolata in a latitudinal gradient in the Mexican Caribbean

Sánchez Pelcastre, D. W.[1], Carricart Ganivet, J. P.[1], Tortolero Langarica, J. d. J. A.[2], Cabral Tena, R. A.[3], Alvarez Filip, L.[1]
[1]Universidad Nacional Autónoma de México, Instituto de Ciencias del Mar y Limnología, Puerto Morelos, Mexico
[2]Tecnologico Nacional de México, Nayarit, Mexico
[3]Centro de Investigación Científica y de Educación Superior de Ensenada (CICESE), Ensenada, Mexico

wendypelcastre[at]gmail.com

Abstract

During the process of coral calcification in massive scleractinian corals, a double annual banding of different densities (high and low density) is formed in their skeletons, with this banding pattern it is possible to determine biological and environmental factors associated with their life history. The coral calcification process is mediated mostly by the sea surface temperature (SST), where prolonged exposure to SST of +1°C above the maximum average SST of the reef location could cause thermal stress and lead to coral bleaching and negative effects on calcification rates. The world's tropical reefs are increasingly affected by climate change and overexploitation. One of the main reef-building corals in the Caribbean is *Orbicella faveolata*, hence it is important to recognize how its sclerochronological characteristics have been responded to different SST´s a latitudinal gradient (20°54’25” N to 18°16’37” N), as well as to understand how the calcification of *O. faveolata* may be changing in different places in the current natural environment. Using optical densitometry technique and counting of exotecal dissepiments, three sclerochronological characteristics were evaluated; skeletal density (g cm-3), annual extension rate (cm yr^{-1}), and annual calcification rate (g cm^{-2} yr^{-1}) from 19 colonies of *O. faveolata* from 4 different sites along the Mexican Caribbean (Puerto Morelos, Punta Allen, Mahahual and Xcalak). The results showed that within the latitudinal gradient, the annual SST and the calcification rate increase with a significantly positive correlation (R^2= 0.935; p= 0.0329). The highest value of the calcification rate was found in Xcalak reef (1.20 g cm^{-2} $year^{-1}$), while the lowest was in Puerto Morelos reef (0.85 g cm^{-2} $year^{-1}$). Furthermore, the correlations between the three sclerochronological characteristics show that *O. faveolata* uses its calcification resources to build denser skeletons. The variability in the calcification rate of *O. faveolata* in the Mexican Caribbean indicates that the SST is benefiting the corals nearest to the equator, nevertheless, they could be found in an optimal limit range of thermal threshold. Therefore, if the temperature continues to increase, calcification might decline due to thermal-stress effects. As well the calcification may be susceptible to a combination of stress factors, such as massive arrivals of sargassum, the incidence of diseases or exposure to the wastewater by anthropogenic activities.

Virtual
Oral
A-1693

Trait selectivity in coral reef fisheries

Touchie, E.[1], Judah, A.[1], MacNeil, A.[1], Houk, P.[2], Villéger, S.[3], Mouillot, D.[4], McLean, M.[1]
[1]Dalhousie University, Biology, Halifax, Canada
[2]University of Guam, Marine Biology, Mangilao, Guam
[3]French National Centre for Scientific Research, Marine Biology, Montpellier, France
[4]Université de Montpellier, Marine Biology, Montpellier, France

emma.touchie[at]gmail.com

Abstract

The resilience and diversity of coral reefs have been severely impacted in recent decades by stressors such as unsustainable fishing and global warming. As commercial fishing pressure increases, adaptive fisheries management encompassing organism functionality is increasingly important for conserving the health of these productive ecosystems. Trait-based approaches, which link species' traits to ecosystem process, may be particularly useful for assessing the effects of altering species assemblages on ecosystem functioning. The goal of this study was to uncover differences in, and drivers of, trait diversity of fish assemblages observed on reefs and in fisheries landings around the island of Kosrae, Micronesia. Data from underwater visual censuses of fish communities on the surrounding reefs and a year-long daily survey of market landings were used to compare trait assemblages. Ten morphological traits related to swimming and feeding were measured on 62 species present in both reef observations and market landings. These measurements were used to calculate functional diversity indices and to characterize community trait composition. Linear models were used to assess the drivers of trait diversity on reefs and whether trait diversity in the landings simply reflected reef diversity or was shaped by fisher behaviour or accessibility. Strong mismatches were observed between trait diversity on the reefs and within the landings. Across all locations, the proportions of large-bodied species with traits relating to predatory feeding were greater within the landings than on the reefs, and this was clearly linked to fishing gear and fisher behavior. It therefore appears that fishers are not fishing in accordance with reef composition but are selectively targeting desirable species and prioritizing areas where such species can be successfully captured. Alarmingly, the proportion of functionally distinct species (having unique traits) and species vulnerable to fishing pressure was 3-5 times higher in the landings than on the reefs, potentially endangering unique and uninsured functions. To sustainably manage small scale coral reef fisheries in the face of increasing commercial demand, alternative species should be harvested that are less vulnerable and that do not support unique and uninsured ecological roles.

Virtual
Poster
A-2099

Combined effects of temperature and sand burial events onthe health ofthe reef-building coral Siderastrea stellata in Southwestern Atlantic tide pools

Fernandes do Nascimento, W., A. Vieira, E., Ortigara Longo, G.
Federal University of Rio Grande do Norte, Oceanography and Limnology, Natal, Brazil

wildnaf[at]gmail.com

Abstract

Increasing ocean temperature is often considered one of the main stressors in reef environments, causing coral bleaching and affecting coral populations. Along with warming, sedimentation, burial and related impacts are an additional source of stress to corals that can lead to mortality and consequent loss of coral cover and diversity. The coral *Siderastrea stellata* is one of the main reef-building corals in tropical Brazilian shallow reefs, being common even in stressful habitats such as tide pools. We assessed the health of *S. stellata* colonies along four years (2017-2021) on a twice-a-month basis in a tide pool in Rio Grande do Norte, NE Brazil (5°47'36.96"S 35°10'55.81"O). We aimed to understand the temporal dynamic to which these corals are subjected and how it affects coral health. The colonies were evaluated for the occurrence and proportion of paleness, bleaching, sand burial and mortality. We also collected data on temperature, wind and wave direction and intensity, to evaluate its potential relation to coral health. The colonies remained healthy for most of the time, except for periods after extreme stress events caused by high temperature and high level of sand burial (April 2019) which caused bleaching in up to 100% of the colonies. Sand burial events were related by wind and wave direction, which combined with the shoreline orientation lead to a greater deposition (when orthogonal to coastline) or removal of sand (when tangential to coastline) inside the tide pool. Despite the stress caused by peaks of temperature and sedimentation, the colonies recovered their healthy color within 30 days on average, indicating the high resilience of this species. Our results show that sand burial and high temperature can cause serious damage to *S. stellata*, mainly when occurring simultaneously. However, the high resilience of these colonies highlights the importance of this shallow reef-building species for the Southwestern Atlantic reefs when facing both global and local impact.

Virtual
Poster
A-1044

Assessing the lethal and sublethal effects of Florida red tide Karenia brevis on Acropora cervicornis, Porites astreoides and Siderastrea siderea

Maldonado, A.[1, 2]
[1]Mote Marine Laboratory, Ecotoxicology, Sarasota, United States
[2]UPL, Ecotoxicology, sarasota, United States

aileenmaldo[at]gmail.com

Abstract

Karenia brevis red tide blooms are an annual occurrence on Florida's Gulf Coast, however increasing duration and distance has made it a threat to coral-dense areas in the Gulf of Mexico and Florida Keys. This study investigates the lethal and sublethal effects of K. brevis on Acropora cervicornis, Porites astreoides, and Siderastrea siderea. Corals were exposed for 96 hr to 800,000, 5 million, and 20 million cells/L of K. brevis for lethal assessment and two weeks at 1,000, 50,000, and 100,000 cells/L K. brevis for sublethal assessment. The lethal dose at 50% was based on the mortality of coral exposed, finding A. cervicornis to be the most sensitive and P. asteroides least sensitive with no deaths even at the highest dose. Acropora cervicornis and Siderastrea siderea significantly bleached in sublethal and lethal exposures. In addition, proteomic analysis was conducted on Acropora cervicornis and Siderastrea siderea to assess molecular pathways that were impacted. Lastly, tissue measurements of brevetoxin bioaccumulation was detected in all exposed tissue. The frequency of K. brevis has the potential to increase due to increasing nutrients input and global climate change that is why it is paramount to understand at what concentration it will have sublethal and lethal impacts to coral reefs in Florida that are already struggling to survive.

Session 9B - How do local drivers mediate coral reef ecosystem responses to climate change?

Conceptualized by: **Aaron MacNeil**[1], **Nicholas Graham**[2], **Michelle Devlin**[3]
[1] Dalhousie University (Halifax, Canada)
[2] Lancaster University (Lancaster, UK)
[3] CEFAS Lowestoft (Lowestoft, UK)

Chaired by: **Nicholas Graham**[2], **Michelle Devlin**[3]

Oral
A-1425

CO_2 seeps, rivers, pollution and coral reefs near Cartagena: an approximation into the effects of multi-stressors in Caribbean coral reefs

Barrios, L. M.[1], Gonzalez, R.[2], Navas-S, G. R.[2], Sanjuan-Munioz, A.[3], Hall-Spencer, J. M.[1, 4], Ruiz-Pino, D.[5]
[1]The University of Plymouth, Biological and Marine Sciences, Plymouth, United Kingdom
[2]Universidad de Cartagena, Programa de Biologia, Campus San Pablo, Zaragocilla, Cartagena de Indias, Colombia
[3]Universidad de Bogota Jorge Tadeo Lozano, Facultad de Ciencias Naturales e Ingeniería,, Carrera 2 No. 11-68, Edificio Mundo Marino, El Rodadero, Santa Marta, Colombia
[4]University of Tsukuba, Shimoda Marine Research Centre, Tsukuba, Japan
[5]Sorbonne University, Faculty of Sciences/ LOCEAN-IPSL, Paris, France

linambarrios[at]hotmail.com

Abstract

Multiple stressors are threatening cultural and economic services traditionally provided by coral reefs. Here, Caribbean reefs were surveyed along a distance-gradient of multiple stressors, including riverine inputs, distance to the city of Cartagena, and mud volcano seeps with 63% CH_4 and 37% CO_2 (acidifying the overlying seawater), to identify their relationship with the surrounding coral-reef structure. Biodiversity gradients were explained as a response to the combination of particular stressors. Consequently, reefs were least diverse and with more encrusting forms in areas with higher seawater temperatures and significantly lower salinity and pH, near to Cartagena. The furthest station from the city had, on the contrary, the healthiest reef (highest species richness, diversity, higher pH, and higher aragonite saturation), despite vicinity to the seeps and being affected by fluctuating discharges from the Magdalena River (called bombazo by local communities), which brings daily and seasonal changes in carbonate chemistry, salinity, and sediments. Values of seawater carbonate chemistry near the CO2 seeps and surrounding coral reef environments were compared. Observed changes in species composition and growth forms of corals during the last two decades indicate that further increases in acidic conditions could lead to two basic scenarios, that should be confirmed under future mesocosms experiments to include the natural support from surrounding community to affected corals: 1-further reduction in life coral coverage and complexity in the long term, or 2-adaptation of species to local conditions. The observed gradients in seawater carbonate chemistry near CO_2 seeps and fluctuating river runoffs make this area a natural laboratory to assess how best to secure the economic and social benefits of Caribbean reefs, in the face of climate induced increase in river discharges and local ocean acidification.

Oral
A-1755

Untangling components of reef resilience to bleaching and other pressures to make effective management decisions

Cowburn, B.[1], Obura, D.[2], Sluka, R.[3], Rogers, A.[4], Taylor, M.[5], Bluemel, J.[6], Couce, E.[7], van Katwikj, M.[8]
[1]Centre for Environment, Fisheries and Aquaculture Science, Lowestoft, United Kingdom
[2]CORDIO East Africa, Mombasa, Kenya
[3]A Rocha International, London, United Kingdom
[4]REV Ocean, Lysaker, Norway
[5]University of Essex, Colchester, United Kingdom
[6]Cefas, Weymouth, United Kingdom
[7]Cefas, Lowestofy, United Kingdom
[8]University of Njimegen, Njimegen, Netherlands

benjamin.cowburn[at]cefas.co.uk

Abstract

The use of resilience based management (RBM) for coral reefs has been hampered by a lack of suitable data, a large number of potential resilience indicators, and uncertainty about the interactions between different components of resilience. Watamu Marine National Park (WMNP), Kenya, has been a no-take marine protected area (MPA) since 1968, and supports healthy fish populations due to effective control of human activities in the park. However, pressures from multiple past coral bleaching events, coupled with extensive coastal development adjacent to the park has led to a decline in coral cover. Using data from the 1980s to present, we investigate different components of resilience to determine which factors are preventing a return to historical conditions. Sea surface temperature data show there have been eight bleaching events since 1985 in WMNP, while observations of bleaching response in four of these years indicate that some coral taxa appear to have gained more resistance to thermal stress, especially in relation to the most recent bleaching in 2016 and 2020. Since the most severe event in 1998, there has been a decline in thermally sensitive branching coral taxa, but with no phase-shift to a macroalgal dominated state. The growth and mortality rates of different coral taxa remained similar pre and post-1998, but there was a significant decline in recruitment. We conclude that corals in WMNP have become more resistant to thermal stress, but that recovery potential is reduced because of lower recruitment. For WMNP this narrows down the RBM options to: 1) boosting recruitment by increasing connectivity between WMNP and other MPAs and 2) using restoration techniques to boost the juvenile coral population. Our data demonstrate the unique nature of reef resilience in a local ecological and anthropogenic context, but also show common patterns emerging from our global understanding of reef resilience under multiple pressures.

Oral
A-1904

Environmental stress related spatiotemporal variations in coral reef benthic communities

Jones, N., Gilliam, D.
Nova Southeastern University, Dania Beach, United States

nj350[at]mynsu.nova.edu

Abstract

Global climate change is the primary threat to coral reefs worldwide, where acute thermal stress events have led to extensive bleaching, disease and mortality in recent years. Concurrently, coral reef ecosystems nearshore, close to dense populations, have been directly impacted by local anthropogenic stressors for decades. Chronic poor water quality has facilitated stony coral cover decline, often resulting in community change, but increased turbidity has also been predicted to reduce the impact of thermal stress. High-latitude coral reef communities have been postulated as the first areas to undergo reorganisation under climate change, including the tropicalisation of reefs currently found towards the thermal tolerance limits of corals with increasing water temperature. However, local anthropogenic stress may negate this potential. The Southeast Florida Coral Reef Ecosystem Conservation Area (ECA) is a high-latitude reef system offshore of a highly urbanised coastline. Nine inlets and ports connect the ECA with inland waterways and rivers, bringing elevated nutrients and brackish water. Additionally, six ocean outfalls discharge partially treated wastewater at depth one to five kilometres offshore and coastal construction and beach nourishment cause elevated turbidity and sedimentation nearshore. After heat stress and disease caused extensive stony coral mortality from 2014 to 2017 focus has been placed on assessing recovery potential in the ECA. Here, we assessed how temperature and water quality influenced benthic community change and stony coral health in the ECA from 2018 to 2021. Daily temperature data was collected by HOBO loggers at permanent benthic monitoring sites. Monthly water quality data was collected at nearby reef sites. We collected photographic and demographic data to assess changes to the benthic biological community and stony coral density and health. We used Distance-based Linear Models and Random Forest analysis to assess the relationship between benthic community changes and specific in situ temperature and water quality parameters. Much of the spatiotemporal variation in benthic community cover and stony coral health was explained by temperature, but water quality, particularly high nutrients contributed to changes in benthic cover and stony coral demographics. Combined, the multiplicative impacts of local anthropogenic stress and global climate change are predicted to further reduce stony coral resilience and inhibit recovery.

Oral
A-1280

The changing song of the sea: reef soundscapes as symptoms and drivers of ecosystem change

Lamont, T.[1], Williams, B.[2], Chapuis, L.[3], Harding, H.[4], Maulana, P.[5], Prasetya, M.[5], Razak, T.[6], Nedelec, S.[3], Meekan, M.[7], Smith, D.[8], Radford, A.[4], Simpson, S.[4], Graham, N.[9]
[1]Lancaster University, Lancaster Environment Centre, Lancaster, United Kingdom
[2]University College London, London, United Kingdom
[3]University of Exeter, Exeter, United Kingdom
[4]University of Bristol, Bristol, United Kingdom
[5]Mars Sustainable Solutions, Makassar, Indonesia
[6]IPB University, Bogor, Indonesia
[7]Australian Institute of Marine Science, Perth, Australia
[8]Mars Sustainable Solutions, London, United Kingdom
[9]Lancaster University, Lancaster, United Kingdom

tim.lamont[at]lancaster.ac.uk

Abstract

Coral reefs worldwide are degrading rapidly due to climate change and local anthropogenic stressors, necessitating novel approaches for their management. The biotic composition of an ecosystem is reflected in the sounds it produces, meaning reef soundscapes are indicative of community health. Further, many fishes and invertebrates that spend their larval stage in the open ocean use sound to detect, orient toward and settle to suitable reef habitat, meaning soundscapes facilitate local population replenishment of reef organisms. Here, we present three empirical field studies that demonstrate the value of using bioacoustic approaches to understand and mediate the responses of coral reef ecosystems to climate change.
First, we document spatio-temporally matched evidence that reef soundscapes are altered by climate change impacts. On the northern Great Barrier Reef, recent cyclone and bleaching damage caused significant and consistent changes to soundscapes across multiple acoustic parameters: post-disturbance reefs were less acoustically complex and 75% quieter than their pre-degradation states. Complementary field experiments revealed that young fishes are significantly less attracted to these post-degradation soundscapes, threatening to reduce recruitment and jeopardise reef recovery chances.
Second, we show that at one of the world’s largest coral reef restoration programmes, local recovery can be measured by passive acoustic monitoring. Reefs damaged by dynamite fishing, and then subsequently restored by several years of rubble stabilisation and coral transplantation, sound quantifiably similar to nearby healthy reefs but different from nearby damaged reefs.
Finally, we present evidence that loudspeaker playback of healthy reef sound can enhance local restoration efforts by increasing fish settlement and retention. In a six-week field experiment, we compared fish community development on acoustically enriched coral-rubble patch reefs with acoustically unmanipulated controls. Acoustic enrichment enhanced community development across all major trophic guilds, with a doubling in overall abundance and 50% greater species richness. Rebuilding fish communities in this manner could accelerate local ecosystem recovery from climate change related degradation.
In conclusion, bioacoustics offers novel methods to monitor and actively manage coral reef ecosystems. In a world where reefs are changing at unprecedented rates, much can be achieved by learning to listen.

Oral
A-1490

The widely distributed soft coral Xenia umbellata exhibits high tolerance against warming, acidification, and eutrophication

Mezger, S. D., Caporale, G., Tilstra, A., El-Khaled, Y. C., Wild, C.
University of Bremen, Marine Ecology, Bremen, Germany

mezger[at]uni-bremen.de

Abstract

Coral reefs worldwide are affected by global (e.g., ocean warming and acidification) and local (e.g., eutrophication) factors. Alone, or in combination, these factors can lead to phase shifts, often from hard coral to algae dominated reefs, yet also to alternative states dominated by soft corals. While reefs show increasing abundances of soft corals worldwide, knowledge about the effects of global and local factors on these organisms is scarce. Thus, we here investigated how such factors impact the ecophysiology of the widespread pulsating species *Xenia umbellata* as a model for soft corals. In an interconnected series of five laboratory experiments, we exposed *X. umbellata* to different concentrations of dissolved organic carbon (DOC; 10, 20, and 40 mg/L), nitrate (NO_3; 5.5 and 37 µM), or phosphate (PO_4; 1, 2, and 8 µM) under warming (from 26 °C as control, to 28, 30, 32 °C) and acidification scenarios (from a pH of 8.3 as control, to 7.9, 7.7, and 7.5). Along with a range of ecophysiological parameters, we quantified mortality, pulsation, and gross photosynthesis (P_{gross}) as indicators of coral fitness. Findings revealed that there was no significant mortality observed under any factor, alone or combined. Both inorganic and organic eutrophication alone did not change pulsation, but acidification alone and in combination with inorganic eutrophication led to a 16 – 30 % reduction. Warming alone led to a reduction in pulsation of 45 – 68 % in two of three experiments. Interestingly, both DOC and PO_4 had a mitigating effect on pulsation under warming, as corals were able to maintain or even increase their pulsation compared to warming alone. P_{gross} was significantly reduced by 56 % under high NO_3 concentrations (37 µM) alone, while it was reduced by warming in only one of three experiments. This suggests a high variability in the response of the soft coral towards warming and a high tolerance of P_{gross} towards the other factors. Overall, *X. umbellata*, other than hard corals, seems to be tolerant against most of the investigated global and local factors, alone and combined. Thus, our findings contribute to explaining the observed competitive advantage of soft corals under currently changing environmental conditions.

Oral
A-2093

Fine-scale tracking of coral bleaching and mortality during a thermal stress event in Kaneohe Bay, Hawaii

Yadav, S., Roach, T., McWilliam, M., Miller, S., Caruso, C., Rocha de Souza, M., Drury, C., Madin, J.
Hawaii Institute of Marine Biology, Kaneohe, United States

shreyay[at]hawaii.edu

Abstract

Patterns of coral bleaching and mortality can show significant spatial and taxonomic heterogeneity, making it challenging to understand the drivers and impacts of thermal stress at local scales. In this study, we used structure-from-motion photogrammetry to track coral bleaching, mortality, and changes in community composition during a marine heatwave in 2019 in Kāneʻohe Bay. We surveyed 30 shallow reef patches every 3 weeks for the duration of the bleaching event, and one year after. This resulted in a total of 210 large-area mosaics that enabled us to track the fate of thousands of coral colonies through time. We also measured environmental variables such as temperature, sedimentation, depth, and water velocity at each of these sites, along with estimates of habitat complexity (rugosity and fractal dimension). We found that up to 80% of corals experienced some amount of bleaching in this period, with peak bleaching occurring in October when accumulated heat stress (DHW) was at its maximum. Mortality continued to increase even as bleaching levels dropped, driving large declines in heat-susceptible species (77% loss of *Pocillopora* cover) and moderate declines in heat-tolerant species (19% and 23% for *Porites compressa* and *Montipora capitata*, respectively). Declines in live coral were accompanied by an increase in algal cover. We found that spatial differences in bleaching severity were strongly linked to sediment loads and coral composition, with reefs that were dominated by *Pocillopora* or had lower suspended sediment levels experiencing most severe bleaching. Mortality was primairly driven by thermal stress and species composition, with the highest mortality occurring in reefs with *Pocillopora* or where degree heating weeks were highest. Our results demonstrate that while local environmental conditions may help mediate the effects of temperature stress in Kāneʻohe Bay, species life-history traits and thermal tolerance are likely to determine eventual mortality. More resistant taxa like *Montipora capitata* and *Porites compressa* may be able to resist and adapt to future warming, but vulnerable species like *Pocillopora* are likely to decline or be limited to select reef refugia.

Oral
A-2008

Catch of the day: Towards the sustainability of the world's coral reef fisheries

Zamborain Mason, J.[1], Connolly, S. R.[2], Cinner, J. E.[3], MacNeil, M. A.[4], Socio-ecological research frontiers group (SERF)
[1]Harvard University, Nutrition and Environmental Health, Boston, United States
[2]Smithsonian Tropical Research Institute, Panama city, Panama
[3]ARC Centre of Excellence for Coral Reef Studies/James Cook University, Townsville, Australia
[4]Dalhousie University, Halifax, Canada

jessica.zamborainmason[at]my.jcu.edu.au

Abstract

Assessing the status of fish stocks is essential to successfully managing and sustaining fishery resources. However, the vast majority of multispecies reef fisheries around the globe remain unassessed.These fisheries tend to be data-poor and typically lack research and monitoring capacity (e.g., long-term fishery data), preventing the estimation of sustainable reference points against which stocks can be assessed. By combining biomass data for over 2000 reefs worldwide with catch estimates from 99 jurisdictions, we develop a way to estimate context-specific multispecies sustainable reference points for coral reef fisheries and assess the status of coral reef fish stocks. From a long-term fisheries production perspective, we show that reference points can vary by almost an order of magnitude depending on their environmental context (e.g., coral cover, whether the reef is an atoll). Using these, we also reveal that ~ 67% of jurisdictions have passed at least one sustainability benchmark and have fisheries of conservation concern. We quantify the trade-offs between long-term fisheries production and other fisheries goals (e.g., ecosystem status or food security), highlighting potential pathways to manage reef fisheries. Overall, our study provides essential benchmarks for reef fisheries, providing a promising means for enhancing the sustainability of these critical resources.

Poster
A-1791

Global-scale evidence for human impacts on coral reefs

Gleason, A.[1], Purkis, S.[2], Bakker, A.[2], Dempsey, A.[3], Carlton, R.[3], Faisal, M.[4]
[1]University of Miami, Coral Gables, United States
[2]University of Miami - RSMAS, Miami, United States
[3]Khaled bin Sultan Living Oceans Foundation, Annapolis, United States
[4]Michigan State University, East Lansing, United States

art.gleason[at]miami.edu

Abstract

Globally, coral reefs have been declining in health for the past few decades, at least. Determining the relative importance of global and local effects on this trend has proven difficult, however. One of the main problems has been the lack of suitable data taken at high resolution (i.e. locally) over appropriately large spatial and temporal scales using comparable survey methods. Lacking suitable datasets measuring local reef stressors such as nutrient or sediment loads, fishing pressure, runoff, and so forth, an alternative approach has been to use human population density (or proximity, or presence/absence) as a proxy for the cumulative effects of all of these local stressors. A few recent studies have used this approach: Sandin et al. (2008) found coral cover on reefs adjacent to less populated atolls in the Northern Line Islands was greater than that on reefs closer to more people. Smith et al. (2016) and Bruno and Valdivia (2016), however, did not find this trend when using larger datasets. Specifically, both studies failed to find an inverse correlation between population and coral cover, nor a direct correlation between population and macroalgal cover. On the other hand, Smith et al. (2016) did find a strong inverse relationship between fleshy algae (macroalge + turf) and reef accretors more broadly defined (corals + crustose coralline algae). Moreover, they found uninhabited islands were dominated by accretors whereas inhabited islands were dominated by fleshy algae.

This study used data compiled during the "Global Reef Expedition" (GRE), a 10-yr survey of some of Earth's remotest reef sites. The GRE acquired ~4,900 benthic transects at 1240 dive sites across 11 countries. The GRE dataset is ideal for "space for time" type analysis, similar to those cited above. As in previous studies, the GRE dataset exhibited no correlation between coral and macroalgal cover. There was an inverse correlation between fleshy algae and reef accretors in some habitats (forereef, barrier reef, fringing reef) but not others (patch reefs), however the variance explained ($R^2 \sim 0.32$) was less than Smith et al (2016). Populated vs. unpopulated islands did not have average differences in macroalgal, fleshy algae, coral, or reef accretor percent cover, nor was there any correlation of these variables with local population size. These results are consistent with the idea that remote reefs are not necessarily "healthier" or less impacted than those closer to developed areas.

Poster
A-1323

Calorimetric Monitoring of Coral Reefs – Sensing Trouble

White, B.[1], Harmes, E.[1], White, L.[2], Rohwer, F.[1]
[1]San Diego State University, San Diego, United States
[2]JPL California Institute of Technology, Pasadena, United States

brandiewhite10[at]gmail.com

Abstract

Higher viral and microbial abundances, a greater proportion of potential coral pathogens, and localized hypoxia are hallmarks coral reef microbialization. Increased dissolved organic carbon (e.g., products of ungrazed algae) and temperature increase the metabolic rates of heterotrophs microbes. Increasing temperature also lowers dissolved oxygen, favoring microbial metabolisms that use alternate electron acceptors. Even though these processes are well documented through a variety of methods, there is no method for measuring microbial activity *in situ*. Microcalorimetry is a potential solution as it directly monitors biologic activity. We have built a custom microcalorimeter designed for monitoring microbial biological activity on coral reefs. These microcalorimeters will allow us to directly monitor microbialization.

Virtual
Oral
A-1933

Effects of coastal anthropisation and hurricane impacts in the Mexican Caribbean coral reefs

Contreras Silva, A. I.[1, 2], Navarro Espinoza, E.[3], Migani, V.[4], Valderrama Landeros, L.[5], Velazquez Salazar, S.[5], Tapia Silva, F. O.[6], Reuter, H.[1, 2], Alvarez Filip, L.[3]
[1]University of Bremen, Faculty for Biology and Chemistry, Bremen, Germany
[2]Leibniz Centre for Tropical Marine Research, Theoretical Ecology and Modelling, Bremen, Germany
[3]National Autonomous University of Mexico, Biodiversity and Reef Conservation Lab, Puerto Morelos, Mexico
[4]Institute of Ecology, Faculty of Biology and Chemistry, University of Bremen, Population and Evolutionary Ecology Group, Bremen, Germany
[5]National Commission for the Knowledge and Use of Biodiversity (CONABIO), Mangrove Monitoring System Lab, Mexico City, Mexico
[6]Metropolitan Autonomous University, Hydrobiology, Applied Geomatics Lab, Mexico City, Mexico

amerisixcontreras[at]gmail.com

Abstract

Coral reefs around the world face unprecedented cumulative impacts originating at various scales and resulting from global anthropogenic climate change as well as local human pressures. In the Mexican Caribbean coastal development has begun in the 1970s without managing or planning to safeguard the adjacent ecosystems.
We aim to analyse the effects of local anthropogenic stressors and hurricane impacts on the benthic communities in the Mexican Caribbean reefs. We used an extensive collection of remote sensing data to generate mangrove and anthropogenic indexes of change, coupled with 91 monitoring coral reef sites from 2005 to 2016. Additionally, we developed a hurricane index based on hurricane intensity and its area of influence in each reef site. Estimates of the change of coral cover percentage were related to each index considered as a potential local driver of change (anthropogenic, mangrove change, and hurricanes) using mixed-effects models and reef sites as the unit of replication.
Our results show a negative effect of the anthropogenic index on the coral cover change, and as expected, a negative correlation with the hurricane index. The anthropogenic index incorporates the increasing pressures from urban development; presumably it masked the mangrove index effects losing its explanatory power when fitted into the model. Widespread impacts on coral reefs from global warming occur concurrently with local pressures, such as increases in nutrients and suspended sediments through coastal development. We discussed that the future of Mexican Caribbean coral reefs is at high risk due to cumulative impacts from both local and global stressors. Our findings highlight the importance of managing coastal development projects such as road, port, and resort constructions, to sustain tourism, also in the face of climate change. In conclusion, our analyses show that reef degradation in the Mexican Caribbean is directly linked with coastal development pressures.

Session 9C - How will anthropogenic stressors influence the roles of consumer-derived nutrients on coral reefs?

Conceptualized by: **Deron Burkepile**[1], **Nina Schiettekatte**[2], **Sébastien Villéger**[3], **Jacob Allgeier**[4]
[1] University of California Santa Barbara (Santa Barbara, CA, USA)
[2] Université de Perpignan (Perpignan, France)
[3] Université de Montpellier (Montpellier, France)
[4] University of Michigan (Ann Arbor, MI, USA)

Chaired by: **Nina Schiettekatte**[1], **Simon Brandl**[2]
[1] Université de Perpignan (Perpignan, France)
[2] The University of Texas Marine Science Institute (Port Aransas, USA)

Oral
A-1680

Influence of seabird nutrient subsidies on coral reef biodiversity, ecosystem function, and resilience

Benkwitt, C.[1], Wilson, S.[2, 3], Graham, N.[1]
[1]Lancaster University, Lancaster Environment Centre, Lancaster, United Kingdom
[2]Western Australia Department of Biodiversity Conservation and Attractions, Marine Science Program, Kensington, Australia
[3]University of Western Australia, Oceans Institute, Crawly, Australia

c.benkwitt[at]lancaster.ac.uk

Abstract

Seabirds are key vectors of cross-ecosystem nutrient subsidies, as they transfer and concentrate nutrients from their oceanic feeding grounds to islands where they nest and breed. Nutrients from seabirds can then flow onto nearshore coral reefs, where they have similar benefits as consumer-derived nutrients from coral-reef fishes. However, seabird populations are experiencing intense population declines and local extirpations due to various human activities. Here, we show that introduced rats and non-native vegetation on tropical islands reduce seabird biomass and biodiversity, which in turn reduces their provisioning of nutrients to coral reef food webs. Furthermore, coral reefs in the Anthropocene face many other stresses, one of the most pervasive being increased frequency and severity of coral bleaching events due to warm water anomalies. We therefore test how coral bleaching and introduced rats influence the biodiversity and ecosystem function of coral-reef fishes, and whether seabirds can enhance the resilience of corals reefs to bleaching events. Overall, there were positive, non-saturating biodiversity-ecosystem functioning (BEF) relationships on remote coral reefs in the Indian Ocean. Despite having only minor effects on these relationships, both rats and coral bleaching still decreased ecosystem function via direct and indirect pathways. Following a mass coral bleaching event, coral cover rebounded within six years around both rat-free islands with abundant seabirds and rat-infested islands with few seabirds. However, there were differences in community composition around rat-free and rat-infested islands, and corals near islands with high seabird-derived nutrients had faster growth rates. We conclude that restoring natural nutrient pathways may be an important management strategy for preserving at least some coral reef ecosystem functions.

Oral
A-1409

Estimating the effects of inter- and intraspecific variation in consumer behavior on primary production

Munsterman, K., Hesselbarth, M., Allgeier, J.
University of Michigan, Ecology and Evolutionary Biology, Ann Arbor, United States

kmunster[at]umich.edu

Abstract

Consumers are important sources of nutrients for primary production in many tropical coastal ecosystems that are characterized by low ambient nutrients and high consumer biomass. But the extent that consumers influence primary production is dependent on consumer movement behavior and whether consumers recycle local nutrients within an area or translocate novel nutrients from one area to another. While movement behavior can vary both across species and between individual consumers, few studies have estimated the effects of inter- and intraspecific variation in consumer behavior on nutrient cycling. We used an individual-based model of two reef fish species to test the how differences in inter- and intraspecific movement behavior influence seagrass primary production surrounding a single patch reef. We simulated two different fish species that shelter on and forage off the reef, while constantly excreting nutrients based on empirical data on species-specific movement behavior and energetic demands. Results show that production rates are higher in simulations with high species-level movement rates, as individuals translocate novel nutrients from the seagrass bed to the reef. However, variation in intraspecific movement matters more for species with low movement rates, as few individuals provide novel nutrients to the reef. Our study suggests that both inter- and intraspecific variation in behavior should be considered when estimating the effects of mobile consumers on the nutrient dynamics they mediate.

Oral
A-1620

The role of fish feces in coral reef nutrient-cycling

Schiettekatte, N.
Hawai'i Institute of Marine Biology, Kane'ohe, United States

nina.schiettekatte[at]gmail.com

Abstract

Consumers play an important role in biogeochemical cycles through the consumption and release of essential elements such as carbon (C), nitrogen (N), and phosphorus (P). A large proportion of consumed elements are rapidly released back into the environment in inorganic (i.e., excretion) or organic form (i.e., egestion). On coral reefs, fishes represent a large part of the consumer biomass and thus play a key role in the recycling of nutrients. In recent years, excretion rates have been studied intensively, but less is known about the rate and quality of coral reef fish egestion. Nonetheless, fish feces can be an important food source for other animals or fuel the microbial community. We aimed to fill this knowledge gap by quantifying the elemental contents of fish feces,
estimating absorption efficiencies, and comparing egestion and excretion rates for 51 coral reef fish species. We show that elemental concentrations decrease remarkably little from food to feces, due to predominantly low absorption efficiencies, resulting in large amounts of energy and nutrients being egested. Moreover, we highlight that the quality of fish feces varies across trophic guilds but remains highly variable even within trophic guilds. Finally, we demonstrate that the N and P release is higher in fish egestion compared to excretion for most species. Overall, our study affirms the need for incorporating animal egestion in assessments of ecosystem functioning and food web
structures.

Session 9D - Is ocean deoxygenation a key factor regulating global decline of coral reefs?

Conceptualized by: **David Hughes** [1], **Andrew Altieri** [2], **Michael Kuhl**[3], **Maggie Johnson**[4], **Adrienne Correa**[5]
[1] University of Technology Sydney (Sydney, Australia)
[2] University of Florida (Gainesville, Fl, USA)
[3] University of Copenhagen (Copenhagen, Denmark)
[4] Smithsonian Tropical Research Institute (Florida, USA)
[5] Rice University (Houston, TX, USA)

Chaired by: **Andrew Altieri** [2], **Michael Kuhl**[3], **Maggie Johnson**[4], **Adrienne Correa**[5]

Oral
A-2021

Coral bleaching and microbial shifts during a hypoxic event on a Caribbean coral reef

Altieri, A.[1], Johnson, M.[2], Lucey, N.[3], Leray, M.[3], Scott, J.[3], Rodriguez, L.[4], Wied, W.[5]
[1]University of Florida, Gainesville, United States
[2]King Abdullah University of Science and Technology, Thuwal, Saudi Arabia
[3]Smithsonian Tropical Research Institute, Panama City, Panama
[4]Universidad Autónoma de Baja California, Ensenada, Mexico
[5]Florida International University, Miami, United States

andrewaltieri808[at]gmail.com

Abstract

Ocean deoxygenation is now recognized as a growing threat to coral reefs that can result in mass mortality. As hypoxia spreads into new areas and occurs with increasing frequency, it is important to develop a predictive understanding of this threat by identifying the indicators of stress and potential resilience of reef communities. We conducted a rapid assessment during a hypoxic event on the Caribbean coast of Panama where hypoxia now occurs predictably along a spatial gradient with increasing frequency. To examine the ecological response to the onset of hypoxia, we characterized coral physiological responses as well as the microbial community composition in the overlying water column at two sites spanning this gradient. We found that corals exhibited precipitous declines in zooxanthellae densities and photopigment concentrations at the hypoxic site that were less than 30% the values observed at the normoxic site. This bleaching response was associated with mortality that resulted in 50% loss of live coral cover and a shift in benthic community structure still evident over a year later. The microbial community also exhibited a response to hypoxia with a composition that was distinct from the normoxic conditions. During the event, 16s rRNA analysis revealed that the hypoxic site had overall higher microbial diversity, and a unique taxonomic profile that included classes not found at the normoxic site. Closer examination with metagenomic analyses identified taxa unique to the hypoxic site, including Arcobacter which are indicative of anoxic conditions. Following the event, the microbial community at the previously hypoxic site rebounded to resemble that of the normoxic site. We found that the onset of hypoxia rapidly triggers indicators of stress on coral reefs including bleaching and declines in photosynthetic performance of corals and shifts in community structure of microbes. However, the eventual death of corals and rebound of the microbial community reveal sharp contrasts in the resilience of these two critical functional groups with important implications for shifts in the structure and function of coral reef ecosystems with onset of deoxygenation.

Oral
A-1679

Shifts in the coral microbiome in response to in situ experimental deoxygenation

Howard, R.[1], Schul, M.[2, 3], Rodriguez Bravo, L.[3, 4], Altieri, A.[2, 3], Meyer, J.[1]
[1]University of Florida, Soil and Water Sciences Department, Gainesville, United States
[2]University of Florida, Department of Environmental Engineering Sciences, Gainesville, United States
[3]Smithsonian Tropical Research Institute, Balboa, Ancon, Panama
[4]Universidad Autónoma de Baja California, Facultad de Ciencias Marinas, Ensenada, Mexico

r.howard[at]ufl.edu

Abstract

Global climate change impacts ocean communities through rising surface temperatures, ocean acidification, and deoxygenation. While the response of the coral holobiont to the first two effects has been relatively well studied and documented, little is known about the response of the coral microbiome to deoxygenation. Previous work has documented mass mortality and loss of coral diversity during low oxygen events, which are becoming more prevalent in tropical waters, but has also revealed strong differences among species in their tolerance to hypoxia. In this study, we investigated the response of the microbiome to hypoxia in two coral species that differ in their relative tolerance to hypoxia. We conducted *in situ* oxygen manipulations on a coral reef on the Caribbean coast of Panama, which has previously experienced episodes of low dissolved oxygen concentrations. Naïve coral fragments (previously unexposed to hypoxia) of massive starlet coral (*Siderastrea siderea*) and whitestar sheet coral (*Agaricia lamarcki*) were transplanted to a reef and either enclosed in chambers that created hypoxic conditions or left at natural oxygen levels. We collected surface samples of mucus and tissue after 48 hours of exposure to these conditions and characterized the microbiome by sequencing 16S rRNA genes. We found that the microbiomes of the two coral species were distinct from one another and remained so after exhibiting a shift of similar magnitude in response to hypoxia. Additionally, there was an overall increase in anaerobic microbes after hypoxic exposure, and fourteen families in particular that changed significantly in abundances, including Desulfovibrionaceae, Midichloriaceae, Nitrincolaceae, and Clostridia Family XII. We also identified four indicator species of hypoxia that may include nitrogen or sulfur cyclers. Our findings provide a basis for further investigation into understanding how microbial shifts may mediate coral resilience in response to ocean deoxygenation.

Oral
A-2072

Reef-building corals exhibit high tolerance to severe deoxygenation

Johnson, M.[1, 2], Swaminathan, S.[3], Nixon, E.[4], Paul, V.[2], Altieri, A.[3]
[1]King Abdullah University of Science and Technology (KAUST), Red Sea Research Center, Thuwal, Saudi Arabia
[2]Smithsonian Marine Station, Fort Pierce, United States
[3]University of Florida, Gainesville, United States
[4]Scripps Institution of Oceanography, UC San Diego, La Jolla, United States

maggie.johnson[at]kaust.edu.sa

Abstract

Ocean deoxygenation threatens the persistence of coastal ecosystems worldwide, yet despite the increasing awareness of how acute deoxygenation events impact tropical habitats, there remains a substantial gap in our understanding of the response of reef-building corals to oxygen stress. To address this, we conducted a series of laboratory experiments with three common Caribbean coral species, *Acropora cervicornis*, *Siderastrea radians,* and *Orbicella faveolata*. We tested the effects of continuous exposure to conditions ranging from severe deoxygenation to normoxia (~0.5 to 6.0 mg L^{-1} DO) on coral bleaching and survival. Species demonstrated different temporal resistance to deoxygenation, and within a species there were minimal genotype-specific treatment effects. *Acropora cervicornis* was sensitive to deoxygenation, and showed signs of tissue loss and mortality within a day of persistent exposure to severe deoxygenation, dissolved oxygen conditions of ~1.0 mg L^{-1}. Conversely, O. faveolata remained unaffected after 11 days and *S. radians* after 20 days of continuous exposure to the same level of deoxygenation. The species investigated in this study demonstrated tolerance to levels of deoxygenation that have been found to be lethal for other marine taxa. For example, all species were minimally or unaffected by the two intermediate deoxygenation treatments (~2 mg L^{-1}, ~4 mg L^{-1}). These findings demonstrate the importance of elucidating species-specific hypoxia-thresholds, shed light on the effects of hypoxia on coral physiology, and provide insight into the potential for coral resistance to deoxygenation. With deoxygenation emerging as a critical threat to tropical habitats, there is an urgent need to incorporate the impacts of oxygen-loss into coral reef research, management, and action plans to facilitate a better understanding of the future of coral reefs in an era of rapid environmental change.

Oral
A-1082

Hypoxia tolerance assessment of multiple scleractinian species through the calculation of Critical Oxygen Partial Pressure (PO_2 crit)

Pontes, E., Langdon, C.
University of Miami Rosenstiel School of Marine and Atmospheric Science, Marine Biology and Ecology, Miami, United States

e.pontes1[at]umiami.edu

Abstract

Anthropogenic climate change and the release of greenhouse gases such as CO_2 have caused major environmental shifts in temperature and oxygen availability, both of which threaten sensitive marine life, especially those that live close to their thermal limits such as scleractinian corals. Scleractinian coral populations have experienced mass mortality events in coastal areas such as Panama and Flower Garden Banks due to hypoxic conditions brought on by thermal stress and nutrient input. Because an increase in temperature directly results in a net loss of oceanic dissolved oxygen, measurements of hypoxia tolerance will become critical tools to accurately predict what coral reefs will look like under climate change. Calculating the Critical Oxygen Partial Pressure (PO_2 crit) is one method of determining hypoxia tolerance among marine organisms, with a lower PO_2 crit indicating a greater tolerance for low oxygen. PO_2 crit is defined as the oxygen concentration at which an organism switches from maintaining its metabolic function (regulating) to adjusting its metabolic rate to conform with oxygen availability (conforming). In this experiment the PO_2 crit of five species was measured for the first time: *Orbicella faveolata*, *Siderastrea radians*, *Siderastrea siderea*, *Porites asteroides*, and *Acropora cervicornis.* Twenty replicate pieces of each scleractinian species were acclimated in an indoor flow-through aquarium at 28°C for three weeks. Corals received lighting from Cool-White fluorescent lights (300 mmol/cm^2/s) on a 12:12 photoperiod and were fed Ziegler's Larval Diet AP100 twice weekly. Corals were then exposed to 16 distinct oxygen concentrations ranging from 7 mg/L to 1 mg/L, selected in a random order, for one hour. Following the exposure phase, net photosynthesis and dark respiration were measured for two, ten-minute periods using closed-system intermittent flow respirometry. Reduced oxygen concentrations were achieved by bubbling nitrogen gas. PO_2 crit was determined by fitting a hyperbolic tangent function to MO_2 vs. pO_2 data. Results for *A. cervicornis* show the PO_2 crit is 6.8±0.8 kPa, slightly higher than the generally accepted hypoxia threshold of 5.2 kPa (2 mg/L O_2), suggesting that *A. cervicornis* has a low tolerance to hypoxic conditions. Furthermore, this research determines hypoxia tolerance in multiple scleractinian species, which will assist in reef restoration practices that prioritize out planting species with a higher hypoxia tolerance.

Oral
A-1521

Effects of hypoxia on phage-bacteria-coral symbioses

Silveira, C.[1], Rohwer, F.[2]
[1]University of Miami, Biology, Coral Gables, United States
[2]San Diego State University, San Diego, United States

cynthiabsilveira[at]gmail.com

Abstract

Coral reef microbialization causes reef deoxygenation due to high heterotrophic microbial oxygen consumption rates. Bacteriophages (viruses that infect bacteria) typically kill bacteria through lytic infections. However, oxygen availability can affect phage replication strategies. The effects of these replication switches on phage-bacteria-coral interactions are unknown. Here, we analyzed the combined microbial and primary producer (coral and algae) metabolisms contributing to the reef oxygen budget using field incubations. Almost 70 % of algae oxygen production was lost by ebullition and microbial consumption, dramatically impacting the oxygen budget. The heterotrophic bacteria growing on algae exudates shifted their metabolism towards low O_2 consumption per cell and increased cell sizes. Despite low oxygen consumption per cell, the total microbial consumption was 10 times larger in algae incubations compared to corals, due to high abundances. In another set of field incubations, we reproduced the effects of algae exudates (high dissolved organic carbon and low oxygen availability) in mesocosms using nitrogen enrichment, along with normoxic and superoxic treatments. Low oxygen availability led to a decrease in the virus-to-microbe ratio, an indication of the frequency of phage lytic infections, compared to normoxic and superoxic environments. When the viral and microbial communities from hypoxic mesocosms were inoculated in tanks containing fragments of the coral *Orbicella faveollata*, 90 to 100% mortality was observed. These results indicate that a positive feedback between primary producer and heterotrophic bacterial metabolisms reduces oxygen availability, ultimately reducing the predation pressure of viruses on bacteria and leading to coral mortality.

Oral
A-1736

Understanding anoxic tolerance in marine sponges and their symbiotic microbes

Strehlow, B.[1], Schuster, A.[1], Eckford-Soper, L.[1], McAllen, R.[2], Francis, W.[1], Canfield, D.[1]
[1]University of Southern Denmark, SDU, Odense M, Denmark
[2]University College Cork, Cork, Ireland

brian.strehlow[at]gmail.com

Abstract

The world's oceans face many anthropogenic stressors, which can affect dissolved oxygen concentrations. Globally, climate change is causing oxygen minimum zones (OMZs) to expand, and locally, increased nutrient runoff can deplete oxygen concentrations following eutrophication. The effects of decreased oxygen concentrations on animals are generally detrimental given the importance of oxygen in aerobic respiration. However, some sponges (Porifera) exhibit hypoxic and anoxic tolerance, though the mechanisms underlying this tolerance are unknown. Sponges are also known to host dense, highly specific microbiomes, including microbes with anaerobic capabilities, which can have interlinked metabolisms with their hosts. Since sponges lack key components of the hypoxia-inducible factor (HIF) pathway responsible for hypoxic responses in other animals, it was hypothesized that sponge tolerance to hypoxia and anoxia may be facilitated by the activity of its microbiome.
To investigate the former hypothesis, we determined the microbial composition of sponge species tolerating seasonal anoxia and hypoxia in situ in a semi-enclosed marine lake, using 16S rRNA amplicon sequencing. We discovered a high degree of cryptic diversity among sponge species tolerating seasonal deoxygenation, including at least nine encrusting species of the orders Axinellida and Poecilosclerida. Despite significant changes in microbial community structure in the water, sponge microbiomes were species specific and remarkably stable under varied oxygen conditions, though some symbiont sharing occurred between host species under anoxia. At least three symbiont combinations, all including large populations of *Thaumarchaeota*, corresponded with deoxygenation tolerance, and some combinations were shared between distantly related hosts. To determine the molecular pathways involved in deoxygenation tolerance, the holotranscriptomes, i.e. the transcriptome of the host and symbiont (holobiont), will be compared between normoxic, hypoxic and anoxic conditions in situ for two sponge species: *Hymeraphia stellifera* and *Eurypon* sp.2. Studying how sponges and their associated microbes tolerate deoxygenation will provide key insights into the structure and function of future marine ecosystems.

Oral
A-1226

Resilience of the Acropora cervicornis microbiome to hypoxia and host physiological stress

Swaminathan, S. D.[1], Johnson, M.[2], Meyer, J.[1], Paul, V.[3], Altieri, A.[1]
[1]University of Florida, Gainesville, United States
[2]King Abdullah University of Science and Technology, Thuwal, Saudi Arabia
[3]Smithsonian Institution, Fort Pierce, United States

sara.swaminathan[at]ufl.edu

Abstract

Ocean deoxygenation is intensifying as a result of human activities and represents a grave and burgeoning threat to coral reef ecosystems. Prior studies have documented that hypoxia commonly follows onset of elevated temperature stress. We examined responses of the three primary components of the coral holobiont – the coral animal, the endosymbiotic algae, and the microbiome – to hypoxia across differences in prior thermal stress exposure. Acropora cervicornis fragments were outplanted to two sites in the Florida Keys National Marine Sanctuary that experienced contrasting temperature regimes for the duration of the summer. Corals were then brought into a laboratory mesocosm experiment, where we tested host physiological and microbial responses to varying dissolved oxygen concentrations (ambient, 4.0, 2.0, and 0.5 mg/L). The animal response to these predictors was measured by survivorship and tissue loss. The response of *Symbiodiniaceae* spp. was quantified by Pulse Amplitude Modulated (PAM) fluorometry and cell densities. The composition of the coral microbiome was characterized using 16S rRNA sequencing and analyzed to examine differential abundance of key taxonomic groups, alpha diversity, and beta dispersion. We document resilience of the coral holobiont to dissolved oxygen concentrations as low as 2.0 mg/L. The coral host and endosymbionts showed tissue loss and signs of bleaching in the hypoxic treatment (0.5 mg/L), while the coral microbiome remained stable. While not substantial enough to drive shifts in overall community composition, populations of some microbial taxa did increase or decrease in response to hypoxia, resulting in shifts in the relative abundance of taxa. Signatures of thermal history and genotype played a role in animal and endosymbiont responses to hypoxia but had no detectable influence on the coral microbiome. Our findings suggest that different members of the coral holobiont respond to hypoxia in divergent ways and that, unlike the coral host and endosymbiont, the coral microbiome has the capacity to withstand severe hypoxic stress.

Poster
A-1756

Effects of natural variability in temperature, dissolved oxygen, and pH on massive coral growth and calcification in a seagrass meadow

Pezner, A.[1], Charles, C.[1], Chou, W.-C.[2], Chu, H.-C.[2, 3], Courtney, T.[1, 4], Frable, B.[1], Kekuewa, S.[1], Syu, R.-W.[2], Wei, Y.[5, 6], Soong, K.[5], Andersson, A.[1]
[1]Scripps Institution of Oceanography, University of California San Diego, La Jolla, United States
[2]National Taiwan Ocean University, Keelung, Taiwan
[3]Academia Sinica, Research Center for Environmental Changes, Taipei, Taiwan
[4]University of Puerto Rico at Mayagüez, Department of Marine Sciences, Mayagüez, Puerto Rico
[5]National Sun Yat-sen University, Kaohsiung, Taiwan
[6]National Taiwan University, Institute of Oceanography, Taipei, Taiwan

apezner[at]ucsd.edu

Abstract

Coral reefs are increasingly facing threats from many different stressors, including warming, ocean acidification, and eutrophication. However, relatively few studies have investigated the impacts of hypoxia on coral reefs. Recent research has shown that corals may be differentially tolerant to hypoxia, depending on exposure level, duration, and interactions with other environmental parameters. Further, despite the likely co-occurrence of low oxygen and low pH conditions in the field, few studies have examined the simultaneous impacts of these parameters on coral calcification and growth. In this study, we investigated coral calcification rates across a natural gradient in seawater temperature, pH, and oxygen variability in a seagrass bed on the Dongsha Atoll, Taiwan. Spatial surveys of water chemistry across a 0.7 km^2 section of seagrass with small patches of massive *Porites* spp. and *in-situ* sensor measurements showed dramatic changes in temperature, dissolved oxygen (DO), and pH over space and time. Temperature in the seagrass ranged from 29.1°C to 32.2°C from early morning to midday. Corresponding DO levels were as low as 16 $\mu mol\ kg^{-1}$ (8% saturation) in the early morning, and as high as 332 $\mu mol\ kg^{-1}$ (181% saturation) in the late afternoon. Similarly, pH ranged from 7.7 in the early morning to 8.6 in the late afternoon. Cores were collected from colonies of massive *Porites* spp. along a gradient of zero to high seagrass densities and analyzed for annual calcification rates and skeletal isotopic composition to determine whether seagrass environments affected coral growth rates. Understanding how coral growth and calcification is affected by pH, temperature, and DO variability will help us better assess how coral reefs may fare under increased ocean acidification, warming, and hypoxia.

Session 9E - Ocean acidification and coastal acidification: What are the drivers, processes and consequences for coral reef ecosystems?

Conceptualized by: **Katharina Fabricius** [1], **Joy Smith**[1], **Rebecca Albright**[2]
[1] Australian Institute of Marine Science (Townsville, Australia)
[2] California Academy of Sciences (San Francisco, CA, USA)

Chaired by: **Katharina Fabricius** [1], Ian Enochs[2]
[1] Australian Institute of Marine Science (Townsville, Australia)
[2] NOAA/AOML (Miami, USA)

Oral
A-1059

Changes in pH and dissolved oxygen on Caribbean Reefs

Cryer, S.[1, 2], Evans, C.[2], Carvalho, F.[2], Fowell, S.[2], Ludgate, J.[2], Andrews, G.[3], Rosado, S.[3], Young, A.[3], Delgallerie, D.[4], Theophille, D.[4], Strong, J.[2], Sanders, R.[2, 5], Loucaides, S.[2]
[1]University of Southampton, National Oceanography Centre, Southampton, United Kingdom
[2]National Oceanography Centre, Southampton, United Kingdom
[3]Coastal Zone Marine Authority and Institute, Belize City, Belize
[4]Dominica Fisheries Division, Roseau, Dominica, [5]NORCE, Bergen, Norway

s.e.cryer[at]soton.ac.uk

Abstract

The health of coral reefs can influence processes such as calcification and dissolution, which has consequence for coastal ocean acidification. Globally reefs are degrading with unhealthy reefs typically characterised by a phase shift from hard coral to macroalgae dominance, with an increase in soft corals and sponges. The resulting changes in ecology, and therefore net reef metabolism, have the potential to drive changes in carbonate chemistry. We investigated the incidences of dissolution and the strength of the 'metabolic pulse' using high temporal resolution monitoring of pH and dissolved oxygen (DO) in the seawater at four Caribbean reefs sites with distinct differences in relative dominance of hard and soft coral, sponges and macroalgae.

Custom-built lab-on-chip pH sensors were deployed alongside conductivity, temperature and DO sensors to record measurements every 1-2 hours for periods of 1.5 – 6.5 weeks. Dissolution was only detected during daylight and at a site where sponges and macroalgae were present together, and where they represented a greater proportion of benthic cover than coral. The apparent requirement for daylight could indicate dissolution was driven by the macroalgae, although no dissolution was detected at a site with macroalgae and similar coral characteristics. In this case though, macroalgae made up a lower proportion of the benthos indicating that either macroalgae cover needs to reach a certain threshold to cause dissolution, or that sponges must be present in tandem with macroalgae to create the conditions required for dissolution. The strength of the metabolic pulse, i.e. the amplitude of the oscillations in pH and DO concentrations driven by the balance of photosynthesis and respiration over the diel cycle, was not directly proportional to hard coral cover alone or total benthic cover but apparently driven by broader indicators of reef health and specifically the relative proportions of coral, macroalgae and sponges.

We found the increased dominance of macroalgae and sponges, which is indicative of poor reef health, facilitated dissolution. This would indicate that once degradation has progressed to benthic ecological changes, further degradation is perpetuated from the reef components themselves.

Oral
A-2124

Diel CO_2 fluctuations influence coral calcification, with implications for persistence under future acidification conditions

Enochs, I.[1], Manzello, D.[2], Formel, N.[3], Lirman, D.[4]
[1]NOAA/AOML, Miami, United States
[2]NOAA, Coral Reef Watch, College Park, MD, United States
[3]University of Miami, Cooperative Institute for Marine and Atmospheric Studies, Miami, FL, United States
[4]University of Miami, Rosenstiel School for Marine and Atmospheric Science, Miami, FL, United States

ian.enochs[at]noaa.gov

Abstract

Coastal marine ecosystems experience dynamic carbonate chemistry conditions, markedly different from static ocean acidification (OA) treatments often applied in laboratory studies. Diel oscillations in CO_2 naturally occur due to light-mediated fluctuations in the balance of photosynthesis and respiration, as well as calcification and dissolution. These fluctuations can result in periodic exposure to CO_2 concentrations expected to occur by the end of the century and the amplitude of these swings will likely increase due to OA. Temporal carbonate chemistry variation therefore has strong implications for organismal responses to OA and for ecosystem persistence in general. In order to investigate this, we developed an automated seawater system for precisely manipulating the mean and magnitude of CO_2 fluctuations in 16 independent aquaria. Five genotypes of *Acropora cervicornis* were subjected to five treatments representing a range in diel oscillations under present-day and advanced OA conditions. Calcification was enhanced under dynamic versus static contemporary conditions, indicating that the benefits of diurnal CO_2 drawdown presently outweigh the costs of nocturnal enrichment, for this species. This pattern, however, did not hold under more-advanced OA scenarios, reflecting the importance of considering both the mean and magnitude of diel oscillations when assessing species sensitivities. We further investigate these trends during day and night using an automated system for rapid assessment of calcification and propose a conceptual model where the relative contribution of light and dark calcification, coupled with dynamic CO_2 conditions, will modulate the OA response. These data can be used to better predict ecosystem responses to OA and to identify potential refugia.

Oral
A-1461

Physiological and Molecular Impact of Ocean Acidification on Two Common Caribbean Bioeroding Sponges

Morris, J.[1, 2], Enochs, I.[1], Mayfield, A.[1, 2], Studivan, M.[1, 2], Young, B.[1, 2], Soderburg, N.[1, 2], Kolodziej, G.[1, 2], Manzello, D.[3]
[1]NOAA-AOML, Ocean Chemistry and Ecosystem Division, Miami, United States
[2]University of Miami, Cooperative Institute for Marine and Atmospheric Studies, Miami, United States
[3]NOAA-Coral Reef Watch, Center for Satellite Applications and Research, Satellite Oceanography & Climate Division, College Park, United States

john.morris[at]noaa.gov

Abstract

Coral reef ecosystems are experiencing a shift towards net dissolution due to the impacts of ocean acidification (OA) on coral reef calcifiers and bioeroders. While the stimulating effect of OA on bioerosion has been demonstrated experimentally, primarily in the Pacific, the underlying mechanisms behind the response are still unknown. Here, we tested the physiological and molecular responses of common zooxanthellate (*Cliona varians*) and azooxanthellate (*Pione lampa*) Caribbean sponges to OA under pre-industrial (8.15 pH), present-day (8.05 pH), and two future OA scenarios (7.85 pH and 7.75 pH). Total bioerosion, day and night chemical dissolution, and mechanical bioerosion were measured one month into treatment conditions, and tissue samples were collected from sponge specimens in the 8.05 and 7.75 treatment groups for the analysis of differential gene expression. The influence of OA on sponge bioerosion was asymptotic for both species, with the most substantial long-term bioerosion and chemical dissolution rates found in the 7.85 treatment, and decreasing under the more extreme 7.75 conditions. Pre-industrial bioerosion rates were similar to those measured under present-day conditions but were significantly lower than the two OA treatments. These responses were further investigated using transcriptomics, where substantial species and colony differences in gene expression were characterized. These results, coupled with the gene expression data, reveal that the relative importance of bioeroding sponges in Caribbean reef ecosystems will likely increase under future OA scenarios, which could accelerate habitat loss and reduce ecological services throughout the region.

Oral
A-1320

Carbonate system along the Florida Reef Tract: Long term trends, seasonality, and regional variation

Palacio-Castro, A. M.[1], Manzello, D.[2], Besemer, N.[3], Jankulak, M.[1], Boyd, A.[1], Kolodziej, G.[1], Webb, A. E.[1], Hirsh, H. K.[1], Towle, E. K.[4], Smith, I.[1], Kelble, C.[3], Enochs, I. C.[3]
[1]NOAA/AOML, Cooperative Institute for Marine & Atmospheric Studies - University of Miami, Miami, United States
[2]National Oceanic and Atmospheric Administration - NOAA, Coral Reef Watch, Center for Satellite Applications and Research, Satellite Oceanography & Climate Division, College Park, United States
[3]National Oceanic and Atmospheric Administration - NOAA, Atlantic Oceanographic and Meteorological Laboratory, Miami, United States
[4]Lynker, Inc, National Oceanic and Atmospheric Administration Coral Reef Conservation Program Contract, Leesburg, United States

apalacio[at]rsmas.miami.edu

Abstract

Global Ocean Acidification (OA), caused by increasing atmospheric carbon dioxide (CO_2), threatens the physiology and ecology of calcifying organisms including reef-building corals. The local chemistry of shallow water environments, including those in South Florida and the Florida Keys, is influenced by physical (e.g., water flow) and biological processes (e.g., production/respiration, calcification /dissolution), which may modulate an organism's susceptibility to global OA. These processes vary in both space and time, and remain poorly quantified despite their importance. As part of the NOAA National Coral Reef Monitoring Program (NCRMP), carbonate chemistry was characterized along 10 inshore-offshore transects located along the Florida Reef Tract during the South Florida Ecosystem Restoration Research cruises. Discrete seawater samples were collected bimonthly from 2015 to 2021 (n=1318). We assessed long-term trends and seasonal patterns in the carbonate chemistry of major biogeographic regions (Biscayne Bay, Upper Keys, Middle Keys, and Lower Keys) further distinguished by shelf position (inshore, mid-channel, and offshore). Significant declines in aragonite saturation state (Ω_{ar}) and pH were detected in the mid-channel and offshore reefs in every biogeographic region. These OA patterns were not detected at the inshore reefs, where long-term trends were obscured by strong seasonal variations. On average, total alkalinity (TA) and dissolved inorganic carbon (DIC) were depleted relative to offshore signals at all inshore sites during the spring and summer, indicating net calcification and photosynthesis during these seasons, respectively. Conversely, TA and DIC were typically elevated on inshore reefs in the fall and winter indicating net dissolution and respiration. Inshore DIC depletion during the spring also resulted in increased Ω_{ar} in the Upper and Middle Keys. This was not the case in Biscayne Bay where there was a smaller magnitude change in DIC relative to other regions. These results indicate that inshore reefs of the Florida Keys may serve as refugia by buffering global OA stress. Significant alteration in benthic community composition in the area, however, may quickly eliminate this buffering capacity or lead to acidification enhancement. The metabolic influence of the local benthic community may provide a mechanism for long-term regional OA amelioration in the Florida Keys.

Oral
A-2184

Metabarcoding coral reef communities in naturally low pH environments reveals reduced diversity and deep shifts in community composition

Plaisance, L.[1], Matterson, K.[2], Fabricius, K.[3], Casey, J.[4], **Knowlton, N.**[2]
[1]EDB - Université Paul Sabatier, Toulouse, France
[2]National Museum of Natural History, Washington DC, United States
[3]Australian Institute of Marine Science, Cape Cleveland, Australia
[4]École Pratique des Hautes Études (EPHE), Perpignan, France

knowltonn[at]gmail.com

Abstract

Naturally occurring low pH marine environments have been extensively studied during the past decade as they provide us with a unique opportunity to characterize the effects of ocean acidification on marine species and communities. Most studies to date have concentrated on conspicuous and ecologically important species such as corals, algae, sea grasses, fish, crustaceans or microbes. Those studies have shown complex responses that are sometimes in contradiction with laboratory experiments highlighting the need for in situ studies to reveal direct and indirect effects on species, populations and communities. Applying metabarcoding to whole communities in these environments can provide novel insights into changes of coral reef communities that are naturally exposed to lower pH environment.
In this study, we deployed standardized artificial sampling units (ARMS) on two acidified coral reefs in Papua New Guinea as well as two adjacent control sites. Three pH categories were investigated: control pH (~8.0), intermediate pH (~7.85), and low pH (>7.8). The ARMS units were retrieved after two years and all the organisms (sessile and motile) were removed from the ARMS. For each ARMS, the DNA of the whole community were extracted and metabarcoded using high-throughput sequencing of three loci: 18Sr RNA for eukaryotes, 23S rRNA for algae and plants and the 16S rRNA for the prokaryotes. The choice of these molecular markers allowed us to characterize the breadth of diversity found on coral reefs.
Following removal of singletons and low quality and chimeric sequences, we obtained 16,079,131 18S rDNA sequences, 7,210,551 23S rDNA sequences and 24,768,150 16S rDNA sequences. Following rarefaction to the lowest sequence count per sample for each separate dataset and OTU clustering using a 97% threshold, we obtained 5,371 OTUs for the 18S rDNA belonging to 47 phyla, 1,356 OTUs for the 23S rDNA belonging to 8 phyla and 23,173 OTUs for the 16S rDNA belonging to 33 phyla. For the three genes and the two localities, we observed a remarkably homogeneous trend of decreased diversity with decreasing pH and an effect of pH on the community structure. Sampling season (April and November) was also an explanatory variable for the plants and algae (23SrDNA). Our analyses allowed us to quantitatively asses the response of well-known taxa (e.g. arthropods, mollusks), as well as poorly studied taxa (e.g. chaetognaths, protozoans) to ocean acidification.

Poster
A-1509

Ecophysiology of the pulsating soft coral Xenia umbellata is affected by acidification but not phosphate enrichment

Caporale, G., Mezger, S. D., Paul, J., Schmidt, N., Tilstra, A., El-Khaled, Y. C., Wild, C.
University of Bremen, Faculty of Biology and Chemistry, Department of Marine Ecology, Bremen, Germany

gcaporale.pers[at]gmail.com

Abstract

A combination of local and global factors can cause a decline of reef-building corals and a shift towards alternative benthic reef communities dominated by algae or other invertebrates, particularly soft corals. Most previous studies focused on the response to such drivers separately and concentrated on hard corals. Thus, we here investigated the ecophysiology of the widespread pulsating soft coral *Xenia umbellata* under acidification and phosphate enrichment, both factors expected to increase under future ecological scenarios. For this, we exposed coral colonies to i) declining pH conditions (from 8.3 as control, to 7.9, 7.7 and 7.5), ii) phosphate enrichment of 2 µM, and iii) a combination of both. Over a period of three weeks, we regularly observed ecological parameters, such as growth, survival, and polyp pulsation, along with photo-physiological parameters, such as oxygen fluxes, Symbiodinaceae density and relative chlorophyll *a* concentration. Our results show that acidification significantly increased respiration and Symbiodinaceae density, but reduced chlorophyll *a* concentration. Additionally, pulsation gradually decreased with lowered pH throughout the experiment. Phosphate enrichment only caused a significant increase in Symbiodinaceae density after one week of exposure. The combination of acidification and phosphate enrichment led to similar results compared to acidification alone in terms of respiration, Symbiodinaceae density, and pulsation. Interestingly, pulsation was on average lower by 32 % in the combined treatment than in the phosphate enrichment treatment alone. Among the observed parameters, reduced pulsation indicates acidification as a potential stressor for *X. umbellata*. This stands in contrast with previous studies on soft corals where no effects of acidification were detected on pulsation, Symbiodinaceae density and chlorophyll *a* concentration. Conversely, our findings confirm previous observations on gorgonian soft corals where phosphate enrichment did not cause any significant changes on physiological and stoichiometric parameters. Finally, stable survival and growth suggest a higher tolerance of *X. umbellata* than hard corals, which often experience increased mortality and slower growth rate under acidification and phosphate enrichment. In conclusion, this study contributes to explain the predicted and observed competitive advantage of soft corals over reef-building corals under ocean acidification and eutrophication conditions.

Poster
A-1559

Natural spatio-temporal coastal and oceanic variability of carbonate systems around gorgona island reefs, Eastern Tropical Pacific Corridor

Preciado Garcia, A.[1], Cifuentes, J.[1], **Acosta, A.**[1], Murcia, A.[1], Gutierrez, S.[1], Londoño, N.[2], Gallego, J.[2], Hernandez-Ayon, J. M.[3], Celis Zambrano, C.[1], Giraldo, A.[2]
[1]Pontificia Universidad Javeriana, Biology, Bogotá, Colombia
[2]Universidad del Valle, Biology, Cali, Colombia
[3]Universidad de Baja California, Biology, Tepic, Mexico

laacosta[at]javeriana.edu.co

Abstract

Within the Eastern Tropical Pacific, there is no available information of natural carbonate systems variability (SOCAT-CDIAC). Hence, we did the first continuous and discrete measurements in the National Natural Park Gorgona Island, Colombian Pacific. Six stations were compared, three depths (tropical superficial water mix, thermocline, and under the thermocline), during five months (high rainy season), from Guapi river (coastal platform, estuarine zone between the river and the island, salinity average of 29) to the open ocean (oceanic platform). pH in total proton scale (pH_T), total alkalinity were measured, and pCO_2 and omega Aragonite (Ω_{ar}) were derivate. The results indicate high variability in pH and alkalinity measurements, both in space and time (7.600 and 8.156); being less basic at higher depths (minimum pH = 7.600, under the thermocline 45 m; sep-nov 2021) and November. There is a protons flow from the river to the ocean, and that effect showed a delay through time. Alkalinity was ~1900 at 2 m and got higher with depth ~2256 at 70 m. The variability is associated with the mixture of the river with coastal (pH = 7.606-8.156) and oceanic waters (pH = 7.639-8.112) and tide effect (~4.3 m amplitude; dial pH cycle oscillating between 7.987 to 8.128 for two high and low tides). The delta of pCO_2 suggest that the ocean it's a CO_2 sink (pCO_2 at 2 m 294 µatm; southern Ocean) while the estuarine zone a CO_2 source (pCO_2 of 436 µatm; northern estuarine station) during the sampling months, taking in account the global average 416.45 µatm reported by the NOAA in 2021 . The values of Ω_{ar} (0.95-4.96) and CO_3 (61-198 µmol/kg) suggest adverse conditions for the development of corals and other marine organisms around the island, though organisms could have evolved in corrosive waters.

Poster
A-1377

Calcareous sponges can synthesize their skeleton under ocean acidification

Ribeiro, B.[1], Farias, C.[1], Emilly Pereira, S.[1], Peixoto, R.[2], Klautau, M.[1]
[1]Universidade Federal do Rio de Janeiro, Rio de Janeiro, Brazil
[2]King Abdullah University of Science and Technology, Thuwal, Saudi Arabia

barbara.pitt[at]gmail.com

Abstract

Marine calcifying organisms are potentially more vulnerable to climate change, especially regarding ocean acidification effects on their skeleton. Thus, the aim of this study was to investigate if the calcareous sponge *Paraleucilla magna* can synthesize its skeleton (*i*.*e*. spicules) under ocean acidification conditions. To accomplish this goal, an adult individual of *P*. *magna* was collected and its cells were mechanically dissociated in order to form sponge cellular aggregates, called primmorphs. These primmorphs, that can develop into a functional sponge, were submitted to a short-term experiment of five days with two treatments in triplicate: control (pH 8.1) and acidic conditions (pH 7.6), both under 24ºC throughout the experiment. At the end of the experiment, it was observed in the Scanning Electron Microscope that *P*. *magna* can synthesize its skeleton even under low pH and form a functional sponge with osculum and choanocyte chambers. The spicules presented a normal shape in both control and treatment conditions. Then, our results suggest that *P*. *magna* is probably a less vulnerable species under the future oceans' conditions regarding acidity. However, crystal fragility and chemical composition shall be further investigated.

Virtual
Oral
A-1282

Elevated CO2 alters the heat stress response of Acropora cervicornis

Langdon, C., Haider, K.
University of Miami, RSMAS, Marine Biology and Ecology, Miami, United States

clangdon[at]rsmas.miami.edu

Abstract

Rising temperatures are thought to be greatest threat to the survival of corals, causing mass bleaching and mortality events at a frequency that will make survival and recovery between heat stress events impossible. Little is known about the role that increasing ocean acidification will play. Will its role be relatively insignificant as some studies seem to indicate or could it acerbate the effect of heat stress causing corals to bleach at lower temperatures or after fewer days of thermal stress? Is there genotypic variability in the vulnerability of corals to heat and OA stress? Here long-term heat stress experiments are described where ramets of *Acropora cervicornis* representing nine genotypes were split into three control and three treatment groups. Control corals were acclimated at 30C and normal CO_2 (400 uatm) for 30 days and treatment corals were exposed to 30C and elevated CO_2 (1000 uatm) for 30 days. After the acclimation the temperature was slowly ramped (0.3C/d) to 30.5 or 32C. Throughout the acclimation and heat stress phases the corals were buoyant weighed weekly and fed twice weekly. Once the target temperature was reached, the corals were observed daily for signs of stress (bleaching and loss of feeding activity by the tentacles) and eventual death as evidenced by tissue sloughing and overgrowth by algae. Days of survival at 30.5C averaged 127±31 (range 109-176) at low CO_2 and 103±30 (range 59-131) at high CO_2. Days of survival at 32C averaged 17±5 (range 13-27) at low CO_2 and 11±3 (range 9-17) at high CO_2. In summary, pre-exposure to elevated CO_2 shortened days of survival at a very mild heat stress by 19% while at a more severe heat stress it shortened survival by 35%. While this finding is not great news for corals, the finding of significant genotypic variance in the fitness of corals to deal with the combined stresses points to ‘adaptive potential’ and that is cause for hope.

Virtual
Oral
A-1056

Calcification and Photosynthetic Responses of Reef-Building Corals to Ocean Acidification

van der Heide, W.[1], Cornwall, C.[2], Schoepf, V.[3]
[1]Cornell University, Neurobiology & Behavior, Ithaca, United States
[2]Victoria University of Wellington, School of Biological Sciences, Wellington, New Zealand
[3]University of Amsterdam, Institute for Biodiversity and Ecosystem Dynamics, Amsterdam, Netherlands

woutvanderheide[at]gmail.com

Abstract

Reef-building corals are threatened by ocean acidification (OA), which typically has a negative effect on coral calcification. However, OA can elicit both linear and tipping point (i.e. non-linear) responses, yet it remains poorly understood which of these responses dominate. In contrast to calcification, it has been hypothesized that photosynthesis rates may increase under OA; however, whether such a fertilization effect exists is currently also unknown. To address these two knowledge gaps, we conducted (1) a response type analysis for both calcification and photosynthetic responses, and (2) a meta-analysis to assess how OA impacts photosynthetic response (photosynthesis rates and photochemical efficiency of Fv/Fm). Using published raw calcification and photosynthetic response data, linear and parabolic models were fitted to OA treatments which revealed that linear responses dominated in 71% (calcification) and 67% (photobiology) of cases. This demonstrates that tipping-point responses for calcification and photobiology under OA are likely rare. The meta-analysis assessing effect-sizes, revealed that decreases in pH corresponding to the emission-intensive IPCC scenario SSP 8.5 for 2100 (pH 7.7) had no effect on photosynthetic response. This was independent of whether photosynthesis rate and Fv/Fm were analyzed together or independently. When all published treatment responses were used for the meta-analysis, including those with pH <7.7, coral photosynthetic response was reduced by 10% for every 0.1 unit reduction in pH, Fv/Fm alone was unaffected by OA. These results demonstrate that a fertilization effect for photosynthetic responses does not exist, suggesting that any benefits from increased CO_2 levels are outweighed by the physiological cost of operating in a low pH environment. The prevalence of linear responses for both calcification and photobiology, as well as the lack of a fertilization effect, will significantly improve our ability to predict future coral responses to OA. However, challenges remain, including the consolidation of both response types and magnitudes, as well as the incorporation of more aspects of coral life history when modelling physiological responses.

Session 9F - Plastics in corals reefs: What is there and how does it impact reef organisms?

Conceptualized by: **Jessica Reichert**[1], **Maren Ziegler**[1], **Mia Hoogenboom**[2]
[1] Justus Liebig University (Giessen, Germany)
[2] James Cook University (Townsville, Australia)

Chaired by: **Jessica Reichert**[1], **Maren Ziegler**[1]

Oral
A-1261

Microplastics ingestion and adhesion by reef-building corals under different flow rates

Axworthy, J.[1], Wang, S.[1], DiBenedetto, M.[2], Baker, L.[2], Padilla-Gamino, J.[1]
[1]University of Washington, School of Aquatic and Fishery Sciences, Seattle, United States
[2]University of Washington, Mechanical Engineering, Seattle, United States

jeremyax[at]uw.edu

Abstract

Microplastics, small plastic particles less than 5 mm in size, are increasing in marine environments worldwide. However, where they accumulate is still an active area of research. Reef-building corals are thought to serve as considerable sinks for microplastics via two processes: 1) active removal from the water through ingestion and 2) passive removal by adhesion to their surface. However, it is not known which type of plastics are more likely to be ingested or adhered to corals and whether water flow rate or coral morphology affects these processes. To address this knowledge gap and understand the mechanisms associated with microplastic removal, we exposed the corals *Montipora capitata* (branching and plating morphologies) and *Pocillopora damicornis* (branching morphology) to weathered polyester fibers, acrylic fibers, and polystyrene fragments. All microplastic exposures were performed using different flow rates (2, 5 and 10 cm s^{-1}) in a custom experimental flume system. Adhesion was measured visually under a microscope. Ingestion was measured by examining filters on which digested coral tissue is filtered. Additionally, we analyzed high speed video images to visualize microplastics-coral interactions and to characterize hydrodynamic processes that affect ingestion and adhesion rates. Preliminary observations show that adhesion rates are higher than ingestion rates and that fibers are more likely to adhere to corals' surface than fragments. We observed higher adhesion rates on non-living sections of the coral fragments than areas of live tissue suggesting that non-living sections of the reef may also serve as an important sink for microplastics pollution in addition to living corals. Current analyses include comparing adhesion and ingestion under different water velocities and between different coral morphologies. These data will be crucial for determining which environments corals are more likely to interact with microplastics and which corals remove more microplastics from the water, ultimately helping to understand the risk to corals and the fate of this pervasive pollutant.

Oral
A-1549

The impact of plastic debris on the health status of deep corals

Lartaud, F.[1], Chapron, L.[1], Meistertzheim, A.-L.[2], Galand, P.[1], Ghiglione, J.-F.[3], Mouchi, V.[4], Peru, E.[1], Pruski, A.[1], Vétion, G.[1]
[1]Sorbonne University, Banyuls Oceanological Observartory, LECOB, Banyuls-sur-mer, France
[2]Plastic[at]sea, Banyuls-sur-mer, France
[3]Sorbonne University, Banyuls Oceanological Observatory, LOMIC, Banyuls-sur-mer, France
[4]Sorbonne University, Roscoff Biological Station, Roscoff, France

franck.lartaud[at]obs-banyuls.fr

Abstract

There is an increasing interest in the impact of plastics on marine ecosystems and organisms. Most studies focus on coastal organisms although the deep-sea is now recognised as a major sink for plastic debris. Plastics particularly aggregate in submarine canyons where they represent the dominant part of the marine litter. In the Mediterranean canyons, plastic litters represent ca. 70% of the observed wastes, with macro debris concentrations reaching >1 item 100 m^{-1}. Deep-sea fauna such as gastropods, echinoderms, crabs and cold-water corals have been shown to ingest microplastics and they could be impacted by the plastic pollution.
The PLAISCOOL project aimed to explore the impact of plastic wastes on the health status of emblematic deep-sea species: the reef-builders cold-water corals *Lophelia pertusa* and *Madrepora oculata*. Aquaria experiments were conducted to estimate the effects of macro- and microplastics on diverse physiological functions of corals, through an integrated approach at different levels of biological organization. It included the joint analysis of the skeletal growth processes, the feeding behaviour, the energy status of the host, and the characterisation of the associated microbiome.
The results show species-specific responses to plastic exposure. *Lophelia pertusa*, which forms the biggest reefs in the deep, appears particularly sensitive to plastic contamination. Both macro- and microplastics limit colony extension but long-term (6 months) experiments show that this species can cope with the barrier effect of large debris using an avoidance strategy, contrary to microplastics that have persistent effects. The physiological indicators measured for *M. oculata*, which form smaller reefs, indicate lower effects of plastic exposure, making this species likely more resistant to the plastic threat. Those results suggest that plastics would affect differently microhabitats for deep-sea reef-associated organisms and related resources.

Oral
A-2062

Nanoplastics impair photosynthetic capacities of Symbiodinaceae and promote coral bleaching

Marangoni, L.[1], Beraud, E.[2], Ferrier-Page, C.[2]
[1]Smithsonian Tropical Research Institute, Naos Marine Laboratories, Panama city, Panama
[2]Centre Scientifique de Monaco, Monaco, Monaco, (laurafbmarangoni[at]gmail.com)

Abstract

Reef-building corals are increasingly threatened by global and regional stresses, which affect the stability of the coral-Symbiodiniaceae association. Among them, plastic pollution has been an ongoing and growing concern. Whereas several studies have highlighted the detrimental impact of microplastics (0.1 µm - 5mm) on corals and their symbiotic dinoflagellate algae, the physiological changes induced by nanoplastic (NP, < 0.1 µm) pollution are still poorly known. Therefore, the main goal of our study was to give the very first insights into the danger that NPs may represent to corals and their associated symbionts. Long-term experiments (4 weeks) were conducted to investigate the effects of ecologically relevant NP concentrations (0 to 0.5 mg/L of 20 nm polystyrene NPs) on two Symbiodiniaceae in culture [CCMP2467 or Clade A1 and pd44b or Clade F1]. The effects of 0.5 mg/L NPs were also evaluated on the coral *Stylophora pistillata* in symbiosis with Clade A1. The photosynthetic efficiency of photosystem II, the oxidative status of the Symbiodiniaceae and the coral host as well as the host-symbiont stability were evaluated at the end of the experiment. Symbiodiniaceae in culture exhibited a significant decrease in the maximal electron transport rate (ETR_{max}) at NP concentrations as low as 0.005 mg/L, highlighting an impairment of the photosynthetic capacities of the dinoflagellates in presence of NPs. Also, Clade A1 exhibited a significant decrease in its Total Antioxidant Capacity (TAC) and an increase in Lipid Peroxidation (LPO), which evidence oxidative stress and cellular damage. Interestingly, Clade A1 *in hospite* did not show any signs of oxidative stress, however, the coral host exhibited increased TAC and LPO. Additionally, exposure of *S. pistillata* to 0.5 mg/L NPs induced significant bleaching (loss of symbionts and photosynthetic pigments). The main goal of our study was to give the very first insights into the danger that NPs represent to corals and their associated symbionts. Overall, NPs were detrimental for both the Symbiodiniaceae in culture and the host-symbiont association. The question then arises as to how corals and their symbionts will respond to chronic exposure to environmental relevant NP concentrations and whether this can influence their susceptibility to other anthropogenic and global climate-change stressors.

Oral
A-1356

Heating up – The combined effects of microplastic pollution and global warming on reef-building corals

Reichert, J., Tirpitz, V., Anand, R., Bach, K., Knopp, J., Schubert, P., Wilke, T., Ziegler, M.
Justus Liebig University Giessen, Animal Ecology and Systematics, Giessen, Germany

jessica.reichert[at]allzool.bio.uni-giessen.de

Abstract

Pollution of the marine environment with microplastics (MP) has become an emerging stressor, increasing pressure on coral reefs that are already threatened by climate change. However, the interactions between plastic pollution and global warming are poorly understood. Therefore, the aim of our study was to investigate the combined effects of microplastic pollution and heat stress on reef-building corals and to compare the impacts of both stressors. We conducted a series of three controlled experiments and exposed a wide range of coral species (*Acropora muricata*, *Montipora digitata*, *Porites lutea*, *Pocillopora verrucosa*, *and Stylophora pistillata*) to different microplastic mixtures (from different sources of pollution) and concentrations (2.5–2,500 particles L^{-1}) at ambient temperature and under heat stress. We find that microplastics can occasionally affect the heat tolerance of some coral species (i.e., *P. verrucosa* and *S. pistillata*). However, compared to heat stress, microplastics constitute a minor stressor. While exposure to microplastic particles alone had little impact on the physiology and health of the coral species tested, heat stress had strong impacts on photosynthetic efficiency of the algal symbionts and caused bleaching, tissue necrosis, and mortality. Our results underline that while efforts to reduce plastic pollution should continue, they should not replace the more pressing efforts to halt global warming that are critical for protecting the remaining coral reef ecosystems.

Oral
A-1555

Limited effect of plastic additives on the development of early life stages of Rhytisma fulvum, Stylophora pistillata, and Millepora dichotoma

Vered, G.[1, 2], Shenkar, N.[3, 4]
[1]Tel Aviv University, School of Zoology, George S. Wise Faculty of Life Sciences, Tel Aviv, Israel
[2]The Interuniversity Institute for Marine Sciences in Eilat, Eilat, Israel
[3]Tel-Aviv University, School of Zoology, George S. Wise Faculty of Life Sciences, Tel Aviv, Israel
[4]Tel-Aviv University, The Steinhardt Museum of Natural History, Tel Aviv, Israel

galvered1[at]mail.tau.ac.il

Abstract

Plastic pollution endangers marine ecosystems and biodiversity worldwide. Plastic additives (PAs) are chemical compounds incorporated into the plastic during production. Phthalate acid esters, bisphenols, and nonylphenols are PAs found in marine environments and are associated with endocrine disruption activity in mollusks, fish, and mammals. However, our knowledge regarding the impact of endocrine disrupting PAs on coral reef organisms is still scarce. As reef population structure is directly linked to reproduction and offspring settlement processes, the endocrine disruptor properties of PAs can play an important role in a coral reef community structure, even more so, if these effects differ among species. In this study, we have examined the effect of environmental concentrations in seawater, and three orders of magnitude higher concentrations of dibutyl phthalate (DBP), dimethyl phthalate, (DMP), 4-nonylphenol (4-NP), and bisphenol A (BPA) on the success of the early life stages of three tropical coral-reef invertebrates: planulae of the surface-brooder soft coral *Rhytisma fulvum fulvum*, planulae of the brooding stony coral *Stylophora pistillata,* and gametes of the calcifying hydrozoa *Millepora dichotoma*. Our findings show that while there was no effect of exposure to the environmental concentrations for all compounds in all tested organisms, the high concentration of 4-NP had a large negative effect on all species (Significant difference compared to the control tested with a generalized linear mixed-effects model (GLMM), and Tukey HSD $p = 0.05$). However, we argue that the environmental concentrations measured in seawater are not the biologically relevant PAs concentrations that marine invertebrates experience. We suggest that the level of PAs within the body of the organism that the developing gametes and brooding planulae are exposed to is the key factor. Therefore, despite the limited effect of PAs detected in the current study it triggers the question of what is the actual concentration we should use in future toxicological assays.

Poster
A-2242

Microplastic intake by the Australian sharpnose shark Rhizoprionodon taylori on the Great Barrier Reef

Schlawinsky, M.[1], Kroon, F.[2], Motti, C.[2], Santana, M.[2]
[1]ICBM, Oldenburg, Germany
[2]Australian Institute of Marine Sciences, Cape Cleveland, Australia

merle.schlawinsky[at]gmail.com

Abstract

Plastics, the majority of which are non-biodegradable in nature, represent the largest component of marine debrisglobally. In this context, it is important to understand the current extent of plastic pollution in marine environments and within
biota. Despite the many approaches reported in the scientific literature to extract plastics from marine samples, field studies still face methodological impediments to establish accurate and standardized protocols to process and analyse microplastic items (i.e. < 5 mm). Presented here is a validated workflow to process and analyse microplastics separated from various environment sample matrices, which involves sample filtration using a customised stainless steel filtration unit that allows for more streamlined microscopic photography and micro-attenuated total reflection Fourier transform infrared spectroscopy (micro-ATR-FTIR). As a case study, the gastrointestinal tract of three juvenile Australian sharpnose sharks, Rhizoprionodon taylori, collected from the Great Barrier Reef, Australia, were processed. In total 125 items (both fragments and fibres) were separated and characterized. Advantages and disadvantages of the workflow are discussed, and recommendations for future improvements to the workflow are presented.

Virtual
Oral
A-1024

Does the dose make the poison? - Concentration dependant effects of microdebris on reef-building corals

Tirpitz, V., Hutter, M., Hutter, H., Schubert, P., Reichert, J.
Justus Liebig University Giessen, Department of Animal Ecology & Systematics, Giessen, Germany

vanessa.tirpitz[at]bio.uni-giessen.de

Abstract

The pollution of the environment with anthropogenic debris is increasing and considered to be a major threat to marine ecosystems. Particularly microplastic (1-1000 µm) has gained attention in public and science. Inter alia, reef-building corals appear to be affected by it. While effects of microplastics, commonly studied as single polymer types, are increasingly better understood, knowledge on the effects of naturally occurring mixtures of microplastics, known as 'marine microdebris', is still scarce. Thus, the goal of our study was to assess the influence of 'typical' marine microdebris on reef-building corals. As a representative mixture, we chose an assortment of fibers (polyamide, polyester, polypropylene) and particles (polyethylene, polyvinylchloride, polystyrene) in four different concentrations (0.1, 1, 10, and 100 mg/l corresponding to ~ 2, 20, 200, and 2000 particles/l respectively). In a twelve-week experiment, we exposed two common reef-building corals species (*Stylophora pistillata* and *Pocillopora verrucosa*) to microdebris in the four concentrations and compared changes to those observed in a microdebris-free control treatment. We found that calcification, growth in volume, and coral health decreased in the highest concentration treatment (2000 particles/l). In addition, coral polyp activity decreased with increasing microplastic concentration. In contrast, the photosynthetic activity of the photosymbionts was barely impacted by the microdebris treatments. Taken together, our results show that the effects of microdebris mixtures on reef-building corals may be concentration dependant. However, only the highest concentration, which presents a high pollution scenario and lays several orders of magnitudes above regularly occurring concentrations, caused small, yet significant impacts on the coral host. This indicates that in fact the dose does make the poison and provides hope that efforts to reduce plastic pollution can alleviate the stress posed on reef corals.

Session 9G - Thinking outside the reef: how do open-ocean processes influence coral reefs now and in the future?

Conceptualized by: **Katie Shamberger** [1], **Kristen Davis**[2], **Andrea Kealoha**[3], **Andrew King**[4]
[1] Texas A&M University (College Station, TX, USA)
[2] University of California, Irvine (Irvine, CA, USA)
[3] University of Hawaii (Maui, HI, USA)
[4] University of Melbourne (Victoria, Australia)

Chaired by: **Katie Shamberger** [1], **Kristen Davis**[2]

Oral
A-2038

Internal wave influence from the forereef to the backreef.

Davis, K., Reid, E.
University of California Irvine, Irvine, United States

davis[at]uci.edu

Abstract

Internal waves strongly influence the physical and chemical environment of coastal ecosystems worldwide through the shoreward transport of subthermocline water. We report novel observations that tracked the transformation of internal waves from the forereef (50 m) to the backreef on Dongsha Atoll in the South China Sea. Instrumentation included a distributed temperature sensing (DTS) system which resolved spatially and temporally continuous temperature measurements over a 4-km cross-reef section. We find that during summer, internal waves shoaling on the shallow atoll regularly transport cold, nutrient-rich water shoreward, altering near-surface water properties on the fore reef. This water is transported shoreward of the reef crest by tides, breaking surface waves and wind-driven flow, where it significantly alters the water temperature and nutrient concentrations on the reef flat.

Oral
A-1185

Ocean currents magnify upwelling and deliver pelagic subsidies to reef-building corals during El Niño heatwaves

Fox, M.[1], Guillaume-Castel, R.[2], Edwards, C.[3], Glanz, J.[3], Gove, J.[4], Green, M.[2], Juhlin, E.[3], Smith, J.[3], Williams, G.[2]
[1]King Abdullah University of Science and Technology (KAUST), Red Sea Research Center, Thuwal, Saudi Arabia
[2]Bangor University, School of Ocean Sciences, Bangor, United Kingdom
[3]Scripps Institution of Oceanography, University of California San Diego, La Jolla, United States
[4]NOAA Pacific Islands Fisheries Science Center, Honolulu, United States

michael.fox[at]kaust.edu.sa

Abstract

Coral reefs are intricately linked to open-ocean processes that regulate their physical, chemical, and biological environments. Yet little is known about how marine heatwaves alter these processes and what the ecological consequences are. Heatwaves are devastating coral reefs globally, underscoring the need to identify mechanisms that facilitate coral survival and recovery. To this end, we integrated coral and macroalgal stable isotope data with sub-surface temperature measurements and 40-years of oceanographic data to demonstrate how ocean currents can amplify island-scale upwelling and bolster pelagic subsidies to a central Pacific coral reef during major El Niño associated heatwaves. We show that the 2015-2016 El Niño reduced surface ocean chl-a concentrations by 56%, compromising pelagic resource supply to coral reefs in the central Pacific. Despite regional declines in oceanic productivity, reef-building corals on Palmyra Atoll increased heterotrophy relative to non-El Nino years, enabled by upwelling enhancement more than 1000% above normal. This surge in upwelling coincided with the period of peak thermal stress and widespread bleaching on Palmyra. Increased velocity of the North Equatorial Countercurrent and pronounced shoaling of the mixed layer fueled this upwelling, and these same conditions also occurred during the 1982-1983 and 1997-1998 El Niños. Our findings reveal a recurrent suite of interconnected oceanographic processes that redistribute upwelling to off-equatorial reefs and provide valuable pelagic subsidies to reef organisms during major El Niños. Resolving ocean-reef connections that promote coral reef survival and recovery will illuminate new conservation strategies and improve projections of coral reef futures under climate change.

Oral
A-1410

Sea surface temperature variability between 2014-2019 in the Red Sea during the third massive coral-bleaching event based on in situ temperature data.

Palacios-Narvaez, S., Villalobos, R., **Kalampokis, A.**, Carvalho, S., Jones, B. H.
King Abdullah University for Science and Technology, Red Sea Research Center, Division of Biological and Environmental Science and Engineering, Thuwal, Saudi Arabia

stephania.palaciosnarvaez[at]kaust.edu.sa

Abstract

Coral reefs are among the most vulnerable ecosystems in the world, being highly influenced by both local pressures and global changes in ocean conditions. Small variations in temperature (1°C higher than average summer sea surface temperature (SST)) can stress corals, inducing the expelling of their intracellular symbiotic zooxanthellae causing coral bleaching. During 2015, 2016, and 2017 extreme atmospheric and oceanic temperatures were recorded, representing the highest annual globally averaged temperatures recorded since the 1800s. During this period, significant bleaching was observed in the Red Sea, similar to other tropical regions in the world. Although several studies have examined Red Sea sea surface temperature (SST) variability utilizing remotely sensed SST, relatively few long-term in situ temperature records exist. This study describes a continuous time series of near-surface (10 m) temperature variability at 16 reefs of the Red Sea between 2014 and 2019, spanning from 16 to nearly 28 ˚N, obtained at 30-minute intervals, and extending for up to 4 years. With these observations, time scales from hours to years can be examined, and the results compared with remotely sensed SST. The results indicate significant differences in the local temperature response from the magnitude of diel variations to distinct latitudinal differences in the seasonal patterns. This study highlights the importance of resolving ocean temperature at a range of temporal and spatial scales and incorporating both *in situ* and remotely sensed SST to better understand the effects of increased SST on coral reefs affected by strong temperature anomalies, such as those resulting from El Niño events.

Oral
A-1029

Offshore pelagic subsidies dominate carbon inputs to coral reef predators

Skinner, C.[1], Mill, A. C.[1], Fox, M. D.[2], Newman, S. P.[3], Zhu, Y.[1], Kuhl, A.[4], Polunin, N. V.[1]
[1]Newcastle University, Newcastle Upon Tyne, United Kingdom
[2]Woods Hole Oceanographic Institution, Woods Hole, United States
[3]Banyan Tree Marine Lab, Male, Maldives, [4]Bristol University, Bristol, United Kingdom

christina.skinner[at]live.com

Abstract

Coral reefs were traditionally perceived as productive hot spots in oligotrophic waters. While modern evidence indicates that many coral reef food webs are heavily subsidized by planktonic production, the pathways through which this occurs remain unresolved. We used the analytical power of carbon isotope analysis of essential amino acids to distinguish between alternative carbon pathways supporting four key reef predators across an oceanic atoll. This technique separates benthic versus planktonic inputs, further identifying two distinct planktonic pathways (nearshore reef-associated plankton and offshore pelagic plankton), and revealing that these reef predators are overwhelmingly sustained by offshore pelagic sources rather than by reef sources (including reef-associated plankton). Notably, pelagic reliance did not vary between species or reef habitats, emphasizing that allochthonous energetic subsidies may have system-wide importance. These results help explain how coral reefs maintain exceptional productivity in apparently nutrient-poor tropical settings, but also emphasize their susceptibility to future ocean productivity fluctuations.

Oral
A-1698

The interacting roles of mesoscale dynamics and internal waves in coral reef thermal refuges

Wyatt, A.[1], Leichter, J.[2], Toth, L.[3], Miyajima, T.[4], Aronson, R.[5], Nagata, T.[4]
[1]The Hong Kong University of Science and Technology, Department of Ocean Science, Kowloon, Hong Kong SAR China
[2]University of California San Diego, Scripps Institution of Oceanography, La Jolla, United States
[3]United States Geological Survey, St. Petersburg, United States
[4]The University of Tokyo, Atmosphere and Ocean Research Institute, Kashiwa, Japan
[5]Florida Institute of Technology, Department of Ocean Engineering and Marine Sciences, Melbourne, United States

wyatt[at]ust.hk

Abstract

Coral reefs are gravely threatened by global warming and increasingly frequent pan-tropical bleaching events. Widespread coral bleaching often coincides with El Niño events, with the 2015–2016 El Niño leading to some of the hottest sea-surface temperatures on record and widespread bleaching in shallow-water environments. Using in situ reef-level time series we will demonstrate an important disconnect between sea-surface and in situ conditions across depths over reef slopes due to internal-wave upwelling. Temperature fluctuations associated with internal waves reduced the duration and magnitude of thermal extremes during the peak of the 2015–2016 warm anomaly over reefs across the Pacific. In the presence of internal waves, cumulative heat exposure was reduced by up to 88 %. The durations of severe thermal anomalies above 8 °C-days were decreased by >36 % at some sites and were prevented entirely at others. Like internal waves, tropical storms often coincide with peak summer-time thermal anomalies and might protect reefs from more severe bleaching conditions by upwards mixing of cooler ocean layers. However, our data suggest that localised typhoon cooling over a few days may be short-lived relative to their capacity to prevent internal-wave propagation and cooling over several weeks due to the regional breakdown of stratification associated with the typhoon's passage. With the causes of spatial variation in coral bleaching poorly understood, it is important to understand how large-scale oceanographic processes influence local reef environments. Our continuous, in situ data allow us to demonstrate that, in the absence of mixing or thermocline depression, internal waves have the potential to create and support thermal refuges in which heat stress and coral bleaching risk may be modulated. However, internal waves may also exert strong influences on potential refuge habitats by altering nutrient concentrations, fluxes of organic particles, and exposure to low-oxygen and low-pH waters. Exploring shifts in community structure and function, including productivity and relative abundances of auto- and hetero-trophic organisms, in response to internal-wave exposure is an ongoing challenge. Internal waves may ultimately limit reef development in particularly dynamic locations with reef futures dependent on the response of internal-wave climates to continued warming and the strengthening of ocean stratification associated with climate change.

Poster
A-1418

Decomposed variability of sea surface heights around Palau: Seasonal variability, climate index correlation, and linear trend

Kim, S. Y.
Korea Advanced Institute of Science and Technology, Department of Mechanical Engineering, Deajeon, South Korea

syongkim[at]kaist.ac.kr

Abstract

The variability of sea surface height anomalies (SSHAs) at tide gauges and satellite altimetry around Palau and relevant outer circulations are investigated to understand long-term environmental physical pressure on the coral reefs. The SSHAs spatially averaged over the northwest and southeast areas of the Palau exhibit the intra-seasonal variability and their spatial difference show an increasing tendency, which indicates the enhanced geostrophic circulation across the island. The SSHAs are modeled as linear combinations of an annual cycle and its five harmonics, as well as three standard climate indices [El Nino-Southern Oscillation (ENSO), Pacific Decadal Oscillation (PDO), North Pacific Gyre Oscillation (NPGO)], and a mean and linear trend without time lags. The SSHAs at the Malakal Harbor are explained by signals related to seasonality and ENSO with approximately 40% variance of the total variance.

Session 9J - What do we know about cyclone impacts on reefs and how can it help target where to take conservation action?

Conceptualized by: **Marji Puotinen**[1], **Nicholas Wolff**[2], **Manuel Gonzalez Rivero**[3], **Joshua Madin**[4]
[1] Australian Institute of Marine Science (Crawley, Australia)
[2] The Nature Conservancy (Arlington County, VA, USA)
[3] Australian Institute of Marine Science (Townsville, Australia)
[4] University of Hawaii (Honolulu, HI, USA)

Chaired by: **Marji Puotinen**[1], **Manuel Gonzalez Rivero**[3], **Joshua Madin**[4]

Oral
A-1486

How well can we predict where cyclone waves harm and help coral reefs: now and in a warming climate?

Puotinen, M.
Australian Institute of Marine Science, Crawley, Australia

m.puotinen[at]aims.gov.au

Abstract

Most of the world's coral reefs are periodically exposed to heavy seas generated by tropical cyclones (hurricanes, typhoons) which can cause major structural damage to coral communities. Over time, these repeated impacts can play a key role in shaping coral reef and associated fish communities. However, cyclone wave exposure, when appropriately timed and located, can also help corals by lowering rising and/or high thermal stress enough to reduce or prevent coral bleaching. This happens when cyclone wave action causes upwelling of cooler waters to the surface if water depth is sufficient. While direct in situ observations of cyclone waves are rarely possible, reliable methods exist to spatially reconstruct both their likely damaging wave zones and their potentially beneficial 'cool wakes.' These can be used to build disturbance histories of cyclone impacts at reefs over the recent past, and with synthetic cyclone tracks from climate models, into the future. I will present examples of these datasets that range from relatively coarse to fairly detailed for a variety of regions and show how they have been (or are being) used in studies around Australia and beyond. Such datasets are key not only for untangling the mix of causes of coral loss at any given time in a reef system, but are also essential inputs into the spatial prioritisation of conservation action. Using some of these data, I will demonstrate that spatial variability in both damage and cooling is high, and how failing to consider this variability in models introduces considerable uncertainty. Equally important is that the key characteristics of cyclones that drive their ability to generate damaging wave climates (intensity, duration, translation speed) are changing as the climate warms, yet considerable uncertainty remains in predictions of this. While most experts agree that more of the cyclones that form will reach higher intensities, they also find that less cyclones will form overall. Some empirical evidence from the North Atlantic suggests cyclones are slowing down, but little is known about how their sizes and track locations will change. Using data from a suite of climate models for Australia, I'll show how this uncertainty has major consequences for how well we can predict future cyclone impacts at the scale of individual coral reefs and reef regions.

Session 9K - Beyond single-species experiments: how do marine populations, communities, and ecosystems respond to global change? / How do organismal responses scale to ecosystem processes?

Conceptualized by: **Kristen Brown** [1], **Tyler Cyronak**[2], **Keisha Bahr**[3], **Nyssa Silbiger** [4], **Steve Doo** [4], **Robert Nowicki**[5]
[1] University of Queensland (Brisbane, Australia)
[2] Nova Southeastern University (Dania Beach, FL, USA)
[3] Hawaii Institute of Marine Biology (Kaneohe, HI, USA)
[4] California State University, Northridge (Northridge, CA, USA)
[5] Mote Marine Laboratory (Summerland Key, FL, USA)

Chaired by: **Nyssa Silbiger** [4], **Steve Doo** [4]

Oral
A-1307

Modelling and Mapping Local-to-Regional Scale Coral Reef Health and Resilience in the South Pacific

Bakker, A.[1], Purkis, S.[1], Gleason, A.[2], Dempsey, A.[3], Faisal, M.[4]
[1]University of Miami - RSMAS, Marine Geosciences, Miami, United States
[2]University of Miami, Department of Physics, Miami, United States
[3]Khaled bin Sultan Living Oceans Foundation, Annapolis, United States
[4]Michigan State University, Department of Fisheries and Wildlife, East Lansing, United States

annabakker[at]rsmas.miami.edu

Abstract

Millions of people rely on healthy coral reef ecosystems for sustenance, storm protection, and economic opportunity. However, increasing intensity of climate-driven stressors, coupled with wayward resource management, is conspiring to stimulate coral reef mortality episodes at an unprecedented rate. Grounded in intensive field surveys and remote sensing, we have developed a spatial model to map the local-to-regional scale impacts on coral reefs across the breadth of Palau, the Solomon Islands, New Caledonia, Fiji, Tonga, the Cook Islands, and French Polynesia – reefs which, in aggregate, compose a sufficiently large bioregion of the South Pacific to be subject to pronounced gradients in both environmental and anthropogenic stress. Using predictive modelling for 27 biophysical and anthropogenic remote sensing data and 650 field surveys, each conducted at five fixed depths, we created continuous spatial layers for coral cover and diversity, reef fish biomass, and macroalgae cover across the South Pacific region. These data layers were then correlated using random forests to model site-specific statistics to assess coral reef health. Using this workflow, spatial maps of coral reef health and resilience could be produced to predict and quantify ecological response to natural and anthropogenic disturbance. The correlations generated from this model allowed us to evaluate the relative importance of our broad portfolio of variables when examining combinations of the biophysical and anthropogenic stressors that mediate reef health across scale. Whereas a selection of key variables held meaningful predictive power at all spatial scales, the optimum combination systematically varied from local to regional scale, emphasizing the complex interplay between anthropogenic and natural gradients. We hope that our techniques and results developed through this Pacific-wide study will lead to improved conservation outcomes, including more effective multi-nation reserve network planning.

Oral
A-1614

Assembling a comprehensive coral reef food web to model trophic interactions in a changing world

Casey, J. M.[1], Parravicini, V.[2]
[1]The University of Texas Marine Science Institute, Port Aransas, United States
[2]Ecole Pratique des Hautes Etudes, CRIOBE, Perpignan, France

jcasey508[at]gmail.com

Abstract

Reef degradation threatens the ecosystem services that reefs provide to humans; however, the repercussions of anthropogenic stressors on trophic interactions throughout a coral reef ecosystem remain unclear. Defining trophic relationships among species is essential to understand the potential of the system to buffer external perturbations and to maintain the flow of energy and nutrients through coral reef communities. Yet, current trophic categorizations and food web models on coral reefs are limited by poor data resolution and insufficient to make reliable projections of food web structure under climate change scenarios. Here, we present the highest resolution food web ever assembled for a coral reef ecosystem utilizing next-generation sequencing data of fish gut contents and stable isotope analysis of over 250 fish species on coral reefs around Mo’orea, French Polynesia. Mapping trophic interactions with fish gut content metabarcoding permits the reconstruction of a complex trophic network, and niche-based modelling reveals fine-scale partitioning among species, emphasizing the importance of examining fish diet beyond broad trophic categories. We use this data alongside fish and coral community data to make projections about the long-term resilience of food webs under climate change scenarios. This research offers a unique opportunity to couple molecular data with future projections to quantify the role of natural and anthropogenic disturbances on a coral reef ecosystem.

Oral
A-2041

Temporal scaling of coral reef community metabolism under ocean acidification scenarios

Doo, S. S.[1], Edmunds, P.[2], Carpenter, R.[2]
[1]King Abdullah University of Science and Technology, Physical Sciences and Engineering, Thuwal, Saudi Arabia
[2]California State University, Northridge, Biology, Northridge, United States

stevedoo[at]gmail.com

Abstract

Understanding how tropical coral reef communities will be altered by ocean acidification (OA) has been difficult due to logistical constraints associated with scaling laboratory experiments from weeks-months to ecologically relevant time scales greater than a few months. As a result, evaluating how processes such as ecological interactions among species, the effects of organism acclimatization to changing CO_2 conditions, or the capacity of communities to tolerate these conditions through changes in community structure is unclear. Here, we present data from a fore reef coral community in Mo'orea, French Polynesia, that were established in three large (5.0 x 0.3 m) flumes and incubated under contrasting CO_2 conditions (ambient ~380 µatm, ~730 µatm, and ~1310 µatm) for a year. Daytime net community calcification (NCC) was depressed by 54% in the 730 µatm treatment, and by 95% in the 1310 µatm treatment compared to ambient conditions. Relative to ambient conditions, a significant depression resulting in a shift to dissolution was observed in night-time NCC in the 730 µatm treatment (150% decrease), and 1310 µatm treatment (272% decrease). There was a 27% decrease in net community production (NCP) at all elevated CO_2 treatments compared to the ambient pCO_2, and respiration was reduced by 31% in all elevated CO_2 treatments. The slope of the association between NCP and NCC did not vary among CO_2 treatments, but the relationships were reduced in elevation by 65% in the 730 µatm treatment, and 121% in the 1310 µatm treatment. The reduction in elevation of the NCP-NCC relationship suggests dissolution is the primary cause of decrease in NCC documented. Overall, our results suggests that temporal effects of year-long exposure to elevated CO_2 is primarily driven by feedback interactions between inorganic and organic carbon cycling, further highlighting the need to elucidate interactions between living coral reef biota and carbonate substrata in projected elevated pCO_2 conditions.

Oral
A-1432

Effects of ocean acidification on bleaching, survival, and calcification of Porites porites and P. astreoides near Cartagena, Colombia

Gonzalez, R.[1], **Barrios, L. M.**[2], Navas-S, G. R.[1]
[1]Universidad de Cartagena, Programa de Biologia, Campus San Pablo, Zaragocilla, Cartagena de Indias, Colombia
[2]The University of Plymouth, Biological and Marine Sciences, Plymouth, United Kingdom

linambarrios[at]hotmail.com

Abstract

CO_2 emissions into the atmosphere have promoted the absorption rate by the ocean, lowering the pH and causing its acidification. This change in pH affects all marine biota, particularly reef-building corals. Estimations of the ocean acidification-OA effects on marine environments indicate that coral reef structures will collapse, so it is important to establish mitigation strategies based on the most probable effects of pH reduction on corals. This study aimed to determine the effects of OA and its associated carbon chemistry on corals near the Colombian Caribbean city of Cartagena, taking as model organisms the species *Porites astreoides* and *P. porites*. For each species, OA effects on bleaching, survival, and calcification were determined using artificial systems with concentrations of 700 ± 50 ppm pCO_2 (pH 7.879 ± 0.004) and 950 ± 50 ppm pCO_2 (pH 7.789 ± 0.007). The results showed that under concentrations of 700 ± 50 ppm, bleaching in *P*. *astreoides* increased to 57.88% and its survival decreased by 80.56%, while at 950 ± 50 ppm, bleaching increased to 65.74% and survival decreased by 87.5%. In the case of *P*. *porites*, at 700 ± 50 ppm, bleaching increased to 63.86% and survival decreased by 30.56% and at 950 ± 50 ppm, bleaching increased to 71.76% and survival decreased by 13.39%. In both species, calcification was reduced by more than 90% at 700 ppm pCO_2 and their skeletons began to dissolve at 950 ppm pCO_2. This study represents the first effort to determine OA effects on Colombian Caribbean's marine biota.

Oral
A-1462

Influence of submarine groundwater discharge on the physiology, community composition and microbial diversity of early successional reef communities

Jorissen, H.[1], Zeff, M.[2], Barnas, D.[2], Kerlin, J. R.[2], McClintock, R.[3], Donahue, M. J.[3], Nelson, C. E.[3], Silbiger, N.[2]
[1]University of Hawaii, Center for Microbial Oceanography: Research and Education (C-MORE), Honolulu, United States
[2]California State University Northridge, Northridge, United States
[3]University of Hawaii, Honolulu, United States

hendrikjejorissen[at]gmail.com

Abstract

Submarine groundwater discharge (SGD) is a natural feature of coral reef ecosystems and a dynamic source of nutrients and fresh water to these systems. The nearshore biogeochemistry varies both temporally and spatially as a result of SGD, depending on the location of SGD seeps and the equilibrium between sea level and hydraulic head in the aquifer. The biogeochemistry of SGD typically reflects higher nutrients, cooler temperature, and lower salinity than receiving waters, and SGD can be a conduit for anthropogenic nutrients. These differences in biogeochemistry have implications for local species composition, organismal physiology, the associated microbial community and, ultimately, ecosystem functioning. Here, we investigate how the local environmental context of SGD affects ecological processes on tropical nearshore coral reefs. Along well-characterized biogeochemical gradients at two SGD-influenced nearshore reef sites on Mo'orea (French Polynesia), we examined early successional benthic community composition, microbial diversity, and community metabolism. We estimate the relative importance of community composition and water chemistry in determining the net community production and community respiration. Preliminary analyses indicate that SGD gradients influence algal and microbial early successional dynamics that translate to differential benthic metabolism. This advances our understanding of the mechanisms by which SGD affects ecosystem functioning and future coral reef management.

Oral
A-1475

Effects of submarine groundwater discharge and coral-coral interactions on common coral species, Porites rus

Kerlin, J., Barnas, D., Silbiger, N.
California State University, Northridge, Biology Department, Northridge, CA, United States

jamie.kerlin.481[at]my.csun.edu

Abstract

The maintenance of healthy coral reefs is dependent on the growth and physiological responses of corals to abiotic and biotic factors on the reef. Submarine groundwater discharge (SGD) is the flow of freshwater from land, through the marginal seabed, and onto the reef. SGD can affect corals by altering the biogeochemical properties of the water (increased nutrients, lower salinity, lower temperature). Additionally, corals are also affected by biotic interactions, such as competition with other coral colonies. The ecological effects of SGD are not yet well-studied, and this study tests the interactive ecological effects of SGD and competition on coral growth rate, metabolism, and endosymbiont physiology. Four coral-coral competition treatments (no competition, space control, intraspecific competition, and interspecific competition) were deployed at twenty locations along a gradient of SGD for two weeks. We measured growth, net photosynthetic, and respiration rates as well as symbiont counts and chlorophyll content of *Porites rus* before and after deployment. Photosynthesis and respiration rates both showed a significant positive linear relationship with silicate concentration, a commonly used proxy for SGD. However, we saw a weak effect of competition on coral growth or metabolism, indicating that the abiotic effect of SGD may outweigh biotic factors at this site and on short timescales. This experiment was conducted during the dry season, when SGD fluxes are minimal, indicating the possibility of an even stronger effect of SGD on corals during the rainy season. As coral metabolism changes along an SGD gradient, there will likely be cascading effects onto the community, such as further shifts in biogeochemistry, changes to the community composition, and altered species diversity.

9K - Beyond single-species experiments: how do marine populations, communities, and ecosystems respond to global change? / How do organismal responses scale to ecosystem processes?

Oral
A-1121

Collapse and early recovery of reef community structure and carbonate production following mass coral bleaching in the Chagos Archipelago

Lange, I. D.[1], Perry, C. T.[1], Stuhr, M.[2]
[1]University of Exeter, Geography, Exeter, United Kingdom
[2]Leibniz Centre for Tropical Marine Research, Bremen, Germany

i.lange[at]exeter.ac.uk

Abstract

Coral reefs in the remote Chagos Archipelago (central Indian Ocean) were severely affected by the global coral bleaching event in 2015/2016. Mass coral mortality and changes in community composition can diminish the important geo-ecological functions reefs provide, including habitat provision and reef accretion. Net reef carbonate budgets, the balance between carbonate production and erosion processes, are thus important functional indicators of reef health. We quantified changes in coral community composition and population size structures following the bleaching event, and the resultant impacts on reef carbonate budget trajectories. *ReefBudget* surveys were conducted at 12 sites across three atolls in 2015, 2018 and 2021, with calculations of biological carbonate production and erosion supported by locally obtained calcification and bioerosion rates. Mass coral mortality in 2015/2016 caused a 69% decline in coral cover, mostly driven by mortality of tabular *Acropora* spp. As a result, carbonate budgets (in G = kg $CaCO_3$ m^{-2} yr^{-1}) shifted from net positive states in 2015 (mean±SE: 3.7±0.8 G) to net negative states in 2018 (-2.4±0.4 G). By 2021, all sites were on a trajectory of recovery, but net budgets differed significantly between atolls (-2.0±0.8 to 2.2±0.7 G). At Salomon atoll, the 3-fold faster recovery of carbonate production and return to positive reef budget states only six years post-bleaching was associated with the persistence of high structural complexity and the rapid recovery of fast growing *Acropora* spp. Inter-atoll differences in colony size distributions furthermore illustrate that coral identity and size class are more important predictors of reef functions and post-disturbance recovery speed than coral cover alone.

Oral
A-1169

Effect of wastewater and water quality changes on the functional structure of reef fish assemblages: a systematic review and meta-analysis

Plazas Gomez, R. A., Fujitani, M.
Leibniz Zentrum für Marine Tropenforschung, Bremen, Germany

rapblue8[at]gmail.com

Abstract

Wastewater and its effects on coral reef ecosystems have concerned the world for decades. Currently, more than one-quarter of the coral reefs in the world are threatened by sewage inputs. For instance, highly disturbed areas present a decrease in the abundance and richness of corals and reef fish, followed by a phase shift from coral to algae cover. However, the ecosystem's responses to low disturbances might be hard to assess or detect in time. In fact, traditional methods such as the taxonomy-based indices, ignore the biological and functional differences of species and assume that they have nothing in common. Conversely, the functional approach has proven to be more sensitive and provide further information on disturbances because it includes the species traits in the analysis. Traits are any biological, physiological, or phenological attributes measured on an individual that affects its performance and fitness. Despite the advantages of functional ecology, there are just a few studies using this approach in the marine environment, and even less address the issue of wastewater pollution.

We conducted a systematic literature review on the direct impact of wastewater and water quality changes on reef fishes. We included published manuscripts in English between 1980 and 2021. The studies were selected based on two main criteria: i) the study shows the effect of urban wastewater or water quality changes on at least one reef-fish trait, and ii) the paper provides fish abundances in polluted versus control scenarios or water quality gradients. As a result, 53 studies from 20 different countries were included in the analysis. A total of 474 species from 75 families were reported. Here, we summarize the traits affected by wastewater disturbances in each area and analyze the patterns and similarities between each scenario. Herbivore fish and big predators were among the most affected traits by pollution. Additionally, we performed a meta-analysis to compare relative fish abundances between disturbed and control areas and assess wastewater pollution on the functional structure of the reef-fish assemblages. Moreover, we discuss the differences observed between natural and anthropogenic disturbances and compare the sensitivity of the functional approach with the methods used in the original papers. Finally, we highlight the advantages of a functional trait-based approach and its use across broad geographic scales.

Oral
A-2231

Coral reef monitoring, management and restoration: unless both sides of the carbonate budget are understood, we fly (dive) blind and risk failure

Schönberg, C.[1], Tribollet, A.[2], Wisshak, M.[3], Carreiro-Silva, M.[4], Hei Fang, J. K.[5]
[1]University of Western Australia, Crawley, Australia
[2]Institut de Recherche pour le Développement, Paris Cedex, France
[3]Senckenberg am Meer, Wilhelmshaven, Germany
[4]University of the Azores, Horta, Portugal
[5]The Hong Kong Polytechnic University, Hong Kong, Hong Kong SAR China

christine.schonberg[at]uwa.edu.au

Abstract

It is well established that existing local and global pressures have a devastating effect on coral reef health. Predominant environmental drivers affect the entire ecosystem, often leading to phase shifts and an increasingly negative carbonate budget. This suggests that we need to know about the biology, chemistry and geology of erosive processes - generally consequences of such shifts. A large part of reef erosion is generated via bioerosion, which has repeatedly been shown to intensify proportionally with environmental deterioration, at least mid-term. Funding and science effort, however, are often strongly biased towards calcifiers. Many aspects of bioerosion thus remain superficially understood or inexpertly studied. This often prevents pattern recognition, comparison between studies, representative quantification of bioerosion, generalisation and modelling, thereby limiting our knowledge of future conditions and improved strategies for reef management. Hence, this talk will summarize our knowledge on drivers of bioerosion, will reveal gaps and will identify format and procedural problems in bioerosion research.
Moving beyond the problems that cause the perceived science imbalance will include
1. the use of uniform units and standardized approaches - for better comparability,
2. synergistic science approaches in collaboration with expert taxonomists - accumulating data concerning recognizable biota,
3. developing research across a wider taxon range and including multiple factors - allowing wider generalization and therecognition of interaction and cascade effects,
4. using approaches more relevant to natural conditions and testing laboratory results in nature - to create more realistic data,
and
5. quantifying dominant bioeroders in monitoring projects - generating spatio-temporal data sets that will allow future projections.

Oral
A-2082

Phylogeny-informed analysis of coral-Symbiodiniaceae interaction networks to assess bleaching-susceptibility and symbiont thermotolerance

Swain, T.[1], Lax, S.[2], Gilbert, J.[3], Backman, V.[4], Marcelino, L.[5, 6]
[1]Nova Southeastern University, Marine and Environmental Science, Dania Beach, Florida, United States
[2]Massachusetts Institute of Technology, Department of Physics, Cambridge, Massachusetts, United States
[3]University of California San Diego, Scripps Institution of Oceanography, La Jolla, California, United States
[4]Northwestern University, Department of Biomedical Engineering, Evanston, Illinois, United States
[5]Northwestern University, Department of Civil and Environmental Engineering, Evanston, Illinois, United States
[6]Field Museum of Natural History, Integrative Research Center, Chicago, Illinois, United States

tswain[at]fieldmuseum.org

Abstract

Our understanding of coral species susceptibility to ocean heating, and its relationship to their species traits and the physiological capabilities of their associated Symbiodiniaceae, is based on observations or experiments involving few species of either partner. While these data are invaluable in their own right and form the basis of all current knowledge, they can also critically inform broader scale analyses that integrate multiple lines of evidence including (but not limited to) coral and Symbiodiniaceae species traits (e.g. physiology, ecology, symbiosis biology, biogeography, stress-susceptibility, etc.), the potential for and frequency of their symbiotic interactions, and the evolutionary relationships among species. If the goal is to include all available species to generate the broadest analysis possible given the current state of knowledge, then these higher-level meta-analyses require the compilation and standardization of disparate datasets spanning decades of research. Here we present a phylogeny-corrected meta-analysis of 152 coral species (18% of extant reef corals) and their associated 385 Symbiodiniaceae ITS2-phylotypes, representing 1,283 unique interactions compiled from 15,915 relationship observations, to assess broad-scale patterns in the relationship between Symbiodiniaceae thermotolerance and coral bleaching susceptibility. We concentrated on a subset of all available data that we interpret as currently the greatest in scope and the most data rich (i.e., Symbiodiniaceae ITS2-phylotypes), however new data are added to this field at a rapid pace and this analysis should be viewed as both an assessment of previously undetectable patterns in the available data and as a summary of current data that serves as a roadmap for further data collection and knowledge expansion.

9K - Beyond single-species experiments: how do marine populations, communities, and ecosystems respond to global change? / How do organismal responses scale to ecosystem processes?

Poster
A-1848

Impacts of the 2014-2017 global bleaching event on Aldabra Atoll, a remote UNESCO World Heritage Site in the Western Indian Ocean

Cerutti, J. M. B.[1], Burt, A. J.[2, 3], Haupt, P.[4], Bunbury, N.[3, 5], Mumby, P. J.[6], Schaepman-Strub, G.[7]
[1]Inter-University for Marine Sciences, Eilat, Israel
[2]University of Oxford, Department of Plant Sciences, Oxford, United Kingdom
[3]Seychelles Islands Foundation, Mahé, Seychelles
[4]Rhodes University, Department of Ichthyology and Fisheries Science, Grahamstown, South Africa
[5]University of Exeter, Penryn, United Kingdom
[6]University of Queensland, Brisbane, Australia
[7]University of Zürich, Zürich, Switzerland

juliamb.cerutti[at]gmail.com

Abstract

Caused by prolonged elevated sea surface temperatures, the 2014-2017 global bleaching event heavily impacted coral reefs worldwide. This study determines changes in benthic community following this bleaching event at a UNESCO World Heritage Site in the Western Indian Ocean. Remote and protected, Aldabra Atoll offers an important baseline to study ongoing ecological processes and long-term impacts of climate change disentangled from local anthropogenic stressors. Satellite-derived and in situ sea surface temperature data indicated Aldabra was exposed to a bleaching-risk close to the 4°C-week threshold from December 2015 to June 2016. Benthic cover was established pre- and post-bleaching from 21 transects across two reef locations (lagoonal reef, 2 m depth; seaward reef, 5 and 15 m depth). From a pre-bleaching benthic community in which living corals and epilithic algal matrix (EAM) predominated, Aldabra's reefs switched to an EAM-dominated community 8 months after bleaching. Soft corals declined by 93% of their overall pre-bleaching cover to <1%. Although overall hard-coral cover was also reduced, the decline varied among depths and might indicate local adaptations of the lagoonal reef, due to greater variability in sea surface temperature compared to the seaward reef. With the exception of Isopora palifera, all taxomorphic coral groups experienced a decline following bleaching. Overall, Rhytisma experienced a near-complete extirpation, Acroporids (excluding I. palifera) and branching Poritids declined by more than 80%, Merulinidae lost ca. 60% of their pre-bleaching cover, while massive Poritids cover slightly decreased. Aldabra's benthic community therefore underwent substantial changes following the 2014–2017 bleaching event and showed that protected areas isolated from local anthropogenic pressures are not immune to global change impacts. Given the increasing frequency of mass coral bleaching events, this study suggests further loss of hard and soft corals, with some species unlikely to be able to recover over the shortening intervals between major episodes of coral loss, and thereby a compromised future for the marine status of this regional and global benchmark site.

Poster
A-1068

Net calcification rate by secondary calcifiers in coral reefs: seasonal variation and thermal stress during 2014-2016 ENSO event.

Orrante-Alcaraz, J. M.[1], Carballo, J. L.[2], Yáñez, B.[2]
[1]Posgrado en Ciencias del Mar y Limnología. Instituto de Ciencias del Mar y Limnología. Universidad Nacional Autónoma de México, Laboratorio de ecología del bentos, Mazatlán, Mexico
[2]Instituto de Ciencias del Mar y Limnología, Universidad Nacional Autónoma de México, Laboratorio de ecología del bentos, Mazatlán, Mexico

jessica.orrante25[at]gmail.com

Abstract

Coral reefs across the world have been seriously degraded and currently face an uncertain future in response to predicted global warming and ocean acidification. Secondary calcifiers (i.e., calcareous algae [CCA], bryozoans, mollusks, etc.) through biocalcification contribute to store carbon, to reinforce coral structures, to stabilize the substrate, and allow other organisms to settle. These organisms are part integral of the structural complexity and long-term persistence of coral reefs, yet their study has received less research attention than the own corals reef. Therefore, it is necessary to know the contribution and spatiotemporal variation of calcifiers. In this work, seasonal calcification and coverage of secondary calcifiers were determined in two coralline ecosystems (LM and BT) by Calcification Accretion Units since 2014 to 2016. The calcification (average± SD g $CaCO_3$ m^{-2} day^{-1}) was 1.17±1.13; the means ranged from 0.65 in rainy season in BT-15 to 2.50 y rainy season in LM-14. Overall, calcification was similar in both seasons, however in BT (1.02±1.01 [dry] and 0.65±0.37 [rainy]) and exposed microhabitats (0.77±0.62 [dry] and 0.35±0.35 [rainy]) seasonally differences were significant. Coverage (%) showed a seasonal pattern (dry>rainy) but the analyses were not consistent. Seasonality in BT was mainly attributed to high sedimentation and grazing during rainy season that affected the calcifiers of BT (CCA). CCA dominated in both reefs, whereas bryozoans also dominated in LM. Calcification in LM (1.51) was almost double that in BT (0.83). Both calcification and coverage decreased from 2014 (1.57 and 74%) to 2016 (0.99 and 62 %), while the dominant calcifiers group not changed. These decreases were related to the ENSO in 2015-2016 that increased the temperature by almost 1°C above the decadal average, which led to a mass coral bleaching. The extreme temperatures recorded in 2015-2016 probably have masked a clearer seasonal pattern in carbonate production; and anomalous and persistent high seawater temperatures affect net carbonate production by secondary calcifiers.
Our results highlight the need to study the effects of climate stressors on both primary and secondary calcifiers. More studies are necessary in order to be able to evaluate with greater certainty the physical, chemical, and biological conditions that will prevail in coral reefs in the coming years.

Virtual
Oral
A-2086

The effect of zoanthid competition on branching hydrocorals under ocean warming

Vieira, E., Lonzetti, B., Longo, G.
Federal University of Rio Grande do Norte, Dept. Oceanography and Limnology, Natal, Brazil

edsonvfmar[at]gmail.com

Abstract

The role of algae in competitive interactions with corals are widely known, placing them as one of the major threats to coral health and survival. However, invertebrates may also impose risks to corals. Zoanthids, for instance, cover large areas and are commonly seen competing with corals in Brazilian tropical reefs in Southwestern Atlantic. This is concerning for Brazilian reefs given the aggressive overgrowth of corals by zoanthids and that many of the interactions are with branching hydrocorals, one of the few organisms that contributes to reef structural complexity in Brazil. Given that zoanthids are expected to endure warming and persist throughout the Atlantic, and that ocean warming can affect the outcomes of competition by changing organisms' competitive ability and recovery capacity, the threat of zoanthid competition to corals is expected to increase in a close future. We experimentally investigated the competitive interaction between the zoanthid Palythoa caribaeorum and the branching hydrocoral Millepora alcicornis through field and laboratory experiments in a tropical site in Brazil. We addressed I) the response of M. alcicornis upon contact with P. caribaeorum; II) the hydrocoral recovery after contact removal; III) whether this interaction is chemically mediated; and IV) how ocean warming (27 °C vs. 30 °C) can affect the outcome and recovery from this interaction. We assessed the competitive outcome by estimating the contacted area and color on hydrocoral fragments and found that P. caribaeorum caused more damage to M. alcicornis than its control in the field and lab at 27 °C, with M. alcicornis recovering after the competitive interaction ceased. Under the warming simulation in the laboratory, both P. caribaeorum and control damaged M. alcicornis, but filamentous algae colonized the area of M. alcicornis contacted by P. caribaeorum, jeopardizing the hydrocoral recovery. Contact with P. caribaeorum chemical extract caused more damage on M. alcicornis than the control under current temperature but not under the warming simulation, when any contact was harmful to the hydrocoral. These results highlight that warming increased M. alcicornis susceptibility to any physical contact and reduced its recovery potential, indicating that it may be outcompeted and overgrown by P. caribaeorum as ocean warms, resulting in reef flattening and consequently diversity loss.

Session 10A - Open Session: Organismal physiology, adaptation and acclimation

Conceptualized by: **Jasper de Goeij**[1], **Verena Schoepf** [2], **Manuel Aranda Lastra** [3], **Ulisse Cardini**[4], **Adriana Verges** [5]
[1] University of Amsterdam (Amsterdam, The Netherlands)
[2] University of Western Australia (Perth, Australia)
[3] KAUST (Thuwal, Saudi Arabia)
[4] Stazione Zoologica Anton Dohrn (Napoli, Italy)
[5] University of New South Wales (Kensington, Australia)

Chaired by: **Jasper de Goeij**[1], **Verena Schoepf** [2], **Manuel Aranda Lastra** [3]

Oral
A-1124

The Internal Microenvironment of the Symbiotic Jellyfish Cassiopea sp. From the Red Sea

Arossa, S., Barozzi, A., Callegari, M., Klein, S. G., Parry, A. J., Hung, S.-H., Steckbauer, A., Aranda, M., Daffonchio, D., Duarte, C. M.
King Abdullah University of Science and Technology, Thuwal, Saudi Arabia, (silvia.arossa[at]kaust.edu.sa)

Abstract
The characterization of the internal microenvironment of symbiotic marine invertebrates is essential for a better understanding of the symbiosis dynamics. Microalgal symbionts (of the family: Symbiodiniaceae) influence diel fluctuations of in host O2 and pH conditions through their metabolic activities (i.e., photosynthesis and respiration). These variations may play an important role in driving oxygen budgets and energy demands of the holobiont and its responses to climate change. In situ measurements using microsensors were used to resolve the O2 and pH diel fluctuations in the oral arms of non-calcifying cnidarian model species Cassiopea sp. (the “upside-down jellyfish”), which has an obligatory association with Symbiodiniaceae. Before sunrise, the internal O2 and pH levels were substantially lower than those in ambient seawater conditions (minimum average levels: 61.92 ± 5.06 1SE μmol O2 L–1 and 7.93 ± 0.02 1SE pH units, respectively), indicating that conditions within Cassiopea’s oral arms were acidified and hypoxic relative to the surrounding seawater. Measurements performed during the afternoon revealed hyperoxia (maximum average levels: 546.22 ± 16.45 1SE μmol O2 L–1) and internal pH similar to ambient levels (8.61 ± 0.02 1SE pH units). The calculated gross photosynthetic rates of Cassiopea sp. were 0.04 ± 0.013 1SE nmol cm–2 s–1 in individuals collected at night and 0.08 ± 0.02 1SE nmol cm–2 s–1 in individuals collected during the afternoon.

Oral
A-1146

The effects of marine heatwaves on the physiology of a coral reef snapper

McMahon, S.[1, 2], Munday, P.[2], Ravasi, T.[1], Donelson, J.[2]
[1]Okinawa Institute of Science and Technology, Onna-son, Japan
[2]James Cook University, Townsville, Australia

shannon.mcmahon[at]jcu.edu.au

Abstract

The increasing frequency and intensity of marine heatwaves (MHWs) pose a significant threat to marine organisms, especially those evolved to live in relatively stable thermal environments, such as coral reefs. However, while there is extensive research into how MHWs cause mass coral bleaching and mortality, there is little known about how MWHs directly affect fishes living on coral reefs. In this study we investigated how MWH conditions affect whole-organism physiological traits and associated biochemical markers in the blood of a coral reef mesopredator, *Lutjanus carponotatus*. Specifically, we exposed mature adults to two different MWH intensities, +1°C (29.5°C) and +2°C (30.5°C), and tested how their physiological performance was effected at two and four weeks exposure, and then at two weeks post-exposure. We found that MWH conditions had a direct physiological costs on adult coral reef snapper with elevated metabolic rates, blood lactate, hemoglobin, and also increased time to recover from capture stress. Interesting, we also found that while individuals mostly recovered at 2 weeks post-exposure there was evidence of ecologically relevant residual effects. These findings provide new insight into the effects of MWHs on the physiological performance of coral reef fishes. By expanding out understand of how coral reef mesopredators fare under MHW conditions we can hope to better manage these important and valuable populations.

Oral
A-1217

Regeneration variability in Ricordea florida

Millar, Z., Kecheliev, D., Horricks, R., Lumsden, J.
University of Guelph, Pathobiology, Guelph, Canada

zmillar[at]uoguelph.ca

Abstract

Ricordea florida is a tropical species of corallimorpharian coral popular in the saltwater aquarium industry. It is frequently propagated via fragmentation to enhance rates of asexual reproduction, however, thousands of individuals are still collected in the wild. Better understanding coral regenerative abilities will help refine aquaculture methods for coral propagation and reduce the need for wild-capture. Multiple experiments were performed in which *R. florida* were fragmented through the mouth in the oral disc and the foot, creating two identical halves. These halves were used for tandem mass tag mass spectrometry-based proteomic analysis. In the first experiment, samples were taken immediately post-fragmentation at 6, 12, 24, and 48 h, as well as 4 and 14 d and used to identify differentially abundant (DA) proteins during the regeneration process. PEAKS Xpro was used for protein quantification and over 100 DA proteins at various timepoints were identified. Of these, the second greatest increase in protein abundance was observed in cytochrome c, a known trigger of cell death. During this experiment and subsequently, a dramatic range in time for polyps to complete regeneration was observed; requiring 4 to 24 d. To understand the proteomic basis for this variability, fast and slow-regenerating corals were compared in a second experiment. After fragmentation, the first three corals that had regenerated were collected as well as the three corals that had least progressed towards regeneration. Additional samples were collected once two thirds of the experimental population had completed regeneration. The final sampling timepoint was when only three polyps remained that had not completed regeneration. Samples were then processed in a similar fashion to those in the first experiment. Initial proteomics analysis on the second experiment has identified a total of 3366 proteins using the National Center for Biotechnology Information Cnidarian protein database. In total, 218 proteins were DA (2% false discovery rate) between all groups. Comparisons between the initial regeneration timeline (experiment 1) and those that are fast and slow at regeneration (experiment 2) will be made upon completion of analysis.

Oral
A-1516

Standardized thermal performance curves as a tool to investigate the thermal threshold of corals in the central Red Sea

Osman, E. O.[1], Low-Decarie, E.[2], Santoro, E. P.[1], Garcias-Bonet, N.[1], Aranda, M.[1], Smith, D. J.[2], Voolstra, C. R.[3], Peixoto, R.[1]
[1]King Abdullah University of Science and Technology (KAUST), Red Sea Research Center (RSRC), Thuwal, Saudi Arabia
[2]University of Essex, Coral Reef Research Unit, School of Biological Sciences, Colchester, United Kingdom
[3]University of Konstanz, Department of Biology, Constance, Germany

eom.osman[at]gmail.com

Abstract

Coral bleaching has become a widespread phenomenon due to high intensity and frequency of marine heatwaves during the last couple of decades. The actual temperature (i.e., thermal threshold) that triggers the breakdown of the symbiosis between the coral host and their associated endosymbiont is key to explore the capacity of corals to tolerate accumulative heat stress. Here, we propose to employ Photosynthesis:Respiration ratios (P:R) as a standardized proxy to assess the thermal threshold of corals, considering that this threshold would be achieved when P:R ratio equals 1. To test this hypothesis, we determined thermal performance curves on two coral species, *Pocillopora verrucosa* and *Acropora humilis*, collected from the central Red Sea. Corals were exposed to 9 light/dark cycles (15hrs), each cycle at different heat stress regimes, in order to evaluate the P:R ratio over the temperature profile (27-35°C). Further, we compared our results with those obtained from the use of Coral Bleaching Automated Stress System (CBASS), to assess the consistency of the results. Our data showed a linear decline of P:R in *P. verrucosa* and *A. humilis* that reached the hypothesized thermal threshold (P:R=1) at 33.7 and 34°C, respectively. Further, there was a significant decline in the photobiological traits (F*v*/F*m* and rETR) in both coral species at end of heat stress (i.e., 35°C). CBASS results provided an ED50 thermal threshold, i.e. the temperature at which one can observe a 50% decline in F*v*/F*m,* at 35.7 and 37.4°C for *P. verrucosa* and *A. humilis*, respectively. P:R ratio results using thermal performance curves were aligned with bleaching field observations and remote sensing data that showed bleaching when summer temperature exceeds ca. 33°C for a prolonged period in the central Red Sea. These results suggest that our proposed proxy and experimental setup was successful to estimate the temperature that caused the breakdown of coral symbiosis, while also evaluating their thermal resistance (using CBASS). Ongoing analysis on repeated P:R experiments are being performed for the optimization of our setup. This experimental setup adds to the toolbox that can allow the identification of resistant corals that can be used for the development of nature-based solutions for coral reef rehabilitation.

Oral
A-1478

Modelling of photon, mass and heat transfer in multilayered coral tissue

Picioreanu, C.[1], Taylor Parkins, S. K.[2], Novoa, A.[1], Martinez, F.[1], Murthy, S.[3], Kühl, M.[3]
[1]King Abdullah University of Science and Technology, Biological and Environmental Science and Engineering, Thuwal, Saudi Arabia
[2]Delft University of Technology, Biotechnology, Delft, Netherlands
[3]University of Copenhagen, Marine Biology Section, Helsingør, Denmark

cristian.picioreanu[at]kaust.edu.sa

Abstract

The symbiosis between coral animals and the microalgae hosted in their tissue takes place in the presence of steep and dynamic gradients of light, temperature and chemical species. These gradients are affected by the structural and optical properties of several distinct tissue layers and by their interaction with incident irradiance and water flow. Microenvironmental analyses have enabled quantification of such gradients and bulk coral tissue and skeleton optical properties, but the multi-layered nature of corals and its implications for the optical, thermal and chemical microenvironment remain to be studied in more detail. Here we present a multiphysics modelling approach aiming at representing physical-chemical processes at a single polyp scale. Three-dimensional Monte Carlo simulations of the light field in a coral polyp morphology with multiple tissue layers were used as input for modelling the heat dissipation, photosynthetic oxygen and carbohydrate production with carbon dioxide consumption, all driven by photon absorption. By coupling photon, heat and mass transfer, the model explains light, temperature, oxygen, carbonic species, carbohydrate and pH gradients in the coral tissue and skeleton, under environmental conditions simulating e.g. tissue contraction/expansion, symbiont loss via coral bleaching (an example in Figure), or different distributions of coral host pigments. The model reveals basic structure-function mechanisms that shape the microenvironment and ecophysiology of the coral symbiosis in response to environmental change.

Oral
A-1388

Size structure and physiological condition of Stylophora pistillata across reef flat zones of the central Red Sea

Rich, W., Schönherr, S., Carvalho, S., Berumen, M.
King Abdullah University of Science and Technology, Red Sea Research Center, Thuwal, Saudi Arabia

walter.richiv[at]kaust.edu.sa

Abstract

At a fundamental level, the growth and maintenance of coral reefs is dependent on the demographic rates of individual coral species. These vital rates are linked to the fitness of individuals in a population, and can be driven by environmental conditions at small spatial scales. However, these population-level characteristics are sometimes overlooked in evaluations of reef health. Simple assessments such as size structure can offer a snapshot of the state of a population, and presents a way to compare populations of different sites that may experience different abiotic conditions. While assessing size structure does not necessarily identify the drivers of population trajectories, coupling it with physiological data of individuals at each site can help link individual fitness to population-level trends. In this study, we assess size structure and the physiological condition of individuals of the coral *Stylophora pistillata* inhabiting sites with different environmental conditions. We surveyed different reef flat zones (exposed, midreef and sheltered) of six reefs over a cross-shelf gradient in the central Red Sea to measure the size structure (colony density and size), color morph distribution, and frequency of partial mortality. In addition, five colonies from each site were repeatedly sampled for physiological analyses from Dec. 2020 to Oct. 2021. Colony density and mean size were extremely variable, both among reef flat zones and reefs, but overall, both metrics were higher on the offshore reefs. Yellow colonies comprised 90% of the population, but purple colonies were more often found in exposed reef flat zones. Frequency of partial mortality was positively correlated with colony size but no spatial patterns were apparent. Seasonal and spatial patterns of symbiont density, protein content, and lipidomics will also be analyzed to relate possible links between population-level dynamics and colony physiology. The results presented here can provide a deeper understanding of population structure and coral physiology which has implications for reef health.

Oral
A-1415

Lack of kleptoplast photoacclimation and the role of parapodia in the sacoglossan sea slug Plakobranchus ocellatus

Richards Dona, A.[1], Evertsen, J.[2], Johnsen, G.[3]
[1]University of Hawaii at Manoa, Honolulu, United States
[2]Norwegian University of Science and Technology, Department of Natural History, NTNU University Museum, Trondheim, Norway
[3]Norwegian University of Science and Technology, Centre of Autonomous Marine Operations and Systems, Trondhjem Biological Station, Department of Biology., Trondheim, Norway

angela.dona[at]gmail.com

Abstract

The sacoglossan sea slug *Plakobranchus ocellatus* is a pan-tropical gastropod that incorporates stolen algal chloroplasts (kleptoplasts) into its digestive cells. Kleptoplasts are separated from their algal nuclei and are unable to divide but continue to produce photosynthate within host cells. The mechanisms that promote kleptoplast viability are poorly understood and the extent and limitations of functionality have not yet been fully characterized. We identified pigments and quantified retention times in kleptoplasts from three tropical sacoglossan species, *Elysia ornata*, *Thuridilla gracilis*, and *P. ocellatus*, collected from various depths and light fields. *Plakobranchus ocellatus* had the highest estimated retention time and maintained the highest ratio of photoprotective to photosynthetic pigments. A subsequent manipulative experiment on *P. ocellatus* specimens collected at the same site, depth, and time, involved a 7-day exposure to three different irradiances and showed that kleptoplasts did not photoacclimate over time. No significant changes in *in vivo* kleptoplast photosynthetic parameters or corresponding spectral reflectance occurred. Reflectance of the external surface of the mottled, wing-like parapodia, however, showed significant increases in the medium and high light treatments on day seven indicating localized kleptoplast degradation. These results, supported by preliminary confocal analyses, suggest that closed parapodia play an important role in kleptoplast protection by shielding internal kleptoplasts while permitting filtered light energy to reach kleptoplasts on the parapodial undersides. The cryptically-patterned parapodia provide camouflage and assume the role of photoprotectant, compensating for kleptoplast inability to photoacclimate. This may help explain why *P. ocellatus* is able to forage for algae in high light, exposed, sandy habitats while other sacoglossans likely avoid these high-risk areas and food resources.

Oral
A-2153

Pseudodiploria strigosa immune response to a white syndrome

Rivera-Ortega, J.[1], Thomé, P. E.[2], Jordán-Dalhgreen, E.[1]
[1]Unidad Académica de Sistemas Arrecifales, Instituto de Ciencias del Mar y Limnología, Universidad Nacional Autónoma de México, Laboratory of Reef Ecology, Puerto Morelos, Quintana Roo, Mexico
[2]Unidad Académica de Sistemas Arrecifales, Instituto de Ciencias del Mar y Limnología, Universidad Nacional Autónoma de México, Laboratory of Molecular Microbiology, Puerto Morelos, Quintana Roo, Mexico

jacq.rior[at]gmail.com

Abstract

Since 2018, the Mexican Caribbean experienced a lethal white type syndrome outbreak that is killing a large number of coral colonies in many Caribbean reefs, including those at the National Reef Park of Puerto Morelos, México. This outbreak is characterized by a rapid tissue loss of the important reef-building coral species, primarily meandroid forms such as Pseudodiploria strigosa.

We evaluated the activity of phenoloxidase (PO) in the mucus, the presence of melanin in coral tissue and the antibiotic activity of the surface mucus layer against Serratia marcescens and Aurantimonas sp. The assessment was conducted both in apparently healthy and white syndrome diseased P. strigosa colonies, taking samples at the border of lesions and 15 cm away.

We observed an increased response of the PO activity in the mucus close to the lesion (12.24 ± 5), relative to samples from apparently healthy colonies (0.88 ± 0.1), and those of diseased colonies at 15 cm away from the lesion (2.53 ± 0.85). However, the PO activity in these P. strigosa samples, suggest an exacerbated immune response when compared with healthy P. strigosa (0.09 ± 0.008) assessed one year before the outbreak. Furthermore, we did not observe melanin in the coral tissue in any of these samples.

We also observed a large antibacterial activity of the surface mucus layer of both healthy and diseased coral samples, against the two pathogenic strains. Similarly, the antibacterial mucus response was exacerbated compared with the antibacterial mucus response tested before the outbreak in healthy P. strigosa.

We conclude that the immune response that the mucus naturally provides to P. strigosa, was compromised when the coral was faced with this white syndrome, even in apparently healthy corals, suggesting that corals may be affected well before signs are evident.

Oral
A-1192

Resource competition regulates the cnidarian-algal symbiosis

Rädecker, N.[1], Pogoreutz, C.[1], Voolstra, C. R.[2], Meibom, A.[1]
[1]EPFL, ENAC, Lausanne, Switzerland
[2]University of Konstanz, Limnological Institute, Konstanz, Germany

n.raedecker[at]gmail.com

Abstract

The evolutionary success of the cnidarian-algal symbiosis has given rise to the formation of coral reef ecosystems. Yet, climate change and other anthropogenic impacts are disrupting this symbiosis at increasing frequencies and scales. Understanding the collapse of this symbiosis will not be possible without considering its ecological foundation: the nutrient exchange between the coral host and its algal symbionts. Here we investigated the metabolic regulation of symbiotic interactions combining starvation, light and heat stress experiments. We show that mutualistic nutrient exchange in the symbiosis is passively maintained by competition for inorganic nutrients between the host and its symbionts as well as between individual symbionts. A breakdown of this resource competition during heat stress, in turn, destabilizes nutrient cycling and thus the symbiosis itself. Taken together, we conclude that the functioning of this symbiosis is a direct consequence of the coupling of heterotrophic and phototrophic metabolisms. While this passive regulation has underpinned the evolutionary success of coral holobionts for millions of years, it also renders these organisms highly vulnerable to the rapid environmental change of the Anthropocene.

Poster
A-1384

Autofluorescence of Symbiodiniaceae reveal photophysiological plasticity amidst a changing climate

Anthony, C., Bentlage, B.
University of Guam, Marine Laboratory, Mangilao, Guam

colin_anthonynw[at]outlook.com

Abstract

Physiological plasticity determines an organism's capacity to acclimate to changing environmental conditions. Considering the central role of Symbiodiniaceae in coral health, understanding photoacclimation mechanisms is necessary to predict reef resilience. Using flow cytometry, we generated a fluorescent profile that quantifies symbiont density, light-harvesting pigments, and antioxidant fluctuation in response to a changing climate. We transplanted 80 fragments from 10 Acropora pulchra colonies across high and low-stress reef flats, then tracked their responses to the abrupt environmental change. Additionally, a repetitive sampling of 20 wild A. pulchra colonies from five distinct reef flats revealed signatures of seasonal photoregulation. While Symbiodiniaceae in wild A. pulchra colonies maintained stable population densities, LHC-associated photopigments and antioxidants had variable fluorescent signatures during initial environmental change. Alternatively, transplanted A. pulchra colonies demonstrated elevated fluorescence and fluctuating symbiont densities indicating stress-induced holobiont instability following transplantation. Despite elevated water temperatures and diverse ecosystems, all colony fluorescent signatures converged on high-similarity profiles after environmental stabilization.

Poster
A-1932

Photosynthetic activity in relation to the distribution of fluorescent host pigments within coral tissue

Ferreira, G., Bollati, E., Kühl, M.
University of Copenhagen, Helsingør, Denmark

gabriel.ferreira[at]bio.ku.dk

Abstract

Coral reefs have the particularity to show a wide range of colors. These organisms, living in association with dinoflagellates of the genus *Symbiodinium* named zooxanthellae, get up to 90% of their energy requirements covered by the photosynthesis of their symbionts. This performance is due to the high efficiency of the photosynthesis among this symbiosis. Indeed, corals are able to colonize a wide variety of habitats, showing great differences in light spectral composition or intensity. In order to adapt to these conditions, corals manage to photo acclimate using different mechanisms: increase in the zooxanthellae concentration inside the tissues, increase in chlorophyll pigment concentration, change of body shape, etc. However, there is a lack of investigation on how host pigments interact with the composition of light within the tissues, and about their role on the photosynthetic capacities of the organism. The characteristic bright colors of corals are mainly due to the GFP-like protein host pigments comprised within their tissues. Several hypotheses try to explain the role of these pigments, that could serve as ROS scavenger, UV protectant, photosynthesis enhancer, etc. These pigments are found in several forms in the organism: fluorescent (fluorescent protein) or non-fluorescent (chromoprotein), and can be organized in several ways within the tissues of the animal, as granules or homogeneously distributed. Depending on their spectral characteristics, their location among the tissue, and their organization, these proteins could have an impact on the photosynthetic performance of the organism. The spatial distribution of the fluorescent host pigments was studied within the tissues of several coral species using confocal microscopy and hyperspectral camera imaging. The photosynthetic performance of corals was evaluated using an oxygen micro sensor, coupled with a programmable LED light source targeting the excitation spectrum of GFPs. Finally, light scattering properties of the GFP present in the corals species investigated was also analyzed using optical coherent tomography.

Poster
A-1442

Exploring the potential physiological diversity among massive Porites - Focusing on the scars by fish grazing.

Ikeuchi, E.[1], Yasuda, N.[2], Iguchi, A.[3], Nakamura, T.[4], Fukami, H.[1]
[1]University of Miyazaki, Miyazaki, Japan
[2]The University of Tokyo, Tokyo, Japan
[3]AIST, Ibaraki, Japan, [4]University of the Ryukyus, Okinawa, Japan

e.ikeuchi[at]aist.go.jp

Abstract

Massive corals are widely distributed in coral reefs and are relatively more tolerant of high-water temperatures and rapid changes in water quality than other coral species, making them important bioindicators of global climate and marine environmental change. Massive corals are also used directly by a wide variety of organisms, including burrowing organisms and colonies of other coral species. The relationship between fishes and corals is one of the most important biological factors that can have a direct negative impact on community growth and survival. In general, in field populations of massive *Porites*, we find that some adjacent colonies show little or nothing of fish grazing scars, while others show a high density of scars. However, it is not clear what is responsible for the difference between these two groups. In this study, we conducted a field survey, continuous observation of tagged coral colonies for one year, and rearing experiments using the observed colonies in order to gain new insights into fish grazing scars on the surface of massive *Porites* colonies from an ecological perspective.

The results of the field survey indicated that the number of scars was reduced in bleached groups and sites. We suggest that fish selection is the main reason for the marked difference in the density of scars between groups of massive corals. In addition, a decrease in the density of scars was observed in groups with high photosynthetic activity and during the high-water temperature period when the growth rate increased, suggesting that differences in the growth (repair) rate of the coral community itself are interrelated. However, there was no clear relationship between the growth rates observed in the rearing experiments and the increase or decrease in the number of scars observed in the continuous observations, suggesting that differences in growth rate alone cannot explain the causes of differences in scar density.

Massive *Porites* corals are thought that support the biodiversity of coral reefs as microtopography and structure. The presence of group-specific differences revealed in this study is important for understanding how biodiversity is maintained in coral reef ecosystems.

Poster
A-1511

Effect of oxidized fatty acids on Symbiodiniaceae-cnidarian symbiosis

Micha, M., Plumier, J.-C., Roberty, S.
Ecophysiology and Animal Physiology (inBios, ULiege), Liège, Belgium

maudjjc[at]hotmail.com

Abstract

Direct role of reactive oxygen species (ROS) in the signalisation cascade leading to coral bleaching is not completely understood. Among molecules produced by ROS potentially playing a role in this cascade are oxidized fatty acids (FA). This assumption is based on the observation that oxidized polyunsaturated fatty acids/PUFA (e.g. oxylipins) can be used as cross-kingdom messengers and can induce immune response of the partners involved in this communication. In our study, we tested the possible role of oxidized FA as messengers leading to coral bleaching. Here, we present our first results on the effects of different concentrations of 2,4-decadienal (2,4-DD), originating from peroxidation of n-6 PUFA, on the physiology of *Breviolum minutum* both in culture and in symbiosis. In cultured cells, we observed a decline of 80% of effective photosynthetic yield (ϕPSII) after 30 min of exposure to 500 µM, then it did not significantly change between 30 min and 4 hours. Chlorophylls were not impacted after 30 min of exposure to this concentration. The most affected pigment was diadinoxanthin, with a reduction of 20%. The diminution of pigments slightly continued between 30 min and 4 hours, reaching 80%, 90% and 65% of the control content for chl-*a*, chl-c_2 and diadinoxanthin respectively. Respiration was reduced by nearly 60% after 30 min, and the impact was even greater after 4 hours of exposure with a reduction of 80% compared to control cells. Ascorbate, a non-enzymatic antioxidant, was less affected than physiological traits after 30 min of exposure, with a decrease of only 20%. However, it fell to 17% of the control content after 4 hours. When we exposed cultured cells to a ten-fold lower 2,4-DD concentration (i.e. 50 µM), we did not observe any significant effect on their photosynthetic activity. By contrast, the holobiont appeared very sensitive to 2,4-DD. One hour after the addition of 50 µM 2,4-DD, *Exaiptasia pallida* H2 hosting *Breviolum* spp. entered a stress state characterized by tentacles retraction and body shrinkage. Animals exposed to 5 µM did not show significant sign of stress, even after several days. That suggests that symbionts could be more resistant to oxidized FA and that a transfer of those compounds from the algae to the animal could potentially play a role in triggering bleaching.

Poster
A-1906

In situ measurement of metabolic rates P, R, P/R, RQ/PQ and calcification of the coral Orbicella faveolata with CISME, a novel underwater respirometer

Szmant, A.[1], Whitehead, R. F.[1], Farmer, J.[2], Weil, E.[3]
[1]University of North Carolina Wilmington, Center for Marine Science, Wilmington, United States
[2]Keys Marine Laboratory, Long Key, Florida, United States
[3]University of Puerto Rico Mayaguez, Marine Science, Mayaguez, Puerto Rico

alina[at]cisme-instruments.com

Abstract

CISME (Coral *In Situ* MEetabolism; pronounced "KISS ME) is a new tool used to non-destructively measure coral bioenergetics *in situ*. It was developed to facilitate previously not possible novel research into the physiology of corals and coral reefs under ambient conditions. CISME was used to make *in situ* metabolic measurements for 40 tagged colonies (20 per reef, 2 reefs) of the Caribbean hermatype, *Orbicella faveolata*, in La Parguera, Puerto Rico, repeated 4 times over 12 months. The instrument isolates and recirculates small volumes of seawater over the coral tissue; changes in dissolved oxygen and pH in this water are used to calculate rates of respiration (R) and photosynthesis (P). Calcification rates were measured as changes in total alkalinity between ambient water samples collected at the beginning and incubation water subsamples collected at the end of the incubation with the build-in sample loop. P_{Gross} rates were measured using the same saturating light level for all sample dates. P_{Gross} was only significantly higher for September for one of the reefs (mean for all dates and samples 2868 ± 443 nmol O2 cm^{-2} h^{-1}). Respiration was lowest (668 ± 175 nmol O2 cm^{-2} h^{-1}) and mid-day P/R ratio highest (4.37 ± 0.84) during the cooler March sampling period, and R was highest (1000 ± 195 nmol O2 cm^{-2} h^{-1}) and mid-day P/R lowest (3.08 ± 0.38) during the warmest month, September. Estimates of 24 h P/R ratios assuming 12 hours of light and high water clarity, which seldom occur in this area, range from 1.7 to 2.0 suggesting that heterotrophy is important for these corals to satisfy their energetic, growth and reproduction requirements under usually moderate-to-high turbidity. Calcification rates measured at a saturating light level were highly variable but on average, 30 % or more higher than rates previously reported in the laboratory for the same species. In September, calcification rates measured during long dark incubations were 20 % of light enhanced calcification rates. Changes in TA and pH were used to calculate CO_2-based R and P rates and from these, respiratory quotients (RQ) and photosynthetic quotients (PQ). RQ and PQ represent valuable indicators of the types of substrates used for R and produced by P, respectively. Our ability to measure *in situ* metabolic rates, calculate P/R ratios, RQs and PQs in under 20 minutes per coral shows that CISME has the potential to greatly improve our ability to study coral physiology *in situ* and non-destructively.

Poster
A-1426

Rhythm of the reef: pulsation ontogeny in soft corals

Vaknin, S., Benayahu, Y.
Tel Aviv University, Faculty of Life Sciences, School of Zoology, Tel Aviv, Israel

stavvaknin[at]mail.tau.ac.il

Abstract

Octocorals are abundant in coral reefs around the world, inhabiting hard substrate from the Indo-Pacific to the Red Sea. Although they grant brilliance and high biodiversity to the reef as their stony counterparts, they are understudied. Several species of the family Xeniidae are characterized by the unique pulsation of their polyps. Such rhythmicity turns a motionless reef into an animated and mesmerizing structure. Moreover, pulsation is of biological and ecological importance that has been noted and studied throughout the past 200 years. Yet, the ontogenetic aspects of this phenomenon have remained greatly uninvestigated. The overall goal of this study is to examine the commencement of pulsation in early life stages of the pulsating soft coral *Heteroxenia fuscescens*. It compares the development of pulsation in newly metamorphosed planulae, also in relation to algal symbiont acquisition by the sexual offspring. For this purpose, adult colonies of *H. fuscescens* are collected from the shallow reefs of Eilat (northern Red Sea). Each colony is transferred to a container inside an outdoor flow-through tank and monitored for planulation. Released planulae are collected and transferred to laboratory for settlement and metamorphosis. Simultaneously, several polyps are detached from parent colonies for the isolation of endosymbiont cells. Part of the newly settled primary polyps are infected with parental algal isolates, others are kept azooxanthellate, both for ontogenetic comparison. Metamorphic events, commencement of pulsation and survival rate are monitored and photographically recorded for several weeks post settlement. Hitherto findings indicate that at the initiation of metamorphosis, both zooxanthellate and azooxanthellate polyps exhibit asymmetrical growth as well as independent and sluggish motion of tentacle buds. In contrast, at a later stage, tentacles of azooxanthellate primary polyps cease movement and converge, whereas the zooxanthellate ones expand and contract fully. The sole dependence of xeniid corals on their endosymbionts for energy supply contributes to the significance of the crucial host-algae relationship in today’s changing environment. Thus, emphasizing the need to highlight ontogenetic aspects of the pulsation process.

Virtual
Oral
A-2078

Effects of heat stress and hypoxia on the photosynthetic efficiency and growth rate of three scleractinian corals

Jain, T.[1, 2], Ying, L.[1, 2], Buapet, P.[2, 3], Yucharoen, M.[1, 2]
[1]Prince of Songkla University, MACORIN, Faculty of Environmental Management, Hat Yai, Thailand
[2]Prince of Songkla University, Coastal Oceanography and Climate Change Research Center, Hat Yai, Thailand
[3]Prince of Songkla University, Division of Biological Science, Faculty of Science, Hat Yai, Thailand

6310920012[at]psu.ac.th

Abstract

In recent decades, coral reefs have been suffering an unprecedented decline due to environmental stress, especially climate change caused by natural fluctuations and anthropogenic drivers. There is a lack of research in heat-stressed & hypoxic coral reefs. It is urgent to figure out the extent of this problem and its potential consequences. This study investigated the physiological response of corals to low dissolved oxygen concentration and assessed heat stress's synergistic or antagonistic effects with low dissolved oxygen. We collected three coral species representative of different growth forms, *Porites lutea*, *Montipora tuberculosa* and *Pocillopora verrucosa* from Phuket, Thailand and subjected them to nine days of heat stress (32 ^{o}C), hypoxia (DO < 2 mgl^{-1}) and heat stress + hypoxia treatments. Photosynthetic parameters (F_v/F_m and F_v/F_0) were measured daily while the growth rate was quantified at the end of experiment. We found that the initial response of *P. lutea* to hypoxia was an increase in F_v/F_m and F_v/F_0 during light availability which started declining from Day 5. *P. verrucosa* (branching coral) was found to be most sensitive and severely affected by these stressors in comparison to *P. lutea* (massive) and *M. tuberculosa* (tabular).

Virtual
Oral
A-1682

Kinship and selection in aquarium-bred Acropora hyacinthus coral colonies

López-Nandam, E.[1], Payne, C.[2], Larkin, L.[3], Delbeek, C.[3], Ross, R.[1], Albright, R.[1]
[1]California Academy of Sciences, Institute for Biodiversity and Sustainability Studies, San Francisco, United States
[2]Stanford University, Biology, Stanford, United States
[3]California Academy of Sciences, Steinhart Aquarium, San Francisco, United States

elopez-nandam[at]calacademy.org

Abstract

Recent advances in *ex situ* system design and operation have made it possible to complete gametogenic cycles of broadcast spawning corals. This method has proven successful in facilitating the induction of predictable broadcast spawning and breeding in both Indo-Pacific and western Atlantic species. Spawning and breeding corals *ex situ* are critical advances for population management, particularly in the form of genetic rescue. Genetic rescue projects for corals are already underway to bring threatened species into *ex situ* culture and propagation. However, while breeding corals for population management and conservation is increasingly viable, the consequences of the aquarium environment on the genetic and physiological composition of captive-bred coral populations is unknown. The aquarium environment may itself be a selective pressure on corals in some ways, but it also presents relaxed selective pressures in other respects. In 2019 and 2020, *Acropora hyacinthus* coral colonies were collected from the wild in Palau and shipped to the California Academy of Sciences (CAS), in San Francisco. In both years, the CAS colonies spawned at the same time as their still-wild counterparts, and gametes were fertilized to generate larvae that were settled and reared to recruits.As of April 2021, 23 individuals of the F1 generation born at CAS in 2019 and 10 of the F1s born at CAS in 2020 had survived to two and one year old, respectively. We sequenced the full genomes of 33 F1 corals and their 15 potential parents (F0s) to an average of 22x depth of coverage. Differential parentage is quite clear: 22 of 23 babies from 2019 shared both parents, while 1 parent produced just one of the 23 offspring and the fourth spawner produced no surviving offspring. For the 2020 cohort, five adults parented the 10 surviving offspring while the other 10 spawners had no surviving offspring. After scanning 16.9 million single nucleotide polymorphisms (SNPs) in the population, we identified 652 single nucleotide polymorphisms (SNPs) that appear to be under selection due to the lab environment, and we lay out the genes and physiological pathways these SNPs affect. These results will inform future genetic rescue and coral breeding projects by showing how the lab environment may select for different traits than the wild environment, and how adaptation to a lab environment is something to consider when breeding corals *ex situ* for conservation purposes.

Session 10B - How do ecological processes affect the adaptation and evolution of coral reef organisms in the Anthropocene?

Conceptualized by: **Timothy Ravasi**[1], **Iliana Baums**[2], **Jose M. Eirin-Lopez**[3], **Gergely Torda**[4]
[1] Okinawa Institute of Science and Technology (Okinawa, Japan)
[2] Pennsylvania State University (State College, PA, USA)
[3] Florida International University (Miami, Fl, USA)
[4] ARC Centre of Excellence for Coral Reef Studies (Townsville, Australia)

Chaired by: **Iliana Baums**[2], **Jose M. Eirin-Lopez**[3]

Oral
A-1042

Environmental drivers of genetic adaptation in two coral species from Florida

Black, K., Rippe, J., Matz, M.
University of Texas at Austin, Integrative Biology, Austin, United States

kblack[at]utexas.edu

Abstract

While coral reefs in the Florida Keys are rapidly declining, reef restoration efforts face the challenge of matching outplanted corals to the environment where they would most likely survive. In this study, we aimed to identify environmental gradients that drive the most genetic specialization in two coral species from the Florida Keys. We hypothesized that corals exhibit fine-scale population structure associated with certain abiotic differences, particularly depth. Using 2bRAD sequencing, we developed a large genomic dataset for two ubiquitous coral species- *Porites astreoides* and *Agaricia agaricites*- across all reef habitats in the Florida Keys. We compared genetic structure and loci under selection to 126 environmental variables from public remote-sensing and water quality datasets. Both species revealed three sympatric cryptic genetic lineages, specialized to different depth ranges. These cryptic lineages within each species maintain gene flow across part of the genome while simultaneously adapting to different water quality gradients, most notably nitrogen. Our findings suggest that depth drives the strongest adaptive divergence of corals in the Florida Keys, generating semi-isolated cryptic genetic lineages, which then proceed to adapt to water quality gradients on their own.

Oral
A-1759

Molecular mechanisms of transgenerational plasticity in a coral reef fish acclimating to global warming

Bonzi, L. C.[1], Spinks, R. K.[2], Donelson, J. M.[2], Munday, P. L.[2], Ravasi, T.[2, 3], Schunter, C.[4]
[1]Red Sea Research Center, King Abdullah University of Science and Technology, Thuwal, Saudi Arabia
[2]ARC Centre of Excellence for Coral Reef Studies, James Cook University, Townsville, Australia
[3]Marine Climate Change Unit, Okinawa Institute of Science and Technology Graduate University, Onna, Japan
[4]Swire Institute of Marine Science, The University of Hong Kong, Hong Kong, Hong Kong SAR China

lucrezia.bonzi[at]kaust.edu.sa

Abstract

Anthropogenic activities are causing a global increase in ocean water temperature with serious implications on the persistence of marine species. In order to cope with these rapid changing climates, some organisms are able to acclimate to the new environment through phenotypic plasticity. Studies have shown that besides within generation phenotypic plasticity (WGP), coral reef fish can better respond to the challenges of elevated temperature if warm conditions are maintained transgenerationally. However, the mechanisms of this trangenerational plasticity (TGP) are still poorly understood and many of its key aspects still need to be investigated. In the present study we analysed the molecular traits in the spiny chromis *Acanthochromis polyacanthus* exposed developmentally or transgenerationally to an average of +1,5°C. We applied a split-brood experimental design involving reciprocal crosses with respect to sex and environment and tackled some of TGP less understood aspects. We sequenced and assembled 184 liver transcriptomes of juvenile *A. polyacanthus* and analysed differential gene expression. The analysis enabled us to answer fundamental questions regarding TGP in this species, such as the importance of the exposure timing to the environmental cue in the adults, the relative parental contributions (maternal and paternal), as well as the different molecular pathways involved in TGP compared to WGP. These findings represent important advances in understanding a critical biological mechanism, transgenerational plasticity, relevant to many species that will have to cope with climate change effects spanning across several generations.

Oral
A-1073

Energetic model for the quantification of the effects of ocean acidification on coral calcification

Brown, D., **Boville, E.**
The Pennsylvania State University, Biology, State College, United States

evb5530[at]psu.edu

Abstract

The large rates of calcification allow hermatypic corals to build the largest biological structures in the planet. Calcification is an energy demanding process, which in the case of symbiotic corals is provided by the translocation of photosynthates from symbiotic microalgae. A large body of evidence has documented that coral calcification is negatively affected by ocean acidification (OA), although the deleterious effects appear to be species-specific. These species-specific responses to OA have been attributed to differences in energetic cost of calcification, tissue thickness, heterotrophic abilities, or the presence of different microbiomes. Alternatively, these differences could be the results of changes in energy allocation patterns of each host species. Here, we tested this hypothesis utilizing a novel approximation to estimate the energetic cost of OA on the calcification rates of two species of Caribbean corals. Planar explants of Orbicella faveolata and Porites astreoides were acclimated for three weeks to different levels of OA. Coral calcification rates were determined at varying levels of irradiance. The results of our experiments indicate, in one hand, that the slopes of $CaCO_3$ deposition as a function of photosynthesis showed no significant differences between species and were independent of OA levels. On the other, that the intercepts of the linear relationships, equivalent to dark calcification, were species-specific and highly dependent on the OA treatment. The results suggest that the actual cost of calcification is independent of the external pH and that the reduction in calcification rates result from changes in the energy allocation of each coral species to other, yet unidentified, homeostatic processes. Our results also indicate that the negative effects of decreasing pH were species-specific. O. faveolata decreased $CaCO_3$ deposition rates double to that observed in P. astreoides. Considering no differences in photosynthetic production were detected between the two species, these results suggest species-specific differences in energy allocation patterns. Furthermore, when corals were exposed to different levels of OA without a period of acclimation the responses where less intense indicating that acclimation in terms of energy allocation is required. We will also discuss how the development of energetic models could be useful tools to quantify the effects of other environmental stressors on coral physiology.

Oral
A-1469

Genomic signals of adaptation to ocean acidification, temperature, and low water quality in three coral species

Leiva, C.[1], Pérez-Portela, R.[2], Lemer, S.[1]
[1]University of Guam, Marine Laboratory, Mangilao, Guam
[2]University of Barcelona, Department of Evolutionary Biology, Ecology, and Environmental Sciences, Barcelona, Spain

cleivama[at]gmail.com

Abstract

Strong environmental gradients can serve as natural laboratories to test evolutionary theories and species/ecosystems adaptation capabilities to current and future anthropogenic stressors. In order to unveil genomic signals of selection related to variable environmental conditions, and predict the adaptive potential of various coral species, we reanalyzed previous published transcriptomic datasets that illustrated adaptation mechanisms through differential gene expression and gene expression plasticity. Using the available genomic and transcriptomic resources, we searched for signatures of selection in Single Nucleotide Polymorphisms (SNPs) in coral populations facing various levels of ocean acidification (in *Acropora millepora*), low water quality (in *Acropora tenuis*), and elevated seawater temperature (in *Porites astreoides*). For each dataset, we combined different selection scans and genotype-environmental association analyses, obtaining a total of 73, 100, and 14 SNPs under selection for *A. millepora*, *A. tenuis*, and *P. astreoides*, respectively. Functional annotation revealed genomic targets of natural selection with some common functions across datasets that are also related to previous gene expression results. These functions include, for instance, transcription factors and cell cycle regulators, ribosomal and translation-related proteins, cytoskeletal components, and enzymes involved in fatty acid metabolism. Overall, our results provide a new broad perspective on how coral reef species respond to environmental stressors, which includes, besides acclimatization through changes in gene expression, also natural selection acting in particular genomic regions.

Oral
A-1364

Mild heatwaves increase acute heat tolerance in corals

Marzonie, M.[1, 2, 3], Bay, L.[2, 3], Bourne, D.[2, 4], Matthews, S.[1], Nielsen, J.[2, 3, 5], Harrison, H.[1, 2, 3]
[1]Centre of Excellence for Coral Reef Studies, James Cook University, Townsville, Australia
[2]Australian Institute of Marine Science, Townsville, Australia
[3]AIMS[at]JCU, Townsville, Australia
[4]College of Science and Engineering, James Cook University, Townsville, Australia
[5]College of Public Health, Medical and Veterinary Science, James Cook University, Townsville, Australia

magena.marzonie[at]my.jcu.edu.au

Abstract

Marine heat waves are an increasing selective pressure for heat tolerance in corals. Yet we do not have a clear understanding of how heat tolerance varies across spatial scales spanning broad climatic gradients and disturbance regimes, or the processes that underpin variation. Here we investigate the environmental drivers of heat tolerance for isolated populations of three coral species in the Coral Sea Marine Park through quantification of their phenotypic response to heat stress. The dark-adapted maximum photosynthetic yield of coral samples (F_v/F_m) was used as a measure of coral condition following exposure to acute heat stress (+3˚C, +6˚C and +9˚C above local maximum monthly mean temperatures) for *Acropora cf. humilis*, *Pocillopora meandrina* and *Pocillopora verrucosa* to develop a standardised metric of heat tolerance (PSII-50) for comparison across species and populations. We recorded 0.8 ˚C to 1.7 ˚C phenotypic variation in heat tolerance among reefs within species, indicating spatial heterogeneity in heat tolerance across broad climatic gradients. Higher tolerance to heat stress was strongly associated with increased exposure to mild heatwaves (Degree Heating Weeks > 3) since 1985. Phenotypic variation associated with local environmental conditions provides supportive evidence that marine heatwaves are selecting for highly tolerant individuals, providing a basis for evolutionary and adaptive processes to act upon.

Oral
A-1064

Impact of ocean warming on the development, metabolic rate, and transcriptome of larval clownfish

Moore, B., Jolly, J., Izumiyama, M., Kawai, E., Ryu, T., Ravasi, T.
Okinawa Institute of Science and Technology, Marine Climate Change Unit, Okinawa, Japan

billy.moore[at]oist.jp

Abstract

Ocean warming has been demonstrated to have a range of negative impacts on coral reef fish. However, despite a wealth of studies of juvenile/adult reef fish, studies of how early developmental stages respond to ocean warming are limited. As overall population persistence is influenced by the development, dispersal and survival of early life stages, further studies of larval fish will elucidate how reef fish respond to ocean warming across multiple generations. Here, in an aquaria-based study we investigate how temperatures associated with future warming (+3°C) impact the development, metabolic rate, and transcriptome of larval clownfish (*Amphiprion ocellaris*). We show that larvae reared at +3°C grow and develop significantly faster than those in control conditions, with larvae reaching ecologically important settlement stages faster at higher temperatures. Furthermore, our results indicate that the impact of warming on larval metabolic rate will be stage specific, with later developmental stages exhibiting increased metabolic rate at higher temperatures. Finally, we highlight the molecular mechanisms underpinning the response of larvae from different developmental stages to higher temperatures. Overall, these results indicate that clownfish development will be altered under future warming, with developmental rate, metabolic rate, and gene expression all affected. Such changes may lead to clownfish displaying reduced dispersal, survival and ultimately population size in a future warmer ocean.

Poster
A-1101

The role of diel thermal variability on Symbiodiniaceae physiology, gene expression, and thermal tolerance

Huzar, A., Aichelman, H., Davies, S.
Boston University, Biology, Boston, United States

ahuzar[at]bu.edu

Abstract

As ocean temperatures continue to rise, coral bleaching episodes are increasing in frequency, forcing corals to adapt to survive. However, corals' natural evolution is outpaced by rapid environmental changes, which has led to the proposal of assisted evolution to preserve coral reefs. Previous research has demonstrated a limited ability to experimentally evolve algal symbiont cells to increase the thermal tolerance of the algae in culture and in coral hosts.These previous studies have primarily exposed algal cultures to constant higher temperatures to increase their thermal tolerance; however, recent studies have demonstrated that corals exposed to increased diel thermal variability (DTV) have enhanced coral thermal tolerance *in situ*. Therefore, we hypothesize that DTV can be leveraged to evolve Symbiodiniaceae strains in culture to increase their thermal tolerance both in and out of symbiosis. To test this hypothesis, cultures of four Symbiodiniaceae species from the *Durusdinium*, *Breviolum*, *Symbiodinium*, and *Effrenium* genera have been exposed to control (26°C) or DTV temperatures (23°C-29°C) for 4 months (~20 generations) thus far. Photosynthetic performance is assessed weekly and growth rates are calculated each month. Cultures are given fresh media every 2 weeks to increase growth and are transferred to new flasks every 4 weeks at which point a subsample of each strain is preserved for transcriptome profiling using TagSeq, which will allow characterizations of gene expression as strains evolve. Next, cultures maintained in control and DTV environments will be exposed to control temperature (26°C) and thermal stress (31°C) for 3 weeks. During this thermal stress phase, photosynthetic performance and cell growth will be monitored twice a week. Subsamples of cultures will be taken before and after thermal stress for subsequent gene expression analysis. These strains will continue to be maintained in DTV conditions with thermal stress tests being conducted every few months both *ex hospite* and in symbiosis with *Exaiptasia pallida*. While this experiment is on-going, results will provide insights into whether DTV can be leveraged to enhance the thermal tolerance of algal symbiont cells.

Virtual
Oral
A-1120

Mobile DNA response to ocean acidification in a coral reef fish

Dauyey, K.[1, 2], Celii, M.[3], Schunter, C.[4], Orlando, V.[3], Munday, P.[5], Ryu, T.[2], Ravasi, T.[2, 5]
[1]SOKENDAI University, Department of Genetics, Mishima, Japan
[2]Okinawa Institute of Science and Technology, Marine Climate Change Unit, Onna-son, Japan
[3]King Abdullah University of Science and Technology, Biological and Environmental Sciences & Engineering Division, Thuwal, Makkah, Saudi Arabia
[4]The University of Hong Kong, Swire Institute of Marine Science, Hong Kong, Hong Kong SAR China
[5]James Cook University, Australian Research Council Centre of Excellence for Coral Reef Studies, Townsville, Australia

kaisar.dauyey[at]oist.jp

Abstract

Mobile DNA such as transposable elements (TEs) have been long considered a driving force in evolution. Large body of research has confirmed that about 90% of lungfish genome as well as 45% of orange clownfish genomes are comprised of highly repetitive DNA including TEs. We hypothesize that TE insertion sites might change across the genome of fish exposed to ocean acidification conditions. Previous research findings based on transgenerational behavioral and genomic studies of reef fish have demonstrated existence of “tolerant” and “sensitive” individuals to high pCO_2 concentration. Those studies confirmed that “sensitive” spiny damselfish (*Acanthochromis polyacanthus*) raised in projected end of the century pCO_2 concentrations have noticeable behavioral changes with underlying gene expression difference in circadian rhythm regulation. In addition to that, the offspring of tolerant and sensitive fish raised in 4 different time-lines of high pCO_2 exposure demonstrated substantial differences in brain-related gene expression patterns. Based on these results we have attempted to explore genomic landscape of TEs in the offspring of “tolerant” and “sensitive” spiny damselfish. We have identified the presence of hundreds of different TE types across the whole genome. Most of the TEs identified belong to Tc1-Mariner DNA-TE family as well SINE and LINE families. We have noticed that a large number of TE insertions have tendency to migrate in various genomic regulatory regions like promoter and terminator regions suggesting a potential regulatory role in controlling gene expression. These findings suggest that gene expression promoting acclimation to ocean acidification may be driven by TE insertions.

Session 10D - The tropicalization of marine ecosystems, and do microbes play a role in mediating species redistributions?

Conceptualized and chaired by: **Ulisse Cardini** [1], **Adriana Vergés**[2]
[1] Stazione Zoologica Anton Dohrn (Napoli, Italy)
[2] University of New South Wales (Kensington, Australia)

Virtual
Poster
A-1491

Biogeography of endosymbionts (Symbiodiniaceae) associated with zoanthids (Anthozoa) species from the Macaronesia and Cape Verde ecoregions

Zamora Jordán, N.[1], Hernández Ferrer, M.[1], López Batista, C.[2]
[1]University of La Laguna, Department of Biochemistry, Microbiology, Cell Biology and Genetics., San Cristóbal de La Laguna, Spain
[2]University of La Laguna, Department of Animal Biology, Soil Science and Geology., San Cristóbal de La Laguna, Spain

nu.zamjor[at]gmail.com

Abstract

In the current context of global warming and with the increasing loss of coral reef ecosystems, determining advantage host-symbiont assemblages is essential to assess the resilience of the different holobionts against changes in the environmental conditions. In this sense, zooxanthellae zoantharian species, have been shown to be more resistant and some populations have been able to proliferate in areas where environmental factors hinder the settlement and survival of scleractinian corals. In our study, symbiont associated with 63 specimens of Zoantharia Brachycnemina species were identified to examine their distribution patterns and biodiversity along the Madeira (40ºN) – Cape Verde (16ºN) latitudinal gradient.

PCR-RFLP analysis of the LSU-rDNA showed that most specimens analysed hosted symbionts of only one genus, *Symbiodinium* (former Clade A) or *Cladocopium* (former Clade C) and only three out of 63 specimens screened showed symbionts of both genera cohabiting the same host. Subsequently, the ITS2-rDNA marker was analysed to accurately identify the dominant ITS2 genotype inhabiting each host specimen. The ITS2-rDNA analysis demonstrated that zooxanthellae diversity rises towards the tropics, with two ITS2 types inhabiting Madeira, three in the Canary Islands and four in Cape Verde. An ITS type not yet described in *Palythoa*, that we have named C_M, was found in some specimens from Madeira. In the other archipelagos, all *Palythoa* species hosted the generalist and more abundant ITS2 type C1, regardless depth and location. Conversely, genotypes belonging to *Symbiodinium* (A3 and A4), which are adapted to higher levels of irradiance, were found exclusively within *Zoanthus* species inhabiting the intertidal zone of Cape Verde. These host-zooxanthellae associations might be related to the lack of sand and detritus in the body wall of *Zoanthus* species that in *Palythoa* spp. would protect zooxanthellae against excessive UV radiation.

Among zoantharians, *Palythoa*-symbiont associations have proven to be more tolerance to a wide temperature and radiation ranges, making them a potential winner species in a climate change scenario.

Session 10E - What phenotype, genotype, and environmental factors underlie coral vulnerability and resilience to thermal stress and bleaching?

Conceptualized by: **Andrea Grottoli** [1], **Robert Toonen** [2], **Robert van Woesik** [3], **Ann Marie Hulver** [1], **Rowan McLachlan** [1]
[1] The Ohio State University (Columbus, OH, USA)
[2] Hawaii Institute of Marine Biology (Lillipuna, HI, USA)
[3] Florida Institute of Technology (Melbourne, Fl, USA)

Chaired by: **Andrea Grottoli** [1], **Ann Marie Hulver** [1]

10E - What phenotype, genotype, and environmental factors underlie coral vulnerability and resilience to thermal stress and bleaching?

Oral
A-1393

Genotypic variability within Staghorn coral, Acropora cervicornis, under combined thermal and UVR Stress on coral survival

Al-Mutairi, Y., Langdon, C.
Rosenstiel School of Marine and Atmospheric Science, Marine Biology and Ecology, Miami, United States

yna5[at]miami.edu

Abstract
The majority of studies on the effects of heat stress on corals focus on the dissociation of the symbiosis from the perspective of the algal symbiont; loss of photosynthetic capacity, loss of chlorophyll, and decrease in symbiont density. Few studies have looked at the dissociation from the coral host's point of view. This raises a number of questions, including how long the coral can sustain life while performing vital functions despite receiving a decreasing supply of energy from its symbionts. Can the coral host adapt physiologically to increase its survival time under heat stress? Is there evidence of heat stress survivor variability within genets of a coral species known to host only one type of Symbiodium?
A long-term heat stress experiment was conducted outdoors under natural light using six genets of Acropora cervicornis, which has only been found to host Symbiodium type A3 in Florida. A total of 108 corals from six genets were randomly assigned to three tanks and three treatments (80 % UVR, 50 % UVR, and 2 % UVR, PAR was kept constant in all treatments). Corals were preconditioned at 30°C for two months before being slowly ramped up to the experimental temperature of 32°C.
The corals were fed biweekly and checked every other day for signs of activity by the coral host, such as calcification and tentacle movement. The number of live and dead corals in each treatment was counted daily. Death was indicated by tissue sloughing and algae covering the skeleton. Photographs were taken to document the progression. We discovered that the corals could be classified into three groups based on their survival days (most heat sensitive-A, moderate heat sensitivity-B, and least heat sensitive-C). The single genotype in group C demonstrated 'climate change adaptive potential' by surviving twice as long as the other genotypes under 32°C and all three levels of UVR, making it the least heat sensitive and adaptable genotype.

Oral
A-1275

Tracking heavy metals in tissue, skeleton, and gametes during bleaching stress and recovery in the Hawaiian reef building coral Montipora capitata

Backstrom, C.[1], Brown, T.[1], Rodrigues, L.[2], Padilla-Gamiño, J.[1]
[1]University of Washington, School of Aquatic and Fishery Sciences, Seattle, United States
[2]Villanova University, Department of Geography and the Environment, Villanova, United States

callumhb[at]uw.edu

Abstract

Rising sea surface temperatures have led to increased rates of coral bleaching, causing thermally stressed corals to expel their algal symbionts, stunting growth and reproduction. During bleaching, corals can rely heterotrophically on zooplankton/detritus for energy. However, these food sources could also cause bleached corals to bioaccumulate heavy metals, which can be toxic in elevated concentrations. To date, it is not known if concentrations of heavy metals fluctuate in bleached corals, change during recovery from bleaching, and/or affect coral gametes after parent colonies bleach. In this study, we investigated two questions: 1) Does thermal stress increase the concentration of heavy metals in coral tissue and skeleton due to increased heterotrophy? 2) Does bleaching status influence the concentrations of heavy metals in coral gametes? In September 2017, we thermally stressed *Montipora capitata* colonies in Kāne'ohe Bay, Hawai'i and sampled bleached and nonbleached colonies every two months through July 2018. We collected egg-sperm bundles released during the 2018 summer spawning event to quantify metals within gametes. We analyzed tissue, skeleton, and egg-sperm bundles of each colony with an Inductively Coupled Plasma Mass Spectrometer for ten heavy metals of environmental concern and/or known bioaccumulation: As, Ba, Cd, Co, Cu, Mn, Pb, Sr, V, and Zn. After thermal stress, As, Cd, Mn, and V decreased in coral tissue, ranging from 25% (for As) to 57% (for Cd), possibly due to the loss of symbiotic algae. All depleted metals increased to pre-bleaching levels by the time full symbiont recovery was recorded (June 2018), suggesting these metals are stored or acquired only in the presence of symbionts, and not by increased heterotrophy. Only Sr/Ca and Ba/Ca were reliably detected in skeletons, and their concentrations did not fluctuate through July 2018. Previous bleaching history of parent colonies did not affect concentrations of metals in egg-sperm bundles, and most concentrations of metals in gametes were at least one order of magnitude lower than in parent tissue. However, gamete concentrations of As were notably high (up to 70% of concentrations measured in parent tissue). High concentrations of As could be stored in coral gametes due to arsenic’s high lipid affinity. This study shows the variability in heavy metal loss and acquisition in bleached corals and the relative consistency of heavy metal transfer to gametes despite prior bleaching stress.

Oral
A-1870

Iberostar Climate Change Simulator: Defining bleaching thresholds of Caribbean corals for resilient reef restoration in the private sector

Blanco Pimentel, M.[1], Calle Triviño, J.[2], Cortés Useche, C.[2], Galvan, V.[3], Harms, E.[3], Morikawa, M.[3]
[1]Iberostar Hotels & Resorts, Sustainability Office, Bávaro, Dominican Republic
[2]Iberostar Hotels & Resorts, Sustainability Office, Playa Paraiso, Mexico
[3]Iberostar Hotels & Resorts, Sustainability Office, Miami, United States

macarena.blanco[at]iberostar.com

Abstract

As the private sector is increasingly adopting reef restoration, research is needed to ensure resilient efforts in the face of climate change. At Iberostar Hotels and Resorts, a Coral Lab was built in 2019 in the Dominican Republic to serve as a genetic bank, outreach center, and to experimentally stress coral to find thermotolerant corals. Here we present the first results from this facility. Bleaching thresholds at different scales have been utilized to predict the future of reefs. However, taxon-level bleaching has barely been taken into account yet playing an important role in coral community structure. Most of these studies have been focused on the Indo-Pacific, highlighting the need to study bleaching responses in Caribbean corals. Species-specific bleaching thresholds can be estimated as the temperature at which 50% of the bleaching response is observed (T50). Establishing specific bleaching thresholds also allows finding intraspecific variability and thus spotting the most heat-tolerant colonies. Here we determined the T50 of seven common reef-building species in the Caribbean: *Acropora cervicornis, Diploria labyrinthiformis, Montastraea cavernosa, Orbicella annularis, O.faveolata, Porites astreoides* and *P. porites*. Samples were collected for 70 unique colonies across the 7 species in the Southeast of the Dominican Republic. Thermal tolerance was assessed using 3-hour heat pulses with seven temperatures over the local maximum mean monthly temperature (MMM). Intraspecific thermo-tolerance was evaluated for three of the species (*D. lab, O. ann* and *O. fav*) at their T50, using 20 known parent colonies. Bleaching response was assessed by visual ranking, picture analysis and pulse amplitude modulated (PAM) fluorometry. Interspecific variability highlights the need for reef restoration to include multiple species. Intraspecific variability emphasizes the implications that selecting locally discovered thermally resilient individuals could have in reef restoration practices. By identifying diversity amongst species, we boost overall biodiversity and ensure that species such as Acroporids, which have been historically vulnerable to bleaching, can be maintained in restoration efforts. Furthermore, these findings directly inform the private-sector driven coral restoration program of Wave of Change at Iberostar with the aim of restoring ecosystem services of coastal protection while remaining resilient to climate change.

Oral
A-1416

Coral spawning and reproductive physiology in a changing climate: the role of temperature, photosynthetic active radiation, and ultraviolet radiation

Bouwmeester, J.[1, 2], Daly, J.[1, 2], Zuchowicz, N.[1, 2], Lager, C.[1, 2], Henley, E. M.[1, 2], Quinn, M.[1, 2], Hagedorn, M.[1, 2]
[1]Smithsonian Conservation Biology Institute, Front Royal VA, United States
[2]Hawaii Institute of Marine Biology, Kaneohe HI, United States

bouwmeesterj[at]si.edu

Abstract

Coral reefs worldwide are undergoing profound changes due to climate change. Coral bleaching has now been reported in all tropical regions with coral reef ecosystems. Corals that survive bleaching events can suffer from temporary reproductive failure, sometimes lasting several years. While water temperature is the main driver in causing coral bleaching, other environmental factors are involved, such as solar radiation. These factors are often linked in natural reefs but can be decoupled in artificial systems. We investigated the individual and combined effects of temperature, photosynthetically active radiation (PAR), and ultraviolet radiation (UVR) on the spawning patterns and reproductive physiology of the mushroom coral *Lobactis scutaria* (Scleractinia: Fungiidae) over a three-month spawning period, using long-term experiments in aquaria. We observed effects on spawning timing, fertilization success, sperm and egg physiology, and growth. Both high temperature and blocked UVR altered the timing of spawning. High temperature caused a drop in fertilization success. High temperature and high PAR both negatively affected sperm and egg physiology. High temperature also slowed coral growth. These results help us to understand the mechanisms of how environmental factors that are known to cause damage to corals, affect coral reproduction. While thermal stress from global climate change will need to be adequately addressed to ensure the survival of reef-building corals in their natural environment throughout the next century and beyond, some damage related to photo-oxidative stress may be mitigated through shading reefs or corals on a regional scale, to reduce bleaching, maintain coral fitness, and maintain coral reproduction.

Oral
A-2032

The tradeoffs of niche partitioning across nutritional symbioses

Conti-Jerpe, I.[1], Thompson, P.[2], Wong, C. W. M.[2], Oliveira, N.[3], Duprey, N.[4], Moynihan, M.[5], Baker, D.[2]
[1]University of California Berkeley, Integrative Biology and Museum of Vertebrate Zoology, Berkeley, United States
[2]The University of Hong Kong, The Swire Institute of Marine Science, School of Biological Sciences, Pok Fu Lam Road, Hong Kong SAR China
[3]Universidade Estadual de Santa Cruz, Departamento de Ciências Biológicas, Ilhéus, Brazil
[4]Max Planck Institute for Chemistry (Otto Hahn Institute), Mainz, Germany
[5]Marine Biological Laboratory, Falmouth, United States

ingacontijerpe[at]gmail.com

Abstract

Coral reefs thrive in nutrient-limited tropical seas due to the nutritional symbiosis that exists between benthic invertebrates and endosymbiotic algae in the family Symbiodiniaceae. This syntrophic mutualism affords the holobiont access to both autotrophic (inorganic nutrients) and heterotrophic (particulate food) nutrition, maximizing nutrient assimilation from multiple sources and providing the energetic basis for one of the ocean's most productive and diverse ecosystems. Evidence suggests that the contribution of autotrophic vs heterotrophic food sources varies across species, however determining these differences in trophic niche is challenging due to the labor-intensive methods required to measure different nutritional pathways. We compared the trophic strategies of seven coral genera with Stable Isotope Bayesian Ellipses in R (SIBER) analysis applied to paired host and symbiont $\delta^{13}C$ and $\delta^{15}N$ values. We employed the overlap of host and symbiont isotopic niches (a proxy for trophic niche) and the distance between host and symbiont niche centroids as metrics of nutrient sharing and/or recycling within the holobiont. Our results revealed that corals exhibited a breadth of trophic strategies; some species had nearly complete overlap of host and symbiont isotopic niches, indicating strong mutualisms and a high reliance on autotrophy, while others had partial or non-overlapping niches, indicating mixo- and heterotrophy, respectively. Further, we investigated linkages between trophic strategy and bleaching resistance by subjecting seven coral species to a controlled warming experiment, eliciting bleaching responses. We found a significant correlation between the overlap of host and symbiont isotopic niche areas and the degree heating weeks at which >50% of individuals within a species bleached. Finally, we compared the trophic strategies of corals to that of five species of giant clams and three species of zoanthids. Clams and zoanthids were predominantly heterotrophic, but still exhibited variation in the extent of nutrient sharing. Our results support trophic niche partitioning across symbiotic benthic invertebrates, indicating that they play varying roles in nutrient import and cycling on reef ecosystems. Further, this work suggests tradeoffs between trophic strategies and indicates that autotrophic species which predominantly use inorganic nutrients will be the first to disappear from reefs.

10E - What phenotype, genotype, and environmental factors underlie coral vulnerability and resilience to thermal stress and bleaching?

Oral
A-1325

Transcriptomic Signatures of Physiological Response to Climate Change Stressors in a Threatened Coral

Dilworth, J.[1], Million, W.[1], Ruggeri, M.[1], Hall, E. R.[2], Dungan, A.[3], Muller, E.[4], Kenkel, C. D.[1]
[1]University of Southern California, Department of Biological Sciences, Los Angeles, United States
[2]Mote Marine Laboratory, Ocean Acidification Program, Summerland Key, United States
[3]The University of Melbourne, School of BioSciences, Parkville, Australia
[4]Mote Marine Laboratory, Coral Health and Disease Program, Sarasota, United States

jennadilworth[at]gmail.com

Abstract

Climate change is the most severe threat facing coral reefs worldwide. The combined effects of increasing sea surface temperatures and ocean acidification are of particular concern, and are likely to impact the recovery of coral reefs in the Florida Keys, where many threats have already contributed to the deterioration of these ecosystems in recent decades. Understanding how increased temperatures and ocean acidification interact and affect the physiology of reef-building corals and the mechanistic basis of these effects will be key to developing effective interventions to restore coral populations in a changing climate. We conducted a 2-month aquaria-based experiment to quantify the individual and combined effects of increased temperatures and pCO2 on 10 genotypes of the endangered coral *Acropora cervicornis*, a key species in coral restoration efforts. Previous work showed that the combined stressors often caused greater reductions in host, symbiont, and holobiont physiological functioning than temperature or acidification stress alone. However, significant genetic variation for most traits and a lack of negative correlations for any measured metrics suggest there are no significant trade-offs between adaptation to temperature and acidification stress, and that some level of resistance to these threats is already present among A. cervicornis genotypes widely used in restoration. To understand the underlying mechanisms of these physiological responses, we will use weighted gene co-expression analysis of RNA-seq data to quantify the effects of genotype and treatment on gene expression patterns in addition to examining correlations with higher order physiological traits. Preliminary results indicate that the synergistic effects of the combined heat and ocean acidification treatments previously observed in the coral physiological response are reflected in gene expression patterns. Several potential gene expression modules showed an increased response to the combined treatment compared to temperature treatment alone. Further investigation of these modules will expand our understanding of the mechanistic basis of differential physiological responses to stress, which will be essential to leveraging existing adaptive diversity to increase the resistance of restored coral populations.

Oral
A-1836

Enhanced hydrogen peroxide flux in corals by high water flow mitigating coral bleaching

Fujimura, A.[1], Mitarai, S.[2]
[1]University of Guam, Marine Laboratory, Mangilao, Guam
[2]Okinawa Institute of Science and Technology, Onna, Japan

fujimuraa[at]triton.uog.edu

Abstract

Studies in the last few decades have shown that bleaching of various coral species are mitigated by high water flow. One of the well-supported theories behind is enhancement of mass transfer by water current. High flow causes a thinning of the momentum boundary layer as well as the diffusive boundary layer that facilitates gas flux between the coral and the environment, thus efflux of harmful reactive oxygen species (ROS) from coral tissues increases. However, no study has directly measured ROS in the boundary layer under the water current. In this study we measured concentrations of hydrogen peroxide, a common ROS, within a few mm above the coral surface in a laboratory flume. Nubbins of Galaxea sp. and Acropora sp. were exposed to four different regimes (two temperatures 27°C and 32°C; two flows 3 cm/s and 15 cm/s) for 48 hours. In the high-temperature regime, concentrations of hydrogen peroxide over the corals and bleaching severity in the high-flow condition were lower than those in the low-flow. Additionally, we observed interspecific variability: Acropora sp. bleached more harshly than Galaxea sp. which produced less hydrogen peroxide and may be more heat-tolerant. This study supports the fact that water flow mitigates bleaching and adds the strong evidence to the theory that the mass transfer of ROS controls degrees of coral bleaching.

10E - What phenotype, genotype, and environmental factors underlie coral vulnerability and resilience to thermal stress and bleaching?

Oral
A-1915

The role of the endolithic alga during coral bleaching recovery.

Galindo-Martínez, C. T.[1], Weber, M.[1, 2], Avila-Magaña, V.[1, 3], Enríquez, S.[2], Kitano, H.[4, 5], Medina, M.[1], Iglesias-Prieto, R.[1]
[1]Penn State University, Department of Biology, University Park, United States
[2]Universidad Nacional Autónoma de México, Laboratory of Photobiology, Unidad Académica de Sistemas Arrecifales, Puerto Morelos, Mexico
[3]University of Colorado, Department of Ecology and Evolutionary Biology, Boulder, United States
[4]Okinawa Institute of Science and Technology Graduate School, Okinawa, Japan
[5]The Systems Biology Institute, Shinagawa, Tokio, Japan

czg30[at]psu.edu

Abstract

The optical properties of the scleractinian coral skeleton allow corals to be one of the most efficient light collectors in nature. However, this high light absorption efficiency combined with high solar irradiance makes scleractinian corals particularly vulnerable to increases in temperature. Any reduction in scleractinian coral optical cross-section, due to any stress, produces a large increase in the light availability due to the multiple light scattering by the coral skeleton. A considerable reduction in the optical cross-section causes a positive feedback loop that may surpass the limits of tolerance for the coral-dinoflagellate symbiosis and produce its breakdown (i.e. coral bleaching). Excessive light stress makes recovery of the remaining dinoflagellates impossible within the coral tissue. This raises the question about how different mechanisms by which scleractinian corals can recover after a bleaching event. In the current study we explored how corals can recover from bleaching, by monitoring the optical properties and pigment content in the coral *Orbicella faveolata* during and after a thermal induced bleaching event. Our results show that only coral fragments with high *Ostreobium* spp. presence in their coral skeleton are able to recover after bleaching. The scleractinian coral optical properties analysis suggest that, the *Ostreobium* bloom near the coral skeleton surface reduces the high light environment within the coral tissue by reducing the coral skeleton reflectivity. Consequently, it produces a dramatically reduction in the efficiency of harvesting sunlight by the dinoflagellates and allows them to recover. The proposed coral bleaching recovery mechanism focusses the need of the high light stress reduction in order to allow the dinoflagellates recovery but also, emphasizes the fact that the scleractinian coral skeleton optical properties are the main factor that modulate the internal light environment in the coral tissues.

Oral
A-1344

Increasing comparability among coral bleaching experiments and maximizing sample utility across studies

Grottoli, A.[1], Vega Thurber, R.[2], van Woesik, R.[3], Toonen, R.[4], Warner, M.[5], McLachlan, R.[1, 2], Schmeltzer, E.[2], Price, J.[1], Dobson, K.[1], Bahr, K.[6], Barott, K.[7], Barshis, D.[8], Baums, I.[9], Baumann, J.[10], Castillo, K.[11], Chapron, L.[1, 12], Coffroth, M. A.[13], Combosch, D.[14], Cunning, R.[15], Correa, A.[16], DeCarlo, T.[17], Donahue, M.[18], Felis, T.[19], Ferrier-Pagès, C.[20], Hagedorn, M.[4, 21], Hedouin, L.[22], Hench, J.[23], Hoadley, K.[24], Iglesias-Prieto, R.[9], Kemp, D.[25], Kenkel, C.[26], Kline, D.[27], Kuffner, I.[28], Matthews, J.[29], Mayfield, A.[30], Medina, M.[9], Meyer, C.[31], Oster, C.[19], Padilla-Gamino, J.[32], Palumbi, S.[33], Putnam, H.[34], Sawall, Y.[35], Voolstra, C.[36], Weis, V.[2], Wu, H.[37]
[1]The Ohio State University, School of Earth Science, Columbus, United States
[2]Oregon State University, Corvalis, United States
[3]Florida Institute of Technology, Melbourne, United States
[4]Smithsonian Conservation Biology Institute, Fort Royal, United States
[5]University of Delaware, Lewes, United States
[6]Texas A&M University, Corpus Christi, United States
[7]University of Pennsylvania, Philadelphia, United States
[8]Old Dominion University, Norfolk, United States
[9]Pennsylvania State University, University Park, United States
[10]Mt Holyoke College, South Hadley, United States
[11]University of North Carolina - Chapel Hill, Chapel Hill, United States
[12]Université Sorbonne, Banyuls-sur-Mer, France
[13]University at Buffalo, Buffalo, United States
[14]University of Guam, Mangilao, United States
[15]Shedd Aquarium, Chicago, United States
[16]Rice University, Houston, United States
[17]Hawaii Pacific University, Honolulu, United States
[18]University of Hawaii, Honolulu, United States
[19]University of Bremen, Bremen, Germany
[20]Centre Scientifique de Monaco, Monaco, Monaco
[21]Smithsonian Conservation Biology Institute, Kaneohe, United States
[22]Centre de Recherches Insulaires et Observatoire de l'Environnement, Papetōai, French Polynesia
[23]Duke University, Beaufort, United States
[24]University of Alabama - Tuscaloosa, Tuscaloosa, United States
[25]University of Alabama - Birmingham, Birmingham, United States
[26]University of Southern California, Los Angeles, United States
[27]Smithsonian Tropical Research Institute, Panama, Panama
[28]United States Geological Survey, St. Petersburg, United States
[29]University of Technology Sydney, Ultimo, Australia
[30]Atlantic Oceanographic and Meteorological Laboratory (NOAA), Miami, United States
[31]National Museum of Natural History - Smithsonian, Washington, United States
[32]University of Washington, Seattle, United States
[33]Hopkins Marine Station of Stanford University, Pacific Grove, United States
[34]University of Rhode Island, Kingston, United States
[35]Bermuda Institute of Ocean Sciences, St. George's, Bermuda
[36]Konstanz University, Konstanz, Germany, [37]ZMT, Bremen, Germany

grottoli.1[at]osu.edu

10E - What phenotype, genotype, and environmental factors underlie coral vulnerability and resilience to thermal stress and bleaching?

Abstract

Coral bleaching is the single largest global threat to coral reefs worldwide. Integrating the diverse body of work on coral bleaching experiments and maximizing what we can learn from each coral sample collected is critical to understanding and combating this global problem. Two National Science Foundation-funded workshops were held to develop common frameworks to 1) increase comparability among coral bleaching experiments but not stifle innovation and 2) optimize steps for coral collection, preservation, and archiving to increase the potential for collaboration and downstream analyses of coral samples. For coral experiments, reporting the number of genets used, collection site conditions, the experimental temperature offset(s) from the maximum monthly mean (MMM) of the collection site, experimental light conditions, flow, and the feeding regime will greatly facilitate comparability across studies. In addition, quantifying common response variables of Symbiodiniaceae and holobiont phenotypes (i.e., color, chlorophyll, endosymbiont cell density, mortality, and skeletal growth) could further facilitate cross-study comparisons. For coral samples, the rapid freezing of samples collected from experiments and field studies in liquid nitrogen or placing at −80℃ to −20℃ is optimal for most Omics and Physiology studies. Storage in aldehydes without freezing is optimal for Microscopy & Imaging-based analyses. Across all disciplines, the use of aseptic techniques during collection, preservation, and archiving allows for the greatest number of possible downstream analyses. While no single bleaching experiment can provide the data necessary to determine global responses of all corals to current and future ocean warming, broad adoption of these frameworks by the global coral research community would foster greater transparency, enhance the potential for collaborations, strengthen comparisons among studies, increase the information garnered from each sample, and facilitate synthetic insights into the causes and underlying mechanisms of bleaching. In turn, this would help inform coral reef management and facilitate conservation strategies to mitigate coral bleaching worldwide.

Oral
A-1188

Stable symbiont communities persist in parents, gametes, and larvae of Montipora capitata across historical bleaching phenotypes

Harris, C.[1], Bean, N.[2], Baker, A.[3], Gates, R.[4], Drury, C.[4]
[1]Nova Southeastern University, Halmos College of Natural Sciences and Oceanography, Dania Beach FL, United States
[2]California State University, Northridge CA, United States
[3]University of Miami, Rosenstiel School of Marine and Atmospheric Science, Miami FL, United States
[4]University of Hawaiʻi at Mānoa, Hawaiʻi Institute of Marine Biology, Kāneʻohe HI, United States

charris1[at]nova.edu

Abstract

Parental effects on early life history stages of corals are poorly understood, but with severe environmental disturbances, these impacts may be increasingly important in understanding future coral survival trajectories on reefs. This study investigated whether bleaching of *Montipora capitata* parent colonies in 2015 influenced offspring symbiont community composition and size three years after recovery. In July 2018, gametes were collected from Reef 13 in Kāneʻohe Bay, Oʻahu, Hawaiʻi, USA and selectively crossed to produce three different parental phenotype histories: 1) both parents previously bleached (“bleached” phenotype), 2) both parents previously non-bleached (“non-bleached” phenotype), and 3) crosses from a combination of both parental histories (“crossed” phenotype). Parental bleaching history affected the symbiont community composition in three different life history stages – parents, gametes, and larvae, with the bleached phenotype dominated by *Cladocopium* and non-bleached phenotype dominated by *Durusdinium*. Symbiont densities were also different between bleaching phenotypes in parents and gamete bundles but not in larvae, with non-bleached phenotypes having slightly higher symbiont densities than their bleached counterparts. Larvae from each phenotype were then exposed to either ambient or high-temperature conditions for 72 h and larvae from bleached phenotype parents were smallest regardless of temperature treatment. With these findings, larval recruitment to the reef from previously bleached parents is suspected to decline as ocean warming becomes more frequent and severe, potentially leading to generational symbiont community shifts. The direct heritability of thermal tolerance from parent to offspring in *M. capitata* provides opportunities for restoration by selectively breeding for traits that may increase community resilience to thermal stress.

10E - What phenotype, genotype, and environmental factors underlie coral vulnerability and resilience to thermal stress and bleaching?

Oral
A-1480

Bleaching resilience and recovery capacity of northwest Australian coral reefs - the role of coral host and symbionts

Jung, E. M. U.[1, 2, 3, 4], Stat, M.[5], Thomas, L.[2, 6], Koziol, A.[7, 8], Schoepf, V.[2, 3, 9]
[1]The University of Western Australia, School of Biological Sciences, Perth, Australia
[2]The Indian Ocean Marine Research Centre, The Oceans Institute, Perth, Australia
[3]The University of Western Australia, Oceans Graduate School and ARC Centre of Excellence for Coral Reef Studies, Perth, Australia
[4]University of Bremen, Department of Biology and Chemistry, Bremen, Germany
[5]The University of Newcastle, School of Environmental and Life Sciences, Callaghan, Australia
[6]The Indian Ocean Marine Research Centre, Australian Institute of Marine Science, Perth, Australia
[7]Trace and Environmental DNA (TrEnD) Laboratory, School of Molecular and Life Sciences, Perth, Australia
[8]Center for Evolutionary Hologenomics, GLOBE Institute, University of Copenhagen, Faculty of Health and Medical Sciences, Copenhagen, Denmark
[9]Institute for Biodiversity and Ecosystem Dynamics, University of Amsterdam, Department of Freshwater and Marine Ecology, Amsterdam, Netherlands

maria.jung[at]research.uwa.edu.au

Abstract

As marine heatwaves are increasingly threatening coral reefs, it is necessary to improve our understanding of mechanisms underlying coral heat tolerance. Insights into such mechanisms could be given by coral reefs which naturally experience strong temperature fluctuations. In northwest Australia's Kimberley region, coral reefs are exposed to the world's largest tropical tides which lead to highly fluctuating temperatures in the intertidal. Corals in the subtidal, however, experience only moderate daily temperature changes as they remain mainly submerged. In 2016, a marine heatwave caused unprecedented mass bleaching in the Kimberley where subtidal corals bleached more and recovered slower than intertidal corals. To better understand the mechanisms driving the observed differences in bleaching and recovery response in these corals, we investigated indicators of bleaching resilience in both host and symbionts of the coral *Acropora aspera*. We determined host tissue energy reserves (lipids, protein and carbohydrates), symbiont community composition and density, and chlorophyll *a* content in both visibly bleached and healthy corals during peak bleaching and seven months later. Corals bleached more severely in the subtidal than intertidal, and symbionts at low-abundance background levels differed significantly between bleached and healthy corals, and between habitats. However, the dominant symbiont type was the same in all corals (*Cladocopium* C3). Protein reserves were consumed by bleached/recovered corals from both habitats, however, in the subtidal, corals also catabolized energy-poor carbohydrate reserves yet suffered extensive mortality. In contrast, energy stores were predominantly maintained in intertidal corals which recovered rapidly after bleaching. Overall, the findings of this study demonstrate that the consumption of tissue energy reserves can be decoupled from bleaching resilience. This was unexpected because high levels of energy reserves and/or the ability to catabolize them during bleaching are widely thought to promote both bleaching resistance and recovery.

Oral
A-1893

Testing the relative ability of twelve Caribbean coral species to shuffle symbionts following bleaching in a controlled experiment

Karp, R.[1], Dennison, C.[1], Wen, A.[1], Cunning, R.[2], Baker, A.[1]
[1]University of Miami - Rosenstiel School of Marine and Atmospheric Science, Marine Biology and Ecology, Miami, United States
[2]John G. Shedd Aquarium, Daniel P. Haerther Center for Conservation and Research, Chicago, United States

rfk30[at]miami.edu

Abstract

Reef building corals form obligate symbiosis with dinoflagellates in the family Symbiodiniaceae whose identity can drive important phenotypes. One species, *Durusdinium trenchii*, is relatively heat tolerant, increases bleaching thresholds of its host, and is often found in higher abundances in corals after bleaching events. *D. trenchii* abundance, however, varies by coral species and environment. We used a controlled bleaching and recovery experiment to compare the relative propensities of twelve different Caribbean coral species (*Acropora cervicornis*, *Colpophylia natans*, *Diploria labyrinthiformis*, *Montastraea cavernosa*, *Orbicella faveolata*, *Meandrina meandrites*, *Porites astreoides*, *Porites porites*, *Pseudodiploria strigosa*, *Siderastrea siderea*, *Solenastrea bournoni*, and *Stephanocoenia intersepta*) to shuffle their symbiont communities in favor of *D. trenchii*. Fifteen genets of each species, dominated by symbionts in the genera *Symbiodinium*, *Breviolum*, and *Cladocopium*, were collected from six sites in Florida, and each genet was cored into four replicates. Cores were maintained in common-garden conditions for four weeks, and quantitative PCR (qPCR) was used to characterize initial Symbiodiniaceae communities. Temperatures were then increased by 0.5ºC per day to a temperature of 32ºC, and bleaching was quantified by measuring declines in photochemical efficiency (using chlorophyll fluorometry). Individual cores from each genet were moved to a recovery tank at 29ºC after 12, 16, 20, 22, and 30 days at 32ºC (corresponding to ~5.0, 6.0, 7.5, 9.0, and 11.0 DHWs respectively) and then sampled monthly to quantify changes in *D. trenchii* using qPCR. Non-metric multidimensional scaling (NMDS) evaluated symbiont shuffling and showed that nine of the twelve species significantly shuffled their symbiont communities ($P=0.001$). The ability for corals to associate with *Durusdinium* after bleaching was then quantified using a quasi-binomial GLM and identified significant effects of coral species ($P<0.01$), initial *Durusdinium* proportion ($P<0.01$), and degree of thermal stress ($P<0.01$). This study is the first to apply controlled methods to a suite of Caribbean species to reveal a hierarchy in their ability to shuffle symbionts in favor of *D. trenchii* and identify the factors that drive these changes, with important implications for the survivorship of these species, the future community composition of Caribbean reefs, and their management in an era of continued warming.

Oral
A-2063

Resilience mechanisms of coral populations in thermally fluctuating reef environments in Palau and the Florida Keys

Keister, E.[1], Warner, M.[2], LaJeunesse, T.[3], Fitt, W.[4], Kemp, D.[1]
[1]University of Alabama at Birmingham, Birmingham, United States
[2]University of Delaware, School of Marine Science and Policy, Lewes, United States
[3]Pennsylvania State University, Department of Biology, University Park, United States
[4]University of Georgia, Odum School of Ecology, Athens, United States

ekeister[at]uab.edu

Abstract

Many nearshore coral populations have an increased thermal tolerance compared to offshore conspecifics. We investigated coral organismal and symbiotic attributes from nearshore and adjacent offshore communities in Palau, Micronesia and the Florida Keys, USA. Nearshore Palauan coral populations were found to have stable and homogeneous associations with *Durisdinium trenchii*, a thermally tolerant microalgal symbiont, with no apparent physiological tradeoffs. Conversely, nearshore Florida Keys corals may be dominated by *D. trenchii* but these associations are often ephemeral. Additionally, maintaining high energy reserves and utilizing heterotrophy are both strong predictors of survivorship during stress events. This study compared these attributes between coral populations to identify organismal-specific strategies that enhance thermal tolerance. Specifically, we analyzed the prevalence of energy reserves (lipids, carbohydrates, and proteins) between nearshore and offshore coral populations. Next, we used stable isotopes ($d^{13}C$ and $d^{15}N$) to compare the diets between Palauan and Floridian nearshore and offshore coral populations. We found contrasting energy reserve quantities between near and offshore reefs in the Florida Keys, with significantly greater concentrations of important storage (wax esters, etc.) and structural (phospholipids) lipids found in nearshore populations. Intriguingly, conformity was found between energy reserves and important lipid classes from nearshore and offshore coral populations in Palau. Stable isotopes of animal tissue, skeleton, and algal symbionts indicated nearshore Palauan corals rely heavily upon heterotrophy to maintain metabolism, while for nearshore Floridan corals show a similar trend. These results reveal enhanced thermal tolerance can be achieved by utilizing multiple strategies, including organismal traits, trophic function, and symbiotic associations.

Oral
A-1452

Phenotypic and genotypic responses of restoration Acropora cervicornis under long-term and rapid thermal stress

Klepac, C.[1], Petrik, C.[1], Muller, E.[2]
[1]Mote Marine Laboratory, International Center for Coral Reef Research and Restoration, Summerland Key, United States
[2]Mote Marine Laboratory and Aquarium, Sarasota, United States

cklepac[at]mote.org

Abstract

To ensure the long-term survival of restored coral reef ecosystems, it is imperative to understand the responses of nursery corals to current and projected climate change stressors. For several years, Mote Marine Laboratory has exposed multiple coral species to increased temperatures and/or atmospheric carbon to determine overall phenotypic responses and which genotypes are more resistant. Although long-term studies emulate natural environmental stress, their laborious nature likely generates tank-acclimation effects and takes considerable time to inform restoration practitioners of which coral genotypes are best suited for long-term persistence. Alternatively, acute stress tests lasting <24 hours have the advantage of rapidly screening multiple genotypes from multiple species, a promising approach for Mote's hundreds of broodstock corals. Here, we sought to resolve potential overlap and differences in phenotypic responses of *Acropora cervicornis* under long-term and acute thermal stress. From April-June 2021, we exposed the same 10 genotypes of *A. cervicornis* to two months and 18 hours of increased temperatures. Non-destructive photophysiological measurements conducted during acute heat stress were made to compare the effects of temperature and genotype. Photochemical efficiency (*Fv/Fm*) values fitted to a dose-response curve revealed a species-level bleaching threshold of 34.45°C, 3°C greater than the maximum exposure temperature used during long-term or chronic stress (31.5°C). Visible bleaching and the decrease in *Fv/Fm* values differed over time, where bleaching responses were detected within 7 hours of the acute experiment but took 6 weeks in the chronic experiment. The acute experiment also revealed genotypic differences in heat tolerance that may have been masked by long-term acclimation in the chronic experiment, despite a lower overall photochemical efficiency in acute versus chronic heat stress. Seven of the ten genotypes were comparatively similar between the two experiments where only three genotypes displayed an effect of experiment type. Other physiological bleaching responses (chlorophyll content, host protein, and algal symbiont density) illuminated similarities and differences between the two types of experiments, highlighting the utility of acute experimental systems in the large-scale determination of resilient genotypes for prioritization in Mote's reproduction and restoration pipeline.

Oral
A-1694

Effects of symbiont community and environmental history on acute heat tolerance in two common coral species across the Great Barrier Reef

Nielsen, J.[1], Quigley, K.[2], Cooke, I.[3], Strugnell, J.[1], Suggett, D.[4], Bay, L.[2]
[1]James Cook University, College of Science and Engineering, Townsville, Australia
[2]Australian Institute of Marine Science, Townsville, Australia
[3]James Cook University, College of Public Health, Medical, and Veterinary Sciences, Townsville, Australia
[4]University of Technology Sydney, Climate Change Cluster, Sydney, Australia

spaekhugger[at]gmail.com

Abstract

Rising seawater temperatures associated with global climate change pose a significant challenge to the continued survival of many tropical corals due to the increased risk of coral bleaching. However, corals exhibit differential thermal tolerance and resilience to bleaching both within and among species and across populations. The causes of this variation are not well-understood. It is likely that genetic and physiological mechanisms as well as the capacity for plasticity in organismal stress responses underpin differential thermal tolerance and bleaching resilience in tropical corals.
To assess the variation in thermal tolerance between coral species and across multiple populations, we conducted acute thermal stress assays along the latitudinal gradient of the Great Barrier Reef (GBR) on two commonly occurring coral species (*Pocillopora verrucosa* and *P. meandrina*). Field-collected corals were distributed across four treatments (Max Monthly Mean; MMM, +3 ºC, +6 ºC and +9ºC) following standardised protocols. We quantified photosynthetic efficiency (F_v/F_m), tissue colour change, chlorophyll content, and Symbiodiniaceae densities after the experiments to provide insight into coral responses to acute thermal stress. To compare thermal tolerance between populations and species, we calculated ED_{50} temperature thresholds for multiple traits. For photosynthetic efficiency, ED_{50} temperatures varied by 2.4ºC above site-specific MMM in *P. verrucosa* over seven reefs and by 2.62ºC above MMM in *P. meandrina* over eight reefs. We discuss differences in thermal tolerance with respect to community composition of Symbiodiniaceae of each sampled colony. Finally, we combine data from physiology and symbiont communities with environmental drivers of tolerance such as thermal history to provide an overview of where to find tolerant populations of each species across the GBR.

Oral
A-1655

Gene expression analyses indicate hybrid vigor in the Caribbean Acropora hybrid "Acropora prolifera"

Osborne, C. C.[1], Fogarty, N. D.[2], Baums, I. B.[1]
[1]Pennsylvania State University, Biology, State College Pennsylvania, United States
[2]University of North Carolina, Biology Department, Wilmington North Carolina, United States

cco38[at]psu.edu

Abstract

Hybridization may be a route for corals to survive in a changing ocean climate, either through the introduction of novel alleles into an existing species via introgression or by forming a completely new and better adapted lineage. One of the best studied coral hybrid systems are the offspring of crosses between the Caribbean corals *Acropora palmata* and *A. cervicornis*, also known as *A. prolifera.* Though hybrid colonies originating from such crosses were infrequent in the past, recent field observations show an increase in *A. prolifera* thriving in shallow habitats that are exposed to extreme temperatures and irradiance as well as spreading into parental species' habitats. Additionally, preliminary evidence suggests the hybrid is more disease resistant than either parental species, demonstrating potential resilience in a warming ocean. This superior performance of a hybrid offspring to its parental species is termed 'heterosis'.

Here, we investigate the inheritance patterns underlying hybrid vigor, as well as the evolutionary/ecological implications of introgressive hybridization. To help elucidate the mechanisms of heterosis in *A. prolifera*, we placed fragments from the three acroporid taxa into tanks set at ambient temperature (30.5-31º C) or treatment stress temperature (31.5-32.5º C) until these samples showed signs of tissue sloughing. The experiment was done twice, once with colonies growing in a common garden at ~2 meters, and 5 months later with samples collected from their natal environment of varying depth (1-12 meters). Performance of the coral frags of each taxon were scored using mortality (tissue sloughing), *Symbiodinium* counts, and host protein concentration. *De novo* transcriptomes were assembled and annotated for all three taxa and gene expression patterns were evaluated via TagSeq. Finally, we evaluated which genes deviated from expected mid-parent gene expression value in the hybrid offspring and tabulated the expression pattern of inheritance (i.e additive, dominance, or over dominance) before using a network-based analysis. This approach revealed functional groups that help explain *A. prolifera's* superior performance in extreme environments and heightened stress tolerance, and may inform predictions of the evolutionary trajectory of the three taxa in response to rising ocean temperatures.

Oral
A-1952

Resilience from the physical environment: high flow conditions mitigate the onset of physiological stress in corals exposed to bleaching temperatures

Page, C.[1], Leggat, B.[2], Heron, S.[3], Fordyce, A.[2], Ainsworth, T.[1]
[1]University of New South Whales, Sydney, Australia
[2]University of Newcastle, Newcastle, Australia
[3]James Cook University, Townsville, Australia

c.page[at]unsw.edu.au

Abstract

The effects of thermal anomalies on tropical coral endosymbiosis can be mediated by a range of environmental factors, which in turn ultimately influence coral health and survival. One such factor is the water flow conditions over coral reefs and corals. Although the physiological benefits of living under high water flow are well known, there remains a lack of conclusive experimental evidence characterizing how flow mitigates thermal stress responses in corals. Here we use *in situ* measurements of flow in a variety of reef habitats to constrain the importance of flow speeds on the endosymbiosis of an important reef building species under different thermal regimes. We find that flow conditions affect coral endosymbiosis under thermal stress. Under high flow speeds (0.15 m s^{-1}) and thermal stress, coral endosymbionts retain photosynthetic function and recovery capacity for longer compared to low flow conditions (0.03 m s^{-1}). We hypothesize that this may be due to increased rates of mass transfer of key metabolites under higher flow, putatively allowing corals to maintain photosynthetic efficiency for longer. We also record a positive interactive effect between high flow and a pre-stress, sub-lethal pulse in temperature. While higher flow may delay the onset of photosynthetic stress, it does not appear to confer long-term protection. Sustained thermal stress eventually overwhelmed the coral meta-organism as evidenced in eventual declines in photo-physiological function and endosymbiont densities. Investigating flow patterns at the scale of meters within the context of these beneficial physiological impacts can reveal interesting avenues for coral reef management. This study increases our understanding of the effects of water flow upon coral reef health in an era of climate change and highlights the potential to learn from existing beneficial bio-physical interactions for the effective preservation of coral reefs into the future.

Oral
A-2036

Investigating the contribution of symbiont community on coral holobiont performance under long-term experimental warming and acidification

Rocha de Souza, M.[1], Bruce, J.[2], Conklin, E.[1], Cros, A.[3], Drury, C.[1], Jury, C.[1], Toonen, R.[1]
[1]University of Hawaii at Manoa, Hawaii Institute of Marine Biology, Kaneohe, United States
[2]Princeton University, High Meadows Environmental Institute, Princeton, United States
[3]Woods Hole Oceanographic Institution, Woods Hole, United States

mrds[at]hawaii.edu

Abstract

Coral reefs are increasingly threatened by climate-driven ocean acidification and warming, which can lead to reduced coral growth, increased coral bleaching and mortality. One mechanism of long-term acclimatization to thermal stress is the potential to modify the community composition of coral dinoflagellate endosymbionts (Family: *Symbiodiniaceae*) to more thermally tolerant lineages. While certain symbionts have been shown to increase thermotolerance of the coral holobiont, response of the coral endosymbiont community to acidification are less clear. Here we report results from a ~2.5 year mesocosm factorial design experiment, of temperature and pH, that investigated the composition and role of Symbiodiniaceae on holobiont performance in individual colonies of each of eight coral species (*Porites* spp., *Montipora* spp. & *Pocillopora* spp.) to future ocean conditions predicted under Paris Climate Agreement targets. Our results confirm that Symbiodiniaceae communities are highly specific in all coral species, but that community composition within individuals can change given enough time under different conditions. Temperature was found to be the main driver of changes in symbiont composition with no significant influence of acidification. Environmental legacy impacted the final Symbiodiniaceae community composition such that corals sourced from some sites developed significantly different symbiont communities under warmed conditions. In addition, we found that heat stress leads to an increase in proportional representation of thermally tolerant symbionts, but a decrease in overall Symbiodiniaceae diversity. Coral holobiont responses to future ocean conditions were variable among species. Some corals increase stress resilient symbionts (e.g., *Durusdinium*) whereas others became more vulnerable to the infection of opportunistic symbionts (e.g., *Symbiodinium* or *Breviolum*). We show that the algal symbiont community composition of corals changes in response environment, and that this response is dependent on both the coral species and their site of origin, highlighting the role of symbiont specificity and environmental memory in shaping coral resilience.

Oral
A-1721

Allocation of carbon and nitrogen for egg development in two coral species after natural and experimental bleaching events

Rodrigues, L. J.[1], Jaffe, M.[1], Brown, T.[2], Kreitman, G.[1], Padilla-Gamino, J.[2]
[1]Villanova University, Geography and the Environment, Villanova, United States
[2]University of Washington, Seattle, United States

lisa.rodrigues[at]villanova.edu

Abstract

The persistence of reefs will not only require the survival of adult colonies but will depend on continued sexual reproduction while thermally stressed. Little is known about the physiological mechanisms that corals use to develop gametes when stressed. Using pulse-chase experiments, we followed the acquisition of carbon and nitrogen by autotrophic and heterotrophic pathways in *Montipora capitata* and *Porites compressa* after a natural bleaching event and *M. capitata* after experimental bleaching. At 6, 8 or 9 months after each event, colonies that did and did not bleach were exposed to ^{13}C- and ^{15}N-labeled seawater or zooplankton; resulting stable carbon and nitrogen isotopic values were measured in host tissue, symbionts, eggs and egg-sperm bundles. Acquisition and allocation of autotrophic and heterotrophic carbon and nitrogen were traced to coral gametes for the first time. In both bleached and non-bleached corals of both species, autotrophy allowed for the acquisition of carbon and nitrogen to eggs, while heterotrophy favored the acquisition of nitrogen. After experimental bleaching, we traced the allocation of ^{13}C and ^{15}N to developing eggs of bleached and non-bleached *M. capitata* within 8 hours. This was consistent at 6 and 9 months after thermal stress. These labelled eggs were incorporated into egg-sperm bundles that were released from 1 week to 4 months later during the spawning season. Current analyses will quantify allocation of ^{13}C and ^{15}N to eggs in these same colonies during a second reproductive season (22 months after bleaching). Although there was no difference in the allocation of ^{13}C and ^{15}N for bleached and non-bleached corals after experimental bleaching, there were differences after a natural event. Adult tissues of bleached *M. capitata* and *P. compressa* incorporated 10-50% more labeled ^{13}C via autotrophy than corals that did not bleach during the natural event. Furthermore, naturally bleached *M. capitata* allocated more ^{13}C to developing eggs than to adult tissues during the spawning season. Thus, suggesting longer recovery times and greater impacts to reproduction after natural compared to experimental bleaching events, even when temperature stress was similar. Our findings have important implications for coral reproduction under frequent bleaching scenarios with less recovery time between events. This work provides an important baseline to assess the long-term impacts of bleaching on physiological recovery and sexual reproduction.

Oral
A-1122

Nanoceria alleviates thermally-induced oxidative stress in Symbiodiniaceae (Breviolum minutum)

Roger, L.[1], Russo, J.[2], Jinkerson, R. E.[2, 3], Giraldo, J.-P.[3], Lewinski, N. A.[1]
[1]Virginia Commonwealth University, Chemical and Life Science Engineering, Richmond, United States
[2]University of California Riverside, Chemical and Environmental Engineering, Riverside, United States
[3]University of California Riverside, Botany and Plant Sciences, Riverside, United States

rogerlm[at]vcu.edu

Abstract

Dysbiosis between cnidarian hosts and dinoflagellate algae partners (i.e. bleaching) has been linked to an immune-like response pathway brought on by a nitro-oxidative burst, a symptom of thermal stress. Nitro-oxidative stress is a problem common to aerobic systems. In this study we tested the antioxidant effects of engineered cerium oxide (CeO_2) nanoparticles on free-living Symbiodiniaceae (*Breviolum minutum*), a microalgae associated with reef building corals and anemones. Results show that poly(acrylic acid) coated CeO_2 with average particle diameters ~4 nm are internalized by *B. minutum* in under 30 minutes and subsequently localized in the cytosol. Nanoceria exposure does not inhibit cell growth over time, reaching an exponential growth phase between 25 and 30 days of exposure. Aerobic activity and thermal stress (culture temperature 34°C or +6°C above control for 1H) led to increased intracellular reactive oxygen species concentration with time. A clear scavenging effect of the nanoceria was observed with a 5 fold decrease in intracellular ROS levels during thermal stress. The nitric oxide (NO) concentration decreased by ~17% with thermal stress suggesting the rapid involvement of NO scavenging enzymes or proteins within 1 hour of stress onset. The presence of nanoceria did not appear to affect the NO concentration. Furthermore, aposymbiotic anemones (*Aiptasia pallida*) were reinfected with nanoceria loaded *B. minutum*, demonstrating that endosymbionts could serve as delivery agents of nanoparticles. Preliminary tests using nanoceria dispersions show that *Pocillopora acuta* nubbins treated with 0.5 ug/mL of nanoceria for 10H better tolerate acute thermal stress (+10°C). Future work will consist of additional endpoints such as enzyme and protein concentration measurement, investigating the delivery of nanoceria to coral cells, and applying thermal stress to reinfected anemones and corals to test this new treatment approach for bleaching.

Oral
A-1940

Assessing change in thermotolerance following manipulation of algal symbiont communities (Family Symbiodiniaceae) in five species of Caribbean coral

Wen, A., Karp, R., Yeager, E., Dennison, C., Baker, A.
University of Miami - RSMAS, Miami, FL, United States

adw44[at]miami.edu

Abstract

Many scleractinian reef-building coral species can host multiple algal symbiont taxa (Family Symbiodiniaceae). However, the increase in thermal tolerance that accompanies changes in symbiont communities, particularly those involving *Durusdinium trenchii*, has never been compared among coral species hosting different initial symbionts and, consequently, the relative benefit of hosting these symbionts during times of thermal stress has never been directly quantified across species. To assess these differences, we used controlled bleaching and recovery of five species of Caribbean coral (*Montastraea cavernosa, Orbicella faveolata, Siderastrea siderea, Solenastrea bournoni,* and *Stephanocoenia intersepta*) to manipulate algal symbiont communities in favor of *D. trenchii.* Ten colonies of each species were collected from Emerald Reef in Miami, Florida and cut into two halves. One half was bleached by exposure to high temperatures (32.5°C for 28 days, with an initial ramp rate of 0.5°C per day), while the other half was maintained at ambient conditions (28°C). Complete bleaching of the heated fragments was observed after ~5.3 to 11.0 degree heating weeks (DHWs), and these corals were then allowed to recover for 5.5 months at 29°C. Bleached corals recovered with *D. trenchii* as a function of coral species, initial symbiont community, and degree of heat stress. Following recovery, both manipulated and non-manipulated halves were divided into replicate cores that were then exposed to a second episode of heat stress (at temperatures up to 33.5°C and >25 DHWs) to compare the relative increase in thermotolerance following exposure to heat stress and symbiont community shifts towards *D. trenchii*. Differences in thermal tolerance were measured by assessing changes in symbiont to host cell ratio (using quantitative PCR) and photochemical efficiency (using chlorophyll fluorometry) and bleaching susceptibility rankings were produced as a function of coral host species and algal symbiont community structure. These findings will help assess the degree to which different coral species might change their thermal performance in response to more frequent and severe episodes of heat stress and help improve the success of interventions that use pre-exposure to heat stress as a means of improving the climate resilience of restored corals.

Poster
A-1230

Patterns and implications of morphological and physiological trait variation in Acropora hyacinthus

Benson, B., Bay, R.
University of California, Davis, Evolution and Ecology, Davis, United States

bebenson9[at]gmail.com

Abstract

Efforts to investigate drivers of intraspecific variation in bleaching have traditionally focused on genetic and physiological differences in the coral host. This work has shown that energy budgets in the form of proteins and lipids, light capture strategies, symbiont type and density, tissue thickness, metabolic rates and more all influence bleaching responses. Nevertheless, the mechanisms underlying the links between trait variation and bleaching outcomes remain poorly understood. Comparative studies across coral genera have revealed that variation in morphology is also frequently linked to divergence in ecological traits in the coral host. Bleaching susceptibility is known to vary by colony morphology, with massive species tending to be less susceptible than branching species. These differences have been hypothesized to result from covariation in life history and physiology among species. However, the relationship between morphological and physiological traits has rarely been explored at the species level, despite expected links through processes including biomass packing, mass transfer, and light capture. We therefore hypothesize that we can improve models of bleaching responses by incorporating morphological traits and their interactions with physiology. Here, we characterize the major axes of physiological and morphological trait variation in 80 colonies of *Acropora hyacinthus* from Moorea, French Polynesia. We report protein and lipid content, total biomass, symbiont density, and tissue thickness. Landmark morphometric analyses are used to analyze variation in corallite structure and reported alongside additional skeletal characters measured via stereomicroscopy. We couple these data with estimates of relative bleaching susceptibility in these colonies to explore the relationship between morphology and physiology, and to test their impact on bleaching responses in common garden conditions. This work seeks to strengthen our understanding of key trait interactions underlying coral bleaching and provides a basis for the continued development of trait-based approaches to understanding adaptive capacity under global change.

Poster
A-1925

Large-scale restoration of Acropora corals along the Florida Reef Tract: understanding what factors influence restoration success.

Levy, J., Neufeld, A., Moura, A., Winters, S.
Coral Restoration Foundation, Tavernier, United States

jessica[at]coralrestoration.org

Abstract

Once largely abundant throughout the Florida Keys and Caribbean, Acropora cervicornis and A. palmata populations have drastically declined (>98% at some locations). This stark decline is due to multiple, compounding stressors, both natural and anthropogenic in origin. As this decline continues with little sign of abatement, there is a clear need for innovative methods to bolster remaining coral populations. Coral restoration efforts have emerged as a critical discipline in tropical coral-reef conservation and management. While the urgency around coral decline has prompted practitioners to try a variety of restoration techniques, these efforts need to incorporate best-practices that support genetic diversity, ecological function, and resiliency for successful coral restoration outcomes. Incorporating conservation genetics for the recovery of a species is essential, especially in the era of accelerating change.

There are many factors that contribute to survivorship and success of restoration efforts. Here we examine the varying roles of two of those factors: coral genetics and reef environment. Guided under the Acropora Recovery Plan released by NOAA in 2015, an ambitious Acropora coral restoration effort was launched in 2016 to better understand what influences success of coral restoration efforts. Specifically, this restoration effort was designed to understand what factors influences performance of outplanted corals: is it their genotype or the restoration site itself?

For two species (A. cervicornis and A. palmata), nearly 50 distinct genotypes of each species, and over 50,000 corals, were outplanted onto eight reef sites along the Florida Reef Tract. In an effort to promote diversity within outplanted corals, genotypes of each species were sequenced prior to the launch of the project. Corals selected for this outplanting effort were chosen to ensure the largest range of genetic diversity possible. Here, we present preliminary findings from monitoring efforts of the outplanted Acroporids from all eight restoration sites. This information sheds insight into the varying roles genetics and environment plan into the survivorship restored populations. This restoration strategy, coupled with subsequent tracking of coral health post-outplanting, can provide insights as to what factors promote survivorship and resilience of restored coral populations in the face of a changing ocean environment.

Poster
A-1689

Corals in crisis: how temperature and nutrient fluctuations affect physiological responses of corals and their microbiome in Kāneʻohe Bay, Hawaiʻi

Ruben, Z.[1], Pinnell, L.[2], Abdulla, H.[1], Turner, J.[1], Bahr, K.[1]
[1]Texas A&M University - Corpus Christi, Corpus Christi, United States
[2]Texas A&M University, Canyon, United States

ztruben[at]gmail.com

Abstract

Coral reefs are the foundation of the social, cultural, and economic life in Hawaiʻi; however, these reefs have not escaped the conditions that have ravaged coral reefs worldwide. Along the east coast of Oʻahu lies Kāneʻohe Bay, which serves as a living laboratory with a distinct difference in environmental gradients due to variation in circulation and residency times. Landward, there is a distinct gradient of cesspool presence and therefore a gradient of potential effluent intrusion and nutrient loading to these reefs. Together, these provide a unique opportunity to explore the impact of water quality and ongoing ocean warming on coral health, susceptibility, and tolerance. This research investigates how temperature and nutrients influence the coral holobiont across a spatial and temporal environmental gradient. Pairs of known bleached/non-bleached corals were collected at two sites within Kāneʻohe Bay which encompass this spatial gradient in temperature and nutrient influence. Corals were then subjected to experimental treatments (Control, Nutrient, Heated, Heated + Nutrient) for one month. Measurements of bleaching were collected at the beginning, middle, and end of the experiment, and coral subsamples were collected at the beginning and end of the experiment for subsequent metagenomics analysis. I hypothesize that (A) coral subjected to a combined increase in temperature and nutrients will experience higher levels of bleaching and lower levels of survivorship, (B) historically non-bleached phenotypes will show higher levels of survivorship than their historically bleached counterparts, and (C) there will be an observed shift in microbial community composition across corals due to these stressors. If validated, these findings will support that coral bleaching susceptibility is manifested throughout the coral holobiont and the physiological response to stressors such as temperature and nutrient loading can be better understood and potentially mitigated, therefore supporting reef resiliency and restoration in the face of climate change.

10E - What phenotype, genotype, and environmental factors underlie coral vulnerability and resilience to thermal stress and bleaching?

Virtual
Oral
A-2004

Empirically derived thermal thresholds of four coral species along the Red Sea using a portable and standardized experimental approach

Evensen, N.[1], Voolstra, C.[2], Fine, M.[3], Perna, G.[2], Buitrago-López, C.[2], Cárdenas, A.[2], Banc-Prandi, G.[3], Rowe, K.[4], Barshis, D.[1]
[1]Old Dominion University, Norfolk, United States
[2]University of Konstanz, Konstanz, Germany
[3]Bar Ilan University and The Interuniversity Institute of Marine Sciences, Eilat, Israel
[4]University of Waikato, Hamilton, New Zealand

nevensen[at]odu.edu

Abstract

Global warming is causing an unprecedented loss of species and habitats worldwide. This is particularly apparent for tropical coral reefs, with an increasing number of reefs experiencing mass bleaching and mortality on an annual basis. As such, there is a growing need for a standardized experimental approach to rapidly assess the thermal limits of corals and predict the survival of coral species across reefs and regions. Using a portable experimental system, the Coral Bleaching Automated Stress System (CBASS), we conducted standardized 18 h acute thermal stress assays to quantitively determine the upper thermal limits of four coral species across the length of the Red Sea coastline, from the Gulf of Aqaba (GoA) to Djibouti (~2100 km). We measured dark-acclimated photosynthetic efficiency (F_v/F_m), algal symbiont density, chlorophyll a, and visual bleaching intensity following heat stress. F_v/F_m was the most precise response variable assessed, advancing the F_v/F_m effective dose 50 (ED50, i.e. the temperature at which 50% of the initial F_v/F_m is measured) as an empirically derived proxy for thermal tolerance. ED50 thermal thresholds from the central/southern Red Sea and Djibouti populations were consistently higher for *A. hemprichii, P. verrucosa,* and *S. pistillata* (0.1°C - 1.8°C above GoA corals, respectively), in line with prevailing warmer maximum monthly means (MMMs), though were lower than GoA corals relative to site MMMs (1.5°C – 3.0°C). *P. verrucosa* had the lowest thresholds overall. Despite coming from the hottest site, thresholds were lowest for *P. lobata* in the southern Red Sea, suggesting long-term physiological damage or ongoing recovery from a severe, prior bleaching event. Altogether, the CBASS resolved historical, taxonomic, and possibly recent environmental drivers of variation in coral thermal thresholds, highlighting the potential for a standardized, short-term thermal assay as a universal approach for assessing ecological and evolutionary variation in the upper thermal limits of corals.

10E - What phenotype, genotype, and environmental factors underlie coral vulnerability and resilience to thermal stress and bleaching?

Virtual
Oral
A-1085

Investigating genotypic variability of Acropora cervicornis for survivorship and growth rates in response to thermal stress

Haider, K., Langdon, C.
Rosenstiel School of Marine & Atmospheric Sciences, University Of Miami, Marine Biology & Ecology, Miami, United States

khadija.haider[at]rsmas.miami.edu

Abstract

Climate change has been one of the major threats to the coral reefs across the globe. Interestingly, the thermotolerance of coral taxa is associated with; coral species, their symbiont type, location of origination, life stage, microbiota etc., whereas no importance is given to the host's genetic diversity within a species. *Acropora cervicornis*, once a widespread coral in Florida is now on the IUCN's red list of critically endangered species, hence calling for a dire attention to conservation. It is important to note that *A. cervicornis* exclusively hosts *Symbiodinium 'fitti'* in the Florida Reef Tract (FRT). Therefore, this study focused on the response of various genotypes of *A. cervicornis* to the thermal stress in terms of survivorship and growth rates. Two experiments were conducted to identify the thermal stress resistant and susceptible genotypes. The treatments were mild thermal stress (31°C) and severe thermal stress (32°C). *A. cervicornis* ramets (n=106) of known genotypes (n=14) were obtained from upper FRT. After a month of acclimation to the ambient temperature (30°C) in the lab, the temperature was ramped to the treatment temperatures at the rate of 0.3°C /day. Corals were rotated among the lab tanks and were fed twice a week. Coral growth was monitored through tri-weekly buoyant weight measurements, while mortality was monitored through observations for tentacle extension, tissue sloughing and filamentous algae on everyday basis. Results show that there is a two-fold difference in survivorship of different genotypes in response to mild as well as severe thermal stress. Moreover, the stress resistance and susceptibility of genotypes is consistent in both experiments. Interestingly, there is a strong positive correlation in terms of survivorship and growth at individual coral level (R^2=0.37) as well as at the genotypic level (R^2=0.64). This study not only leads to the determination of resistant genotypes of the endangered *A. cervicornis* for active restoration but also ensures that the thermal stress resistant genotypes have the capacity to thrive through faster growth.

10E - What phenotype, genotype, and environmental factors underlie coral vulnerability and resilience to thermal stress and bleaching?

Virtual
Oral
A-2123

Differential thermal stress responses of scleractinian corals from Belle Mare, Mauritius

Jeetun, S.[1], Ricot, M.[1], Munbodhe, V.[1], Taleb-Hossenkhan, N.[1], LaJeunesse, T.[2], Baird, A.[3], Flot, J.-F.[4], Bhagooli, R.[1]
[1]University of Mauritius, Department of Biosciences and Ocean Studies, Faculty of Science & Pole of Research Excellence in Sustainable Marine Biodiversity, Réduit, Mauritius
[2]Pennsylvania State University, Department of Biology, 327 Mueller Laboratory, University Park, United States
[3]James Cook University, ARC Centre of Excellence for Coral Reef Studies, University Drive, Townsville Q 4811, Australia, [4]Université libre de Bruxelles (ULB), Evolutionary Biology & Ecology, Bruxelles, Belgium

sruti.jeetun[at]gmail.com

Abstract

Various studies have shown varying patterns of bleaching susceptibilities of different coral species around the world. For example, various growth forms of coral taxa can affect their bleaching tolerance as can the type of symbiont each colony hosts. However, the situation with the corals in the Mauritian waters is still uncharted with respect to the proper symbiont identification and their respective thermal tolerances. This study investigates the photo-physiological response of eight coral species of different growth forms, branching *Porites* sp. and *Acropora muricata*, tabular *Acropora* sp. and *Acropora branchi*, foliose *Montipora* sp. and *Pavona* sp., solitary *Lithophyllon* sp. and massive *Porites* sp. from Belle Mare, Mauritius. Diving pulse-amplitude modulation fluorometry (D-PAM) was used to examine the PSII functioning of the corals during exposure to elevated temperatures of 27°C, 30°C and 32°C for a period of 48 hours. Genetic characterisation of the symbionts was performed by the amplification of the 18S small ribosomal subunit using zooxanthellae-specific PCR primers followed by Sanger sequencing and BLAST sequence analysis. After 48 h incubation, there was no significant change in the maximum quantum yield of photosystem II (PSII) (F_v/F_m) in the *Pavona*, *Lithophyllon* and massive *Porites* species analysed and their F_v/F_m values were as follows: 0.72 ± 0.02, 0.70 ± 0.02 and 0.58 ± 0.07, respectively. *Montipora* survived at 30°C after 48 h with a Fv/Fm value of 0.72 ± 0.02 but did not at 32°C. However, a drastic decrease in the (F_v/F_m) was observed in tabular *Acropora* sp. and *A.muricata* from 0.69 ± 0.02 and 0.66 ± 0.05, respectively, to 0, at 32°C after 6 h and observations at 19 h showed that they did not survive. Genetic analyses showed that *Durusdinium* sp. was present in *Montipora*, *Cladocopium* sp. in *Lithophyllon* sp., branching *Porites* and *A. branchi* while tabular *Acropora, A. muricata* and *Pavona* sp. harbored *Symbiodinium* sp. symbionts. The massive and foliose coral species were the most tolerant whereas the branching and tabular growth forms were the most affected.

Virtual
Poster
A-1882

Exploring mechanisms of coral thermal tolerance across species and thermal regimes in southern Taiwan: a complementary ex-situ and in-situ approach

McRae, C. J.[1], Keshavmurthy, S.[2], Chen, H.-K.[1], Ye, Z.-M.[1], Meng, P.-J.[1], Rosset, S. L.[3], Huang, W.-B.[4], Chen, C. A.[2], Fan, T.-Y.[1], Côté, I. M.[5]
[1]National Museum of Marine Biology & Aquarium, Checheng, Taiwan
[2]Academia Sinica, Taipei, Taiwan
[3]Victoria University of Wellington, Wellington, New Zealand
[4]National Dong Hwa University, Hualien, Taiwan
[5]Simon Fraser University, Burnaby, Canada

crystal.j.mcrae[at]gmail.com

Abstract

Ocean warming and marine heatwaves are impacting coral reefs globally resulting in increasing instances of mass bleaching and mortality. Coral thermal resistance and resilience to elevated temperatures, however, is not uniform among reef sites and can show inter- and intra-specific variability based on coral host and holobiont characteristics. We compared the performance of three species of corals (*Acropora nana, Pocillopora acuta*, and *Porites lutea*), sourced from two reefs with distinct thermal regimes (stable vs. variable), within: 1) a chronic (12 weeks at 26°C or 30°C) and then acute (8 days at 32°C) heat stress experiment, and 2) a 15-month in-situ monitoring study. Under chronic elevated temperature exposure, we found species-specific responses and some differences between reef sites, but overall corals were able to tolerate long-term warming above seasonal mean temperatures. In contrast, substantial bleaching occurred after acute exposure to temperatures ~2°C above their mean summer maxima across all species regardless of their source reef. Seasonal in-situ monitoring of these 3 coral species revealed that a higher proportion of colonies from the thermally variable reef consistently hosted a more thermally tolerant genus of algal symbiont (*Durusdinium*), whereas colonies from the thermally stable reef typically hosted a more thermally sensitive genus (*Cladocopium*). Assessment of the coral holobiont lipidome showed that neither total lipids nor the ratio of storage to structural lipids differed between reef sites for any of the coral species, further no seasonal trends in lipid dynamics were observed. By studying these sites and species, in both an ex-situ and in-situ context, we aim to better understand the role that reef thermal regime and life history traits play in coral thermal adaptive capacity.

Session 10F - What role do non-genetic mechanisms play in adaptation of reef inhabitants to climate change?

Conceptualized and chaired by: **Manuel Aranda Lastra**[1], **Hollie Putnam**[2], **Mikhail Matz**[3]
[1] KAUST (Thuwal, Saudi Arabia)
[2] The University of Rhode Island (Kingston, RI, USA)
[3] The University of Texas at Austin (Austin, TX, USA)

Oral
A-1946

Induced phenotypic plasticity and methylome repatterning derived from changes in light regimes in Acropora palmata

Gomez-Campo, K.[1], Sanchez, R.[1], Martinez-Rugerio, I.[1, 2], Yang, X.[1, 3], Maher, T.[1], Enríquez, S.[2], Baums, I. B.[1], Mackenzie, S. A.[1, 3], Iglesias-Prieto, R.[1]
[1]The Pennsylvania State University, Biology, University Park, United State
[2]Universidad Nacional Autónoma de México, Unidad Académica de Sistemas Arrecifales, Puerto Morelos, Mexico
[3]The Pennsylvania State University, Plant Science, University Park, United States

kellygomezcampo[at]gmail.com

Abstract

Phenotypic plasticity is essential to acclimation, representing a more rapid response to environmental change than through adaptation, and a key element in the fitness of species. Generally, animals are less phenotypically plastic than plants, but symbiotic corals present plant properties. They are photosynthesis-dependent with a sessile and modular construction that facilitates rapid morphological changes within their lifetime. Epigenetic modifications triggered by environmental effects have been linked in plants to plasticity. Here, we investigated whether phenotypic changes are paralleled by epigenetic variation in *Acropora palmata*; well-known for its intraspecific variation. Fragments from 3 genotypes were sampled from uppersides (exposed to direct sunlight) and undersides (exposed to 10% of incident light) of branches, and placed on a reef-deployed structure that simulated the colony position. Once acclimated, each treatment group was exposed to the opposite light condition. Both control and treatment groups revealed characteristic phenotypes, described by fluorescence *in hospite*, photosynthetic and respiration rates, optical and morphological properties. Methylome analysis was performed with a novel signal detection-based approach designed to discriminate methylation regulatory signal from background population variation. The analysis identified 900 to 2000 Differentially Methylated Genes DMGs containing Differentially Methylated Positions. Biologically meaningful enriched networks of DMGs were identified. Hierarchical clustering revealed 2 groups, represented by controls and treatments, suggesting a strong methylome modification with changes in light conditions. PC-Scores derived from principal component analysis prioritized genes carrying the highest discriminatory power that contributed to the clustering: genes related to the regulation of mitotic cell cycle, apoptosis, biomineralization, signal transduction, transcription factors, and alternative splicing. Our results show that *Acropora palmata* presents significant light-driven phenotypic plasticity that is associated with methylome changes. These observations support an emerging link between plasticity and epigenetic modifications. The associated mechanisms may be key in driving acclimation to changing light environments in *Acropora palmata*, especially after natural fragmentation, and should inform our understanding of limits to acclimation of this endangered species.

Oral
A-1076

Epigenetic mechanisms of rapid acclimation in Acropora nana

Guerrero, L., Bay, R.
University of California, Davis, Evolution and Ecology, Davis, United States

leaguerrero[at]ucdavis.edu

Abstract

Thermal acclimation, the process by which thermal history alters tolerance to heat stress, can ameliorate the bleaching response of acroporid corals during warming events by increasing bleaching resistance. Previous studies have found that increased thermal tolerance after acclimation is coupled with dampened response of heat stress gene expression during subsequent heat stress events. This suggests that gene expression plasticity is influenced by cellular mechanisms that preserve the memory of thermal history. Previous studies in acroporid corals and other invertebrate systems show that increased gene body DNA methylation, a stable epigenetic modification, is correlated with a reduction in expression plasticity of environmentally responsive genes. However, we know little about this epigenetic layer as a potential mechanism for thermal memory leading to transcriptional tuning after rapid acclimatory treatments. Here, we hypothesize that gene bodies of genes with differential expression under heat stress are differentially methylated after eleven days of thermal acclimation in the reef building coral, Acropora nana. Fragments of A. nana colonies were acclimated to eleven days of sublethal warming (31ºC) or control (29ºC) followed by a 5-hour acute heat stress assay (34ºC). Tissue was collected for RNA-Seq and whole genome bisulfite sequencing (WGBS). Colonies exposed to acute heat stress following thermal acclimation had a lower magnitude heat stress response in 893 contigs compared to non-acclimated controls. Based on these results and previous studies, we expect that, following acclimation, coding regions of heat stress transcripts are hypermethylated compared to the rest of the genome and compared to non-acclimated controls. Further, we expect that methylation changes induced by acclimation persist through the acute heat stress assay. Results from this study will enhance our understanding of the cellular mechanisms that preserve thermal memory after short-term thermal acclimation, potentially protecting corals from bleaching during warming events.

Oral
A-2000

Environment influences potential for epigenetically-mediated performance legacies across a generation in a reef building coral

Putnam, H.[1], FACE PUF Spawning Team, Hedouin, L.[2]
[1]University of Rhode Island, Biological Sciences, Kingston, United States
[2]CRIOBE CNRS, Moorea, French Polynesia

hputnam[at]uri.edu

Abstract

Parental provisioning and transgenerational epigenetic inheritance are two mechanisms by which information from the environment experienced by the adults can be transmitted to offspring. This is particularly critical information for sessile, reef building corals, as environmental-performance mismatch can be detrimental, and preconditioning may provide beneficial acclimatory capacity. Here using a transplant experiment, we examined the impact of sites with differing thermal variance on the reproductive capacity (fecundity, egg size, eggs per bundle, and sperm motility) of adult *Acropora hyacinthus* colonies in Mo'orea French Polynesia, as well as mechanisms whereby environmental information can be transmitted across a generation (maternal egg mRNA and sperm DNA methylation). *A. hyacinthus* colonies from the lower thermal variance forereef site had consistently higher fecundity, larger egg size, more eggs per bundle, and greater sperm motility compared to those transplanted to the backreef. Significant differentially expressed genes were apparent between the sites, demonstrating that environment during gametogenesis influenced maternal mRNA provisioning. Genes with greater expression levels in the high thermal variance backreef location included, for example, those associated with thermotolerance (e.g., caseinolytic peptidase B protein and sacsin) and a histone variant H2B L4, whereas histone H2A had higher expression in the forereef samples. Sperm samples analyzed with methyl binding domain enrichment and bisulfite sequencing (MBD-BS) showed potential epigenetic inheritance in the functions of translation and sperm capacitation. This study of reproductive performance, in combination with maternally-provisioned gene expression and paternally-inherited methylation patterns, provides a picture of how offspring performance is shaped across a generation by prior environmental history and epigenetic mechanisms.

Poster
A-1945

Symbiotic plasticity in Acropora spp.: juveniles develop symbiosis with heat tolerant Symbiodiniaceae in long-term experiment

Moeller, M.[1], Nietzer, S.[1], Hume, B.[2], Voolstra, C.[2], Schupp, P.[1]
[1]University of Oldenburg, ICBM, Environmental Biochemistry, Wilhelmshaven, Germany
[2]University of Konstanz, Department of Biology, Konstanz, Germany

mareen.moeller[at]uol.de

Abstract

The future of coral reefs depends on the ability of corals to adapt to elevated water temperatures within the century. Developmental plasticity and symbiotic plasticity in juvenile corals have the potential to allow for rapid adaptation of the coral holobiont.
Here we conducted a long-term experiment with two spawning coral species with horizontal Symbiodiniaceae transfer (*Acropora digitifera* and *Acropora hyacinthus* var. *surculosa*). We reared juveniles in reef water and exposed them to different temperature regimes (ambient, +1 °C, +2 °C) during their first year after settlement to assess survival in relation to Symbiodiniaceae association. Remarkably, the survival of the *Acropora* recruits was not significantly affected, even at 31 °C, which is a lethal temperature for their parental colonies within three weeks of exposure. However, the juvenile corals at the higher temperatures grew significantly less than the ones reared under ambient summer water temperatures (29 °C). Determination of Symbiodiniaceae community composition based on ITS2 type profile determination via SymPortal revealed that the juvenile *Acropora* exposed to higher temperatures were exclusively associated with genotypes of the heat tolerant Symbiodiniaceae *Durusdinium trenchii*, which were not found in their parental colonies from the reef.
We conclude that exposure to altered environmental conditions such as elevated temperature during the formation of the symbiosis in juvenile corals with horizontal symbiont transfer affects the types of Symbiodiniaceae association with direct consequences on thermal tolerance and survival of the coral holobiont. Whether the *D. trenchii* association enabled the survival, or was a product of the survival, remains to be investigated. Nevertheless, this form of flexible association could be a form of rapid adaptation to rising water temperatures within just one generation with putative major implications for coral reef resilience.

Session 10G - What role does phenotypic plasticity play in acclimatization or adaptation to environmental change?

Conceptualized by: **Sarah Davies** [1], **Carly Kenkel** [2], **Ross Cunning** [3], **Jeremie Vidal-Dupiol** [4]
[1] Boston University (Boston, Ma, USA)
[2] University of Southern California (Los Angeles, CA, USA)
[3] John G. Shedd Aquarium (Chicago, IL, USA)
[4] Université de Montpellier (Montpellier, France)

Chaired by: **Sarah Davies** [1], **Carly Kenkel** [2]

Oral
A-1724

Genetic drivers of coral response to diel thermal variability

Aichelman, H. E.[1], Benson, B. E.[1, 2], Castillo, K. D.[2], Baumann, J.[2], Nieves, O. C.[1], Pereslete, A. M.[1], Rippe, J.[2], Stanizzi, D. A.[1], Tsang, L. C.[1], **Davies, S. W.**[1]
[1]Boston University, Department of Biology, Boston, United States
[2]University of North Carolina at Chapel Hill, Department of Marine Science, Chapel Hill, United States

daviessw[at]gmail.com

Abstract

Coral bleaching predictions typically consider duration and magnitude of elevated temperatures relative to a locally defined thermal threshold; however, recent work suggests that heterogeneity in bleaching patterns may be better explained by degree of diel thermal variation (DTV). We sourced colonies of the Caribbean reef-building coral *Siderastrea siderea* from six reefs across Bocas del Toro, Panama which ranged in mean DTV (~1-3ºC). We conducted a 50-day common garden experiment to assess the influence of low, moderate, and high DTV (2, 3, and 4ºC, respectively) and then performed a two-week thermal challenge (32ºC) followed by a two-week recovery period. Metrics of coral host (growth, carbohydrate, protein, tissue thickness, corallite area) and symbiont (carbohydrate, chlorophyll, density, and mitotic index) physiology were assessed to disentangle how natal reef DTV modulates a coral's response to experimental DTV, thermal stress, and recovery. Additional factors known to contribute to holobiont (coral host and microbial partners) physiology were also characterized, including ITS2 and 16S metabarcoding to establish algal symbiont and microbiome communities, as well as reduced representation genome sequencing (2b-RAD) to assess host genetics. Results suggest that corals sourced from higher DTV sites outperformed corals from less variable sites, regardless of treatment; however, this pattern was nearly perfectly explained by the presence of two cryptic host lineages (termed lineage1 and lineage2) that exhibit distinct phenomes. Corals belonging to lineage1 tended to host *Durusdinium* algal symbionts, had elevated photochemical efficiencies under thermal challenge, displayed increased baseline phenotypes across all metrics considered, bleached less, and grew more under variable conditions. These data suggest that local environments that vary in DTV and other environmental parameters (i.e., light) serve as selective sieves for coral diversity across relatively small spatial scales, and resulting distributions of genetic variation across the seascape might help explain spatial heterogeneity in coral bleaching. Overall, our results highlight the need to consider cryptic host diversity when evaluating coral resilience to global change and how this diversity may influence reef restoration efforts.

Oral
A-1740

Environmental memory gained from exposure to extreme diel pCO2 variability promotes coral cellular acid-base homeostasis

Brown, K.[1, 2], Mello-Athayde, M.[2], Sampayo, E.[2], Chai, A.[2], Dove, S.[2], **Barott, K.**[1]
[1]University of Pennsylvania, Philadelphia, United States
[2]University of Queensland, School of Biological Sciences, St. Lucia, Australia

kbarott[at]sas.upenn.edu

Abstract

Ocean acidification is a growing threat to coral growth and the accretion of coral reef ecosystems. Corals inhabiting environments that already endure extreme diel pCO_2 fluctuations, however, may represent acidification-resilient populations capable of persisting on future reefs. Here, we examined the impact of diel seawater pCO_2 variability on the cosmopolitan reef-building coral *Pocillopora damicornis* originating from two distinct reef habitats with contrasting environmental conditions (variable reef flat v. stable reef slope) following reciprocal exposure to stable or variable diel pCO_2 mesocosms. Symbiont density, photosynthesis and calcification rates differed between origins, but these traits showed no evidence of phenotypic acclimatization to novel pCO_2 conditions over two months. However, primary calcification (i.e., extension) was affected by pCO_2 treatment, exhibiting an interaction between origin and pCO_2 variability. At the cellular level, corals from the variable reef flat in the variable treatment exhibited less intracellular pH (pHi) acidosis and faster pHi recovery rates in response to acute extracellular acidification stress than corals originating from the stable reef slope, suggesting environmental memory gained from life-long exposure to pCO_2 variability led to an improved ability to regulate acid-base homeostasis. The results of this study highlight the role of cellular processes in maintaining acidification resilience to acute acidification stress and suggest that prior exposure to pCO_2 variability may promote more acidification resilient coral populations in a changing climate.

Oral
A-1820

Beefing Up Corals for the Reef: Is Nutritional Status Predictive of Outplanting Success?

DAlessandro, M., Hesley, D., Unsworth, J., Lirman, D.
University of Miami RSMAS, Miami, United States

mdalessandro[at]rsmas.miami.edu

Abstract

Region-wide losses of numerous coral taxa have prompted coral restoration efforts throughout South Florida and the Caribbean. To date, the majority of population enhancement efforts in the Caribbean have focused on the asexual propagation of the fast-growing, threatened staghorn coral, *Acropora cervicornis*. The University of Miami maintains a diverse stock of staghorn coral originating from a wide range of environments from over 20 reefs along Florida’s Coral Reef that are propagated within two common-garden nurseries. Having access to this large number of genotypes allows us, for the first time, to explore spatial drivers of coral responses, potential for local adaptation, and trade-offs among phenotypic traits within different environments. We completed a reciprocal outplanting study involving more than 1,200 staghorn corals from 20 genotypes, deployed across 6 different reef locations spanning a distance of 50 miles. To test the role of local adaptation, site controls were outplanted alongside nursery-reared corals at each of the study sites. After 6 months, the outplanted corals were measured and sampled to determine if phenotypic traits including coral growth, lipid and chlorophyll concentrations, and endosymbiont community composition varied among genotypes and reefs, which were spread along a latitudinal thermal gradient. With bleaching and disease events predicted to increase in frequency and severity as a result of climate change, it is crucial to consider various physiological and environmental factors when selecting genotypes for restoration to maximize success. Higher lipid concentrations in corals have been linked to a heightened tolerance to disturbances such as thermal extremes, which begs the question: can coral lipids be predictive of productivity and survivorship following the transfer from benign nursery environments to reef? The findings of this study are expected to reveal novel information that will help us understand if restored and wild reefs alike are capable of adapting to rapidly changing environments in the face of climate change.

Oral
A-1634

The role of phenotypic plasticity in Acropora palmata survival in a restoration context

Elder, H.[1], Million, W.[1], Bartels, E.[2], Krediet, C.[3], Lee, S.[1], Kenkel, C.[1]
[1]University of Southern California, Los Angeles, United States
[2]Mote Marine Laboratory, Summerland Key, United States
[3]Eckerd College, St. Petersberg, United States

helder[at]usc.edu

Abstract

The interaction of genotype and environment (GxE) makes it difficult to predict the success of individual coral outplants used in restoration programs. Environments exhibit variation in abiotic parameters that change the number and severity of stressors corals experience. Phenotypic plasticity enables an organism to alter expression of its traits in response to environmental variation without a change in genotype. Genotypes can also differ in their capacity for plasticity, which can influence their evolutionary response. The interaction of plasticity and genotype can change the survival outcome or fitness of a coral outplanted to different reef environments. This study quantifies the contributions of fixed genetic differences and plasticity in coral phenotype on the ultimate survival of a coral outplant to improve predictive understanding of GxE effects. Five genotypes of common garden reared sexually produced *Acropora palmata* were transplanted in replicates of three in each of nine offshore sites in the lower Florida Keys. Growth, bleaching status, and survival were monitored with 3D photogrammetry every three months for two years. Survival of each genotype remained at 80% on average, but significant site-specific effects were observed, with some sites exhibiting 100% mortality by 18 months while others experienced 0% to 30% mortality in as many months. Tissue samples taken at the initial time point and two years post-transplantation will be used to quantify shifts in gene expression, symbiont community, and microbiome composition. This study presents a unique opportunity to observe dynamics and test the stability of symbiont and host relationships across environments as these corals were reared in a land-based coral nursery where they developed a novel association with *Durusdinium trenchii* unlike their wild counterparts which associate with a *Symbiodinium* species. Our preliminary results indicate that genotype as well as plastic response should be considered when determining which corals should be considered for restoration programs and what sites can be considered viable restoration sites.

Oral
A-1917

Contrasting Phenotypic Plasticity of Scleractinian Corals: a Multi-marker Approach within Pacific Ocean Natural Populations

Furla, P.[1, 2], Porro, B.[1, 2], Zamoum, T.[1, 2], Tara Pacific Consortium
[1]University Cote d'Azur, Nice, France
[2]IRCAN CNRS, Nice, France

furla[at]unice.fr

Abstract

Coral reefs are severely threatened by global and local environmental changes. Anthropogenic derived stressors such as climate change and pollution are having devastating consequences on coral reefs, leading to disease and symbiosis breakdown, known as "bleaching", which if persistent, may contribute to high mortality rates. Susceptibility to environmental changes and subsequent mortality varies among coral species. This difference in response to the environment has been attributed variously to different causes as the host genetic background, specific holobiont composition (the combination of different host species with one or multiple Symbiodiniaceae and bacteria lineages), nutrient supply, pre-conditioning to past-repeated environmental changes. However, the contribution of each of these drivers to the coral's phenotypic response, and to what extend this is conserved within a coral genus or within scleractinian corals living in a broad range of environmental conditions, remains unclear. The present study assessed the biological response to the environment of two emblematic coral species complexes with different lifestyles, *Pocillopora* spp. and *Porites* spp. that were sampled at an unprecedented ecological scale throughout the Pacific Ocean. The analysis of the phenotypic signatures of these corals and the correlation of these data to other TARA Pacific Expedition datasets, revealed that the environmental stress response is coral genus dependent, and that *Pocillopora spp* is susceptible to a broader range of environmental drivers than *Porites* spp. Surprisingly, and in contrast to the current idea, this study also reveals that the symbiont content is not responsible of the phenotypic observed responses.

Oral
A-1094

Environment trumps genetics: Cryptic lineages share gene regulatory mechanisms to acclimatize to environmental variation in two Caribbean corals

Gallery, D., Rippe, J. P., Matz, M.
University of Texas at Austin, Integrative Biology, Austin, United States

dgallery[at]utexas.edu

Abstract

A recent study has shown that two common Caribbean corals, *Montastrea cavernosa* and *Siderastrea siderea*, in the Florida Keys each consist of four genetically distinct lineages. These lineages are strongly specialized to a certain depth and, to a lesser extent, to nearshore-offshore reef locations. Here, we aimed to investigate if adaptive regulatory evolution associated with ecological specialization has contributed to the divergence between the genetic lineages. We hypothesized that the genetic differences between lineages would be the primary driver of differential gene expression in nature; however, we find that environmental factors drive the majority of the gene expression variation. We did not detect a significant correlation between genetic differentiation between lineages and gene expression divergence. Overall, these results imply that both *M. cavernosa* and *S. siderea* possess high transcriptomic plasticity to acclimatize to different environmental conditions and that these gene regulatory mechanisms are shared across cryptic genetic lineages.

Oral
A-1529

Relationships between epigenetic modifications and phenotypic plasticity of Acropora cervicornis across spatial and temporal environmental variation

Hackerott, S.[1], Virdis, F.[2], Eirin-Lopez, J.[1]
[1]Environmental Epigenetics Lab, Florida International University, Institute of Environment, North Miami, United States
[2]Reef Renewal Foundation Bonaire, Kralendijk, Caribbean Netherlands

shack013[at]fiu.edu

Abstract

Coral cover has declined globally due to a combination of local and global stressors and the ability of corals to adapt to changing environments is a critical concern. Epigenetic modifications, or heritable modifications to gene function that are responsive to environmental conditions, likely play a major role in coral phenotypic plasticity and acclimatization. As opposed to adaptation through natural selection, the epigenetic regulation of gene function has the potential to promote acclimatization more rapidly, within a single generation. However, the role of epigenetic modifications in modulating coral performance and responses to environmental stress is not yet well described. This study assesses relationships between epigenetic DNA methylation and phenotypic plasticity of an important reef-building species in the Caribbean: *Acropora cervicornis*, or the staghorn coral. Spatial and temporal environmental variation on Bonaire, Caribbean Netherlands, was utilized as a natural experiment, exposing four genotypes of *A. cervicornis* to differing environmental conditions. In collaboration with Reef Renewal Foundation Bonaire, 240 corals were monitored at three sites over a complete seasonal cycle. Temperature, conductivity, and nutrient concentrations varied temporally across seasons, as well as spatially across sites. Demographic performance was quantified by monitoring survival and quantifying growth rate. Physiological performance was characterized with indicators of metabolism and symbiosis including biomass, total protein, and chlorophyll concentration. In addition to genotype, both site and seasonal timepoint were significantly related with coral performance, demonstrating phenotypic plasticity driven by environmental conditions. Patterns of DNA methylation, an epigenetic modification linked to the capacity for phenotypic plasticity in corals, will be described using the Methylation-Sensitive Amplified Polymorphism method. The observed variation in coral performance is expected to be related to variation in epigenetic DNA methylation, particularly between genetic clones experiencing different environmental conditions. Additionally, redundancy analyses will be used to partition the variance of coral performance between epigenetic and genetic influences. This study will provide insights into the role of epigenetic mechanisms in mediating coral phenotypic plasticity across ecologically relevant combinations of environmental stressors.

Oral
A-1361

Evidence for adaptive morphological plasticity in the Caribbean coral, Acropora cervicornis

Million, W.[1], Ruggeri, M.[1], O'Donnell, S.[1], Bartels, E.[2], Krediet, C.[3], **Kenkel, C.**[1]
[1]University of Southern California, Department of Biological Sciences, Los Angeles, CA, United States
[2]Mote Marine Laboratory, Elizabeth Moore International Center for Coral Reef Research and Restoration, Summerland Key, FL, United States
[3]Eckerd College, Department of Marine Science and Biology, St. Petersburg, FL, United States

ckenkel[at]usc.edu

Abstract

Genotype-by-environment interactions (GxE) indicate that variation in organismal traits cannot be explained by fixed effects of genetics or site-specific plastic responses alone. For tropical coral reefs experiencing dramatic environmental change, identifying the contributions of genotype, environment, and GxE on coral performance will be vital for both predicting persistence and developing restoration strategies. We quantified the impacts of G, E, and GxE on the morphology and survival of the endangered coral, *A. cervicornis*, through an in situ transplant experiment exposing common garden (nursery) raised clones of ten genotypes to nine reef sites in the Florida Keys. By fate-tracking outplants over one year with colony-level 3D photogrammetry, we uncovered significant GxE on coral size and survivorship indicating that no universal winner exists in terms of colony performance. Moreover, the presence of GxE also implies the existence of intraspecific variation in phenotypic plasticity. Rather than differences in mean trait values, we find that individual-level morphological plasticity is adaptive in that the most plastic individuals also exhibited the fastest growth and highest survival. This indicates that adaptive morphological plasticity may continue to evolve, influencing the success of *A. cervicornis* and resulting reef communities in a changing climate. As focal reefs are active restoration sites, the knowledge that variation in phenotype is an important predictor of performance can be directly applied to restoration planning. Taken together, these results establish *A. cervicornis* as a system for studying the eco-evolutionary dynamics of phenotypic plasticity that also can inform genetic- and environment-based strategies for coral restoration.

Oral
A-1150

Coral color reflects divergent thermal stress responses

Moscato, V.[1], Combosch, D.[2], **Lemer, S.**[3]
[1]Boston University, Boston, United States
[2]University of Guam, Marine Laboratory, Mangilao, Guam, [3]University of Guam Marine Lab, Mangilao, Guam

sarah.lemer[at]gmail.com

Abstract

Emerging studies suggest that coral color plays a role in bleaching resilience, however the molecular patterns behind coral color and response to heat stress have yet to be characterized. We examine the relationship between environmental stress and color phenotypes in *Acropora surculosa* in their natural environment and in controlled experiments at both physiological and transcriptomic levels. Surveys of *A. surculosa* over a depth gradient showed higher proportions of brown phenotypes at shallow depths, in more variable environments, while red phenotypes were in higher proportions at deeper, more stable environments. We then sequenced 36 transcriptomes of *A. surculosa* to explore gene expression patterns of red and brown color phenotypes during two sequential, acute heat stress assays. For the first time, we show that red and brown phenotypes have drastically different transcriptomic responses to heat stress, despite the absence of genetic structure between the two color morphs. Specifically, red phenotypes are more sensitive to thermal stress and require more energy to manage stress. In contrast, brown phenotypes were better prepared to cope with thermal stress and utilized more oxidative stress management to mitigate stress. We implicate fluorescent protein abundance and type as a driver of observed differences in stress response between color phenotypes due to energetic trade-offs made between synthesis of fluorescent proteins and other processes. Expansion of our research to additional coral genera will have vast applications across coral management and research, as coral color is simple to identify and can be linked to specific life and stress management strategies.

Oral
A-2087

Mechanisms driving symbiont shuffling in corals

Raharinirina, N.[1, 2], Acevedo-Trejos, E.[1, 3], Wild, C.[4], **Merico, A.**[1, 5]
[1]Leibniz Centre for Tropical Marine Research, Theoretical Ecology and Modelling, Bremen, Germany
[2]Zuse Institute Berlin, Mathematics of Complex Systems, Berlin, Germany
[3]German Research Centre for Geosciences, Earth Surface Process Modelling, Potsdam, Germany
[4]University of Bremen, Marine Ecology, Bremen, Germany
[5]Jacobs University Bremen, Physics and Earth Sciences, Bremen, Germany

agostino.merico[at]leibniz-zmt.de

Abstract

The success of scleractinian corals in oligotrophic waters of the tropics is the result of an endosymbiotic association with unicellular photoautotrophs called zooxanthellae (the symbiont). By providing photosynthetic products, the symbionts satisfy most of the corals' metabolic needs. Increasing sea temperature causes the breakdown of this association, the expulsion of the symbionts and, in severe cases, the death of corals. Observational evidence suggests that the shift in the relative abundance of resident symbiont populations within the coral host (symbiont shuffling) enables corals to transcend their thermal tolerance limits because some symbionts are more thermally tolerant than others. The mechanisms of symbiont shuffling, however, are poorly understood. We present here a new trait-based, acclimation dynamics model with which we show that classic competition theory can explain symbiont shuffling when the competitive abilities of different symbionts are driven by their thermal tolerances. We also show that rapid symbiont shuffling can occur (1) with the presence of a positive feedback, according to which some of the symbiotic benefits received by corals are re-allocated to symbiont growth, thus yielding even higher benefits, or (2) by keeping a background population size of non-dominant symbionts, which enables them to become abundant once conditions become favourable. Our results narrow down the mechanisms that could help reconcile the different patterns observed in symbiont population dynamics and provide new model theories that can be tested with laboratory experiments.

Oral
A-1434

Shallow and mesophotic S. pistillata share regulatory strategies of photosynthetic electron transport but differ in their sensitivity to light

Roberty, S.[1], Vega de Luna, F.[2], Pierangelini, M.[2], Levy, O.[3], Plumier, J.-C.[1], Cardol, P.[2]
[1]University of Liège, InBioS - Ecophysiology, Liège, Belgium
[2]University of Liège, InBioS, Liège, Belgium
[3]Bar Ilan University, Lab for molecular marine ecology, Ramat Gan, Israel

sroberty[at]uliege.be

Abstract

Coral endosymbionts of the Symbiodiniaceae family can exhibit a wide range of physiological responses to environmental variations and stress, allowing their hosts to occupy a wide range of environmental niches but also significantly contributing to their persistence under global change. Among the external environmental conditions acting as the driving forces responsible for particular pairings between both partners, light is very likely the most important. In the natural environment, the holobiont has to cope with significant daily variations in light intensities that sometimes exceed endosymbiont photosynthetic capacity and promote the production of reactive species. This implies the existence of regulatory mechanisms in the symbiont that mitigate the excitation pressure. This can be done by dissipating excess light as heat or diverting electrons in excess through alternative electron flow (AEFs). Although a growing number of studies indicated that some AEFs (Cyclic Electron Flow or Mehler reaction) could be important among the Symbiodiniaceae, especially under stress conditions, we have limited information on how these pathways operate in symbiosis.
The scleractinian coral *Stylophora pistillata* has been intensively studied to better understand the photosynthetic acclimation of corals to depth. The main photosynthetic strategy of these corals to acclimate to different light intensities relies on the capacity of photosystem II (PSII) to regulate the light energy input. However, little information is known about the role of the other photosynthetic complex photosystem I (PSI) on the photosynthetic acclimation of these species. In this work, shallow and mesophotic coral colonies were used to evaluate the activity of photosystem I under different light conditions. Under control conditions the maximum PSII activity was consistently lower in mesophotic colonies, contrasting with a PSI activity comparable between colonies from both depths. After exposure to HL intensity, the photosynthetic capacity of mesophotic corals was highly suppressed in contrast to its PSI activity, which remained at a relatively high level. These results indicated the enhanced use of alternative electron pathways, such CEF, although at different extents in colonies from both depths. This study highlights the importance of PSI activity as a photoprotective mechanism under conditions of PSII photodamage, and the extraordinary resistance of PSI activity to high irradiance in corals.

Oral
A-1526

Measuring Coral Feeding in a Changing Ocean: A Metabolic Framework Using Fatty Acids

Love, C.[1], Stuhr, M.[2], Radice, V.[3], Fox, M.[4], Fine, M.[5], Valentine, D.[1]
[1]University of California, Santa Barbara, Earth Science, Santa Barbara, United States
[2]Leibniz Zentrum für Marine Tropenforschung, Bremen, Germany
[3]Old Dominion University, Norfolk, United States
[4]King Abdullah University of Science and Technology, Thuwal, Saudi Arabia
[5]Interuniversity Institute for Marine Sciences, Eilat, Israel

clove[at]ucsb.edu

Abstract

With coral reefs around the world experiencing increasing ocean temperatures, acidification and eutrophication, the innate ability of corals to feed on particles and plankton has never been so important. Coral feeding provides nitrogen and phosphorus during healthy times, enhances resistance to bleaching and is typically the only way corals can meet nutritional needs during bleaching events. Corals that can feed more in the water column when conditions are less than ideal are likely to have increased survivorship in the coming decades. Yet, coral feeding remains poorly understood. Fatty acid (FA) analysis has been used for marine food webs and is gaining popularity to understand the balance between coral heterotrophy and autotrophy on reefs. FA analysis is cost effective and scalable and provides more data (~25 per sample) than bulk tissue stable isotope analysis (1-2 per sample) which has traditionally been used to qualitatively assess coral feeding. However, there currently exists little backbone to interpret FA results of coral samples collected in the field. We conducted a large-scale feeding experiment on *Stylophora pistillata* in the mesocosm tanks of the Red Sea Simulator in Eilat Israel with high replication (n ~ 30/ condition) and four feeding conditions across a gradient from full autotrophy to full heterotrophy. We measured 26 FAs of separate host and symbiont fractions in response to the feeding gradient as well as a suite of physiological parameters (including bulk tissue stable isotope analysis). We show that fatty acids acquired through feeding are reliably recorded into coral tissue and indexes of specific FAs can be made to hone in on consumption of distinct food source types, showing the power of this analysis. Additionally, we employ dimensional-reduction analyses of our 26 fatty acids to assess the ability to measure %heterotrophy of corals as well as proportional contributions from different dietary sources. We put these FA data in context with our physiological data to act as an interpretive metabolic and physiological framework for a more detailed view of coral feeding as it occurs on the reef. Fatty acid analysis of corals has the ability to give detailed information on coral trophic ecology and should be used more frequently if we wish to measure parameters of coral physiology that will affect future survivorship of reefs.

Oral
A-1197

Measuring symbiont expulsion rates in Caribbean reef corals: A non-invasive approach to studying coral-algal symbiosis

Yeager, E., Wen, A., Karp, R., Johnson-Sapp, K., Hardy, K., Williamson, O., Dennison, C., Baker, A.
University of Miami, Rosenstiel School of Marine and Atmospheric Science, Miami, United States

eay8[at]miami.edu

Abstract

The mutualistic relationship between scleractinian corals and diverse dinoflagellate algae (Family Symbiodiniaceae) is critical to the competitive success of coral communities on tropical reefs and underpins their response to ongoing climate change. Corals that associate with different symbiont types have been shown to vary in their growth rates, thermal tolerance, and disease susceptibility, and have been observed to exchange their symbionts with the environment to some degree, but this has seldom been explored in detail. Here we designed a set of experimental protocols to: (1) determine whether symbionts expelled from coral hosts can be detected in the surrounding water; (2) compare expulsion rates in stressed vs. healthy corals; (3) test whether expulsion rates vary by coral species and/or symbiont type; (4) compare temporal differences in symbiont expulsion rate (day vs. night, summer vs. winter); (5) determine whether symbionts in the surrounding water are representative of the symbiont communities in the coral host; and (6) assess whether expelled symbionts can be effective as sources for new symbiont cultures. Standard protocols involved using replicate 2.5cm-diameter cores of Caribbean coral species (including Orbicella faveolata, Montastraea cavernosa, Pseudodiploria clivosa, and Diploria labyrinthiformis) placed in 150mL 0.2µm-filtered seawater and maintained at 28°C and 110 µEinsteins m-2s-1 irradiance for 7h. The surrounding water was then concentrated to 1.5mL, and a 500µL aliquot of each sample removed for quantitative PCR (qPCR) with the remainder fixed for cell counts using a hemocytometer. Cell counts and qPCR data were then paired with chlorophyll fluorometry (I-PAM) data to relate changes in expulsion rate among different Symbiodiniaceae to their physiological status. Preliminary results indicate expulsion rates vary by coral species, symbiont taxa, and stage of stress and recovery. Results also indicate that water sampling can be an effective method of non-destructively characterizing symbiont communities in early-stage coral recruits. Studying symbiont expulsion may help us understand how symbiont populations are regulated to achieve homeostasis (over timescales ranging from hours to seasons), elucidate mechanisms of coral-algal symbiosis and dysbiosis, and quantify symbiont availability in environmental pools,with implications for coral restoration and interventions.

Poster
A-1512

Identifying the traits of coral resilience to climate change on Guam’s reefs

Bentlage, B., Lock, C., Anthony, C., McDermott, G., Miller, T., Raymundo, L.
University of Guam, Marine Laboratory, Mangilao, United States

bastian.bentlage[at]gmail.com

Abstract

Recurring coral bleaching events severely reduced coral cover on the reefs of Guam, Micronesia over the last decade. Rising sea surface temperatures are expected to increase the frequency of coral bleaching, which will have adverse effects on the ecosystem services provided by coral reefs. In addition to partial or complete mortality caused by bleaching, corals affected by or recovering from bleaching may be prone to infection by pathogens, causing disease outbreaks. We employ a common garden approach to generate a time series of trait data and health impacts that will facilitate understanding differences in the stress responses among coral taxa, enabling predictions on how corals will respond to changing environments regionally and globally. In particular, our common gardens focus on three major reef building corals, including their naturally occurring color morphs, that fall along the spectrum of low to high stress and bleaching resilience: 1) *Acropora* cf. *pulchra*, 2) *Porites cylindrica*, and 3) the *Porites lutea*/*lobata* species complex. Functional traits of these corals, including their algal symbionts, will be tracked over a 4-year period to identify traits that confer resilience to environmental change. Following outplanting of coral fragments in early 2021, we began tracking the immediate stress responses of our study corals to transplantation, examining bleaching and color shifts, disease initiation, predation susceptibility, tissue dieback and subsequent recovery via growth, and skeleton deposition onto substrate. To understand algal symbiont diversity and dynamics, we use metabarcoding to track symbiont community composition over time and employ pulse amplitude modulated (PAM) fluorometry to document photosystem performance. We are particularly interested in elucidating the role that coral host pigmentation (color differences between morphs) plays in resilience, including its role in modulating symbiont diversity and photosystem performance.

Poster
A-1492

Biochemical profiles of Acropora digitifera during a mild heat stress event in Palau showed higher total biomass in high heat tolerant corals

Platz, T.[1], Humanes, A.[2], Beauchamp, E. A.[2], Lachs, L.[2], Guest, J. R.[2], Bythell, J.[2], Edwards, A.[2], Golbuu, Y.[3], van der Steeg, E.[2], Martinez, H. M.[2], Hagen, W.[4], Dorschner, S.[4], Strahl, J.[5]
[1]Carl von Ossietzky University Oldenburg, Oldenburg, Germany
[2]School of Natural and Environmental Sciences, Newcastle University, Newcastle upon Tyne, United Kingdom
[3]Palau International Coral Reef Center, Koror, Palau
[4]University of Bremen, Bremen, Germany
[5]HIFMB at the University of Oldenburg, Oldenburg, Germany

tc.platz[at]gmail.com

Abstract

Selective breeding of more heat tolerant coral colonies is an unconventional and original intervention to enhance stress resilience to intensifying environmental conditions as part of an assisted evolution strategy. The underlying principle would be to identify individuals with high acclimation potential and above-average heat tolerance and breed chosen phenotypes to increase the frequency of stress tolerant individuals within populations. For the selective breeding approach to be successful, the underlying physiological mechanisms for increasing heat tolerance in corals must be understood. To investigate a possible correlation between heat tolerance and physiological performance, we examined the biochemical profiles of corals within a population of *Acropora digitifera* during a mild thermal stress event in October 2020 in a nearshore reef in Palau. Seventeen months prior, 94 independent adult colonies had been tagged in the field, and live branches of each colony (6 per colony) were exposed for four weeks to temperature stress (+3.5 C above ambient sea surface temperatures) in a controlled aquarium experiment. Based on their average mortality and bleaching response to gradually increasing temperatures, we assigned a bleaching and mortality index (BMI) to each colony. For this study, 36 colonies representing a range of BMI values from high to low were snap-frozen and used for analysis of health and energy storage markers. In the examined corals, higher heat tolerance significantly correlated with a higher ash-free dry weight percentage. An increased absolute biomass could serve as a useful energy resource for maintaining health during an acute heat stress event. However, analysis of total protein and lipid content and fatty acid composition did not reveal any particular significant shift in energy storage reserves between high and low heat tolerant individuals. Similarly, analyses of photosynthetic pigments and carbonyl protein content, as markers of bleaching and cellular damage accumulation, also did not yield clear trends, suggesting that the mild heat stress event did not significantly affect the corals studied. By linking heat tolerance to biomass, the results of this study offer new insights into the underlying physiological mechanisms of individual heat tolerance in corals. Higher investment in total biomass could serve as a marker of high heat tolerance, as this could improve coral resilience to temperature extremes.

Poster
A-1847

Using gene expression biomarkers to predict stress in Acropora corals in Guam

Sartor, C., Rouzé, H., Lemer, S.
University of Guam, Mangilao, Guam

constancesartor[at]gmail.com

Abstract

As ocean temperatures rise globally, the search for simple tools that can help reef managers better predict and identify coral stress response has become more critical. Certain corals in Guam inhabit more environmentally variable shallow reef flats than their conspecifics in other locations and may provide insight into how some coral individuals respond to stress. We used a combination of *in-situ* reciprocal transplants and *ex-situ* tank experiment approaches to identify and characterize gene expression biomarkers capable of detecting early signs (before visible signs of bleaching) of thermal, light and sediment stress in *Acropora surculosa*. In the reciprocal transplant experiment we used whole transcriptome sequencing to identify distinct transcriptomic patterns in corals living on shallow (i.e. high variations in temperature and light) versus deep (i.e. low variations in temperature and light) reefs. When transplanted to the deeper site, shallow corals showed 'transcriptional dampening', indicating acclimation. When transplanted to the shallower site, deep corals exhibited a pronounced 'Type B' environmental stress response (ESR). After ten-week, there was still evidence of transplantation stress closely resembling a 'Type A' ESR in both transplant groups. We data-mined the transcriptome dataset to select genes with a strong response to stress. We then used RT-qPCRs to characterize their specific expression patterns in early response to thermal and sediment stresses conducted in controlled environment experiments over 14 days. Preliminary results identified at least two genes, *hsp16* and *MyHC*, with distinct expression patterns reflecting early stages of thermal and sediment stress, respectively. We suggest that these genes can be used as gene expression biomarkers to help predict the early stages of stress in *Acropora* corals.

10G - What role does phenotypic plasticity play in acclimatization or adaptation to environmental change?

Virtual
Oral
A-1180

Corals at both latitudinal boundaries of the Red Sea present similar temperature optima.

Banc-Prandi, G.[1], Evensen, N. R.[2], Barshis, D. J.[2], Perna, G.[3], Omar, Y. M.[4], Fine, M.[5]
[1]Ecole Polytechnique Fédérale of Lausanne, Biological Geochemistry, Lausanne, Switzerland
[2]Old Dominion University, Department of Biological Sciences, Norfolk, United States
[3]University of Konstanz, Department of Biology, Konstanz, Germany
[4]Center for Studies and Scientific Research of Djibouti, Djibouti, Djibouti
[5]The Hebrew University of Jerusalem, Department of Ecology, Evolution and Behaviour, Jerusalem, Israel

guilhembp[at]gmail.com

Abstract

Rising ocean temperatures are pushing reef-building corals beyond their temperature optima (T_{opt}), resulting in reduced physiological performances and increased risk of bleaching. Identifying climate refugia with thermally resistant corals and understanding their thermal adaptation strategy is therefore urgent to guide conservation actions. The Gulf of Aqaba (GoA, northern Red Sea) is considered a coral reef refuge from climate change, hosting corals that have originated in populations selected for thermal resistance in the warmer waters of the southern Red Sea and Gulf of Aden. To better understand the thermal adaptation strategy of GoA corals, we conducted thermal performance curve assays (TPC) on six common reef-building coral species from the GoA and the Gulf of Tadjoura (GoT, entrance to the Red Sea and 2000 km south of the GoA) by measuring oxygen production and consumption rates as well as photophysiological performance (i.e. chlorophyll fluorescence), and compared their respective temperature optima (T_{opt}), in relation to local environmental conditions and species-specific symbiont densities. Five out of six species displayed similar T_{opt} between the two locations, highlighting an exceptional continuity in their respective physiological performances across the latitudinal range despite contrasting environmental conditions, supporting the GoA refuge theory. Interestingly, *Stylophora pistillata*, the most common stony coral of the shallow Red Sea reef, was the only species displaying a significantly lower T_{opt} in the GoA, which may suggest an ongoing population-level selection (i.e. adaptation) to the cooler waters of the GoA and subsequent loss of thermal resistance in the future. Interestingly, all T_{opt} were significantly above the local maximum monthly mean seawater temperatures in the GoA (27.1°C) and close or below in the GoT (30.9°C), indicating that GoA corals, unlike those in the GoT, live far under their bleaching threshold. Finally, *Acropora muricata* and *Porites lobata* displayed higher photophysiological performance than most species, which may translate to dominance in local reef communities under future thermal scenarios. Overall, this study is the first to compare the T_{opt} of common reef-building coral species over such a latitudinal range and provides insights into their thermal adaptation in the Red Sea.

Session 10H - Behavioural responses to environmental change: what are the underlying mechanisms, ecological significance, and future consequences?

Conceptualized by: **Celia Schunter**[1], **Rohan Brooker**[2], **Sally Keith**[3]
[1] The University of Hong Kong (Hong Kong, HKSAR)
[2] Deakin University (Victoria, Australia)
[3] Lancaster University (Lancaster, UK)

Chaired by: **Rohan Brooker**[2]

Oral
A-1079

Light pollution increases night activity and brain DNA damage in Chromis viridis fish

Ben-Ezra, S.[1, 2, 3], Harpaz, R.[4], Engert, F.[4], Appelbaum, L.[2], Levy, O.[1]
[1]Bar Ilan University, The Mina & Everard Goodman Faculty of Life Sciences, Ramat Gan, Israel
[2]Bar Ilan University, The Multidisciplinary Brain Research Center, Ramat Gan, Israel
[3]The Interuniversity Institute for Marine Sciences of Eilat, Eilat, Israel
[4]Harvard University, Department of Molecular and Cellular Biology, Cambridge, United States

shachaf.ben-ezra[at]mail.huji.ac.il

Abstract

Artificial light at night (ALAN) has become a primary environmental concern and has been shown to affect various organisms and physiological processes. Sleep is a vital evolutionarily conserved metabolic state, essential for macromolecule biosynthesis, energy conservation, metabolite clearance, synaptic plasticity, and memory consolidation. Recently, sleep has been recognized as essential for the nuclear maintenance and repair of DNA damage accumulated in neurons. Sleep is strongly regulated by light entrainment and the circadian clock, but little is known about the effect of light pollution on sleep in marine animals.
Here, we studied the effect of ALAN on nocturnal behavior and brain DNA damage in a reef fish, the blue-green chromis damselfish (*Chromis viridis*). This diurnal species of damselfish is highly abundant in the Red Sea and throughout the Indo-Pacific region, inhabiting colonies of branching corals. Using infrared cameras and machine-learning based video-tracking, we characterized the nocturnal activity of fish schools within their coral host. We show that the fish remain mostly immobile at night, maintaining conserved territories inside the coral. However, ALAN notably increased their nocturnal activity and spatial use. Furthermore, we quantified neuronal double-strand-breaks (DSBs) during the day, night, and under ALAN using confocal imaging of the DSBs signaling protein γH2AX. We found that neuronal DSBs accumulated during the day are resolved at night in a sleep-related brain region. However, the fish kept the daily levels of DNA damage under a light-polluted night. These findings raise ecological concerns regarding the impact of light pollution on sleep and neuronal health in reef-inhabiting fish.

Oral
A-1700

Coral-fish mutualisms may not withstand continued disturbances as coral-dwelling fish are slower to recovery than their corals

Froehlich, C. Y.[1], Klanten, O. S.[2], Heatwole, S.[1], Hing, M.[1], Dowton, M.[1], Wong, M.[1]
[1]University of Wollongong, Wollongong, Australia
[2]University of Technology Sydney, Sydney, Australia

cymf988[at]uowmail.edu.au

Abstract

As multiple disturbances are intensifying and occurring in quick succession, many mutualisms within disturbed environments are at a pivotal point in their relationship. Will both organisms in a mutualism respond similarly due to their beneficial relationship or will each organism respond unequally to such disturbances? We investigated the responses of coral-fish mutualisms to consecutive climatic disturbances with two studies. We monitored populations of coral-dwelling gobies (genus *Gobiodon*) and their coral hosts (genus *Acropora*) at Lizard Island, Great Barrier Reef, before and after 4 devastating disturbances: 2 category four cyclones and 2 prolonged heatwaves that caused extensive coral bleaching. After an initial but steep decline in coral abundance, corals were twice as abundant 3 yrs post-disturbances than pre-disturbance. However, gobies declined substantially more than corals, and their abundance was still down by 50% 3 yrs post-disturbances. Some goby species showed some signs of plasticity in host occupancy as they changed coral host species when their preferred hosts became rare. Why are corals showing earlier signs recovery than gobies? The predation risk of gobies and their movement decisions between coral hosts may be key to this question. In heavily disturbed reefs such small fish have higher risks of predation due to the lack of structural complexity. To understand whether gobies changed their movement decisions between hosts based on their environment, we compared the movement decisions of *Gobiodon quinquestrigatus* in a relatively pristine coral reef (Kimbe Bay, Papua New Guinea), and heavily disturbed coral reef (Lizard Island, Great Barrier Reef) via a manipulative *in situ* experiment. Gobies did not change their movement decisions based on their environment, which likely led to higher rates of predation in the disturbed reefs. Accordingly, our study demonstrates that organisms within mutualisms do not respond similarly during periods of extensive disturbances, but that host occupancy and movement decisions in these environmental likely explain their slower recovery of the inhabiting species.

10H - Behavioural responses to environmental change: what are the underlying mechanisms, ecological significance, and future consequences?

Oral
A-1631

Can polyp behavior protect a coral colony from climate change?

Goulet, T.[1], McCauley, M.[1, 2]
[1]University of Mississippi, Biology, University, United States
[2]University of Florida, The Whitney Laboratory for Marine Sciences, St. Augustine, United States

tlgoulet[at]olemiss.edu

Abstract

When we talk about corals' response to climate change, we use terms such as acclimate and/or adapt. Studies reporting coral acclimation typically assess a change in biochemical parameters of either the host coral, its mutualistic endosymbiotic dinoflagellate algae (family Symbiodiniaceae), or in both the host and symbiont, collectively called the holobiont. In addition, the loss of Symbiodiniaceae (coral bleaching) often occurs in response to environmental perturbations associated with climate change. Here we present changes in behavior of the coral host that may alleviate the need for the holobiont to change its biochemical composition. Corals (either scleractinian or octocorals) are composed of coral polyps. In gorgonian octocorals, through their hydrostatic skeleton, polyps can alternate between three main states: polyps withdrawn within their calyxes, polyps protruding with their tentacles retracted, or both the polyp and tentacles expanded. Polyps can alternate between these states practically instantaneously, in response to both external and internal environmental cues, fitting within the definition of a behavior. We found that exposing the Caribbean gorgonian octocoral *Eunicea tourneforti* in the summer for seven days to elevated temperature, ultraviolet radiation (UVR), or both stressors simultaneously, substantially influenced polyp behavior at solar noon. Under elevated temperature, 35% of polyps were completely withdrawn and only 10% of polyps expanded their tentacles. With UVR exposure, 46% of the polyps were withdrawn and only 9% of polyps expanded their tentacles. Combining temperature and UVR led to 77% of polyps withdrawn and 0% expanded. Conversely, holobiont parameters did not significantly change and only a few Symbiodiniaceae parameters were affected. Seven days of exposure to another stressor, 4μM phosphate enrichment, led to complete polyp retraction in the gorgonian corals *E. tourneforti* and *Pseudoplexaura porosa* during solar noon. We suggest that modification of polyp behavior may, in the short term, protect the coral holobiont from environmental perturbations.

10H - Behavioural responses to environmental change: what are the underlying mechanisms, ecological significance, and future consequences?

Oral
A-1176

Nutrient disruption by a terrestrial invasive species drives reef fish territorial behaviour

Gunn, R. L.[1], Benkwitt, C. E.[1], Graham, N. A.[1], Hartley, I. R.[1], Algar, A. C.[2], Keith, S. A.[1]
[1]Lancaster University, Lancaster Environment Centre, Lancaster, United Kingdom
[2]Lakehead University, Department of Biology, Thunder Bay, Canada

rlgunn1[at]gmail.com

Abstract

Human induced environmental change, such as the introduction of invasive species, is causing detrimental declines in the transport of nutrients across ecosystems. Territorial behaviour is directly associated with the availability of nutritional resources, yet the role of nutrient disruptions by invasive species on territoriality remains relatively unknown. Territoriality is predicted to occur where the energetic benefits outweigh the costs. We use a rare natural treatment control experiment to investigate how the disruption of a seabird nutrient pathway by invasive black rats (*Rattus rattus*) on remote tropical islands, affects the territorial behaviour of a herbivorous reef fish *(Plectroglyphidodon lacrymatus)* on surrounding coral reef ecosystems. Using *in situ* behavioural observations, we identified that the nitrogen enrichment of turf algae where seabird nutrient subsidies are present allows *P. lacrymatus* individuals to obtain a greater nutritional gain per unit foraging effort. Individuals with access to these enriched resources hold smaller territories and show heightened aggressive defense compared to individuals on reefs around rat infested islands. Furthermore, we show that fine scale variation in the quantity of resources within *P. lacrymatus* territories is driven by broad scale differences in the nitrogen enrichment of *P. lacrymatus* food resources. These results provide a novel insight into how the disruption of nutrient flows by invasive species in terrestrial ecosystems can affect broad and fine scale variation in the territorial behavioural of organisms in surrounding marine ecosystems.

Oral
A-2229

I think we need to take a break: The effects of diver presence on herbivorous reef fish foraging behavior

Renfro, B.
Florida State University, Tallahassee, United States, (brenfro[at]bio.fsu.edu)

Abstract

Nature tourism is often hailed as a solution to consumptive economic uses of wild spaces, however, there is debate within the coral reef literature as to the balance of conservation and economics in this industry. Coral reefs are hotspots for dive tourism, and areas with intense tourism are experiencing environmental degradation. The bulk of studies focus on the effects of tourism on organism abundances, but fewer have addressed how the industry's influence on the environment affects organism behavior. Disruption to herbivory, historically caused by overfishing and disease, is considered a major driver of reef degradation. While divers may not be physically removing herbivorous reef fish, the presence of humans may exert non-consumptive effects on these prey species resulting in unintended consequences from dive tourism. We examined the spatial and temporal effects of dive tourism on herbivorous reef fish foraging behavior. Surveys were conducted in Akumal Bay along Mexico's portion of the Meso-American Barrier Reef. This bay contains a gradient of tourist presence. Field manpulations of experimentally deployed snorkelers and divers exhibiting typical behaviors of a novice on vacation, including poor buoyancy and camera use, revealed significant short-term effects on the behaviors of both surgeonfishes (3 species) and parrotfishes (9 species), in that diver presence caused individuals to switch from foraging and normal swimming to escape behaviors. However, fish returned to their original proportions of foraging within 5 minutes of diver removal. Based on diurnal observations of fish behavior across the bay, these short-term responses to diver presence do not translate into a consistent large-scale variation in the foraging patterns of fishes among sites that varied in tourist intensity. Rather, we found species-specific long-term spatial and temporal responses to chronic tourist exposure, with some species being more tolerant to the presence of humans. We conclude that diver presence on reefs can reduce time spent foraging by herbivorous fishes over short temporal scales, and thus has the potential to alter competitive interactions between reef building corals and macroalgae. We recommend management actions on intensively-visited reefs to designate diver-free periods between exposure to groups of divers and snorkelers, which would allow herbivorous fishes time to periodically resume their normal foraging behaviors.

10H - Behavioural responses to environmental change: what are the underlying mechanisms, ecological significance, and future consequences?

Oral
A-2006

Can foraging plasticity buffer effects of coral bleaching in butterflyfishes?

Semmler, R.[1], Sanders, N.[2], Graham, N.[3], Baird, A.[4], Caradonna, P.[5], Keith, S.[6]
[1]University of Texas, Marine Science Institute, Port Aransas, Texas, United States
[2]University of Michigan, Department of Ecology and Environmental Biology, Ann Arbor, Michigan, United States
[3]Lancaster Univesity, Lancaster Environment Centre, Lancaster, United States
[4]James Cook University, ARC Centre of Excellence for Coral Reef Studies, Townsville, Australia
[5]Chicago Botanic Garden, Chicago, Illinois, United States
[6]Lancaster Univesity, Lancaster Environment Centre, Lancaster, United Kingdom

rsemmler37[at]gmail.com

Abstract

Adaptive behavioural plasticity can shield populations from the effects of disturbance. Specifically, bottom-up changes in dietary specificity or foraging behaviour can help a species to maintain sufficient energy intake when food availability decreases. Bottom-up effects are especially likely to result in wider ecosystem change, because they can alter consumer-resource interactions, ultimately affecting food web structure. However, these changes and their population-level outcomes may vary from species to species as a result of niche overlap and relative competitive ability. We evaluated whether the diets or foraging behavior of coral-feeding butterflyfishes changed in response to the Global Coral Bleaching Event 2015-2017. Specifically, we tested whether butterflyfishes alter their patch-use behaviour or the strength of their dietary preferences in response to changing food (coral) availability, consistent with optimal foraging theory. Following coral mortality, butterflyfishes weakened their dietary preferences, leading to significant rewiring of consumer-resource interactions (Semmler et al. in review). Species also significantly altered their patch-use behaviour, however with varying patterns among specialists and generalists (Semmler et al. in prep). While all species were capable of some degree of behavioural change, these differences, and their effect on overall food intake, help to illustrate why specialist species often suffer the greatest population losses from coral bleaching events.

10H - Behavioural responses to environmental change: what are the underlying mechanisms, ecological significance, and future consequences?

Virtual
Oral
A-2132

Latitudinal variation on the nutritional ecology of nominally herbivorous fishes in the southwestern Atlantic Ocean

Cardozo-Ferreira, G. C.[1], Clements, K. D.[2], Choat, J. H.[3], Mendes, T. C.[1], Macieira, R. M.[4], Franco, M. L.[5], Rezende, C. E.[5], Joyeux, J.-C.[4], Ferreira, C. E. L.[1]
[1]Fluminense Federal University, Marine Biology Department, Niterói, Brazil
[2]University of Auckland, School of Biological Sciences, Auckland, New Zealand
[3]James Cook University, College of Science and Engineering, Townsville, Australia
[4]Federal University of Espírito Santo, Department of Oceanography, Vitória, Brazil
[5]Darcy Ribeiro State University of Northern of Rio de Janeiro, Center for Bioscience and Biotechnology, Campos dos Goytacazes, Brazil

gabrielccf[at]gmail.com

Abstract

Herbivorous reef fishes form a heterogeneous group with a complex and variable trophic ecology. However, the debate on the potential functional role of herbivorous fishes has shown substantial advances recently. Widely distributed, this group is subjected to local environmental fluctuations such as food availability and/or water temperature. We analysed the trophic ecology of three nominally herbivorous fishes over a latitudinal gradient of 17º and ~5ºC on water temperature, using two complementary with different timing-related approaches: i) a two-resolution dietary analysis, and ii) stable isotope analysis (SIA). Although some variation in the proportion of different items has been observed, the main dietary items kept steady for each species across the gradients of latitude and temperature. Shifts in species' SIA trophic position and signatures revealed more complex inter and intraspecific relationships among nominally herbivorous fishes than previously thought. Quantity of algae ingested was also similar across the sampled locations for *Acanthurus chirurgus* and *Kyphosus vaigiensis* but increased towards higher latitudes in *Sparisoma axillare*, contradicting the temperature-constraint hypothesis (TCH) that herbivorous fishes would shift to a more protein-rich diet southwards while reducing algae ingestion due to a digestion impairment while inhabiting cold-water environments. Neither diet nor SIA variations supported TCH predictions, suggesting efficient and effective digestion of algal material of herbivorous fishes across the tested gradients. Our study provides refined details on the nutritional ecology of three nominally herbivorous reef fishes while highlighting their capacity of coping with water temperature variation while aiming to reach their nutritional requirements. Yet, our species-specific results call attention to avoiding generalisations on species trophic relationships, nutritional ecology and physiological features and constraints. The correct understanding of the nutritional ecology of nominally herbivorous fishes is crucial in order to evaluate the effects of the profound changes in natural systems as a result of climate change and the local impacts these populations face.

10H - Behavioural responses to environmental change: what are the underlying mechanisms, ecological significance, and future consequences?

Virtual
Oral
A-1112

Overeating in a 'buffet of turbidity': A preliminary insight into heterotrophy among four common coral species from Singapore's reefs.

Hickey, V.[1, 2], Ow Yong, W. L.[2], Tun, K.[3], Ramsay, R.[1], Tanzil, J.[2]
[1]University College Cork, Cork, Ireland
[2]National University of Singapore, Singapore, Singapore
[3]National Parks Board, Coastal and Marine, Singapore, Singapore

valhick[at]gmail.com

Abstract

Globalisation of the world's tropical coral reefs and exploitation of their ecosystem goods and services have pushed many coral species to the limit of their niche environment. Coral's innate coping strategies and natural acclimation to increasingly turbid environments are often overlooked when developing coastal management strategies in urban areas. The aim of this study was to acquire a better understanding of the extent to which corals living in turbid waters utilise opportunistic heterotrophy of mesozooplankton to supplement their diet. Diurnal and nocturnal feeding rates of four species of scleractinian corals: *Merulina ampliata Pachyseris speciosa, Porites lutea* and *Turbinaria peltata,* commonly found on Singapore's fringing reefs, were collected from Palau Tembakul for investigation. Fragments from replicate colonies were fed freshly hatched nauplii of *Artemia salina* (400-450 μm) for ninety minutes in two separate sessions, once during the day (1 hour after midday) and once at night (1 hour after sunset) under controlled aquarium conditions. Results show that large quantities of zooplankton are consumed, both during the day and at night, subject to food availability. Additional scrutiny for inter-species patterns and intra-colonial effects suggests some species specific preferences with *Pachyseris speciosa* and *Turbinaria peltata* adhering to the theory that heterotrophy occurs mainly at night, while *Porites lutea* and *Merulina ampliata* consuming more during the day when zooxanthellae-led autotrophy is thought to dominate. Distinct colonial variations were observed in all species, however those within *Turbinaria peltata* gave rise to the greatest differences. Further research should be conducted, on these species and other coral species, as the reasoning for these variations may be linked to gene expression, morphological adaptation, or photo-acclimation. These in conjunction with this study may reveal a greater insight into the importance of heterotrophic metabolism for tropical corals in response to environmental stress.

Virtual
Oral
A-1156

Neuromolecular effects of environmental change

Schunter, C.
University of Hong Kong, School of Biological SCiences, Hong Kong, Hong Kong SAR China

schunter[at]hku.hk

Abstract

Anthropogenic activities are causing the global climate to change at an unprecedented rate. A plethora of studies have now shown that such rapid changes in the environment, including thermal anomalies and acidification of aquatic ecosystems can have severe consequences on the ecology as well as crucial behaviours of aquatic organisms. Over the past years I have been investigating the impacts of environmental change on marine fishes in particular on the brain, through experiments, unique field collections, molecular work and computational analyses to understand the neuromolecular responses. Through transgenerational exposure to elevated CO_2 we deciphered short-term, developmental effects as well as the influence of parental effects on the brain. Furthermore, collections in the wild at CO_2 seeps allowed to understand the common and variable responses among species and revealed different levels of plasticity and adaptive potentials owing to evolutionary rates. Lastly, we find that climate change-stressors also alter crucial cooperative behaviors in fish, such as cleaning interactions, and we exhibit the changes to underlying molecular mechanisms in different brain regions revealing a major influence on mutualism maintenance with potential large-scale effects on the coral reef ecosystems.

Session 11A - Open Session: Resilience, phase shifts and novel ecosystems

Conceptualized by: **Peter J. Schupp** [1], **Jasper de Goeij** [2], **Verena Schoepf** [3], **Petra Visser** [2]
[1] University of Oldenburg (Oldenburg, Germany)
[2] University of Amsterdam (Amsterdam, The Netherlands)
[3] University of Western Australia (Perth, Australia)

Chaired by: **Peter J. Schupp** [1], **Jasper de Goeij** [2], **Verena Schoepf** [3], **Lisa Becking** [4]
[1] University of Oldenburg (Oldenburg, Germany)
[2] University of Amsterdam (Amsterdam, The Netherlands)
[3] University of Western Australia (Perth, Australia)
[4] Wageningen University & Research (Wageningen, The Netherlands)

Oral
A-1137

Resilience of American Samoan corals to irregular or infrequent disturbances

Birkeland, C.[1], Fenner, D.[2], Coward, G.[3], Lawrence, A.[3], Green, A.[4], Vaeoso, M.[3]
[1]University of Hawaii at Manoa, Biology, Waipahu, United States
[2]Paci0fic Islands Fisheries Science Center, NOAA, Pago Pago, American Samoa
[3]Department of Marine and Wildlife Resources, Pago Pago, American Samoa, [4]Red Sea Research Center, Thuwal, American Samoa, (charlesb[at]hawaii.edu)

Abstract

Many studies have been published in the past two decades on the resilience of American Samoan corals by acclimatization, epigenetic changes, symbiont shifting, or adaptation to frequent stresses. Here we report on the resilience of American Samoan corals to irregular disturbances such as hurricanes, CoTS outbreaks, and large-scale bleachings as recorded on 9 surveys between 1982 and 2018. The resilience to irregular disturbances was through abundant recruitment and the prevalence of fast-growing species. Of 35,668 coral colony diameters, 23.8% were recruits (< 5 cm) and 0.7% were > 80 cm, which suggests there was vigorous turnover contributing to resilience. The ratios of rapidly-growing branching corals (*Acropora* and *Pocillopora*) to all corals through the years were remarkably constant ($p > 0.83$). Except for Fagatele Bay National Marine Sanctuary (FBNMS), the lack of overall change in population densities of all corals from 1982 – 2018, despite yearly fluctuations because of disturbances, was also remarkable ($p > 0.18$). FBNMS substantially ($p < 0.03$) increased in population density between 1979 and 2018. The most notable species change through all islands was the relatively fast-growing *Porites rus* which increased in population density ($p < 0.05$) from 11th most abundant species (1995) to 3rd (2018). As with most prevalent genera, *P. rus* had exceptional recruitment in 2002, but unlike others, it had increasing numbers in larger size classes to 2018. The massive or mound-shaped *Porites* on Ta'u, the youngest island, had fewer recruits and more in the larger size classes ($p < 0.001$) than on other islands. A survey by Coward et al. (2020) found 891 colonies 2 to 10 m diameter and 84 colonies 10 – 22.4 m. This suggests lower turnover of massive *Porites* on Ta'u. Although *Porites* over 2 m diameter were only 0.017% of the population of massive *Porites*, they made up 56.4 % of the volume of aragonite contribution. Fast-growing branching corals may be important for resilience of the biological community. The slow-growing massive corals may contribute more to the geological reef. We are happy that the coral communities of American Samoa have been resilient over the past four decades, but we are uncertain of their future.

Oral
A-1752

The hidden environmental variability of coral reefs: linking structural traits of reefs to light niches

Brambilla, V.[1], Madin, J.[2], Boutros, N.[3], Pizarro, O.[4], Torres-Pulliza, D.[2], Williams, S.[3], Zawada, K.[5], Dornelas, M.[1]
[1]Centre for Biological Diversity, University of St-Andrews, Saint Andrews, United Kingdom
[2]Hawai'i Institute of Marine Biology, Kaneohe, United States
[3]University of Sydney, Sydney, Australia
[4]Norwegian University of Science and Technology, Trondheim, Norway
[5]University of Technology Sydney, Sydney, Australia

vb42[at]st-andrews.ac.uk

Abstract

In coral reef ecosystems, reef building corals act as obligate ecosystem engineers and build extremely complex and heterogeneous habitats, which harbour some of the most biodiverse communities in the world. By regulating habitats at a local scale, ecosystem engineering can establish population and ecosystem feedback and maintain ecosystem health and resilience. However, the extent to which different coral morphologies and assemblages influence environmental conditions and provide niches for themselves and other organisms is still undetermined. Here, we study how the presence of different coral morphologies modifies light niches within reefs using high-resolution and high-frequency environmental data sampling from the field. We surveyed nine shallow reef sites (each covering ~110 m^2) along a coral coverage gradient at Lizard Island (Great Barrier Reef, Australia), and each time we simultaneously sampled light at 30 to 50 randomly selected points within each site for 24 hours. Light niches of each sampling point were quantified as daily light integral and corrected by depth and light at the surface. To quantify structural features of the reefs, we used Simultaneous Localizations and Mapping algorithms to build georeferenced 3D surface models from overlapping imagery with synchronized depth, orientation, and surface GPS observations. We used these models to calculate reef structural traits of the sampling locations, such as reef fractal dimension and surface rugosity. We then explored the role of depth and each complexity variable in explaining variability in light conditions variability across sites. Among the geometric variables, surface rugosity was consistently found to affect negatively light integrals, probably since high surface rugosity means that there are protuberances that can cast shadows. Contrary to our predictions, depth did not have significant effects on light integral. Predicting environmental niches is important for advancing our understanding of ecological and evolutionary aspects of coral reefs. From an ecological perspective, niche breadth may modulate species coexistence and biodiversity patterns found among structurally different reefs. From an evolutionary perspective, since different shapes of coral skeletons alters the environment in different directional ways, corals may have been biasing natural selection consistently, affecting reef taxa evolutionary history.

Oral
A-1637

Herbivorous Fish and Coral Recovery in Response to a Shipwreck Removal and Associated Alteration of Benthic Habitat

Caselle, J.[1], Koehn, K.[1], Carlson, P.[1], Ladd, M.[2]
[1]University of California Santa Barbara, Marine Science Institute, Santa Barbara, United States
[2]NOAA Fisheries, Southeast Fisheries Science Center, Miami, Fl, United States

caselle[at]ucsb.edu

Abstract

Shipwrecks can have significant localized effects when grounded on shallow coral reefs. These effects are not limited to the immediate physical damage, but can have wide-spread and lasting impacts due to alteration of the chemical makeup of the surrounding water column. This can subsequently impact the growth of benthic organisms, often leading to phase shifts and high levels of mortality of corals in the vicinity of the wreck. At Palmyra atoll, the grounding of a longline fishing vessel on the shallow reef terrace is associated with a phase shift to the corallimorph, Rhodactis howesii. In 2013, a wreck removal effort initiated by the US Department of Fish and Wildlife resulted in the successful extraction and disposal of the wreckage, after which the density and percent cover of R. howesii in the immediate vicinity of the wreck site dropped precipitously. Here, we document the response of the fish community to the wreck removal and localized decline in R. howesii. We show that the biomass of scarid parrotfishes and acanthurid surgeonfishes and unicornfishes (primarily herbivores) increased after the removal of the wreck, while biomass of chaetodontid butterflyfishes (primarily invertivores, many species are known to feed on coelenterate polyps) declined over the study period. The density of small scarids and acanthurids also increased, but only after a few years post removal. As R. howesii receded and fish community assemblages became more diverse, we also initiated an exclusion experiment to track reef recovery post wreck removal across a gradient of fish sizes. Treatments are designed to exclude large (>0.5m tl), medium and small herbivorous fish. We track benthic cover, coral settlement, coral and algal growth, and sedimentation. Preliminary results have shown that a robust fish community has the ability to keep algae and sediment levels low, ultimately fostering coral recovery following wreck removal. Overall these results indicate that Palmyra's unfished herbivore population has rapidly responded to the removal of the wreck and associated decrease in corallimorph cover, and subsequently can maintain high levels of grazing facilitating coral recovery.

Oral
A-1944

Recovery and resilience of Maldivian coral reefs in the face of ongoing disturbance

Lubarsky, K.[1], Zgliczynski, B.[1], Amir, H.[2], Pedersen, N.[1], Alcantar, E.[1, 3], Ibrahim, N.[2], Abdulla, A. S.[2], Angeela, A.[2], Basheer, A.[4], Edwards, C.[1], Ismail, M. A.[2], Najeeb, A.[2], Naseem, A.[5], Nishan, A.[6], Petrovic, V.[7], Shiraz, A. Z.[2], Sullivan, C.[1], Zahir, H.[8], Ahusan, M.[2], Estep, A.[9], Naeem, S.[10], Sandin, S.[1]
[1]UC San Diego, Scripps Institution of Oceanography, La Jolla, United States
[2]Maldives Marine Research Institute, Male, Maldives
[3]University of Amsterdam, Amsterdam, Netherlands
[4]IUCN Maldives, Male, Maldives
[5]Maldives Coral Institute, Male, Maldives
[6]Environmental Protection Agency, Male, Maldives
[7]UC San Diego, Computer Science and Engineering, San Diego, United States
[8]Small Island Research Group, Male, Maldives
[9]Waitt Institute, La Jolla, United States
[10]Maldives Marine Research Institute, Male, United States

clubarsky[at]ucsd.edu

Abstract

As an island nation comprised entirely of coral atolls and low-lying coral islands, the Republic of the Maldives depends heavily on the health of its coral reefs to support the nation's economy and to provide important ecosystem services. Despite its small land area, the Maldives covers a large latitudinal gradient, spanning approximately 650 km north to south and containing 25 distinct atolls. In recent years, the reefs of the Maldives have been subject to several disturbance events- most notably a mass bleaching event in 1998 which all but decimated coral populations throughout the archipelago, a tsunami in 2004, an *Acanthaster planci* outbreak in 2015, and a second bleaching event in 2016, among others. Considering the increasing frequency of disturbance in the Maldives as well as the nation's dependence on coral reefs, it is critical to understand the resilience and recovery potential of Maldivian reefs today and into the future. We conducted surveys of reef benthic communities across leeward forereef habitats of the Maldivian archipelago using photoquadrat and large-area imagery techniques, to determine benthic cover, coral diversity, and coral recruit density at each atoll. These surveys complement a growing time series of data, contributing to a summary of the current state of Maldivian reefs and their future recovery potential. We show that despite ongoing disturbance, mean coral cover has recovered to 19.4% approximately half of pre-1998 values (40.1%; Pisapia et al. 2016) and recruitment rates are quite high. However, while pre-1998 reefs were dominated by *Acropora and Pocillopora*, reefs across the Maldives have shifted towards dominance by more stress tolerant *Porites*. Our study provides a spatially extensive view of leeward forereefs across the archipelago, allowing for inter-atoll and inter-regional comparisons of reef health and recovery, as well as assessments of the degree of anthropogenic impacts on reefs associated with different island use types. These data suggest that while Maldivian reefs show a capacity for recovery, the coral communities have shifted to favor more resilient taxa, which may afford higher resilience in the face of increasing disturbance.

Oral
A-1117

Morphological and ecological trait diversity reveal sensitivity of herbivorous fish assemblages to coral reef benthic conditions

Pombo-Ayora, L., Coker, D., Carvalho, S., Short, G., Berumen, M. L.
King Abdullah University of Science and Technology, Thuwal, Saudi Arabia

lucia.pomboayora[at]kaust.edu.sa

Abstract

Herbivorous fishes play a critical role in the maintenance of coral reefs through grazing and cropping of various benthic algae types. Herbivorous fish assemblages are sensitive to changes in the reef environment and are often targeted by local fisheries. This can lead to a decline in ecosystem functions if key groups are reduced. The present study investigates the morphological and ecological trait diversity of herbivorous reef fish assemblages in habitats differing in relative benthic coverage: i) coral-dominated, ii) algae-dominated, and iii) an intermediate habitat. Trait diversity for conspicuous herbivorous fishes was measured using three trait diversity indices: trait richness, trait divergence, and trait evenness. These indices were derived from in situ community surveys and feeding observations, morphological assessment of feeding mechanics from locally collected specimens, and ecological information obtained from published data. Trait diversity, reflected in higher trait evenness and lower trait richness, was lower within algae-dominated habitats than coral-dominated habitats, suggesting that algae- dominated habitats may be compromised by the lack of essential functions provided by key species. These groups reduce algal biomass and may help facilitate the survival and growth of corals, which in turn can increase coral cover. Algae-habitats were dominated with species known to consume macroalgae (rabbitfish and surgeonfish), appearing to provide essential feeding and habitat resources. These species include browsers and croppers that are fundamental in reducing algal biomass and may help facilitate the survival and growth of corals, which in turn can promote reef health. However, this habitat lacked parrotfishes known to remove turf algae and sedi- ments, an essential function for clearing benthic space for coral settlement and other key benthic invertebrates. This study identified several species with overlapping functional roles in the coral-dominated and intermediate habitats. Still, species that were not redundant showed high trait complementarity, suggesting that their removal may result in the loss of unique functions. Importantly, we show that algae-dominated habitats supported high numbers of juvenile fishes especially in species targeted by local artisanal fishers. The loss of trait diversity is greater than the loss of species diversity through the comparison of taxonomic and trait β-diversity.

Oral
A-1998

Ecological drivers, healing rates, and thresholds for recovery of parrotfish predation on coral communities across the Greater Caribbean

Rempel, H.[1, 2], Barton, E.[2], O'Rourke, T.[2], Lamore, R.[2], Vanderbloomer, P.[2], Adam, T.[3], Burkepile, D.[3], Bodwin, K.[2], Ruttenberg, B.[2]
[1]University of Texas at Austin, Austin, United States
[2]California Polytechnic State University, San Luis Obispo, United States
[3]University of California, Santa Barbara, United States

hannah.rempel[at]gmail.com

Abstract

Parrotfishes (*Labridae*: Scarini) are abundant tropical herbivores that play an important role in reducing coral-algae competition by grazing algae. However, some species also feed on live coral, which may negatively impact coral growth and survivorship. While some researchers have suggested that parrotfish coral predation may have long-term impacts on heavily targeted coral species, the ecological drivers of predation intensity and patterns of coral recovery from predation scars remain poorly understood. To address this, we evaluated how parrotfish predation intensity varied across multiple spatial scales from the scale of individual coral colonies, to reefs within islands, to regions across the Greater Caribbean including the Florida Keys, St. Croix, and Bonaire. Our findings suggest that community composition influences patterns of predation intensity at some spatial scales and that *Orbicella annularis* and *Porites* spp. corals are among the most intensely grazed coral taxa across the Greater Caribbean. Further, our findings suggest that predation scars on *O. annularis* may be particularly large in terms of median scar area. To better understand the capacity of *O. annularis* to heal from parrotfish predation scars, we tracked the fate of over 400 fresh scars for up to two months. We developed a predictive model of coral healing based on colony-level traits, then applied this model to snapshot surveys of fresh predation scars to predict long-term coral tissue loss from a standing stock of scars. Our findings suggest that scar surface area is the most important predictors of long-term coral healing from parrotfish predation and that there is a size threshold above which scars do not fully heal. Combined, this research helps us to better understand the capacity of corals to heal from parrotfish predation scars and how differences in parrotfish and coral community composition influence patterns of coral predation intensity across spatial scales.

Oral
A-1365

The Red Sea coral reef cryptobiome: How do nearby benthic communities influence biodiversity of the hidden majority?

Rosado, J. G., Daraghmeh, N., Justo, M. S., Cadiz, R., Langner, U., Cardoso, P., Curdia, J., Benzoni, F., Berumen, M., Carvalho, S.
King Abdullah University of Science and Technology, Red Sea Research Center, Thuwal, Saudi Arabia

joaogabrieldr7[at]gmail.com

Abstract

Most of the reef's biodiversity remains hidden due to its complex tridimensional structure, the small size of the organisms that compose most of its biodiversity, as well as their nocturnal behavior. To better understand these major players on the reef's environment, artificial cubic-like tools called ARMS (Autonomous Reef Monitoring Structure) were developed to mimic the 3D nature of coral reefs. Here, we deployed 16 ARMS within four distinct habitats on Tahla reef in the Red Sea (Saudi Arabia) to investigate how changes in habitats within a reef reflect changes in the associated cryptobenthic diversity. The following habitats were established after a visual inspection of the reef and based on their prevalence: i) algal pavement; ii) rubble; iii) plating coral; and iv) branching coral. Habitats were located at the same depth contour (~10 m), under similar exposure conditions and separated by at least 35 m. A fixed quadrat of approximately 15 m^2 was marked within each habitat type and four ARMS were deployed randomly within the quadrat. Units were retrieved after a period of approximately seven months for the analysis of the pioneer eukaryotic communities through metabarcoding using COI and 18S primers. For a better understanding of the colonization patterns, water collections next to each ARMS unit were conducted monthly to investigate the biodiversity of the planktonic communities within and among habitats that are potential sources of colonizers. Water samples were filtered using 0.22 µm membranes (*MilliporeSigma*) and analyzed using COI and 18S primers. The rugosity of the habitats was measured using the standardized chain method on 10 m transect triplicates per habitat. On a monthly basis, conductivity, temperature, salinity, dissolved oxygen, and pH records were obtained for each habitat for around 3 days to characterize changes in the water parameters over the course of this study and among habitats. Water collections were also carried out for analysis of nutrients and chlorophyll a. We hypothesize that biodiversity of the pioneer cryptobiome community will change among different habitats and it will be tested through a combination of univariate and multivariate statistical methods. This study aims to better understand linkages between the characteristics of reef benthic communities and the associated cryptobiome assessed using ARMS, contributing to a better knowledge of the impacts on reef biodiversity resulting from benthic habitat changes.

Oral
A-2018

Bioactive invertebrate compounds as a possible factor promoting phase shifts to coral reefs dominated by alternate organisms.

Schupp, P., Reverter, M., Rohde, S., Helber, S., Nietzer, S.
Univverrsity of Oldenburg, Institut of Chemistry and Biology of the marine Envirronment, Wilhelmshaven, Germany

peter.schupp[at]uni-oldenburg.de

Abstract

In recent years there has been an increasing number of reports that sponges and other invertebrates such as soft corals are becoming more abundant and in some regions the dominating benthic organisms on coral reefs. This increase in abundance seems to correlate in many cases with coral cover declines caused by anthropogenic effects such as overfishing, sedimentation as well as climate change[2]. We recently showed that over half of the reefs studied in the Caribbean were dominated by alternative organisms (i.e. non-hard corals)[1]. Although, this proportion was much lower in the Indo-Pacific, we observed that around 15% of the reefs were dominated by non-calcifying invertebrates, mainly by soft corals. To assess if sponges or non-coral invertebrates are indeed becoming the dominant benthic organisms we monitored their abundances on different reefs in North Sulawesi, Indonesia.
One possible mechanism why sponges are successful competitors is the production of bioactive compounds. It has been well established that sponges use secondary metabolites to defend themselves against sponge feeding fishes and invertebrate predators. Studies on sponge allelopathic compounds are however largely lacking. We investigated in a series of field and laboratory experiments if sponges produce alleopathic compounds which affect coral competitors. Results from the monitoring studies and allelopathic experiments will be presented.

[1] Pawlik, J.R., 2011. The chemical ecology of sponges on Caribbean reefs: natural products shape natural systems.
BioScience 61: 888- 898.

Poster
A-1989

Are reduced herbivory and increased sedimentation the key factors driving algal-dominated alternative stable states on Caribbean coral reefs?

Cheramie, J.[1], Nemeth, R.[2], Ruffo, A.[1]
[1]University of the Virgin Islands, St. Thomas, U.S. Virgin Islands
[2]University of the Virgin Islands, Center for Marine and Environmental Science, St. Thomas, U.S. Virgin Islands

jenna.cheramie[at]gmail.com

Abstract

Anthropogenic factors, such as increased sedimentation and overfishing, can lead to suppressed levels of herbivory and increased coral stress, ultimately reducing coral reef resilience and resulting in degradative phase-shifts from a coral-dominated to an algae-dominated community. Recent studies have also shown that increased levels of sedimentation can affect parrotfish species composition, as well as reduce parrotfish feeding rates. Reduced feeding rates can impact the reproductive output of parrotfishes, resulting in declining population densities. These two factors can shift the balance from coral-dominated to algal-dominated reefs. The resulting negative feedback loop (i.e. more sedimentation = reduced feeding and reproduction of herbivores) may explain why many Caribbean reefs are unable to return to a coral-dominated system. This may be a critical link to understanding coral reef resiliency. In the U.S. Virgin Islands, yellowtail parrotfish (*Sparisoma rubripinne*) form resident spawning aggregations and spawn year-round at spatially and temporally predictable sites making them an ideal model species to examine these relationships. A previous study acoustically monitoring *S. rubripinne* in Reef Bay, St. John revealed a negative relationship between foraging rates and the mean size of individuals in Reef Bay. Additionally, foraging rates were much lower at the western FSA site, which is adjacent to extensive development along the coastline and likely has increased terrigenous sediment inputs. Parrotfishes feeding in higher sediment areas visited the spawning aggregation sites at a lower frequency than fish feeding in low sediment areas. Further research is currently being conducted to determine how spawning site visitation frequency (a proxy for reproductive rates) and feeding rates of *S. rubripinne* vary based on differences in the algal composition and sedimentation rates in nearshore foraging habitats. This research has implications for the management and protection of FSAs that engender reproductive output of ecologically important herbivores that aid in coral reef resiliency, as well as mitigation of land-based sources of pollution and sediment runoff that may disrupt nearshore coral reef environments.

Poster
A-1528

Self-Organized Pattern Formation of a Common Tropical Alga

McNamara, D.[1], Edwards, C.[2], Zgliczynski, B.[2], Smith, J.[2], Pedersen, N.[2], Sandin, S.[2]
[1]UNC - Wilmington, Physics and Physical Oceanography, Wilmington, United States
[2]Scripps Institution of Oceanography/UCSD, La Jolla, United States

mcnamarad[at]uncw.edu

Abstract

Patterns in tropical reef communities can be observed at small, microscopic scales. There are also patterns evident at the spatial scale of entire islands. Recent effort in underwater imaging of reefs has revealed a never before seen, intermediate scale pattern. Aggregations of the calcifying algae Halimeda were observed to form polygonal shapes with a characteristic spacing of 3-4 meters. As the observed patterns appear unrelated to bathymetric or hydrodynamic forcing, we present a numerical model that simulates the emergence of the pattern due to self-organization. Specifically, the model contains two feedback mechanisms that act together to cause the polygonal pattern to emerge. First, the model abstracts microbial processes that act to separate regions of preferred coral habitat quality and Halimeda. The second mechanism is preferential growth of Halimeda in a branching manner, down the long axis of surrounding Halimeda. We will present numerical model results that explore the stability of the simulated polygonal pattern in Halimeda over a range of environmental forcing and we will compare these results with underwater image data taken in various locations and environmental regimes in the South Pacific region.

Virtual
Oral
A-2133

Bleaching impacts and recovery potential of Japan's largest reef: Sekisei Lagoon after 2016 global “Bleaching Event”.

Afzal, M. S.[1], Ikeda, K.[2], Takeichi, K.[3], Ueno, M.[4], Iguchi, A.[5], Nakamura, T.[3]
[1]University of the Ryukyus, Nishihara, Okinawa, Japan
[2]Regeneration Network of the Sea in Yoron Island NPO, Yoron-jima, Japan
[3]University of the Ryukyus, Nishihara, Japan
[4]Coral Reef Research Sekisei Lagoon, Ishigaki-jima, Japan
[5]National Institute of Advanced Industrial Science and Technology, Ibaraki, Japan

mshidha[at]gmail.com

Abstract

The reefs of Sekisei lagoon, Japan was severely affected by mass bleaching episode in summer of 2016. During the peak of the bleaching event in September 2016, the overall bleaching severity was recorded to be 66.40% for the 30 sites in lagoon system whereas bleaching induced mortality was 12.85%. There were significant differences in the bleaching intensity and mortality among the commonly found coral genera with Acropora, Goniastrea, Dipsastraea and Favites showing high bleaching intensity and coral genera Millepora, Seriatopora and Isopora suffering high mortality. In order to understand short term changes to the reefs following bleaching the surveys were repeated for years 2017, 2019, 2020 and 2021. Our results indicate that coral cover declined significantly ($p<0.0001$) to 28.91% in 2016 and to 12.68% by 2020. However, our most recent surveys in 2021 shows significant increase in overall coral cover up to 21%. Even though majority of the reefs were severely damaged post bleaching, recovery and dynamics differed among sites. Some of the sites shows up to 10-15% increase in coral cover 5 years post bleaching. Whereas some of the sites shows clear signs of phase shift with an overall decrease in coral cover up to 30-40% post bleaching and an increase of algal assemblages up to 70-80%.The location of these sites also could be the attributing factor for high algal growth as tidal velocity on the north eastern side of the lagoon system is lower compared to south western side. Our results indicates that some of the sites in Sekisei lagoon exhibits both resistance and resilience to overcome bleaching episodes and conservation of these reefs are important given that the increase in frequency and intensity of bleaching episodes in the future.

Virtual
Oral
A-2109

Revisiting 20 years of coral-algae interaction studies to understand and predict future ecosystem changes

Inagaki, K. Y., Ortigara Longo, G.
Universidade Federal do Rio Grande do Norte, Oceanography and Limnology Department, Natal, Brazil

kyuminagaki[at]gmail.com

Abstract

Coral-algae interactions are iconic interactions in reefs ecosystems, with the potential to scale-up to the ecosystem level and cause phase-shifts. We conducted a global systematic review of studies on coral-algae interactions over the past 20 years and investigated general patterns such as: location of the studies, species involved, outcomes of interactions, the influence of herbivores and potential impacts of global climate changes. We found that coral-algae interactions have been extensively studied in the last decades, but mostly in the Pacific and the Caribbean, where branching and massive corals were the main focus, while other coral growth forms were less investigated. Most of studies focused on frondose macroalgae, calcareous algae and algal turfs, that commonly harm adult corals while some benefit coral larvae and juveniles with an impact on recruitment. The competition effects on algae are often neglected but, when measured cause non-lethal effects (e.g. decrease in photosynthetic efficiency). Despite the large emphasis in the literature on the role of herbivores in controlling coral-algae interactions, we found that these evidences are predominantly indirect and that few studies provide direct tests on the impact of herbivory on coral-algae interactions. Our knowledge on the impacts of global climate change on coral-algae-herbivore interactions is also developing, with evidences of warming causing sub-lethal effects on corals reducing their competitive ability, of ocean acidification reducing coral recruitment, and the few works that evaluate warming and acidification combined show an intensification of sublethal effects on corals. Understanding the role of herbivores and the impacts of global climate changes on coral-algae interactions is critical to predict phase-shifts and the rise of novel ecosystems, while providing insights on the resilience of reef ecosystems. By revisiting what we know on this topic shed light to what we still need to unravel to improve our predictive capacity.

Virtual
Oral
A-2208

A Photographic Time-Machine from Discovery Bay, Jamaica: What the Oldest Georeferenced Coral Reef Survey Tells Us About Reef Dynamics and Resiliency

Porter, J. W.
Odum School of Ecology. University of Georgia, Athens, United States

jporter[at]uga.edu

Abstract

Annually, from 1976 to 1986, fourteen 8 m^2 stations (comprised of 32 quarter meter squared images) were monitored photographically between 2 and 50m depth in Discovery Bay, Jamaica. Each photostation was demarcated by stainless-steel survey pins implanted 1 m into the reef. This allowed every image to be georeferenced to + 1 cm. The survey generated 5,768 Hasselblad 70mm film images, which have now all been scanned as high resolution TIFF files. These images will be archived in the Natural History Museum, London as the *Coral Reef Survey Imagery of James W. Porter in Jamaica 1976-1986*. This imagery will be made available to the lay public and the scientific community. These stations were relocated and reoccupied in 2017 with a team from the Scripps Institution of Oceanography.

Preliminary analysis of the archival imagery reveals a relentlessly dynamic seascape. The reef started out in 1976 with extremely high coral cover. Biological controls (mediated by interspecific competition between corals) controlled coral space ownership in the earliest years of the survey. Hurricane Allen (1980) replaced mechanisms of biological control with physical control (mediated by mechanical destruction and scour), and changed the seascape in ways from which it has still not recovered. By 1981, biological controls began to reassert themselves (first in the form of snail predation on the corals that survived the storm, and then in the form of disease which completely eliminated the grazing sea urchin, *Diadema antillarum*). Significant physical controls have now reemerged in the form of climate change and global warming.

Despite the extreme loss and change documented by these archival photographs, the coral reefs of Discovery Bay present at least three reasons for concerted conservation efforts: (1) *Diadema* populations are beginning to rebound, with a noticeable reduction in macro-algal cover. (2) After almost three decades of absence, large colonies of *Acropora palmata* are beginning to reclaim significant shallow-water areas. And (3) the deep-reef stations do not show the same level of degradation and destruction exhibited by their shallow-water counterparts, giving hope that these highly diverse and slow-growing deep reef communities may one day reseed the shallow reef, if human-kind can reverse its disastrous assault on the natural world.

Virtual
Oral
A-1838

Forecasting intensifying disturbance effects on coral reefs

Vercelloni, J.[1, 2, 3, 4], Liquet, B.[4], Kennedy, E.[2, 5], Gonzalez-Rivero, M.[2, 3, 5], Caley, J. M.[4], Peterson, E.[4], Hoegh-Guldberg, O.[2, 3], Mengersen, K.[1, 4]
[1]Queensland University of Technology, School of Mathematics, Brisbane, Australia
[2]The Global Change Institute, The University of Queensland, Brisbane, Australia
[3]ARC Centre of Excellence for Coral Reef Studies, The University of Queensland, Brisbane, Australia
[4]ARC Centre of Excellence for Mathematical and Statistical Frontiers, Queensland University of Technology, Brisbane, Australia
[5]Australian Institute of Marine Science, Townsville, Australia

j.vercelloni[at]qut.edu.au

Abstract

Anticipating future changes of an ecosystem's dynamics requires knowledge of how its key communities respond to current environmental regimes. The Great Barrier Reef (GBR) is under threat, with rapid changes of its reef-building hard coral (HC) community structure already evident across broad spatial scales. While several underlying relationships between HC and multiple disturbances have been documented, responses of other benthic communities to disturbances are not well understood. Here we used statistical modelling to explore the effects of broad-scale climate-related disturbances on benthic communities to predict their structure under scenarios of increasing disturbance frequency. We parameterized a multivariate model using the composition of benthic communities estimated by 145,000 observations from the northern GBR between 2012 and 2017. During this time, surveyed reefs were variously impacted by two tropical cyclones and two heat stress events that resulted in extensive HC mortality. This unprecedented sequence of disturbances was used to estimate the effects of discrete versus interacting disturbances on the compositional structure of HC, soft corals (SC) and algae. Discrete disturbances increased the prevalence of algae relative to HC while the interaction between cyclones and heat stress was the main driver of the increase in SC relative to algae and HC. Predictions from disturbance scenarios included relative increases in algae versus SC that varied by the frequency and types of disturbance interactions. However, high uncertainty of compositional changes in the presence of several disturbances shows that responses of algae and SC to the decline in HC needs further research. Better understanding of the effects of multiple disturbances on benthic communities as a whole is essential for predicting the future status of coral reefs and managing them in the light of new environmental regimes. The approach we develop here opens new opportunities for reaching this goal.

Session 11C - Shift in scleractinian dominated reefs - are we facing new winners - octocorals, sponges and macroalgae? / Sponges on coral reefs: how can we reconcile contradictory reports on controls, population and community dynamics, and functional roles?

Conceptualized by: **Christine Ferrier-Pagès** [1], **Sergio Rossi**[2], **Yehuda Benayahu**[3], **Janie Wulff** [4], **Christine Schönberg**[5]
[1] Centre Scientifique de Monaco (Monaco)
[2] University of Salento (Lecce, Italy)
[3] Tel Aviv University (Tel Aviv, Israel)
[4] Florida State University (Tallahassee, FL, USA)
[5] University of Western Australia (Crawley, Australia)

Chaired by: **Christine Ferrier-Pagès** [1], **Yehuda Benayahu**[3], **Janie Wulff** [4], **Christine Schönberg**[5]

11C - Shift in scleractinian dominated reefs - are we facing new winners - octocorals, sponges and macroalgae? / Sponges on coral reefs: how can we reconcile contradictory reports on controls, population and community dynamics, and functional roles?

Oral
A-1561

Marine Time Machine: Trajectories of change for tropical marine biodiversity in the Anthropocene

Becking, L.[1, 2], Aji, L.[1, 3], Marine Lake Monitoring Team, Maas, D.[1], de Leeuw, C.[1], Purwanto, P.[4], Martinez, S.[1, 2], Tapilatu, R.[5], Ahmad, A.[6]
[1]Wageningen University & Research, Wageningen, Netherlands
[2]Naturalis Biodiversity Center, Leiden, Netherlands
[3]BRIN, Jakarta, Indonesia
[4]Coral Triangle Center, Bali, Indonesia
[5]Universitas Papua, Manokwari, Indonesia
[6]Yayasan Konservasi Alam Nusantara (YKAN), Sorong, Indonesia

lisa.becking[at]wur.nl

Abstract

Marine lakes - islands of seawater – are our marine time machines. These remote lakes currently provide natural states of predicted environmental scenarios and allow glimpses into past biodiversity dynamics with dated sediment cores. We selected 20 marine lakes in West Papua, Indonesia, that all have eutrophic settings, represent a gradient in temperatures and can be divided in four temperature cohorts which are dominated by different major benthic groups: <31ºC coral-macroalgae, 31-32 ºC macroalgae-Benthic Cyanovbacterial Mats (BCMs), 32-33ºC macroalgae-BCMs-sponges, >33 ºC BCMs-sponges. The lakes are not one-to-one identical to openwater reefs, but do provide an understanding of interaction of major benthic groups under variable environments and during dominance of certain benthic groups.

By comparing marine lakes of similar ages, sizes and with high organic matter loads, but differing in temperature regimes (30-37ºC), together with openwater reefs exposed to different levels of land-based organic matter we aim to:
1) examine how tropical marine species communities respond to past and current environmental change;
2) elucidate how food web structure changes with increased temperature and differences in dominance of major benthic groups across natural communities in the marine lake model system.
3) model responses of tropical marine species communities to predicted scenarios in the Anthropocene.

We will show preliminary data based on integrated field-observations of natural patterns with experiments both in aquaria and *in situ* in marine lakes and across openwater reefs exposed to different levels of human-induced organic matter. Using analyses of genomics, images, stable isotopes, water-quality, and paleontology, I are obtaining crucial data to develop a dynamic model to identify understand how non-linear mechanisms may interact to drive regime changes in coral reefs

Oral
A-1772

The dominance of brown seaweed canopies in the lagoon of Moorea: the roles of epilithic bacterial biofilms and sea urchin grazing

Bulleri, F.[1], Pozas-Schacre, C.[2, 3], Bischoff, H.[3, 4], Bramanti, L.[5], Gasc, J.[2, 3], Nugues, M. M.[2, 3]
[1]Università di Pisa, Dipartimento di Biologia, Via Derna 1, 56126, Pisa, Italy
[2]PSL Université Paris: EPHE-UPVD-CNRS, USR 3278 CRIOBE, Université de Perpignan, 66860, Perpignan, France
[3]Laboratoire d'Excellence Corail, 66860, Perpignan, France
[4]PSL Université Paris: EPHE-UPVD-CNRS, USR 3278 CRIOBE BP 1013, 98729, Papetoai, Moorea, French Polynesia
[5]Sorbonne Université, CNRS, Laboratoire d'Ecogéochimie des Environnements Benthiques, LECOB, 66650, Banyuls-sur-Mer, France

fabio.bulleri[at]unipi.it

Abstract

Understanding the mechanisms underpinning shifts between alternative states is key for coral reef conservation. Although reduced consumer pressure is acknowledged as an important driver of macroalgal dominance, few field experiments have assessed whether restoring herbivore communities can promote coral recovery through the provision of substrata suitable for recruitment. In the lagoon of Moorea (French Polynesia), by means of two field experiments, we evaluated 1) how the removal of either canopies formed by brown seaweeds (*Turbinaria ornata* and *Sargassum pacificum*) or that of the entire macroalgal assemblage influenced the composition of epilithic bacterial biofilms and coral recruitment and 2) whether increasing the density of diadematid sea urchins could reduce the cover of canopies and their ability to recover in the aftermath of physical disturbance events. The removal of both macroalgal canopies and understory species resulted in changes in the epilithic bacterial biofilm and promoted coral recruitment. A moderate increase of diadematid urchins was not effective in controlling the recovery of *T. ornata*, but reduced that of *S. pacificum*, increasing space free of macroalgae. These results, together with those of a laboratory experiment, showing that adult thalli of *T.ornata* facilitate the settlement of its germlings, suggest that a moderate enhancement of diadematid urchins is unlikely to reduce the cover of macroalgal canopies to the level necessary to initiate the shift towards coral dominance.

Oral
A-1666

Sponge Persistence and Species Interactions on Future Coral Reefs

Chaves-Fonnegra, A.[1], Spagnolia, C.[2], Perez, A.[3], Gilliam, D. S.[4]
[1]Florida Atlantic University, Harbor Branch Oceanographic Institute/ Harriet L. Wilkes Honors College, Fort Pierce, United States
[2]Florida Atlantic University, Harbor Branch Oceanographic Institute, Fort Pierce, United States
[3]Florida Atlantic University, Harriet L. Wilkes Honors College, Fort Pierce, United States
[4]Nova Southeastern University, Halmos College of Arts and Sciences, Dania Beach, United States

andia.chaves[at]fau.edu

Abstract

Coral mortality is currently occurring in many coral reefs around the world. As corals deteriorate, other organisms may take over the newly available space (coral skeletons). Most predictions capture these shifts on a broad scale without considering ecological interactions and fine-scale processes. In this study, we evaluate the abundance and permanence of sponges and forecast spatiotemporal interactions of corals, sponges, and macroalgae from 15 to 100 years. Photo-quadrats monitored between 2003 and 2018 in South East Florida reefs were used to obtain change probabilities over time. We implemented a state-transition simulation model via manual-tracing analyses to predict microhabitat and interactions trajectories. Results revealed that sponges' regenerative and fragmenting abilities allow their permanence on coral reefs, even after multi-year events of thermal anomalies. Interactions with sponges substantially increased over time, including sponge-sponge, macroalgae-sponge, and coral-sponge. The data implies that sponges will dominate microhabitats and ecological interactions and may function as the main habitat-forming animals to structure future reefs.

Oral
A-1532

Octocoral resilience through a major bleaching event: A study of three host species and their symbionts

Coffroth, M.-A.[1], Buccella, L.[2], Eaton, K.[2, 3], Franklin, H.[2], Gooding, A.[2, 4], Pelosi, J.[2, 5], terHorst, C.[6]
[1]Univeristy at Buffalo, Geology, Buffalo, United States
[2]University at Buffalo, Buffalo, United States
[3]Auburn University, Auburn, United States
[4]University of Minnesota, Minneapolis, United States
[5]University of Florida, Gainesville, United States
[6]California State University, Northridge, Northridge, United States

coffroth[at]buffalo.edu

Abstract

Scleractinian corals worldwide are in decline due to a range of anthropogenic and natural perturbations. These disturbances, such as increased ocean temperatures, have led to repeated episodes of coral bleaching and rampant disease in these stony corals. In contrast to their scleractinian relatives, Caribbean octocorals are not undergoing this rapid decline; rather, these anthozoans are maintaining coral cover and at some sites, increasing in abundance. These observations suggest that octocorals may be more resilient than scleractinians to thermal stress, yet the basis for this is unclear. In this study, we examined three factors that might contribute to the increased resilience of octocorals. Octocoral hosts may (1) naturally harbor thermally tolerant symbionts, (2) switch or shuffle to more thermally tolerant symbionts and/or (3) themselves provide a thermally tolerant habitat which facilitates the continuation of the symbioses. To examine the possibility that symbiont communities within octocorals can change in response to thermal stress, we monitored symbiont density and genotype within three octocoral species before, during, and after the 2015-2016 global bleaching event. Despite a reduction in symbiont density, the dominant symbiont genotypes did not change in the vast majority of colonies that were monitored. When examining symbiont thermotolerance, we found that many symbiont species within the genus *Breviolum*, the dominant symbionts in most Caribbean octocorals, grew as well or better at 30-32ºC (the common bleaching threshold for scleractinians in the Florida Keys) as compared to 26ºC. Finally, variation in the extent of bleaching within and between octocoral genera harboring the same or closely related symbionts suggests an influence of the host environment. Thus, octocoral resistance to bleaching and subsequent recovery in the face of symbiont loss is likely due to a combination of thermal tolerance of the resident symbionts and, at least in some cases, host environment.

Oral
A-1672

The scale and impact of the encrusting red algae Ramicrusta sp. (Peyssonneliaceae) overgrowing coral colonies in the United States Virgin Islands

Ennis, R., Smith, T.
University of the Virgin Islands, St. Thomas, U.S. Virgin Islands

rosmin.ennis[at]uvi.edu

Abstract

Caribbean coral reefs have been subject to multiple stressors over the last several decades, such as land-based pollution and overfishing. Additionally, the 2005 mass coral bleaching event led to coral mortality rates exceeding 50% in some regions. The combination of coral mortality and removal of herbivores renders reefs more prone to colonization and overgrowth by macroalgae. The genus *Ramicrusta* has emerged in prevalence recently in multiple areas of the Caribbean, causing concern due to its ability to aggressively overgrow living corals and other sessile benthic organisms. Large-scale characterizations of *Ramicrusta* distributions and the potential impacts to reef systems have been lacking. Therefore, this study used data from multiple long-term monitoring projects to provide a baseline distribution of the macroalgae in the United States Virgin Islands. Changes in the benthic community structure and impacts to individual coral colony health in relation to Ramicrusta interaction were also assessed. Finally, potential relationships of *Ramicrusta* prevalence and various non-biological factors, such as orbital velocity and temperature, were examined. Distribution of *Ramicrusta* was found to be patchy and it was present at 18.7% of 443 sites surveyed in the USVI. Average *Ramicrusta* cover was low (1.1%); however, it is rapidly expanding at some sites, covering over half of the substrate and actively killing stony corals by overtopping. *Ramicrusta* interaction with living coral tissue was significantly more prevalent on colonies with more extensive old partial mortality, potentially indicating that mass mortality events facilitate overgrowth.

Oral
A-1887

Utilizing 3D photogrammetry to assess coral-algal competition and growth of a rapidly emerging red alga (Ramicrusta sp.) in the U.S. Virgin Islands

Hollister, K.[1, 2], Ennis, R.[1], Spalding, H.[3], Gabrielson, P.[4], Smith, T.[1]
[1]University of the Virgin Islands, St. Thomas, U.S. Outlying Islands
[2]National Park Service, Dry Tortugas National Park, Florida, United States
[3]College of Charleston, Charleston, United States
[4]University of North Carolina at Chapel Hill, Chapel Hill, United States

karlihollister[at]gmail.com

Abstract

Caribbean coral cover has decreased substantially over the last three decades, with much of the live coral being replaced by macroalgae. Encrusting red algae in the genus *Ramicrusta* have recently become abundant throughout the region and have demonstrated widespread harm to corals by overgrowing living tissue, causing colony mortality, and impairing coral recruitment. Despite these negative impacts to coral reef ecosystems, very little is known about *Ramicrusta* in the Caribbean because the emergence of the algae is relatively recent. In this research, *Ramicrusta textilis* was identified by morpho-anatomy and DNA sequencing from nine sites around St. Thomas, U.S. Virgin Islands, and 3D photogrammetry was used to measure the rate of algal growth on stony corals. 3D models of individual coral colonies (five species plus controls, N = 72) competing with *R. textilis* revealed differential competitive abilities among taxa, with *Siderastrea siderea* being the only species capable of inhibiting overgrowth by the alga (mean linear algal growth -1.1 mm per year). Important reef-building coral species such as *Orbicella annularis* and *Orbicella faveolata* were poor competitors (mean linear algal growth +15 mm per year and +7.7 mm per year, respectively), indicating that the emergence of the alga could have significant impacts on Caribbean coral reef species diversity, community composition, and structural complexity.

Oral
A-1335

Octocoral Forests: The new normal for Caribbean Reefs?

Lasker, H. R.[1], Martinez Quintana, A.[2], Bramanti, L.[3], Edmunds, P. J.[4]
[1]University at Buffalo, Dept of Geology, Buffalo, United States
[2]University at Buffalo, Dept of Environment & Sustainability, Buffalo, United States
[3]Observatoire Oceanologique Banyuls sur mer, LECOB-CNRS, Banyuls/Mer, France
[4]California State University Northridge, Dept of Biology, Northridge, United States

hlasker[at]buffalo.edu

Abstract

The accelerating pace of disturbance on Caribbean reefs has dramatically altered their benthic community structure, generating communities that are vastly different from those described in the 1960's. In many cases, reefs are functionally dominated by macroalgae, but dominance by macroalgae is only one of several community states into which coral reefs can transition. Increased octocoral abundance has been reported on shallow reefs in the Florida Keys, the Virgin Islands, and the southwest Caribbean. However, the extent to which these emergent octocoral communities are resistant and resilient to present, and future, disturbances is unknown. The available data suggest that octocorals are not necessarily resistant to disturbances, but unlike scleractinians, they have been resilient to severe pulse disturbances such as hurricanes. We monitored five years of species-level changes in octocoral communities at three sites on shallow reefs (~ 9-m depth) in St. John, US Virgin Islands, and tested for the effects of two category 5 hurricanes that hit the island in 2017. Hurricanes Irma and Maria depressed densities of >5 cm height octocorals by 18-37%, yet the declines in abundance had only weak effects on community structure. Differences in octocoral species densities and relative abundances across sites separated by < 1.5 km were greater than the temporal effects associated with the storms. Recovery (i.e. resilience) following population loss is dependent on recruitment. The abundance of small, <5 cm tall, colonies also declined following the hurricanes with densities that were 53–63% lower than in the summer of 2017. Losses were most acute in the smallest (≤1 cm) size classes, and were not as great among the 1-5 cm colonies, which provide a reservoir supporting the recovery of the populations. In 2019 recruitment returned to, or exceeded, 2017 levels at our 3 study sites. Our results show that the speciose and dense octocoral communities now dominating some Caribbean reefs, when supported by on-going recruitment, are resilient to the physical disturbance of hurricanes. Critically, there was no categorical collapse of these communities as a result of severe hurricanes, thus suggesting that they are not an ephemeral community state. Continuing environmental degradation is a threat to all tropical marine communities, but under current conditions these emergent "octocoral forests" have the potential of becoming structurally dominant throughout the Caribbean.

Oral
A-2005

Rethinking the roles of non-trophic and trophic interactions on coral accretion rates in degraded reef systems

Saldaña, P.[1], Goetz, N.[2], Altieri, A.[1]
[1]University of Florida, Gainesville, United States
[2]San Diego State University, San Diego, United States

psaldana[at]ufl.edu

Abstract

Caribbean reefs are under increasing threats from anthropogenic stressors such as eutrophication, overfishing and climate change that are shifting community composition towards increasingly high cover of sessile invertebrates such as zoanthids, sponges and gorgonians. Although these organisms are usually assumed to directly compete with live stony corals for space, we hypothesize that they also have an indirect effect by mediating the erosional impacts of consumers. Our recent work on the Caribbean coast of Panama has revealed that the reef urchin, *Echinometra viridis*, reaches exceptionally high densities with proportional consumptive effects that prevent algal phase shifts in these reef systems following coral mortality events. However, some herbivores including, *E. viridis,* are bioeroders that can also contribute to the simplification of reef structure as collateral damage from their grazing activities. As such, the shielding of coral substrate from bioeroders by sessile invertebrates may represent an important non-trophic interaction for the structural preservation of reefs in novel reef ecosystems. In this study we conducted a series of experiments in Bocas del Toro, Panama to examine 1) the CaCO3 consumption rates of *E. viridis* on live and dead fragments of three common coral species (*Porites furcata*, *Millepora alcicornis*, and *Agaricia tenuifolia*), 2) the effects of a pervasive zoanthid, *Zoanthus pulchellus,* on *E. viridis* movement, and 3) how the rate of *E. virdis* bioerosion of corals is influenced by zoanthid overgrowth. Lab experiments revealed that *E. viridis* can have substantial erosional impacts on dead corals but not live corals, and that these erosion rates depend on dead coral species. In addition, survey results and field experiments demonstrated that zoanthid overgrowth of dead corals repels urchins, thereby deterring urchin grazing and decreasing coral erosion rates. Together these results suggest that non-trophic interactions involving sessile space-holders such as zoanthids may decrease reef erosion rates and provide a mechanism of resistance to consumer-induced reef simplification. By examining how interactions among newly dominant space holders and consumers influence the fundamentally important process of bioerosion, our research provides mechanistic insights into the ecological trajectory of contemporary coral reefs.

Oral
A-1934

Depth variation in benthic community response to climate change

Sannassy Pilly, S., Roche, R., Turner, J.
Bangor University, School of Ocean Sciences, Anglesey, United Kingdom

s.pilly[at]bangor.ac.uk

Abstract

Since the late 1990s, significant global losses in coral cover and changes in coral reef composition have occurred due to a range of threats. Here we focus on the effects of recurring bleaching events on tropical reef communities. Elevated seawater temperatures have led to pantropical bleaching events, which are increasing in frequency and severity. When coral reefs are impacted by recurring warming events, the recovery rate that might be expected following a discrete event, is likely to be compromised. Significant reef degradation causes loss of biological and ecological functioning along with the potential transition of coral reefs into “alternate states”, resulting in new configurations and dynamics. This study examines 16 sites across the Chagos Archipelago, focussing on how the benthic community composition and reef structure have changed from 2013 – 2014 (pre-bleaching) to 2018 – 2019 (post-bleaching). Using a long-term video archive, we analysed the coral reef community on seaward reef slopes across depth (5 m – 25 m). By assessing the benthic community composition and the morphological traits of scleractinian corals, this research examines altered dominance patterns and spatial variation in recovery and reassembly of coral reef communities, as a response to more frequent and severe bleaching events. Studying the functioning of reefs remote from direct human impacts such as those of the Chagos Archipelago is vital to our understanding of coral reef resilience and climate-mediated community shifts within the Anthropocene era.

Oral
A-1728

Organic eutrophication and ocean warming effects on the ecophysiology of the soft coral Xenia umbellata

Simancas-Giraldo, S. M.[1], Xiang, N.[1, 2], Vollstedt, S.[1], Moger Kennedy, M.[1], Nafeh, R.[3], Zelli, E.[4], Dessì, C.[5], Katzer, N.[6], Wild, C.[1]
[1]Bremen University - UFT, Marine Ecology, Bremen, Germany
[2]Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research, Bremerhaven, Germany
[3]Friedrich Schiller University Jena, Institute of Ecology- Aquatic Geomicrobiolgy, Jena, Germany
[4]University of Waikato, Hamilton, New Zealand
[5]University of Cagliari, Cagliari, Italy
[6]Leibniz Centre for Tropical Marine Research, Bremen, Germany

sussim[at]uni-bremen.de

Abstract

Recent research revealed that eutrophication with dissolved organic carbon (DOC) as a so far under-investigated local stressor may influence coral reefs, particularly hard corals as major reef ecosystem engineers. No studies up to date have investigated the ecophysiological responses of octocorals to such organic eutrophication, or its interactions with other global stressors such as ocean warming. In the present study, we thus evaluated the ecophysiological responses of the soft coral *Xenia umbellata*to 1) three levels of DOC eutrophication simulated by glucose addition over the first 21 days of experiment and 2) warming scenarios where temperature was gradually increased from 26 °C (control condition), to 32 °C over 24 days. We measured respiration, net photosynthesis and gross photosynthesis, pumping rates (a particular trait in this species), and growth rates among other parameters. The ecophysiological assessesments showed no significant differences in response to single DOC treatments. In adition, no treatment-related differences in pumping behavior was detected and growth rates remained positive regardless of DOC addition. Mortality was never observed. Subsequent exposure to ocean warming caused a decrease in gross and net photosynthesis higher than 50%, a decrease in pulsation rates of 56% (averaging 15 bpm) and mortality at water temperatures of 32 °C compared to 26 °C, for soft corals that were not exposed to previous DOC addition. DOC pre-treated soft corals showed not signifincant improvement in their photo-physiological status but improvements in pumping and growth rates under ocean warming scenarios relative to controls. Findings thus suggest that DOC alone does not affect the ecophysiology of the investigated soft coral. This is particularly interesting when comparing with hard corals that are negatively affected by DOC euthrophication in the concentration range hereby tested. The soft coral *X. umbellata* shows negative responses towards warming scenarios, but also potential to endure and mitigate temperature stress effects. Thus, this soft coral may become a winner in reefs under future scenarios.

Oral
A-1459

Dynamics of the Deep The influence of spatial heterogeneity of water quality on phase shifts of dominant benthic groups reefs on Bonaire.

Tahitu, E.[1], Becking, L.[1], Doğruer, G.[2], Meesters, E.[2]
[1]Wageningen University & Research, Wageningen, Netherlands
[2]Wageningen Marine Research, Den Helder, Netherlands

enahutahitu[at]gmail.com

Abstract

Many Caribbean coral reefs seem to be undergoing a community change with an average decline of 80% in coral cover since the mid-1970s, which is generally due to recent disease outbreaks, fluctuations in herbivory and bleaching events. One of the first phase-shifts to be recognized was the shift from coral to macroalgae dominated reefs. These phase shifts arise on the reefs when the cover of macroalgae increases at the expense of Scleractinia, due to a decreased resilience of the coral reef system state driven by altered ecological processes and/or environmental conditions.

Loss of top down controls seem to trigger shifts towards macroalgae dominated states, whereas shifts in bottom-up dynamics often lead to corallimorpharian, soft coral and sponge dominance. The interest in sponges as potential victors of these shifts in the tropical marine environment seems to have increased recently, as they seem to cope better with the increases in temperature and acidification of the ocean than other dominant benthic organisms. In addition, it seems that sponges can benefit from the demise of hard corals and rise of macroalgae and benthic cyanobacterial mats (BCM). However, the idea that sponges will increasingly dominate coral reefs is not shared unanimously.

This research aims to investigate how spatial and temporal variation in water quality influences the benthic cover on reefs from the shallows down to maximum coral depth. Doing so by coupling data on the benthic cover with water quality measurements. In order to see the current state of the mesophotic reefs and whether changes in water quality have similar effects on deeper and shallower parts of the reefs. The choice of Bonaire is made because this island has reefs that are healthy and relatively pristine compared to other reefs in the Caribbean as well as reefs that are facing anthropogenic stressors. It is primarily the access to data of deeper parts of the reef which make this research unique, as it allows us to understand how the effects of water quality on benthic cover vary across depth. Although the shallow reefs of the Caribbean are acknowledged as a biodiversity hotspot, the status of the deeper parts of the reef remain ambiguous.

Preliminary results show that the mesophotic reefs also suffer the consequences of decreasing water quality. Areas that experience higher nutrient loads have larger amounts of barren substrate and seem to effect the cover of BCM’s and sponges less then hard corals.

Oral
A-1966

Bottom-up control of coral reef sponges: for better and worse

Wulff, J.
Florida State University, Biological Science, Tallahassee, United States

wulff[at]bio.fsu.edu

Abstract

Polarized controversies in ecology are often resolved by learning that both sides are 'right' because the relationship between the focal variables is not monotonic. Much of the recent controversy over bottom-up vs. top-down control of coral reef sponges has been presented in the context of sponges as enemies that damage corals and coral reefs when not controlled by either predators or availability of their picoplankton food. Some resolution has been achieved by experimental demonstration that control of sponges on coral reefs (by too little food) differs from control of habitat boundaries between the reef and adjacent seagrass or mangroves (by predators or competitors). The faster growth and larger size of coral reef sponges with access to more food suggests the possibility that, as human beings add ever more picoplankton-spurring nutrients to coastal seawaters, multiplying sponges will smother the reefs. Experiments comparing growth rates of 14 species of coral reef sponges at reef sites differing in availability of nutrients and picoplankton showed that more food allowed them to grow faster (by factors of 2 - 5, depending on the species). But concern that continued increases in nutrients might result in sponges overwhelming corals and reefs is countered by results from long-term monitoring that reveal that mass mortalities (loss of from 4 - 72% of biomass, depending on the species) of these same sponge species can be caused by nutrient-driven dense phytoplankton blooms. Losses of bioeroding sponges and the few sponge species that are capable of overgrowing corals would surely benefit reefs. But most sponge species contribute positively to corals and reefs: they maintain water clarity by efficiently filtering microbes, host many dozens of species of mesofauna, facilitate recovery of physically damaged reefs by stabilizing rubble, increase survival of living corals by gluing them to the reef frame after their bases are eroded, and inhibit action of bioeroders. Preventing addition of excess nutrients is essential to avoid loss of the great majority of sponge species which play these essential functional roles that are played by no other organisms.

Poster
A-1769

Seascape configuration and fine-scale habitat complexity shape parrotfish distribution and function across a coral reef lagoon

Eggertsen, M.[1, 2], Chacin, D. H.[3], van Lier, J.[4], Eggertsen, L.[5], Fulton, C.[6], Wilson, S.[7, 8], Halling, C.[9], **Berkström, C.**[1, 2]
[1]Swedish University of Agricultural Sciences, Dept. of Aquatic Resources, Öregrund, Sweden
[2]Stockholm University, Dept. of Ecology, Environment and Plant Sciences, Stockholm, Sweden
[3]NOAA: National Oceanic & Atmospheric Administration, St. Croix, U.S. Virgin Islands
[4]Fisheries New Zealand, Wellington, New Zealand
[5]Universidade Federal de Santa Maria, Departamento de Ecologia e Evolução, Santa Maria, Brazil
[6]Australian Institute of Marine Science, Indian Ocean Marine Research Centre, Crawley, Australia
[7]Conservation & Attractions, Government of Western Australia, Department of Biodiversity, Marine Science Program, Kensington, Australia
[8]University of Western Australia, Oceans Institute, Crawley, Australia
[9]Swedish University of Agricultural Sciences, SLU Swedish Species Information Centre, Uppsala, Sweden

charlotte.berkstrom[at]slu.se

Abstract

Structural complexity spanning fine to broad spatial scales can influence the distribution and activity of key organisms within marine ecosystems. However, the relative importance of hard (e.g., corals) and/or soft (e.g., macroalgae) structural complexity for marine organisms is often unclear. This study shows how both broad-scale (seascape configuration of coral structure) and fine-scale habitat complexity (structure height, number of holes, and presence of macroalgae) can influence the abundance and spatial ecology of reef fish. Underwater visual census of fish, surveys of habitats, remote underwater videos, and behavioral observations by following individual fish were used to quantify fine-scale habitat characteristics (e.g., complexity, coral structure height, macroalgae presence) and the abundance, size structure, and behavior (rates of herbivory, tortuosity ratios and total distance travelled) of abundant parrotfish. Both seascape configuration and macroalgae influenced the patterns of fish abundance and rates of herbivory. However, these relationships varied with trophic groups and ontogenetic stages. Abundance of adult and intermediate-phase parrotfishes was positively influenced by densely aggregated coral structures, whereas juvenile abundance was positively influenced by the presence of macroalgae. Foraging path and bite rates of an abundant parrotfish, *Chlorurus spilurus*, were not influenced by coral structure configuration or height, but the presence of macroalgae increased the bite rates of all juvenile parrotfish. Our results suggest that a combination of seascape configuration, fine-scale habitat complexity, and microhabitat selectivity influence reef fish community structure and foraging behavior, thus altering herbivory. However, these relationships can differ among functional groups of fish and life-history stages. Information on these fish–habitat interactions is critical for identifying habitats that facilitate ecological functions and ensures the successful management and conservation of essential habitats.

Poster
A-1853

Weed control in the coral garden; herbivory and substrate type influence growth of the invasive macroalgae Eucheuma denticulatum

Eggertsen, M.[1], Larsson, J.[2], Porseryd, T.[2], Åkerlund, C.[1], Chacin, D.[3], Berkström, C.[1], Jiddawi, N.[4], Kautsky, N.[5], Halling, C.[6]
[1]Swedish University of Agricultural Sciences, Dept. of Aquatic Resources (SLU Aqua), Öregrund, Sweden
[2]Södertörn University, School of natural Sciences, Technology and Environmental studies, Huddinge, Sweden
[3]NOAA; National Oceanic & Atmospheric Administration, St. Croiz, U.S. Virgin Islands
[4]Institute of Fisheries Research, Stone Town, Zanzibar, Tanzania
[5]Stockholm University, Dept of Ecology, Environment and Plant Sciences, Stockholm, Sweden
[6]Swedish University of Agricultural Sciences, SLU Swedish Species Information Center, Uppsala, Sweden

maria.eggertsen[at]gmail.com

Abstract

Introduced macroalgae becoming invasive may alter ecological functions and habitats in recipient ecosystems. In the Western Indian Ocean (WIO), non-native strains of the native macroalgae *Eucheuma denticulatum* were introduced for farming practices and consequently spread into the surrounding seascape. We investigated potential effects of non-native and native strains of this macroalgae on a branching coral. We conducted a four-factor field experiment where we examined growth and holdfast development of introduced and native *E. denticulatum* on live and dead branches of *Acropora* sp. in the presence and absence of herbivores in Unguja Island, Zanzibar. Moreover, we estimated coral and macroalgae condition by visual examinations, gene expression analyses, and photosynthetic measurements. Macroalgae did not attach to any live coral and coral condition was not impacted by the presence of *E. denticulatum*, regardless of geographical origin. Instead, necrotic tissue on the macroalgae in areas of direct contact with corals indicated damage inflicted by the coral. The biomass of *E. denticulatum* did not differ between the replicates attached to live or dead corals in the experiment, yet biomass was strongly influenced by herbivory and replicates without protection from herbivores had a significantly lower biomass. In the absence of herbivory, introduced *E. denticulatum* had significantly higher growth rates than native algae based on wet weight measurements. These results contribute to an increased understanding of environmental effects by the farming of a non-native strain of algae on corals and stresses the importance to maintain viable populations of macroalgal feeding fishes in such areas.

Poster
A-1467

Sponge community responses to disturbances on Caribbean reefs

Gochfeld, D.[1], Brandt, M.[2], Chaves Fonnegra, A.[3], Smith, T.[2], Ennis, R.[2], Diaz, M. C.[3], Olson, J.[4]
[1]The University of Mississippi, Oxford, MS, United States
[2]University of the Virgin Islands, St. Thomas, U.S. Virgin Islands
[3]Florida Atlantic University, Fort Pierce, FL, United States
[4]University of Alabama, Tuscaloosa, AL, United States

gochfeld[at]olemiss.edu

Abstract

Caribbean reefs are increasingly subjected to extreme disturbances, including storm events, thermal anomalies, disease outbreaks and more localized stressors. Impacts of these disturbances on coral communities have been well studied, yet less is known about the impacts, recovery and resilience of sponge communities to these events. In 2017, an unprecedented event of two Category 5 hurricanes in rapid succession occurred on St. Thomas, USVI. Pre-storm data from sites that varied in their levels of land-based impacts enabled us to characterize the impacts of these extreme events on benthic communities and established a baseline to evaluate reef recovery. We compared sponge community metrics from pre-hurricane surveys in 2016 to 2, 6, 15 and 22 mo post-storms. Nearly 150 distinct morphospecies were identified during the study. At 2 mo post-storms, sponge volume and cover declined by 25% overall, and subsequent changes were site specific. In contrast, sponge densities exhibited site-specific increases or decreases at 2 mo post-storms, and an overall increase of 42% over pre-storm densities after 22 mo. Significant losses of upright sponges were offset by an increase in encrusting sponges, and these changes persisted for at least 22 mo. At all sites, sponge recruitment and/or regrowth were observed soon after these extreme events, but recovery of sponge communities was gradual and variable across sites. Caribbean sponge communities vary in their resilience to disturbances, and the reasons for this variability in response remain to be determined.

Virtual
Oral
A-2095

Macroalgae and zoanthids require direct physical contact with corals to be effective competitors in Southwestern Atlantic

Grillo, A. C., Ortigara Longo, G.
Universidade Federal do Rio Grande do Norte, Department of Oceanography and Limnology, Natal, Brazil

a.grillomonteiro[at]gmail.com

Abstract

Space can be a limiting factor in reef ecosystems prompting competitive interactions among sessile organisms. Corals, for instance, often compete with macroalgae and zoanthids that use different mechanisms to succeed in this interaction including chemical warfare. Macroalgae and zoanthids can use allelopathic compounds to compete with corals, with some of them being lipid-soluble and acting when contacting competing organisms, while others are water-soluble metabolites that reach competitors without physical contact. We conducted a short-term laboratory
experiment to investigate the coral response to both competition mechanisms, direct contact and proximity to competitors, using macroalgae and zoanthids. We simulated contact and proximity interactions with the scleractinian coral species *Siderastrea* sp. and the hydrocoral *Millepora alcicornis*, using the macroalgae *Dictyopteris delicatula* and the zoanthid *Palythoa caribaeorum* as competitors. These pairs of interactions are commonly observed in the tropical Southwestern Atlantic reefs in Northeast Brazil (~5°S) were we conducted this study. Within the same tank we held two colonies of the same species for three days, one in direct contact and the other within 5cm of the competitor (either macroalgae or zoanthid). We monitored the outcome of these interactions for 30 days by taking scaled photographs of corals and measuring their photosynthetic efficiency (PE). Coral bleaching and reduced PE only occurred in corals that were physically in contact with both the alga and zoanthid. While the macroalgae caused a slight damage on *M. alcicornis*, that recovered after 10 days, it had no effect on *Siderastrea* sp. Contacts with *P. caribaeorum* affected both corals, significantly causing bleaching and a decline in the PE. After 30 days, *M. alcicornis* completely recovered both in color and PE, but the contacted areas of *Siderastrea* sp. remained bleached and with a low PE. Our experiment evidences that macroalgae and zoanthid were only effective competitors upon direct contact, with the zoanthid being a stronger competitor in comparison to the macroalgae. Recent findings suggest zoanthids use lipid-soluble allelopathic compounds against corals and given their higher thermal tolerance and growth rates can be highly detrimental to corals. This is especially relevant in reefs with relatively low coral cover where zoanthids and macroalgae are dominant benthic groups, which is the case of shallow tropical Brazilian reefs.

Session 11D - hat are the biological and fishery consequences of losing coral reef complexity that is critical for fish populations?

Conceptualized by: **Alastair Harborne** [1], **Mary Donovan** [2], **David Kochan**[1], **Matthew Mitchell**[3], **Alice Rogers**[4]
[1] Florida International University (Miami, Fl, USA)
[2] University of California, Santa Barbara (Santa Barbara, Ca, USA)
[3] NYU Abu Dhabi (Abu Dhabi, United Arab Emirates)
[4] Victoria University (Wellington, New Zealand)

Chaired by: **Alastair Harborne** [1], **Mary Donovan** [2], **David Kochan**[1]

11D - hat are the biological and fishery consequences of losing coral reef complexity that is critical for fish populations?

Oral
A-1901

Winners and losers of reef flattening: A trait-based assessment of coral reef fishes

Harborne, A.[1], Kochan, D.[1], Zuercher, R.[2], Esch, M.[1], Fidler, R.[1], Mitchell, M.[3], Butkowski, D.[1], González-Rivero, M.[4]
[1]Florida International University, North Miami, United States
[2]University of Rhode Island, Kingston, United States
[3]New York University, Abu Dhabi, United Arab Emirates
[4]Australian Institute of Marine Science, Townsville, Australia

aharborn[at]fiu.edu

Abstract

A range of anthropogenic stressors are causing widespread coral mortality in the Caribbean, leading to negative carbonate budgets and loss of structural complexity. While fish abundance and diversity are typically positively correlated with complexity, we lack a comprehensive understanding of how loss of structure will affect different species. There is a growing interest in using trait-based approaches to build generic frameworks of how species will respond to environmental change, and we use this approach to better understand the implications of reef flattening on fishes. We used a large data set from Florida to isolate the relative importance of structural complexity on each species, which varied from positive for some species (likely future ‘losers’) to negative for others (likely future ‘winners’). Analysis for correlations between the relative importance of complexity and fish traits revealed ‘losers’ tended to be found only in coral reef habitats, have very high or very low aspect ratio caudal fins, have more rounded bodies, were herbivores or piscivores, were larger, found shallower, and were schooling or shoaling. These findings indicate that small generalists are more likely to be winners on flatter reefs, and degraded reefs are likely to have decreased herbivory and predation. The trait-based analysis suggests that groupers will be particularly affected, so we investigated the microhabitat (1m2) preferences of a functionally important mesopredator, the graysby, on patch reefs in the Florida Keys. Larger graysby were more active and had larger observed home ranges. Regressing total time in each 1 m2 area against a range of fine-scale biotic variables, including multiple variables derived from structure-from-motion three-dimensional digital reconstructions of each reef, showed only significant positive correlations with the height of carbonate structures. Reef flattening is thus likely to have significant effects on the abundance and space use of graysby. We also analysed graysby waiting times in each microhabitat. These times were best approximated by a truncated power-law (heavy-tailed) distribution, indicating a “bursty” pattern of relatively long periods of inactivity interspersed with multiple periods of activity. Such a pattern has previously been identified in a range of temperate ambush predators, and we extend this move-wait behaviour, which may optimize foraging success, to a reef fish for the first time.

11D - hat are the biological and fishery consequences of losing coral reef complexity that is critical for fish populations?

Oral
A-1996

Using three-dimensional reef models to understand small-scale herbivorous fish foraging and the potential impacts of structure loss

Kochan, D.[1], González-Rivero, M.[2], Esch, M.[1], Fidler, R.[1], Mitchell, M.[1, 3], Harborne, A.[1]
[1]Florida International University, Miami, United States
[2]Australian Institute of Marine Science, Townsville, Australia
[3]Marine Biology Lab, Division of Science, Abu Dhabi, United Arab Emirates

dkoch010[at]fiu.edu

Abstract

Caribbean coral cover is in sharp decline due to a series of anthropogenic stressors, and decreases in herbivory due to overfishing and disease has reduced resilience. Grazing is critical to limiting the growth of macroalgae which is detrimental to live coral and prevents coral larval settlement. While the importance of herbivory is well documented, grazing studies have been mostly limited to relatively large scales, describing inter-site or inter-reef variation. Within reefs, however, algal patchiness that affects benthic dynamics is driven by small-scale grazing influenced by a range of factors including food availability and quality, predation, and structure. New technology allows us to examine multiple metrics of three-dimensional complexity to better understand the role of structure in herbivore foraging and thus algal patterns on reefs. We created virtual reconstructions of 6 Florida Keys patch reefs (~12x12m) using underwater photogrammetry, a novel, low-cost “structure-from-motion” technique combining still images into a 3D model. We extracted fine-scale habitat metrics at $1m^2$ scales including number of refuges, grazeable surfaces, and field-of-view (FOV), which we hypothesize is important for herbivore decision-making. We correspondingly observed *in situ* movement and grazing behavior of juveniles of a key reef herbivore, *Scarus iseri* (striped parrotfish), and resident predators. Using linear mixed-effect models, we regressed a range of behavioral metrics in each $1m^2$ grid cell against structural metrics, food availability, and predator presence. Metrics of high complexity, including decreased FOV and increased number of crevices, were positively correlated with cell use and foraging. Increased cover of macroalgae was correlated with *S. iseri* grazing. Resident predators were also associated with high complexity, suggesting herbivores may be trading-off increased risk for preferred food sources. 3D complexity affects small-scale grazing decision-making, which may in turn shape the distribution of macroalgae on patch reefs. Loss of structure will alter herbivore behavior, with implications for higher and lower trophic levels. The insights from the 3D models will allow us to simulate grazing on future reefs following current flattening trajectories. Examining the fine-scale effects of complexity is critical to predicting the consequences of continued structure loss on the functioning, resilience, and ecosystem services of Caribbean reefs.

Oral
A-1972

Stereo-video elicits energy-distance trade-offs in foraging surgeonfishes on a degraded coral reef

Lilkendey, J.[1, 2, 3], Zhang, J.[1], Meares, M.[1], Sabetian, A.[1]
[1]Auckland University of Technology (AUT), School of Applied Science, Auckland, New Zealand
[2]Leibniz Centre for Tropical Marine Research (ZMT), Bremen, Germany
[3]University of Bremen, Data Science Center (DSC), Bremen, Germany

julian.lilkendey[at]icloud.com

Abstract

To maximise net energy gain, animals adapt their foraging strategies in order to achieve the greatest benefit at the lowest cost. However, the trade-off between energy and distance travelled, and its influence on small-scale foraging behaviours in ecosystems heavily affected by anthropogenic disturbances, has rarely been studied. On a severely degraded coral reef dominated by epilithic algal turf (EAT) in Eilat (Israel, Gulf of Aqaba) we conducted remote underwater stereo-video surveys to compare the expression of surgeonfish foraging behaviours (feeding pressure, grazed substrate, bite rate, distance between consecutive bites). Although their mean biomass was low compared to other grazing fish species on the reef, striated surgeonfish *Ctenochaetus striatus* and yellowtail surgeonfish *Zebrasoma xanthurum* exerted the majority of feeding pressure on a given area of benthos. *C. striatus* spent its main foraging focus grazing EAT on dead coral substrate, while *Z. xanthurum*, preferentially fed on EAT covering rocks. In the degraded state the reef was in, both species displayed opposing energy-distance trade-offs between bite distance and bite rates due to the occurrence of their preferred substrates. Our research employing highly precise stereo-video measurements highlights the importance of patchily distributed resources on a microhabitat scale in explaining coral reef fish foraging behaviour. It also further exposes the need to consider fine-scale resource use patterns in ecologically similar species for strong conservation and management measures in ecosystems subjected to habitat fragmentation.

Oral
A-1565

Size-driven consequences of elevated moray eel densities on prey habitat usage on heavily fished reefs

Zill, J.[1], Tritsch, J.[2], Porter, A.[2], Donahue, M.[2]
[1]Hawai‘i Institute of Marine Biology, University of Hawai‘i at Mānoa, Marine Biology Graduate Program, Kāne‘ohe, United States
[2]Hawai‘i Institute of Marine Biology, University of Hawai‘i at Mānoa, Kāne‘ohe, United States

jzill[at]hawaii.edu

Abstract

Our previous surveys show that moray eels have higher biomass density on the fished reefs in the Main Hawaiian Islands (MHI) than the unfished reefs of the remote Northwestern Hawaiian Islands (NWHI) where apex predator biomass is high. Although humans effectively replace top predators on heavily fished reefs of the MHI, their prey selectivities differ from that of the natural predator assemblage, resulting in top-down control of targeted fishes, and release of untargeted morays.

This higher eel biomass density corresponds to a shift in size frequency distribution from more large-bodied moray eels in the MHI to mostly smaller eels in the NWHI, which has implications for the top-down effects of eels on their prey: the relative size of predator and prey determines whether prey can utilize spatial refuges or exceed the predator’s gape size. Where morays have a greater size range, fish mortality may be heightened if fishes avoid eel-occupied refuges and increase exposure to transient predators/fishers. Further, eels may reduce the control of algae on reefs by altering grazing behavior.

To test of the effects of eel size on prey fish, we conducted a mesocosm experiment that examined behavioral changes of large/small sizes of an herbivorous reef fish (*Acanthurus triostegus*) of cultural, ecological, and commercial value, in the presence of either a large/small moray (*Gymnothorax undulatus*). We quantified: shelter usage, refuge-seeking behavior during a fear stimulus, and foraging rates.

Shelter usage for small prey fish was reduced in shelters occupied by small eels, and large fish avoided shelter entirely in the presence of large eels; prey fish sought refuge from the transient threat stimulus less often in the presence of eels; and eel presence reduced nearby herbivory rates by ~40%.

Complex coral structures are the domain of tropical morays. To understand how reef communities are affected by the loss of structural complexity, it is essential to identify how fishes alter their habitat usage in response to the predator that specializes in hunting in these spatial refuges of the reef. Community structure may be altered if fishes that rely on habitat complexity for shelter are disproportionately affected. Piscivores play an important role in determining reef fish communities, and eels have been shown to have a particularly high piscivory impact on Hawaiian reefs. Here, we show that the effects of morays on reefs are greater than simply the number of fish they consume.

Virtual
Oral
A-1916

Identifying the drivers of structural complexity on Hawaiian coral reefs using photogrammetry-derived measures of linear rugosity

McCarthy, O.[1, 2], Petrovic, V.[2], Sandin, S.[1, 2], Smith, J.[1, 2]
[1]Scripps Institution of Oceanography, La Jolla, United States
[2]University of California San Diego, La Jolla, United States

omccarth[at]ucsd.edu

Abstract

Structural complexity on coral reefs is commonly associated with high abundance of reef fish and Scleractinian corals. Thus, methods to efficiently and accurately assess structural complexity are relevant for coral reef monitoring and conservation. Recent advances in Structure from Motion (SfM) photogrammetry have given rise to novel techniques for quantifying structural complexity using 3D models of coral reefs. Using the SfM software Viscore, this study quantifies linear rugosity and fractal dimension across multiple scales for reefs in the Maui Nui region of Hawaii. We surveyed 31 fixed 10x10m forereef sites in 2017, 2019, and 2021 to quantify change in 3D structure over time. We found that cross-scale patterns of rugosity were a better predictor of coral cover than a measure of linear rugosity at a single scale. We compared cross-scale changes in 3D structure to changes in community composition, both in years with and without bleaching events, and explored the relationship between change in 3D structure, community composition, and various environmental factors. We find that the most significant drivers of benthic composition and 3D structural change differ from year to year, highlighting the dynamic interplay between reef condition and the environment. This study demonstrates how traditional methods of assessing reef condition can be scaled up to yield new insights using SfM. Overall, the scale of measurement and the rate at which linear rugosity changes across scales are important considerations when assessing reef structure. The ability to rapidly measure rugosity across scales using SfM can improve our ability to identify aspects of the reef (biotic vs. geologic) that drive structural complexity and contextualize change in complexity over time.

11D - hat are the biological and fishery consequences of losing coral reef complexity that is critical for fish populations?

Virtual
Oral
A-2129

Reef fish biomass around Rodrigues Island.

Ricot, M.[1], Anasamy, M.[1], Jeetun, S.[1], Jogee, S.[1], Taleb-Hossenkhan, N.[1], Kaullysing, D.[1], Mbui, M. J.[2], Bhagooli, R.[1]
[1]University of Mauritius, Department of Biosciences and Ocean studies, Faculty of Science & Pole of Research Excellence in Sustainable Marine Biodiversity, Reduit, Mauritius
[2]Macquarie University, Department of Earth and Environmental Sciences, Sydney, Australia

mmelaniericot[at]gmail.com

Abstract

Coral reefs are a system of particular interest; millions of individuals along tropical coasts rely on the benefits they provide. Still, a deterioration of the ecosystem state, processes and potential services provided by coral reefs has been observed around the word and in the Western Indian Ocean as the fish biomass decreases as a result of heavy fishing. Reef fish biomass and diversity play a vital role in maintaining reef structure and processes of coral reefs. Therefore, assessing biomass and diversity and sustaining ecological stability and processes are the main targets for achieving sustainable fisheries management. However, information about fish biomass and their spatial distribution are very limited in the western Indian Ocean region, including the Republic of Mauritius. This study aimed at assessing and comparing the total fisheries biomass and fishable biomass, between protected and non-protected sites, around Rodrigues Island (Republic of Mauritius). Five sites were surveyed, namely, Ti trou, Plateau Benitiers and Antonio's Finger which are non-protected sites and two protected sites; Aquarium and Couzoupa. Triplicate belt transects of 50 m x 2 m were randomly laid to assess the fish communities and percentage live coral cover occurring at the surveyed sites. The highest total biomass and fishable biomass, and percentage live coral cover; 2735.70±1718.60kg/ha and 2714.89±1706.06kg/ha, and 64.033±9.55%, respectively, were recorded at protected site Couzoupa. The lowest total biomass and fishable biomass; 605.02±232.55kg/ha and 602.29±234.90kg/ha, almost 5 folds lower than at Couzoupa, were recorded at the non-protected site Plateau Benitiers. The results indicated no significant difference in the total biomass and fishable biomass between the protected and non-protected sites ($p>0.05$). However, Pearson's r data analysis revealed a positive correlation between the total biomass and the live coral cover, $r=0.57$. The results indicated that a decline in total fish biomass as the live coral cover decreases; highlighting the strong relationship known to exist between reef fishes and live coral. The results presented here suggest that the sustenance of total biomass depends upon coral cover and warrant close monitoring, as determining the changes in fish communities along human environmental gradients are the main step in attaining successful sustainable management.

Oral
A-2229

I think we need to take a break: The effects of diver presence on herbivorous reef fish foraging behavior

Renfro, B.
Florida State University, Tallahassee, United States

brenfro[at]bio.fsu.edu

Abstract

Nature tourism is often hailed as a solution to consumptive economic uses of wild spaces, however, there is debate within the coral reef literature as to the balance of conservation and economics in this industry. Coral reefs are hotspots for dive tourism, and areas with intense tourism are experiencing environmental degradation. The bulk of studies focus on the effects of tourism on organism abundances, but fewer have addressed how the industry's influence on the environment affects organism behavior. Disruption to herbivory, historically caused by overfishing and disease, is considered a major driver of reef degradation. While divers may not be physically removing herbivorous reef fish, the presence of humans may exert non-consumptive effects on these prey species resulting in unintended consequences from dive tourism. We examined the spatial and temporal effects of dive tourism on herbivorous reef fish foraging behavior. Surveys were conducted in Akumal Bay along Mexico's portion of the Meso-American Barrier Reef. This bay contains a gradient of tourist presence. Field manpulations of experimentally deployed snorkelers and divers exhibiting typical behaviors of a novice on vacation, including poor buoyancy and camera use, revealed significant short-term effects on the behaviors of both surgeonfishes (3 species) and parrotfishes (9 species), in that diver presence caused individuals to switch from foraging and normal swimming to escape behaviors. However, fish returned to their original proportions of foraging within 5 minutes of diver removal. Based on diurnal observations of fish behavior across the bay, these short-term responses to diver presence do not translate into a consistent large-scale variation in the foraging patterns of fishes among sites that varied in tourist intensity. Rather, we found species-specific long-term spatial and temporal responses to chronic tourist exposure, with some species being more tolerant to the presence of humans. We conclude that diver presence on reefs can reduce time spent foraging by herbivorous fishes over short temporal scales, and thus has the potential to alter competitive interactions between reef building corals and macroalgae. We recommend management actions on intensively-visited reefs to designate diver-free periods between exposure to groups of divers and snorkelers, which would allow herbivorous fishes time to periodically resume their normal foraging behaviors.

Session 11E - How can multi-taxon studies help us understand ecosystem dynamics under climate change?

Conceptualized by: **Brigitte Sommer** [1], **David Booth**[2], **Yohei Nakamura**[3], **Maria Beger**[4]
[1] The University of Sydney (Sydney, Australia)
[2] University of Technology Sydney (Sydney, Australia)
[3] Kochi University (Nankoku, Kochi, Japan)
[4] University of Leeds (Leeds, UK)

Chaired by: **Brigitte Sommer** [1], **Yohei Nakamura**[3], **Maria Beger**[4]

Oral
A-1806

Multi-taxon study reveals complex interplay of biotic and abiotic drivers of ecosystem dynamics along tropical-to-temperate transition zones

Sommer, B.[1, 2], Beger, M.[3, 4], Obuchi, M.[5], Mizuyama, M.[5], Kawamura, I.[5], Kise, H.[5], Reimer, J.[5, 6], Pandolfi, J.[7, 8]
[1]The University of Technology Sydney, School of Life Sciences, Sydney, Australia
[2]The University of Sydney, School of Life and Environmental Sciences, Sydney, Australia
[3]University of Leeds, School of Biology, Leeds, United Kingdom
[4]The University of Queensland, Centre for Biodiversity and Conservation Science, Brisbane, Australia
[5]University of the Ryukyus, Graduate School of Engineering and Science, Okinawa, Japan
[6]University of the Ryukyus, Tropical Biosphere Research Center, Okinawa, Japan
[7]The University of Queensland, ARC Centre of Excellence for Coral Reef Studies, Brisbane, Australia
[8]The University of Queensland, School of Biological Sciences, Brisbane, Australia

brigitte.sommer[at]uts.edu.au

Abstract

Biogeographic transition zones, where tropical, subtropical and temperate species overlap, are being transformed by changes in species distributions and interactions and provide a unique ‘window’ into how climate change might influence complex biological systems. Here, we examine these dynamics across >50 reefs along the tropical-to-temperate transition (25°-35° latitude) in Australia and Japan, where corals occur at their high-latitude range limits and overlap with cold-water species such as kelp seaweeds. We combine fine-scale field data for multiple taxa with environmental data to investigate the mechanisms that shape ecological dynamics. Dominance of algae and non-coral benthic invertebrates (e.g. sponges, ascidians, barnacles) on most reefs points to the important role of these taxa on high-latitude reefs. In particular, hard coral cover was negatively associated with algae cover in both Hemispheres, highlighting the potential for coral-algae competition on high-latitude reefs. We also found clear separation in biotic and abiotic patterns between Northern and Southern Hemispheres. In Japan, sea surface temperature was warmer and hard corals were more abundant than at equivalent latitudes in Australia, whereas chlorophyll-a concentrations and the abundance of non-coral invertebrate taxa were higher in Australia. Multivariate multiple regression further highlights the complex interplay of biotic and abiotic drivers, with variation in multivariate community structure across sites best explained by gradients in temperature, light availability, and the abundance of herbivores, with sea urchins particularly important on high-latitude reefs in Australia. These findings highlight that multi-taxon studies are crucial to understanding ecological dynamics at biogeographic transition zones and the future trajectories of these dynamic systems under climate change.

Oral
A-1697

Changing habitats, species reshuffling and ecological generalism in the world's reef fish communities

Stuart-Smith, R.[1], Mellin, C.[2], Bates, A.[3], Edgar, G.[1]
[1]University of Tasmania, Hobart, Australia
[2]University of Adelaide, Adelaide, Australia
[3]University of Victoria, Victoria, Canada

rstuarts[at]utas.edu.au

Abstract

Climate change, direct human disturbance and altered ecological pathways are changing the structure of coral and rocky reef habitats, placing new selective pressures on their communities. Such processes have been predicted to lead to homogenisation and prevalence of more generalist species. Using the global Reef Life Survey data on benthic habitat cover and reef fish community structure, we characterised contemporary local-scale habitat configurations on rocky and coral reefs and quantified the habitat niche breadths of fishes that occupy them. Scaling species' habitat niche breadths up to the entire fish community in a Community Generalisation Index, we then evaluated evidence for directional shifts in fish community structure related to habitat change. This index suggested a broad-scale community generalisation in Australian reef fish fauna related to habitat change, following regional coral bleaching and cyclone damage in the tropics and on sea urchin barren habitats on temperate reefs. Species' habitat niche breadths also help explain which tropical fishes extend further polewards. This index opens new opportunities to refine predictions of range shifts and future reef community composition in warmer seas, where reef habitats are changing through loss of corals and kelps.

Poster
A-1031

Resilience of coral reefs to thermal stress in the Eastern Tropical Pacific

Romero, M.[1], **Acosta, A.**[1], Treml, E. A.[2], Zapata, F. A.[3], Paz-Garcia, D. A.[4], Palacio-Castro, A. M.[5], Porter, J. W.[6]
[1]Pontificia Universidad Javeriana, Biology, Bogotá, Colombia
[2]Deakin University, School of Life and Environmental Sciences, Victoria, Australia
[3]Universidad del Valle, Cali, Colombia
[4]CONACyT-Centro de Investigaciones Biol gicas del Noroeste, La Paz, B.C.S., Mexico
[5]University of Miami, Miami, United States
[6]University of Georgia, Odum School of Ecology, Athens, United States

laacosta[at]javeriana.edu.co

Abstract

Coral reefs are declining worldwide as they are affected by human activities and climate change. El Niño Southern Oscillation (ENSO) events have affected the Eastern Tropical Pacific (ETP) coral reefs and caused massive coral bleaching and mortality. However, after ENSO disturbances it is unknown if the coral cover is in regional decline, because rates of reef recovery have been idiosyncratic, and localities differ in response. Here, we tested whether: i) the live coral cover declined through time across the ETP, and ii) if the accumulated thermal stress explains the annual rate of coral cover change. To this end, we synthesized the literature and built a coral cover dataset since 1970. Using linear mixed models, we tested if the coral cover declined from 1970-2014 and through three time intervals delimited by ENSO cycles (1973-82, 1983-97 and 1998-2014). Also, to explain coral cover changes, we quantified the annual rate of coral cover change and established a relationship with the maximum degree heating weeks (DHW) between 1982 to 2014. We found that between 1970 and 2014, the coral cover does not exhibit a downward trend. ETP corals reefs have a recovery time of 10-15 years, and on a decadal scale seems resilient to ENSO disturbances. Accumulative heat stress explained 31% of the overall annual rate of change of living coral cover in the ETP. The resilience can be mediated by the asexual reproduction of reef-building corals and by the adaptation/resistance to thermal stress. Coral reefs of the ETP may provide an example of resilience to thermal stress and reveal mechanisms of how future coral reef ecosystems may confront and respond to climate change.

Virtual
Oral
A-1955

Functional richness promotes the resilience of coral reef communities – a simulation experiment

Carturan, B., Parrott, L., Pither, J.
The University of British Columbia Okanagan Campus (UBCO), Biology, Kelowna, Canada

bruno.carturan[at]alumni.ubc.ca

Abstract

The functional diversity of coral species is changing rapidly within the Anthropocene, putting the resilience of many coral reefs in jeopardy. A better understanding of the relationship between functional diversity and resilience could reveal practical ways to manage the functions they provide. The mechanism by which functional diversity can provide resilience are well understood in theory. Experimental demonstrations are however lacking with coral species, due to the difficulty to manipulate their diversity and the factors affecting their community dynamics over substantial spatiotemporal scales. Such experiments are sorely needed because coral communities have presumably a distinctive diversity-resilience relationship due to the singularity of their functional traits and functional trade-offs.

We conducted a virtual experiment to investigate the diversity-resilience relationship in coral communities using a novel agent-based model that combines trait-based and demographic approaches. Using an imputed trait dataset of 798 coral species and eight key functional traits, we assembled 245 functionally distinct coral communities, which we subjected to a cyclone and a bleaching event. We then measured four different aspects of their resilience and quantified for each measure the respective effect of (*i*) functional richness (FRic), and (*ii*) community weighted means (CWM) of four types of traits: effect, resistance, recovery, and competitive. We found that communities with higher FRic generally had higher coral *vs*. algae prevalence, recovered faster and reached high coral cover and surface rugosity 10 years after the disturbances. By analysing community dynamics and functional trade-offs, we found that FRic increases resilience *via* the selection and the insurance effects due to the presence of competitive species in the functional space. Building from these results, we suggest a strategy that can provide direction to the on-going reef restoration efforts.

Virtual Oral
A-2234

Global hotspots of coherent marine fisheries

Ong, J.[1], Walter, J.[2], Jensen, O.[3], Pinsky, M.[3]
[1]Nanyang Technological University, Singapore, Singapore
[2]University of Virginia, Charlottesville, United States
[3]Rutgers University, New Brunswick, United States

joyce.ong[at]ntu.edu.sg

Abstract

Although fisheries can be tightly linked by human and ecosystem processes, they are often managed as independently. Synchronous fluctuations among fish populations or fisheries catches can destabilize ecosystems and economies, respectively, but the degree of synchrony around the world remains unclear. We analyzed 1092 marine fisheries catch time-series over 60 years to test for the presence of coherence, a form of synchrony that allows for phase-lagged relationships. We found that nearly every fishery was coherent with at least one other fishery catch time-series globally, and that coherence was strongest in the northeast Atlantic, western central Pacific, and eastern Indian Ocean. Analysis of fish biomass and fishing effort time-series from these hotspots revealed that coherence in biomass or fishing effort were both possible. Most of these relationships were synchronous with no time lags, and across catches in all regions, synchrony was a better predictor of regional catch portfolio effects than was catch diversity. Regions with higher synchrony had lower stability in aggregate fishery catches, which can have negative consequences for food security and economic wealth.

Virtual
Oral
A-1807

The resistance and reorganization of coral reef communities following biophysical disturbances

Zgliczynski, B.[1], Pedersen, N.[1], Edwards, C.[1], Sullivan, C.[1], Lubarsky, K.[1], Hanna Holloway, N.[1], Petrovic, V.[2], Bonito, L.[1], Alcantar, E.[1], French, B.[1], Clements, S.[1], Akiona, A.[1], Chancellor, K.[1], Kuester, F.[2], Smith, J.[1], 100 Island Challenge team[1], Sandin, S.[1]
[1]UC San Diego, Scripps Institution of Oceanography, La Jolla, United States
[2]UC San Diego, California Institute for Telecommunications and Information Technology, La Jolla, United States

bzgliczy[at]ucsd.edu

Abstract

Dramatic reductions of reef fish biomass and wide-spread loss of coral cover in many sites worldwide have raised concerns over the future of coral reef communities. While overfishing and pollution can alter communities, biophysical drivers including storms, waves, upwelling, and temperature anomalies (e.g., associated with El Niño oscillations) play an integral role in structuring coral reef communities. The myriad environmental conditions and variable reef communities seen across the insular Pacific offer a unique natural experimental context across which to explore linkages between biophysical conditions and reef change. We use a combination of standardized approaches including *in situ* fish belt transects, benthic photoquadrats, and large area imagery, as well as synthesis of satellite derived oceanographic products, to investigate how coral reef communities of the central Pacific respond to episodic climatic and biophysical forcing events. We examine resistance mechanisms of important groups of corals and fishes to gain insights into their ability to buffer through extreme oceanographic conditions (e.g., El Niño associated reductions in upwelling). We find that the survival of a species is dependent on individual life-history strategies. Fast-growing short-lived species are less well suited to tolerate disturbance events, and in many cases suffer dramatic population reductions at the reef scale. In contrast, larger-bodied fishes or more massive coral species are more resistant to episodic events, demonstrating robust capacity to survive through extreme events. Thus, biophysical disturbances lead to species-specific reductions in coral cover for some species and alterations in relative abundance of reef fish assemblages; however, species that are reduced appear to have life-historical capacity to rebuild populations rapidly. In our study system we observed a complete reorganization of the coral reef community after a significant disturbance event, with evidence of slow but consistent patterns to rebuild toward pre-disturbance structure. In a changing world, the frequency and magnitude of biophysical disturbances are increasing and will determine the fate of coral reef communities. Our findings highlight the complexity of coral reef communities and stress the importance of biophysical forcing on structuring these diverse systems.

Session 12A - Open Session: Conservation and management

Conceptualized by: **Sebastian Ferse** [1], **Annette Breckwoldt** [1], **Kirsten Oleson** [2], **Jason Philibotte** [3], **Marie-Lise Schläppy** [4], **Line Bay** [5], **Anna M. Addamo** [6,7]
[1] Leibniz Center for Tropical Marine Research (Bremen, Germany)
[2] University of Hawaii Manoa (Honolulu, HI, USA)
[3] NOAA Coral Reef Conservation Program (Silver Spring, MD, USA)
[4] UWA/AIMS (Crawley, Australia)
[5] Australian Institute of Marine Science (Townsville, Australia)
[6] European Commission, JRC (Ispra, Italy),
[7] National Museum of Natural Sciences (Madrid, Spain)

Chaired by: **Sebastian Ferse** [1], **Annette Breckwoldt** [1], **Marie-Lise Schläppy** [4], **Line Bay** [5], Estradivari [1]

Oral
A-1328

Indonesia's Marine Protection Progress Towards the International Goals

Amkieltiela, A.[1, 2, 3], Handayani, C. N.[1, 3], Andradi-Brown, D. A.[4], Estradivari, E.[3, 5, 6], Ford, A. K.[7], Beger, M.[8], Hakim, A.[9], Muenzel, D. K.[8], Carter, E.[10], Agung, F.[9], Veverka, L.[4], Iqbal, M.[3], Lazuardi, M. E.[3], Fauzi, M. N.[3], Tranter, S. N.[8], Ahmadia, G. N.[4]
[1]Yayasan PADMI Mandiri, Jakarta, Indonesia
[2]KU Leuven, Department of Earth and Environmental Science, Leuven, Belgium
[3]WWF-Indonesia, Marine and Fisheries Program, Bali, Indonesia
[4]World Wildlife Fund, Ocean Conservation, Washington, D.C., United States
[5]Leibniz Centre for Tropical Marine Research (ZMT), Ecology Department, Bremen, Germany
[6]University of Bremen, Marine Ecology Department, Faculty of Biology and Chemistry (FB2), Bremen, Germany
[7]University of the South Pacific, School of Agriculture, Geography, Environment, Ocean and Natural Science (SAGEONS), Suva, Fiji
[8]University of Leeds, School of Biological Science, Faculty of Biological Sciences, School of Biological Science, Leeds, United Kingdom
[9]Ministry of Marine Affairs and Fisheries, Jakarta, Indonesia
[10]Sustainable Solutions International Consulting (SSIC), Croydon, United Kingdom

amkieltiela[at]padmi.org

Abstract

Indonesia is located in the heart of the coral triangle, containing 16% of the world's coral reefs, including the greatest coral and fish diversity, making it a global conservation priority. Faced with high anthropogenic threats, Indonesia has committed to protecting its reefs – with marine protected areas (MPAs) a key approach. This study assesses Indonesia's progress towards reaching global agreements for marine area-based protection, including specific regional targets for coral reef protection. We find that Indonesia currently includes 7.3% of coastal and marine areas within MPAs, spanning 23.9 million ha. Indonesian MPAs include 43% of coral reefs nationally, with approximately 30% of these coral reefs (equivalent to 7% of all reefs in Indonesia) within MPAs fully protected from fishing (i.e., in no-take zones). Therefore, while Indonesia has made substantial progress in increased protection, it falls short of international and regional targets (e.g., Aichi Targets, Coral Triangle Initiative 20% no-take reef protection target). Our results also showed that increasing the management effectiveness of all MPAs in Indonesia requires major efforts. We discuss Indonesia's challenges of balancing both MPA expansion and improving management effectiveness to reach national and international goals for biodiversity conservation in the future.

Oral
A-1827

Insuring coral reefs: Challengaes and opportunities

Bohn, J.[1], Schelske, O.[2], Burt, J.[3]
[1]University of California, Berkeley, Center for Data Analytics in Risk, San Francisco, United States
[2]Swiss Re Institute, Zürich, Switzerland
[3]New York University Abu Dhabi, Biology, Abu Dhabi, United Arab Emirates

jeffrey.r.bohn[at]gmail.com

Abstract

Per unit area, coral reefs provide goods and services to humanity that exceed the economic value of all other ecosystems globally. Reefs are among those natural assets, which show a high insurance-protection gap i.e., the difference between what could or should be insured versus what is actually insured. Reducing the insurance gap can lead to economic, financial, and social resilience as damage-causing events (e.g., hurricanes, bleaching, etc.) can be addressed by bringing in global capital resources to drive repair and restoration. An important requirement to insure any asset is to identify value and how value is impaired by a damage-causing event. For coral reefs, we identify several sources of value: tourism, coastal protection, and biodiversity. These value sources can serve as the basis for writing insurance cover. Coral reefs are not the only natural asset that is difficult to value and that suffers from a high insurance protection gap. Mangrove swamps, urban forests, and deep-sea ecosystems are examples of other under-protected natural assets. Developing insurance products to cover coral reefs will not only contribute to protecting this important natural asset, but also provide insight for closing the protection gaps for other natural assets. Expanding insurance cover to natural assets is an exciting area to explore how better to create resiliency in this important sector of the global economy.

This presentation explores the challenges with insuring coral reefs. We will explore insights from natural catastrophe modeling and from research related to assessing the health and structure of coral reefs. For example, category 4 to 5 hurricanes can endanger up to 60% of live coral cover with a secondary effect of endangering beach stability. Important challenges for writing effective insurance cover include objectively measuring a reef's value before and after a damage-causing event. We will present ideas developing in the reef-research context that may have applicability for insurance. In addition, we will discuss how technology has made insuring natural assets—with a specific focus on coral reefs-- more likely from an efficiency perspective. The first part focuses on the general challenges related to insuring natural assets. In the presentation's second part, we discuss the issues specific to coral reefs. We conclude with remarks as to how these natural-asset insurance solutions are developing and areas that still require more research and development.

Oral
A-2009

Toward regional and global ocean learning networks

Christie, P.[1], Gerhardinger, L.[2], Bell, H.[3], Berndtson, D.[4], Dalton, K.[5], Kantner, B.[6], Skrobe, M.[7]
[1]University of Washington, School of Marine and Environmental Affairs and Jackson School of International Studies, Seattle, United States
[2]PainelMar, São Paulo, Brazil
[3]Washington State Department of Ecology, Olympia, United States
[4]Gulf of Maine Research Institute, Portland, United States
[5]Conservation International, Seattle, United States
[6]University of California, Los Angeles, Los Angeles, United States
[7]Freelance filmmaker, Seattle, United States

patrickc[at]uw.edu

Abstract

Formal and semi-formal networks are emerging as effective, collaborative, and adaptable approaches for addressing complex, rapidly evolving ocean governance issues, such as those affecting the world's coral reefs. One such group of networks, which we refer to as marine-related learning networks, bring people with shared interests together across contexts to facilitate knowledge creation, exchange, and dissemination, and foster capacity development of individuals and institutions to address problems and improve coastal and ocean governance.

We will present our research on the emergence, key attributes, and outcomes of marine-related learning networks, which is based on semi-structured interview data from 40 key informants representing 16 different networks that operate around the world at local, national, regional, and global scales. Also, lessons from the Brazil PainelMar (https://painelmar.com.br) learning network and social network analysis of the Coral Triangle Initiative (CTI, https://www.coraltriangleinitiative.org) marine protected area learning network will be presented demonstrating the how investments in learning networks results in tangible, site-level improvements in social and ecological conditions.

Our findings indicate that marine-related learning networks form in response to knowledge and action gaps and the specific needs of network members. They function to build capacity, improve ocean management, and inform policy, particularly in areas of high ecological, social, cultural and economic importance, such as coral reef ecosystems. Their success depends on attributes such as having a distinct purpose, building trust and relationships, emphasizing equitable participation, and supporting clear, sustained leadership.

These networks are typically non-deterministic, and as such are uniquely positioned to act as catalyzers and conduits to develop solutions that draw in socio-cultural knowledge, tempering siloed, mono-disciplinary conservation agendas. Highly deterministic policy making that is over reliant on natural science while de-emphasizing socio-cultural knowledge is inadequate to address current ocean governance challenges. This presentation concludes with an invitation to consider whether the time has arrived to invest in local, regional, and/or global marine-related learning networks as complements and alternatives to traditional policy approaches.

Oral
A-1831

Biophysical modeling predicts population structure across scales for eleven Hawaiian reef species

Conklin, E.[1], Neuheimer, A.[2], Toonen, R.[1]
[1]Hawaii Institute of Marine Biology, University of Hawaii, Kaneohe, United States
[2]Aarhus University, Aarhus Institute of Advanced Studies (AIAS), Aarhus, Denmark

conkline[at]hawaii.edu

Abstract

Population connectivity is an important consideration in determining the correct scale for effective management in marine environments. In the Hawaiian archipelago, connectivity of reef organisms via pelagic larval dispersal has been explored using both population genetic and biophysical modeling approaches. Previous research has simulated particle dispersal at a coarse scale across the Main Hawaiian Islands and Northwestern Hawaiian Islands, as well as at a finer scale for the island of Moloka‘i. Using the individual-based model OceanParcels combined with modules from a previously published model, we use nested ocean current output from the Massachusetts Institute of Technology general circulation model (MITgcm). In this study, we present the finest-scale dispersal model of the Main Hawaiian Islands produced to date for 11 reef species of economic and cultural importance. These 11 species span the range of life history characteristics of Hawaiian coral reef fishes and invertebrates and show different spatial and temporal patterns of connectivity as a result. We map potential species-specific patterns of dispersal across scales, from islands to Native Hawaiian traditional land divisions. These connectivity maps predict areas of high and low exchange that are expected to result in variable population structure across species and scales. To test the model, we present validation across scales using a population genetic analysis of the coral species *Pocillopora meandrina* and the limpet species *Cellana exarata*. Using a network science approach to analyze and visualize the data, we highlight critical larval sources and multi-generational pathways to indicate priority areas for marine resource managers.

Oral
A-1719

Evaluating the impact of non-native seagrass, Halophila stipulacea, on health and survival of economic reef fish yellowtail snapper, Ocyurus chrysurus

Costa, S.[1], Habtes, S.[2], Willette, D.[3], Nemeth, R.[1]
[1]University of the Virgin Islands, St. Thomas, U.S. Virgin Islands
[2]Department of Planning and Natural Resources, St. Thomas, U.S. Virgin Islands
[3]Loyola Marymount University, Los Angeles, United States

sophia.costa[at]students.uvi.edu

Abstract

Yellowtail snapper (*Ocyurus chrysurus*) are one of the most commercially important fish species in the United States Virgin Islands (USVI). Like many reef fish, yellowtail snapper experience a 2-phase shift where juveniles rely on seagrass habitats for critical nursery area before transitioning to the reef. Native seagrasses *Syringodium filiforme* and *Thalassia testudinum* provide juvenile fish with foraging habitat and protection during this vulnerable stage of life. However, these essential habitats are threatened by numerous anthropogenic stressors, including sediment runoff, pollution, and rising sea temperatures. In 2002 a non-native seagrass *Halophila stipulacea* was discovered off the coast of Grenada and has since rapidly spread throughout the Caribbean, arriving in St. Thomas, USVI in 2013. This non-native seagrass poses an additional threat to native seagrasses as it displaces native species. This shift in community composition could have damaging effects on juvenile reef fish populations that depend on these habitats as nursery zones. The purpose of this study was to determine the effects of *H. stipulacea* on juvenile yellowtail snapper settlement, mortality, and condition in St. Thomas, USVI. Settlement and mortality of juvenile yellowtail snapper was compared among *H*. *stipulacea, S. filiforme*, and *T. testudinum* seagrass habitats around southern St. Thomas, USVI. Juvenile yellowtail snapper were trapped and measured for length and weight to derive the condition factor as a measurement of health. Significantly greater settlement of juvenile *O. chrysurus* was found in non-native seagrass habitats when compared to native seagrass habitats. Condition factor did not significantly differ among seagrass species, although trends demonstrated a higher condition in native than non-native seagrass habitats. These results suggest that *H*. *stipulacea* is not as destructive for fish populations and health as previously hypothesized. This study is the first of its kind to explore the realized effects of *H. stipulacea* on commercially important fish species in St. Thomas, USVI.

Oral
A-2048

Predicting the potential distribution of a new Caribbean invader using a species distribution model

Esch, M.[1], Jarnevich, C.[2], Robertson, R.[3], Rosas, C.[4], Simoes, N.[4], McClanahan, T.[5], Harborne, A.[1]
[1]Florida International University, North Miami, United States
[2]United States Geological Survey, Fort Collins, United States
[3]Smithsonian Tropical Research Institute, Balboa, Panama
[4]National Autonomous University of Mexico, Sisal, Mexico
[5]Wildlife Conservation Society, Bronx, United States

mesch003[at]fiu.edu

Abstract

Species distribution models (SDMs) are a valuable research tool for predicting a species' suitable habitat in response to climate change, invasion, or tropicalization. These models require geospatial data and environmental predictor variables combined with physiological constraints for the species of interest to make the best forecast of the species' potential distribution. Using both global- and local-scale distributional and environmental layers, we can evaluate the habitat suitability of a new invader, *Neopomacentrus cyanomos* (regal demoiselle), to help predict future range expansion. Native to the Indo-Pacific, the regal damselfish was first observed in the Gulf of Mexico (GOM) on multiple reefs off the coast of Veracruz, Mexico in 2013. Since these first sightings, this species spread north along the Mexican coast and has been recorded in high abundance in the northern GOM and has an additional location of introduction in Trinidad. The basis of the SDM included extensive distributional data sets of *N. cyanomos* along the entire Great Barrier Reef and east coast of Africa, which provided broad-scale habitat preference within the native range. To aid the prediction of habitat that might be suitable for *N. cyanomos* in the Greater Caribbean (GC), we extracted fine-scale microhabitat data from reefs in the southwest GOM using three-dimensional technology and further investigated physiological constraints using respirometry to test aerobic metabolic performance at a thermal gradient covering the seasonal fluctuations of the GOM. By combining our local fine-scale dataset with larger, more robust data sets from the native range, the model can predict the non-native range expansion for *N. cyanomos* based on a wide range of factors. The SDM predicts the likely spread of *N. cyanomos* throughout the GC, which is critical for risk assessment and the development of a management strategy to limit range expansion.

Oral
A-1382

Marine conservation beyond MPAs: Towards the recognition of other effective area-based conservation measures (OECMs) in Indonesia

Estradivari, E.[1, 2, 3], Agung, M. F.[4], Adhuri, D. S.[5], Ferse, S. C. A.[2, 6], Andradi-Brown, D. A.[7], Campbell, S. J.[8], Iqbal, M.[3], Jonas, H. D.[9], Lazuardi, M. E.[3], Nanlohy, H.[10], Pakiding, F.[11], Pusparini, N. K. S.[12], Ramadhana, H. C.[3], Ruchimat, T.[13], Santiadji, I. W. V.[14], Timisela, N. R.[15], Veverka, L.[7], Ahmadia, G. N.[7]
[1]Leibniz Center for Tropical Marine Research (ZMT), Ecology, Bremen, Germany
[2]Faculty of Biology and Chemistry (FB2), University of Bremen, Marine Ecology, Bremen, Germany
[3]WWF-Indonesia, Marine and Fisheries, Bali, Indonesia
[4]Ministry of Marine Affairs and Fisheries, Jakarta, Indonesia
[5]Research Center for Society and Culture, National Research and Innovation Agency (BRIN), Jakarta, Indonesia
[6]Leibniz Centre for Tropical Marine Research (ZMT), Future Earth Coast, Bremen, Germany
[7]World Wildlife Fund, Ocean Conservation, Washington D.C, United States
[8]RARE Indonesia, Bogor, Indonesia
[9]World Wildlife Fund, Conservation Areas, Washington D.C, United States
[10]Pattimura University, Fisheries and Marine Science Faculty, Ambon, Indonesia
[11]University of Papua, Research and Community Empowerment Division, Papua Barat, Indonesia
[12]Yayasan Pemberdayaan Alam, Desa dan Masyararakat Indonesia (PADMI Foundation), Jakarta, Indonesia
[13]Jakarta Technical University of Fisheries (Poltek AUP), Ministry of Marine Affairs and Fisheries, Jakarta, Indonesia
[14]WWF-Indonesia, Coral Triangle Program, Jakarta, Indonesia
[15]Pattimura University, Agriculture Faculty, Ambon, Indonesia

estradivari.sant[at]gmail.com

Abstract

In a marine environment that is rapidly changing due to anthropogenic activities and climate change, area-based management tools are often used to mitigate threats and conserve biodiversity. Marine protected areas (MPAs) are amongst the most widespread and recognized marine conservation tools worldwide, however, MPAs alone are inadequate to address the environmental crisis. The promotion of other effective area-based conservation measures (OECMs) under draft Target 3 of the Post-2020 Global Biodiversity Framework, i.e., conserving 30% of marine areas by 2030, holds promise to acknowledge sites and practices occurring beyond MPAs that contribute to conservation. Here, we evaluate the potential recognition of OECMs into Indonesia's national policy framework on marine resource management and provide the first-ever overview of distribution and types of potential marine OECMs in Indonesia, including a review of the existing evidence on conservation effectiveness. We identified > 390 potential marine OECMs, led by government, customary and local communities, or the private sector, towards diverse management objectives, including habitat protection, traditional/customary management, fisheries, tourism, or other purposes. While some evidence exists regarding the conservation effectiveness of these practices, the long-term impacts on biodiversity of all potential marine OECMs in Indonesia are unknown. Many OECM elements have been included in several national policies, yet there are no established mechanisms to identify, recognize and report sites as OECMs in Indonesia. We propose four transformational strategies for future OECM recognition in Indonesia, namely: (i) safeguard customary and traditional communities, (ii) leverage cross-sector and cross-scale collaboration, (iii) focus on delivering outcomes, and (iv) streamline legal frameworks. Our study shows that OECMs have the potential to play a significant role in underpinning marine area-based conservation in Indonesia, including supporting the Government of Indonesia in reaching national and international conservation targets and goals.

Oral
A-1430

Distribution, drivers, and protection of functionally distinct fishes on global tropical reefs

Judah, A.[1], MacNeil, M. A.[1,2], Mouillot, D.[3,4], Stuart-Smith, R.[5], Edgar, G.[5], Touchie, E.[1], Loiseau, N.[3,6,7,8], Villéger, S.[3], Thuiller, W.[6], Mouquet, N.[3,9], Violle, C.[8], McLean, M.[1]
[1]Dalhousie University, Department of Biology, Halifax, Canada
[2]Ocean Frontier Institute, Dalhousie University, Department of Biology, Halifax, Canada
[3]MARBEC, University of Montpellier, Montpellier, France
[4]Institut Universitaire de France, Paris, France
[5]University of Tasmania, Institute for Marine and Antarctic Studies, Hobart, Australia
[6]Université Grenoble Alpes, Grenoble, France
[7]Université Savoie Mont Blanc, Chambéry, France
[8]Centre d'Ecologie Fonctionnelle et Evolutive (CEFE), University of Montpellier, Montpellier, France
[9]CNRS, University of Montpellier, Montpellier, France

aaron.judah[at]dal.ca

Abstract

Functionally distinct species, which have rare combinations of ecological traits, are thought to sustain key ecosystem functions by providing unique and uninsured ecological roles. Despite growing interest in functionally distinct species, the socio-economic and environmental conditions that support them, including the effectiveness of marine protected areas (MPAs), have not been investigated. Here, using over 3700 underwater visual surveys from 60 ecoregions worldwide, we assessed the distribution and hierarchical drivers of functionally distinct fish biomass on tropical reefs. We then analyzed the effectiveness of marine protected areas in increasing the biomass of functionally distinct species and identified the conditions that maximize these benefits. Distinct reef fishes were characterized by large body sizes, high trophic levels, and high gregariousness. Northern Australia, the Galapagos and tropical eastern Pacific, and the central and eastern Indo-Pacific were identified as global hotspots harboring disproportionately high biomasses of functionally distinct species. No-take MPAs disproportionately benefited distinct species, increasing their proportional biomass in an assemblage, while human gravity and development were associated with decreased proportional biomass. MPAs around South and Central America and near the Great Barrier Reef protected the greatest proportion of functional distinctiveness, while areas in the southwest Pacific and western Indian Ocean had lower proportional distinctiveness. Our findings show the benefit of conservation actions in supporting functionally distinct species and highlight the importance of effective planning in spatial management. To preserve ecosystem multifunctionality in the face of widespread reef decline, species ecological roles should be increasingly considered, particularly functionally distinct species and those that contribute to key ecological processes.

Oral
A-1732

DO NOT DISTURB: Limiting motorboat disturbance could support reef resilience

Nedelec, S.[1], Radford, A.[2], Gatenby, P.[3], Keesje Davidson, I.[2], Velasquez, L.[4], Travis, M.[5], Chapman, K.[6], McCloskey, K.[6], Gordon, T.[7], Illing, B.[8], McCormick, M.[4], Simpson, S.[2]
[1]University of Exeter, Biosciences, Exeter, United Kingdom
[2]University of Bristol, Bristol, United Kingdom
[3]University of Western Australia, Perth, Australia
[4]James Cook University, Townsville, Australia
[5]University of Puget Sound, Tacoma, United States
[6]University of Exeter, Exeter, United Kingdom
[7]University of Lancaster, Lancaster, United Kingdom
[8]Thünen Institute of Fisheries Ecology, Bremerhaven, Germany

s.nedelec[at]exeter.ac.uk

Abstract

A rising tide of noise pollution threatens humans and wildlife; rapid solutions with wide-reaching impact are needed. Motorised transport underpins a culture of convenience; almost all human activity involves transporting people or goods via motorised vehicles on land, in water and in the air. Vessel noise is the most widespread form of underwater noise pollution and impacts a broad range of species from cetaceans to cephalopods. Behaviour such as feeding and cleaning can be altered temporarily, influencing rhythms of activity. Ultimate consequences of noise pollution include death due to injury or predation, failure to develop and reduced offspring quality and survival. The evidence is robust and clear; the impacts of anthropogenic noise are pervasive across taxa, across ecosystems and across the world.
Here we test the hypothesis that protecting coral reefs from motorboat noise can improve reproductive output in fish, using an established model system on the Great Barrier Reef in Australia. Across an entire breeding season, we limited motorboat traffic at 46 *Acanthochromis polyacanthus* nests on three separate reefs by 1) recommending motorboat drivers to stay further than 100 m from reefs, 2) imposing a speed limit within 100 m and 3) prohibiting anchoring within 20 m. We compared these protected nests with 40 *A. polyacanthus* nests on three further reefs where motorboats drove regularly nearby and could anchor within 10 m; these reefs were typically exposed to 1.5 h of motorboat activity per day. A complementary laboratory study of 22 nesting pairs allowed us to isolate noise as the driving element and study phases of the life cycle that could not be observed in the wild.
We tracked parental-care behaviour, offspring growth and offspring survival in the wild and in the laboratory. Protecting coral reefs from traffic noise was beneficial for breeding fish and their offspring: parental activity, egg fanning and larval predator defence were restored, embryonic and larval growth were enhanced with lower energetic resource use, and reproductive success was enhanced. Mitigation and abatement of noise pollution offer simple and easy wins in protecting coral reefs from human impacts. Limiting traffic noise at the local level presents a valuable opportunity for enhancing resilience in coral reefs by improving reproductive success in fish.

Oral
A-1818

Application of an Ecosystem-Based Fisheries Management Approach: Road to Recovery for the Endangered Nassau Grouper

Nemeth, R. S.[1, 2], Kadison, E.[1], Brewer, R.[3], Henderson, L.[4], Green, D.[1], Olsen, D.[5], Smith, T.[1]
[1]University of the Virgin Islands, Center for Marine and Environmental Studies, St Thomas, U.S. Virgin Islands
[2]University of the Virgin Islands, St. Thomas, U.S. Virgin Islands
[3]University of the Virgin Islands, Center for Marine and Environmental Studies, St Thomas, United States
[4]National Oceanic and Atmospheric Administration, St. Thomas, U.S. Virgin Islands
[5]St. Thomas Fishermen's Association, St. Thomas, U.S. Virgin Islands

rnemeth[at]uvi.edu

Abstract

Nassau grouper (*Epinephelus striatus*) were once the most common large grouper inhabiting coral reefs of the greater Caribbean region. In the 1970's and 1980's populations collapsed due to intensive fishing on their fish spawning aggregations (FSA), a practice that is still common throughout the world. FSA sites are used by many species where 100's to 1000's of individuals gather to spawn at specific times and locations. The hyperstability of FSA sites makes harvests seem sustainable until the spawning population collapses. *E. striatus* has shown few signs of population recovery throughout its range and only a few FSA sites remain. We report on strategic conservation, management and monitoring efforts that have resulted in signs of population recovery in the US Virgin Islands. These regulations included a prohibition on harvest and establishing the Grammanik Bank seasonal closed area to protect a small *E. striatus* FSA site. In addition to regulations, community outreach and fisher participation in data collection has contributed to a promising ecosystem-based fisheries management (EBFM) approach. Annual surveys over 18 years at 30 long-term coral reef monitoring sites have shown a significant increase in *E. striatus* at nearly all monitoring sites around St. Thomas since 2016. Yearly surveys on the Grammanik Bank FSA showed abundance of *E. striatus* increased from 50 fish to over 800 fish in the past 15 years. The increase in abundance is largely attributed to fisher support of conservation and management actions. Population recovery has also accelerated due to two large settlement pulses of juveniles in seagrass habitats in 2006 and 2015. However, since 2012 the invasive seagrass, *Halophila stipulacea*, has rapidly expanded and is replacing native seagrasses across the USVI. Preliminary results suggest that the invasive seagrass may negatively affect juvenile *E. striatus* growth and condition. The current prospect of *E. striatus* population recovery is positive, but long-term effects of *H. stipulacea* on juvenile *E. striatus* life history traits are uncertain, and thus should be incorporated into EBFM efforts.

Poster
A-1896

Incorporation of Non-Acroporids into a Florida Restoration Program

Burdeno, D., Levy, J., **Burrell, S.**, Neufeld, A., Moura, A., Winters, S.
Coral Restoration Foundation, Tavernier, United States

jessica[at]coralrestoration.org

Abstract

Coral reefs in the Caribbean have seen an upwards of 95% decline in hard-coral cover over the last several decades. This decline has been attributed to multiple compounding factors including but not limited to climate change, water pollution, and overfishing. The unprecedented decline being seen has created a need for action and conservation. Within the greater Caribbean and Florida, restoration organizations have focused on restoring the two main reef building species: Acropora cervicornis andA. palmata. For these two species, asexual fragmentation and nursery propagation has been well examined, while curated asexual reproduction for other Caribbean coral species, especially slower
growing massive boulder corals, is just being explored.

Two Caribbean boulder corals Orbicella annularis and O. faveolata have been included on the IUCNredlist and the ESA threatened list, highlighting the need for conservation actions. Our organizationhas developed in-situ micro-fragmentation and growth techniques for O. annularis and O. faveolata. Utilizing existing nursery infrastructure and readily available restoration materials we have been able to implement an effective and low-cost methodology for the asexual propagation of these two species that can be extrapolated to any nursery setting or potential boulder coral species. Following the initial collection and fragmentation of wild genotypes all work is done in-situ at the coral nursery. This eliminates the possibility of transport stress/shock and allows for efficient use of underwater SCUBA
time.

We are currently propagating 30+ putative genotypes for both Orbicella sp. in an offshore nursery environment. Stemming from the success we have had in asexual micro-fragmentation, we have begun to scale-up our boulder coral outplanting program. To date we have outplanted 1660 boulder fragments, utilizing a NEMO underwater drill and a standard two-part marine epoxy. Putative genotypes are outplanted in distinct clusters of 10-20 coral plugs.Initial one-month survivorship across both species and all genotypes is 97%. In 2020 we plan to drastically increase boulder coral outplants to 4000 plugs for each of the two species. Presented herein is our in-situ propagation methodology, capable of producing mass quantities of boulder coral fragments for restoration work, as well as our outplant monitoring data of existing boulder coral outplants from 1-month and 1-year surveys.

Poster
A-1652

Getting a grip on Sudan's Red Sea coral reef fishery

Elbashier, D.[1], Elamin, S.[2], Kolding, J.[3], Johannesen, T.[4], Olsen, E.[4], Moland, E.[4]
[1]Marine Fisheries Administration, Portsudan, Sudan
[2]Red Sea University, Portsudan, Sudan
[3]University of Bergen, Bergen, Norway
[4]Instutite of Marine Research, Bergen, Norway

diayousuf[at]yahoo.com

Abstract

Coral reef fisheries in countries with poor governance share certain features: the fishery is usually data-poor, mixed species and is targeting a wide range of species. Target- and secondary target species are defined based on short-, medium- or long-term status as table fish, as well as demand in domestic- or export markets. Such patterns drive fishers' targeting of certain species, a dynamic with both management and conservation implications. The Sudanese coral reef fishery is considered lightly exploited, but information has been lacking regarding the state of harvested populations. However, since 2015, Sudan's Marine Fisheries Authority (MFA) has maintained a comprehensive fish landing sampling scheme and developed a fisheries statistics tool based on the Pasgear software. Landings are recorded at two landings sites, one of which is the Sigala central fish market in Port Sudan where the majority of landed fish are traded. Here, we illustrate the new situation by presenting landings data for a suite of secondary target species: *Epinephelus tauvina* (Serranidae), *Aethaloperca rogaa* (Serranidae), *Epinephelus summana* (Serranidae) *Variola louti* (Serranidae), respectively – throughout the period (2016-2017-2018), the average (mean of means) length of landed fish was (2016) 63, 33, 38 and 42 cm; (2017) 69,32,37 and 40 cm; (2018) 65,32,34 and 44 cm. Landed biomass for these species was estimated to (2016) 22, 26.7, 32.9 and 58 tons; (2017) 23, 27.6, 33.7 and 59 tons; and (2018) 23.3, 28, 34.3 and 60.1 tons. These estimates ranged from 1.7 – 4.9% of total landings in the period, indicating that these species constitute significant contributions to the total landings. Tor *E. tauvina* landings peaked in the month of February in 2016, October 2017, and March 2018. For *A. Rogaa*, landings peaked in the month of February in 2016, March 2017, and March 2018. For *E. summana*, landings peaked in the month of October in 2016, December 2017 and May 2018. For *V. louti*, landings peaked in the month of February in 2016, March 2017 and July 2018. Using the fishery statistics system to track shorter- and longer-term temporal patterns in landings and -composition is an important first step towards building a sound management regime based on the ecosystem approach to fisheries management (EAFM) in the Red Sea state.

Poster
A-1673

Long-term changes in fish communities after lionfish arrival on mesophotic reefs inside and outside of marine protected areas in the US Virgin Islands

Heidmann, S. L., Kadison, E., Brandtneris, V., Ennis, R., Smith, T. B., Nemeth, R. S.
University of the Virgin Islands, Center for Marine and Environmental Studies, St. Thomas, United States

sarah.heidmann[at]uvi.edu

Abstract

The US Virgin Islands is home to several marine protected areas, some of which encompass mesophotic coral ecosystems. Two of these are the Hind Bank Marine Conservation District, located ~8 km southwest of St. Thomas, and the Virgin Islands Coral Reef National Monument, which extends south of St. John. These managed areas were established to protect native fish communities, especially commercially-important species, from the effects of overfishing. With the 2008 arrival of the invasive Indo-Pacific lionfish to the area, however, some of these benefits may not be realized due to high predation rates on small native fishes. This study sought to evaluate fish populations inside and outside these regionally-important protected areas using fishery-independent surveys, assessing 122 sites before and ~10 years after the first observation of lionfish. Surveys were first completed inside the MCD in 2007, and inside and outside the VICRNM in 2002-2005, and were repeated in both locations in 2018-2019 with added sites outside the MCD. Lionfish density was low, with a maximum observed density of 7 individuals per 100 m^2, and overall mean of 0.5 individuals per 100 m^2. There were higher densities of lionfish present around the MCD than around the VICRNM ($p=0.005$), but density was not significantly different inside and outside protected areas ($p=0.21$). Overall fish abundance and species richness increased over time inside the MCD ($p < 0.0001$ for both metrics) but decreased around the VICRNM ($p < 0.0001$ for both metrics). Abundances of large-bodied, commercially important piscivores did not change significantly over time in the MCD ($p=0.29$) or around the VICRNM ($p=0.95$), suggesting that any positive effects of protection may be cancelled out by reduced recruitment or survival of young. Even at low lionfish densities, the relationship between this invasive predator and native fish communities is complex, and may alter the apparent efficacy of protected areas, especially in emergingly important mesophotic coral ecosystems.

Poster
A-2015

Building A Comprehensive Monitoring Network: RESTORE CMAP's Habitat and Water Quality Monitoring and Mapping Framework for the Gulf of Mexico

Hile, S. D.[1, 2], Howell, J.[1, 3], Burkart, H.[1, 2], Clark, R.[3], Monaco, M.[2], Giordano, S.[4]
[1]CSS, Inc., Fairfax, United States
[2]NOAA/NOS/NCCOS, Marine Spatial Ecology, Silver Spring, United States
[3]NOAA/NOS/NCCOS, Marine Spatial Ecology, Stennis Space Center, United States
[4]NOAA/NMFS/SERO, St. Petersburg, United States

sarah.hile[at]noaa.gov

Abstract

In 2012, two years after Deepwater Horizon (DWH) oil spill, the RESTORE Act was signed into law; calling for a regional approach to restoring the long-term health of the ecosystem and economy of the Gulf Coast region. In addition to the environmental disaster of DWH, recognition of the many threats and events that have impacted the natural resources and the people of the region, led to the development of a long-term Gulf Coast restoration plan. This laid the foundation for plan development and strategies aimed towards a comprehensive approach to restoration from wetlands to coral reef and seagrass ecosystems. Because of this expanded approach, coral reefs were enveloped into this large-scale restoration plan. The Gulf Coast Ecosystem Restoration Council was established to develop and implement a comprehensive plan for recovery. The RESTORE Council Monitoring and Assessment Program (CMAP), administered by NOAA and USGS, has built foundational components for a Gulf of Mexico (GoM)-wide monitoring network, to support the Council in making science-based decisions and evaluating restoration effectiveness. Collaborating with Gulf states, federal and local partners, academia, non-governmental organizations, and industry, CMAP is integrating habitat and water quality monitoring and mapping programmatic information into a comprehensive user friendly framework. CMAP has developed an extensive inventory of existing habitat and water quality observation, monitoring and mapping programs and a catalog of existing assessments of habitat and water quality conditions throughout the GoM. Falling within this Gulf-wide effort are deep, mesophotic and shallow-water coral ecosystems. Response to the spill, in addition to natural and anthropogenic events, have shown that existing information is limited and not easily accessible. CMAP has assembled monitoring program metadata that can serve as the best available science for comprehensive ecosystem restoration. In the context of Gulf conservation and restoration, a coordinated compilation of existing coral monitoring programs will provide essential information to support the development, selection, and application of effective management and restoration alternatives, and inform adaptive management decisions at the local, state, and regional levels.

Poster
A-1782

A Systematic Population Assessment and Genetic Analysis of Giant Clam Stocks in American Sāmoa

Marra-Biggs, P.[1], Velkeneers, X.[2], Kochzius, M.[3], Fatherree, J.[4], Riginos, C.[5], Green, A.[6], Coward, G.[7], Lawrence, A.[8], Toonen, R.[1]
[1]Hawai'i Institute of Marine Biology, Marine Biology, Kane'ohe, United States
[2]Reneco International Wildlife Consultants LLC, Abu Dhabi, United Arab Emirates
[3]Vrije Universiteit Brussel, Marine Biology, Brussels, Belgium
[4]Hillsborough Community College, Tampa, Florida, United States
[5]The University of Queensland, Marine Biology, St. Lucia, Queensland, Australia
[6]Marine Conservation and Management Consultant, Brisbane, Australia
[7]Department of Marine and Wildlife Resources, Coral Reef Advisory Group, Pago Pago, American Samoa
[8]Bangor University, Bangor, Wales, United Kingdom

paolomb[at]hawaii.edu

Abstract

All giant clam species are of conservation concern and are listed on both CITES and IUCN as species vulnerable to extinction. A recent petition to list giant clams under the ESA elevates the need for current evaluation of the status of populations under US jurisdiction. However, molecular work has revealed that morphological identification of giant clams is more difficult than previously realized, and existing assessments of population size and extinction risk are confounded by misidentified and cryptic species. With ongoing changes to taxonomy, there remains debate about the exact number of giant clam species and their distributions. We confirm species boundaries reported in a recent mitogenome study (Tan et al. 2020), and add the first nuclear data in a phylogenomic analyses of this group to assess the currently accepted taxonomy of giant clams found in US jurisdictions. We find that the species list for American Sāmoa is incorrect, and detect *Tridacna noae*, a frequently misidentified cryptic congener to *T. maxima*, as present.

Further, the most recent studies conducted on tridacnid clams in the Samoan Archipelago were published nearly 20 years ago, prior to recognition of *T. noae* and without molecular corroboration of visual identifications. Even then, 97% of live clams in the Samoan Islands are located on the uninhabited and protected Rose Atoll, in comparison to only 16 live clams on the largest and most populated island of Tutuila. The cultural demand and high market value of these clams encourages continued fishing pressure, regardless of their population decline or threatened status. Tridacnids are slow-growing, late to mature, and sessile, leaving them particularly vulnerable to overfishing, and hindering recovery even with protective actions. We revisited these historical surveys using abundance transects on SCUBA along multiple depth profiles to update the current abundance and size classes of clams across American Sāmoa. This information will be reported to territorial management agencies to evaluate clam population statuses which can be incorporated in the updated enforcement protocol. We also seek to infer connectivity amongst tridacnids along the Samoan Archipelago to test the potential of Rose Atoll acting as a refuge for reseeding depleted stocks on populated islands. These survey results will inform the conservation status of giant clams in American Sāmoa and ultimately aid in the evaluation of ESA listing petition.

Poster
A-1291

Intraspecific Variation in Palatability of the Invasive Sepecies Halophila stipulacea

Miller, M.[1], Cruz-Rivera, E.[2], Turner, T.[1], Stanford, A.[1]
[1]University of the Virgin Islands, Marine and Environmental Science, St. Thomas, U.S. Virgin Islands
[2]Morgan State University, Baltimore, United States

madymill24[at]gmail.com

Abstract

Halophila stipulacea is an invasive seagrass that was observed in St. Thomas, US Virgin Islands in 2013. Relatively little is known about its basic ecology outside of its native range, but recent work suggests the seagrass is not readily consumed by Caribbean herbivores. Thus, *H. stipulacea* may be escaping top-down control; an idea known as the Enemy Release Hypothesis. While it was assumed that Caribbean populations of *H. stipulacea* only spread clonally, recent work suggests higher genetic diversity than expected for a species with only clonal individuals. This poses the question of whether variation in palatability among *H. stipulacea* populations could also influence herbivore pressure on the invader. In this study, intraspecific variation in the palatability of *H. stipulacea* is measured against three Caribbean herbivores by comparing seagrass collected at three depths and four locations around St. Thomas in pairwise-choice feeding laboratory experiments. Additionally, samples were collected to analyze grazing patterns and morphological differences in *H. stipulacea* across bays and depths. Although all three invertebrates readily consumed the invasive seagrass when given no other options, only 4 of 30 among depths and 5 of 45 between site comparisons showed any indication of differences in palatability. There was a significant depth to site interaction in the number of grazed leaves per plant, and a significant difference among sites in the number of feeding scars per leaf. In general, the data agree with the previously proposed idea of relatively low genetic diversity and broad physiological tolerance in this invasive seagrass. This suggests that Caribbean herbivores will likely treat *H. stipulacea* populations as equivalent food resources. Although this study looked at the palatability of *H. stipulacea* to common invertebrates found in both seagrass meadows and coral reefs, more work should be done on other herbivores including other marine invertebrates, juvenile reef fish, and sea turtles. Seagrass meadows are known nursery grounds for reef organisms and the introduction of invasive plants could create alterations to the food chain and lead to detrimental impacts on carbon sequestration, nutrient cycling, and wave attenuation. By observing the feeding preference on *H. stipulacea* there will be better understanding of the long-term impacts this invasion might have on Caribbean herbivores.

Virtual
Oral
A-2031

Marine zoning revisited: how decades of zoning the Great Barrier Reef has evolved as an effective marine spatial planning approach

Day, J.[1], Kenchington, R.[2], Tanzer, J.[3], Cameron, D.[4]
[1]James Cook University, ARC Centre for Coral Reef Studies, Townsville, Australia
[2]University of Wollongong, Wollongong, Australia
[3]University of Queensland, School of Biological Sciences, Brisbane, Australia
[4]Great Barrier Reef Marine Park Authority, Townsville, Australia

jon.day[at]my.jcu.edu.au

Abstract

For over 40 years, marine zoning has played a key role while evolving as part of the adaptive management of the Great Barrier Reef (GBR) Marine Park. The statutory Zoning Plan provides the primary integrating component that prohibits many threatening activities and manages the impacts of allowed competing uses. How zoning is applied, however, has changed considerably since the first zoning plan was finalized in 1981. Today zoning is applied in combination with other layers of marine spatial planning (MSP); the effective combination of these management tools provides the integrated approach, considered most appropriate for managing a large MPA. The Zoning Plan provides the foundation for management of the GBR and is the fundamental component of the integrated MSP approach, ensuring high levels of protection for significant areas of the GBR, while also allowing ecologically sustainable use.

Our paper outlines the legal and managerial basis for zoning, providing lessons that may be useful for marine zoning and ecosystem-based management elsewhere. It outlines aspects of zoning that have worked well in the GBRMP and what has changed in the light of experience and changing contexts. It also clarifies various misconceptions about zoning and MSP. The integrated management approach in the GBR utilizes a variety of spatial planning tools, which complement the underlying zoning; some of these comprise statutory management layers (e.g. designated shipping areas, special management areas, plans of management, fishery management arrangements, defence training areas); while other spatial layers are non-statutory (e.g. site plans).

This paper is written for planners, managers and decision makers hoping to use zoning to achieve effective marine conservation, protection and ecologically sustainable use.

Virtual
Oral
A-1294

Equity in environmental governance: perceived fairness of distributional justice principles in coral reef co-management

Gurney, G.[1], Mangubhai, S.[2], Fox, M.[3], Kiatkoski Kim, M.[4], Agrawal, A.[5]
[1]ARC Centre of Excellence for Coral Reef Studies, Townsville, Australia
[2]Wildlife Conservation Society Fiji, Suva, Fiji
[3]Secretariat of the Pacific Community, Suva, Fiji
[4]The University of Western Australia, Perth, Australia
[5]University of Michigan, Ann Arbor, United States

georgina.gurney[at]gmail.com

Abstract

Concerns with distributional justice invariably arise in environmental governance, especially in the conservation and management of common-pool resources. These initiatives generate an array of costs and benefits that are typically heterogeneously distributed. Distribution of these impacts in a way that is considered fair by local stakeholders is not only a moral imperative, but instrumental to achieving social and ecological success given perceived unfairness fosters conflict and undermines cooperation. However, understandings of local stakeholders' conceptions of distributional fairness are rare because research often assesses distributional outcomes based on tacit assumptions about what constitutes fairness (e.g. equality). We examine what local stakeholders consider distributional fairness with respect to monetary benefits arising from a collective payment for ecosystem services scheme in a co-managed coral reef marine protected area (MPA) in Fiji. In six villages associated with the co-managed coral reef MPA, we elicited individuals' fairness judgements of five distributional justice principles: equality, need, and three forms of proportionality based on customary rights, fisheries opportunity-costs, and involvement in co-management. We examine how fairness judgements are associated with socio-demographic characteristics indicative of key identities, thereby building on socially-aggregated approaches typical of the nascent literature on perceived fairness. We find the rights-based principle was considered the 'most fair' and the opportunity-costs principle the 'least fair'. Our findings challenge prevailing understandings of distributional justice in conservation and commons management, which favour the principles of equality or opportunity-cost. We also find that education was significantly positively related to fairness judgements of all principles, whilst wealth was significantly related to the equality and the opportunity-based principles. These results provide insights into how fairness judgements could be influenced by key elements of current social change in the Global South (e.g. increasing formal education, market engagement and wealth accumulation). Overall, our results suggest that fair environmental governance requires explicit identification of distributional fairness conceptions of those most affected by such initiatives, especially in a context of increasing globalisation of conservation knowledge and practice.

Virtual
Oral
A-2126

The second sex in fisheries and marine protected areas: A story of gender imbalance across fourteen MPAs in Indonesia

Lestari, W. P., Suciati, L., Yulistianti, A., Rusmiati, S., Mukminin, A., Ripanto, R., Muchtar, I., Rumahlaiselan, C., Mardhiah, U.
Wildlife Conservation Society, Marine Program, Bogor, Indonesia

plestari[at]wcs.org

Abstract

It's generally perceived that marine resources are predominantly utilized by men, while most of women's activities are seen as unproductive, although their contribution in providing food security and fisheries value chain is palpable. To exasperate this disparity, while women actively engaged in fisheries sector, they remain invisible to fisheries or MPA managers.

This study aims to describe women's situation compare to men in 14 MPAs across Indonesia by using socioeconomic indicators from 6000 households survey in 2018-2019 (*n* male = 3113, *n* female = 2899). Material Style of Life (MSL), monthly income, and expenses are use as proxy for material wealth. We found that female household's material wealth is lower compared to male. Wilcoxon test was used to test the difference between female and male income, expenses, and total saving. We found that female tends to have less income but have more assets. While male tends to have more expenses and save more. Meanwhile for household head, we found that the first three parameters showed similar pattern to male-female in general, but we found no significant difference in MSL. A chi-square test was used to check correlation between gender and their tendency to support MPA management and found significant correlation, where female tends to be associated with neutral response, while male tends to be associated with support for management. Meanwhile, regarding participation in decision making process significant correlation was found, female headed household tends to be passive, while male inclines to have active participation.

Regardless their social status and occupation, women have less income compare to men. This situation might be resulted from gender inequality, where women's labor being valued less and opportunity for income generating activities is limited. Meanwhile for participation in decision making, as part of existing gender role, attending meeting or voicing opinion is considered as men task. Empower both women and men by involving them in decision making process is critical, both women and men need to be actively engaged in fisheries and MPA management. Women need to be encourage to articulate their opinions and men need to be approached to gain their support for women participation. Women's voices need to be taken into account and it's crucial to facilitate this approach.

Virtual
Oral
A-2065

Sustainable aquaculture and valorization of marine sponges in French Polynesia

Maslin, M.
Université de la Polynésie Française, Unité Mixte de Recherche 241 Ecosystèmes Insulaires Océaniens, Faaa, French Polynesia

maslinmathilde[at]gmail.com

Abstract

Marine sponges are sessile animals that fulfill many environmental services in our oceans since at least 600 million years. Among others, they act as reef bioeroders, substrate consolidators or stabilizers and bentho-pelagic exchangers through energy flow and nutrients cycling. They account for an important part of the benthic fauna given their biomass, numerical abundance and longevity. For many years, research has focused on sponges as the most prolific marine source of bioactive compounds. Those natural substances can either help the sponge for competition with other organisms, prevent predation or avoid colonization by fouling life forms. Some of the generated outputs are among the highest active and effective marine natural metabolites, with numerous commercial applications for humankind (e.g. pharmaceutical industry, cosmetology, nanotechnology). Meanwhile, their supply is often limited regarding the tremendous amount necessary to establish an industrial success. Mariculture systems usually require simple techniques, are easy to perform and relatively inexpensive compared to cells culture and synthetic chemistry techniques. They are also the most eco-sustainable ways to obtain metabolites of interest over a long-term perspective and without depleting natural stocks or destructing marine habitats. The exploitation of marine sponges in French Polynesia, included in a Sustainable Blue Economy context, must indeed be rational in order to protect wild stocks from an excessive harvesting pressure. This work involves gathering data on the real distribution and dynamics of wild populations, on the biological requirements of the chosen taxa altogether with the environmental oceanic conditions. To be perennial in time, sponge aquaculture industry should also contribute to the economic development and social well-being of the local people. Broad community must be educated and consulted regarding ecosystem services, farming developments and their potential impacts on marine resources. Marine sponges of the Pacific region are not considered endangered, yet like everywhere else local threats may exist including overharvesting, non-native species introduction and habitat fragmentation. The sea-based activities currently undergoing a feasibility study in the Tuamotu Islands are thus considering economic and social gains against environmental costs within a transparent and explicit regulatory framework.

Virtual
Oral
A-2207

Evaluating and improving fisheries management in coral reefs

McClanahan, T.
Wildlife Conservation Society, Global Marine Programs, New York, United States

tmcclanahan[at]wcs.org

Abstract

Many tropical reef fisheries are underperforming relative to maximum sustained yields despite its importance for the economies of natural resource dependent people. Stock assessments in tropical reefs have been hampered by the logistic difficulty and costs of making empirical estimates in multi-species fisheries. This problem has produced a lack of clear goals for sustainability, which makes it difficult to gauge the status and management needs. I review recent efforts to develop these goals and therefore the status of coral reefs on a large global scale as well as the African context. I focus on marine wilderness and sustainable fishing, where it is located and what are the consequences. One finding is that ecosystems in marine wilderness is significantly different from marine reserves or best-practice seascapes that contain marine reserves and sustainable fishing. The distribution of marine wilderness is uneven globally and many ecoregions and faunal provinces lack it. This makes sustainable fishing critical to their long-term resilience. The Western Indian Ocean Province is one good example. Thus, I build the scientific basis for sustainable yields in this Province and evaluate the status. I show that it is possible to build good status and yield models (i.e., $r^2 = 0.80$) to identify problem locations where efforts are required to avoid lost yields, jobs, and income. Both over- and under-fishing are driven primarily by travel distances between reefs and markets, depth, and fisheries management. Environmental variables are unimodal suggesting optimal conditions for temperature, ocean productivity, and reef area. The inclusion of nation improves models and reflects variation in national cultural governance and diets, dependency, and effectiveness of management restrictions. As a specific example, the East African Coastal ecoregion which has 18,500 km^2 of reef, is estimated to be losing 17,600 tons of commercial fish catch per year due to unsustainable fishing. This is worth between US$ 50 to 150 million per year depending on position in the trade's value chain. I present some case studies that highlight the importance of the strength and qualities of governance institutions for recovering this lost production and reducing biodiversity loss and poverty.

Virtual
Oral
A-2130

The Role of Traditional Marine Custodians, Panglima Laot, in Protecting Aceh's Marine Ecosystems

Nisrina, I.
Wildlife Conservation Society, Indonesia Program, Bogor, Indonesia

inisrina[at]wcs.org

Abstract

Effective management of Marine Protected Areas (MPAs) requires the meaningful participation of all key actors, including the communities that directly interact with the areas. Without community involvement and commitment, MPAs might not be effectively and sustainably managed and achieve their desired impacts for ecosystems and communities. Since 2007, the Wildlife Conservation Society's Indonesia Program has been providing support to the local *Panglima La*<i>ot</i> system for marine and coastal protection in Aceh Province, Indonesia. *Panglima La*<i>ot</i> is one of the oldest customary law institutions in Indonesia; the more than 400 years old system oversees coastal management and remains just as relevant today. The term *Panglima Laot* is also applied to the traditional marine custodians themselves, sometimes translated as "Sea Commanders", who lead the system in each of their respective areas. Coastal resource management is conducted through each area's *Hukom Adat Laot (marine customary laws),* which regulates the *Pantang Laot* (marine prohibitions) concerning the time and location of fishing activities in the sea. These prohibitions include the protection of certain types of fish, protections for forest ecosystems, and regulations of harvesting quotas. The traditional system has also been used to combat modern threats, namely destructive fishing through the use of blast fishing and cyanide. We conducted underwater visual census surveys in 2013, 2016, and 2019 of MPAs in Aceh Besar, Aceh Jaya, and Sabang districts to evaluate the effectiveness of the *Panglima Laot* in coral reef ecosystem protection in Aceh. Significant increases in reef fish abundance and fish biomass were observed at all three locations since they were first surveyed in 2013.

Virtual
Oral
A-1455

Understanding a Novel Approach to Coral Conservation Investments: An Assessment of Impacts of 50 Reefs-Inspired Efforts

Pietri, D., Lam, J., Weathers, E.
Eastern Research Group, Inc., Blue Earth Team, Oakland, United States

diana.pietri[at]erg.com

Abstract

To preserve coral reefs and the valuable social and ecological services they provide, in 2018 a group of scientists used a Modern Portfolio Theory (MPT) framework to identify a suite of coral reefs that, in absence of other impacts, are likely to have a better chance of surviving the projected outcomes of climate change. Known as the 50 Reefs project, multiple donors, non-governmental organizations (NGOs), national and local governments, and academic partners have since prioritized coral conservation investments and on-the-ground activities at these coral reef regions. To understand the impact of 50 Reefs–inspired conservation efforts, Bloomberg Philanthropies' Vibrant Oceans Initiative (VOI) worked with ERG's Blue Earth team to perform a landscape assessment of conservation motivated by the 50 Reefs study, as well as complementary activities to-date. Blue Earth conducted interviews with representatives from NGOs and funding organizations, including VOI grantees, funders supporting activities in 50 Reefs geographies, and organizations implementing activities that are directly informed by the 50 Reefs study.

The landscape assessment found that the 50 Reefs study has provided a clear, science-based framework to prioritize investments in coral reef conservation and has resulted in at least 26 implementing organizations and eight funders conducting projects in over 60 reefs that range across more than 40 countries. Conservation efforts inspired by 50 Reefs include bottom-up interventions paired with national policy reforms that collectively support implementation of on-the-ground and institutional actions to address threats ranging from fishing impacts to climatic stress. The conservation benefits achieved by 50 Reefs–inspired work extend beyond ecological outcomes and include critical social, economic, health, and nutrition benefits for human communities. Moreover, many of the organizations working in the 50 Reefs have begun to demonstrate the importance of considering equity in achieving coral conservation benefits—from ensuring small-scale fishers have the necessary access to their coral resources to elevating the roles and leadership of women in fishing and coastal communities. This presentation will highlight the impacts of and progress of 50 Reefs-inspired efforts to date. We will also detail challenges experienced by implementing organizations and funders and opportunities to expand and strengthen the impact of 50 Reefs-inspired work moving forward.

Virtual
Poster
A-2169

Status of Coral Reefs in The Bird's Head Seascape Papua, IndonesiaStatus of Coral Reefs in The Bird's Head Seascape Papua, Indonesia

Monim, H.[1], Purwanto, P.[1], Matualage, D.[1], Rumengan, I.[1], Awaludinnoer, A.[2], Pada, D.[3], Hasan, A. W.[3], Mambrasar, R.[3], Maulana, N.[3], La Hamid, L. H.[4], Mulyadi, M.[4]
[1]University of Papua, Research and Community Service, Manokwari, Indonesia
[2]Yayasan Konservasi Alam Nusantara, Sorong, Indonesia
[3]Yayasan Konservasi Indonesia, Sorong, Indonesia
[4]Balai Besar Taman Nasional Teluk Cenderawasih, Manokwari, Indonesia

fanrimonim[at]gmail.com

Abstract

Bird's Head Seascape Papua with an area of 22.5 million hectares is located at the center of the highest marine biodiversity in the world. BHS stretches from east of Cenderawasih Bay and west Raja Ampat islands to the coast of Fakfak and east of Kaimana regencies. BHS is home to more than 600 types of coral reefs and 1,600 reef fish species. This study is aimed to assess the status of coral reefs in the Bird's Head Seascape Papua. Data collection is conducted from 2017 to 2019 at the 148 sites at BHS. We use the Point Intercept Transect Method proposed by Ahmadia et al. (2012) and Green & Wilson (2009) to monitor the condition of the coral reefs at BHS. Data collection was carried out at a depth from 8 meters to 12 meters in the ocean using three transect lines positioned horizontally above the coral reefs. We monitor life forms of hard corals as an indicator for healthy corals and other four indicators to assess unhealthy corals, which were Other Algae, Crustose Coralline Algae, Rubble, and Coral Bleaching. Our findings showed that the percentage of healthy corals based on the existence of Hard Corals was 33.61% (low to medium). For unhealthy corals indicators, we found Other Algae 5.72%, Coraline Algae 1.43%, Rubble 14.42%, and Coral Bleaching 0.02%. Based on regulation from the Minister of Environment Indonesia Number 4 of 2001 on Standard Criteria for Damage to Coral Reefs, the condition of coral reefs at the Bird's Head Seascape Papua was in low to medium levels. Further studies still need to be conducted to assess the condition of coral reefs in other sites at BHS where the intervention of human activities is limited.

Virtual
Poster
A-2159

Between Customary Practices and Legal Zones inside the boundary: a case study from the Cenderawasih Bay National Park Papua in Indonesia

Salosso, K. E.[1], Matualage, D.[2], Maryen, P. M.[1], Pakiding, F.[2], Pangulimang, J.[1], Bato, M.[2], Zainudin, F.[2], Purwanto, P.[1], Rumengan, I.[1], Monim, H. F. Y.[1], Ahmad, A.[3], Mulyadi, M.[4], La Hamid, L. H.[4]
[1]University of Papua, Research and Community Service Institute, Manokwari, Indonesia
[2]University of Papua, Manokwari, Indonesia
[3]Yayasan Konservasi Alam Nusantara, Sorong, Indonesia
[4]Cenderawasih Bay National Park Management Office, Manokwari, Indonesia

kesy.salosso[at]gmail.com

Abstract

Cenderawasih Bay National Park is the largest marine national park in Indonesia, and it has 95 percent of the total areas consisting of coral and seas. The National Park has rich marine biodiversity at the Bird's Head Seascape Papua, and it is home to more than 24 groups of tribes, including indigenous Papuan. Since established 1993, the government has set rules and zones to protect the National Park and its resources. However, evidence around the world showed that community traditional practices on marine also play significant roles in enhancing and protecting their local marine, including coral reefs. From 2017 to 2019, we conducted coral reefs monitoring using the Point Intercept Transect method to assess coral reefs' condition and Focus Group Discussions to document local rules in marine areas. We use data from Napan Yaur, Iseren, and Yomber villages that match with coral reef site monitoring. We found that the coral reefs conditions in Napan Yaur were at a high level (>50%). Meanwhile, Iseren and Roswar have the coral reef's condition at the medium level (25%-49%). The factors that influence coral reefs' condition in Napan Yaur was regulation by the governments to limit permits for fishers from outside the village and local rules to use the eco-friendly fishing gear. There were a small number of sanctions for illegal activities in the local marine area. However, in Iseren and Yomber, there were no specific rules from local leaders regarding marine governance. Local communities stated that there was still a lack of socialization by the government for the rules in the National Park. As a result, there were fishers from outside the villages using bombs, potassium, Derris root, and overfishing. We propose further research to document local boundaries of other settlements to provide relevant information for assessing coral reefs conditions in the Cenderawasih Bay National Park sustainably.

Session 12B - Can we help people make smart choices in a time of crisis and uncertainty?

Conceptualized by: **Kenneth Anthony** [1], **Paul Hardisty** [1], **Elizabeth Shaver** [2]
[1] Australian Institute of Marine Science (Townsville, Australia)
[2] The Nature Conservancy (Arlington, VA, USA)

Chaired by: Ian McLeod [1], David Mead [1]
[1] Australian Institute of Marine Science (Townsville, Australia)

Oral
A-1375

The value of guided reef restoration and adaptation

Anthony, K.[1], Iwanaga, T.[1, 2], Crocker, R.[1]
[1]Australian Institute of Marine Science, Decision Support, Townsville, Australia
[2]Australia National University, Institute for Water Futures, Canberra, Australia

ken[at]es5.com.au

Abstract

New interventions are needed to help sustain coral reefs under climate change. In a warming world, restoration and adaptation interventions can benefit reefs and people. However, the extent and nature of those benefits will depend on R&D and deployment choices made in the face of opportunity, costs, risks, and uncertainty.
We present the *Adaptive Dynamic Reef Intervention Algorithms (ADRIA)*. *ADRIA* is a decision-support platform for guided reef restoration and adaptation. In short, *ADRIA* informs intervention-deployment decisions in complex environmental, ecological, and socio-economic settings. Users engage with ADRIA to set the decision criteria, spatial objectives, time horizons, risk tolerance, and performance metrics. Outputs are the scope for one or more new interventions to support reef-ecosystem services relative to the status quo for different climate-change scenarios.
We illustrate *ADRIA* as a decision-support tool in a case study on the Great Barrier Reef. Specifically, we show how the guided deployment of warm-adapted corals and localized shading can provide scope to support tourism, fishing, and non-use (existence) benefits. Simulated deployment can be guided by reef- or site-scale connectivity, heat stress, wave stress, coral cover, coral carrying capacity, management zones, costs, logistics, and a range of other criteria. We show that the realization of those benefits depends critically on the speed and effectiveness of R&D, and both early and guided intervention deployment. Outcomes are highly sensitive to intervention efficacy and assumptions for the rate of natural adaptation. While guided intervention using *ADRIA* may help create significant returns on intervention investments for reefs and people in the short and medium term, long-term sustained outcomes are only possible when combined with climate change mitigation.

Oral
A-1284

World Reef Map: A high-resolution mapping tool for marine spatial planning in remote regions of the world

Dempsey, A.[1], Purkis, S.[2], Faisal, M.[3]
[1]Khaled bin Sultan Living Oceans Foundation, Annapolis, United States
[2]University of Miami, Rosenstiel School of Marine and Atmospheric Science, Miami, United States
[3]Michigan State University, Pathobiology and Diagnostic Investigation, East Lansing, United States

dempsey[at]lof.org

Abstract

Healthy coral reefs provide critical ecosystem services for millions of people globally, but with climate change and anthropogenic stressors, the landscape of these habitats is regularly shifting. During the past 10 years, marine spatial planning has become a crucial step for coastal ecosystem conservation efforts. More recently, the need for detailed benthic habitat and bathymetric maps has become a necessity for effective coastal zone management. Benthic habitat maps are an essential tool in coral reef conservation and marine spatial planning as they provide a snapshot of where reefs are located
and their expanse. Although many types of coral reef data are now available in large, open-access global databases, they are often inaccessible to developing countries with limited infrastructure and analytical training. The World Reef Map, an online interactive coral reef atlas that allows users to explore 92 islands and their shallow water (less than 30 meters depth) marine habitats. With over 65,000 square kilometers of tropical marine ecosystems mapped, this is the largest collection of high-resolution coral reef maps ever compiled. The World Reef Map allows users to access maps from 11 countries, including Fiji, French Polynesia, The Bahamas, Galapagos Islands, and the Saudi Arabian Red Sea. The Map hosts innovative applications including identify, measuring, and habitat analysis tools. Along with the spatial analysis tools, there are layers of over 150 geo-referenced habitat photos and 14,000 videos showing the underwater environment that the user can view. These tools allow coral reef managers to effectively identify critical habitats for marine spatial planning and are similar in function to those found on most GIS platforms. The World Reef Map brings sophisticated technology that may be otherwise unattainable to remote communities and has recently been used for marine spatial planning efforts in Fiji, The Bahamas, and the Kingdom of Tonga.

Oral
A-2183

Making evidence-based decisions to manage coral reefs

Mumby, P. J.[1], Chaloupka, M.[2], Bozec, Y.-M.[1], Steneck, R.[3]
[1]University of Queensland, School of Biological Sciences, Brisbane, Australia
[2]University of Queensland, Ecological Modelling Services Pty Ltd, Brisbane, Australia
[3]University of Maine, School of Marine Science, Orono, United States

p.j.mumby[at]uq.edu.au

Abstract

There are many aspects to making sound management decisions but here we focus on the evaluation and use of scientific evidence. First, we highlight the challenge in evaluating ecological studies of management effectiveness. Specifically, we show that even genuinely large beneficial impacts of marine reserves on coral recovery can be undetectable using current sampling designs leading to false conclusions of 'no effect'. This highlights the need for a more critical assessment of evidence for or against given interventions. We discuss how studies and monitoring can be improved to provide more powerful analyses of management benefits. Second, we describe advances in Resilience-based management, which integrates scientific knowledge to help managers anticipate the consequences of their decisions. By predicting the consequences of actions, managers are better placed to make transparent, efficient decisions, and achieve more specific objectives. We present a new system that predicts the benefits of crown-of-thorns starfish control, MPA zoning, compliance strategy, restoration, and improvements to water quality on the health of reefs under climate change. Specifically, it allows managers to 'try out' different strategies and evaluate their benefits in space and time.

Oral
A-1832

Impact of the COVID-19 pandemic on Indo-Fijians engaged in coral reef fisheries

Nand, Y.[1], Mangubhai, S.[2], Reddy, C.[3], Jagadish, A.[4]
[1]Wildlife Conservation Society, Suva, Fiji
[2]Talanoa Consulting Fiji, Suva, Fiji
[3]International Union for Conservation of Nature, Oceania, Suva, Fiji
[4]Conservation International, Virginia, United States

ynand[at]wcs.org

Abstract

The global COVID-19 pandemic has exposed the shortcomings of our health, social, and economic systems. While mobilising responses to the health crisis, governments are scrambling to understand and address the knock-on economic effects from market disruptions, including those to the coral reeffisheries sector. We conducted individual fisheries actor interviews with Indo-Fijian fishers, fisher-owners, crew members, and traders in May 2020, almost two months after Fiji got its first case of COVID-19. We found the greatest impact of COVID-19 on SSF actors was the reduction in sales of
fish (73.8% respondents) caused by a reduction in local consumption (67.2% respondents), and/or the loss of tourism (32.8% respondents). There was on average a 36.5% drop in fish prices which affected the earnings from SSF. In April, Category 4 Cyclone Harold hit Fiji damaging fishing boats (26.2% of respondents), engines (4.9%) and homes (6.6%). All four Indo-Fijian respondent groups (44.4% of crew members, 16.4% fishers, 11.5% fisher-owners, 8.3% traders) highlighted insufficient food available to meet their families' daily needs.

Many of these fisheries actors do not have access to social security or similar safety nets leaving them vulnerable to the current crisis as well as to other shocks and changes. Although it will be many months before the full impact of COVID-19 on the SSF sector will be known, an early understanding of the initial effects can assist decision-makers to quickly mobilise assistance to help people who are most vulnerable, and avoid widening inequalities between ethnic groups.

Oral
A-1493

Sustainably financing coral reef restoration and adaptation on a large scale, do numbers add up?

Robillot, C.[1], Anthony, K.[2]
[1]Great Barrier Reef Foundation, Reef Restoration and Adaptation Program, Brisbane, Australia
[2]Australian Institute of Marine Science, Reef Restoration and Adaptation Program, Townsville, Australia

crobillot[at]barrierreef.org

Abstract

On the Great Barrier Reef the impact of global warming is evident. Marine heatwaves and mass bleaching are no longer considered extraordinary events. Managers are actively considering how technology options such as those developed by the Reef Restoration and Adaptation Program (RRAP) might become an integral element of managing the World Heritage Site.
Assuming effective interventions can be developed technically, funding models will be critical to take these interventions to scale, safely and fast. We present a funding model that is transparent to investors, anchored in model predictions of intervention efficacy, benefits and risks. Using ecological model outputs and intervention costs as primary inputs, we designed a framework in which intervention deployments are jointly financed by impact investment and government, and revenues generated through successful achievement of agreed reef outcomes.
RRAP interventions are currently at different maturity levels. Corals with improved thermal tolerance, produced by mass aquaculture, could become available for deployment within five years. As test case for the funding model, we simulated deploying 2 million 1-year old warm-adapted corals in a group of reefs with high tourism value. Simulations targeted sites presenting the highest opportunities for corals to survive, grow and spread larvae to other reefs. We simulated deployments over a 10-year period, in pace with aquaculture production and logistical constraints, and modelled benefits for different ecosystem services over a 50-year horizon.
Results showed that early, targeted and at-scale intervention can generate substantial net benefits for a range of ecological metrics underpinning reef biodiversity: coral cover, functional diversity, and habitat availability for fish and invertebrates. For a semi-optimistic climate change scenario (RCP 4.5), this can help sustain tourism and support reef resilience locally. In this model, outcomes payments, and return on impact investment, can be financed by government in line with jurisdictional reef health targets and by companies with an economic and/or social license to operate interested in reef health.
A sensitivity analysis was conducted to assess the impact of various parameters on financial viability, such as: capital versus operational costs; scale; outcome-based payment, timing and distribution. The study shows that impact investment can be a viable financing mechanism for coral reef restoration and adaptation.

Oral
A-2214

NOAA's Coral Intervention Action Plan

Vardi, T.
ECS for NOAA Fisheries, Silver Spring, United States

tali.vardi[at]noaa.gov

Abstract

The US National Oceanic and Atmospheric Administration (NOAA) recognizes the deterioration of global coral reef ecosystems and is committed to intervening in US reefs where it has the authority to act and support, and to promote the restoration and intervention of reefs worldwide. The recently commissioned National Academies of Sciences reports have helped NOAA develop a high level plan of action for coral reef intervention. The priority actions are to (1) research and test priority interventions, (2) develop local or regional structured decision support, (3) review policy implications of coral interventions, (4) invest in infrastructure and research, and (5) coordinate global efforts to maximize results. The most concrete recommendation arising from the NAS reports is to conduct adaptive management planning based on local stakeholder input, predictive decision-making models, and local quantitative reef data. Thanks to decades of investment, NOAA is in the rare position of having many years of biological data, internal capacity for biophysical modelling, and the ability to engage local stakeholders in determining their risk tolerance for novel interventions. This talk will focus on the decision support developed for US jurisdictions and how it might be used in other locations, the interventions in which NOAA is investing, and NOAA's role in coordinating current and future efforts in the coral intervention space.

Virtual
Oral
A-1155

A Decision Framework for Coral Interventions

Baskett, M.[1], Anthony, K.[2], Baker, A.[3], Bhattacharya, D.[4], Bourne, D.[5], Knowlton, N.[6], Logan, C.[7], Naish, K.[8], Palumbi, S.[9], Richmond, R.[10], Smith, T.[11], von Stackelberg, K.[12]
[1]University of California, Davis, Environmental Science and Policy, Davis, CA, United States
[2]Australian Institute of Marine Science, St. Lucia, Australia
[3]University of Miami, Miami, United States
[4]Rutgers University, New Brunswick, United States
[5]James Cook University, Townsville, Australia
[6]Smithsonian Institution, Washington, DC, United States
[7]California State University Monterey Bay, Monterey, United States
[8]University of Washington, Seattle, United States
[9]Stanford University, Monterey, United States
[10]University of Hawaii at Manoa, Honolulu, United States
[11]University of the Virgin Islands, St. Thomas, U.S. Virgin Islands
[12]Harvard University, Boston, United States

mlbaskett[at]ucdavis.edu

Abstract

A growing body of research on coral physiology, ecology, genetics, molecular biology, and responses to stress has revealed new potential avenues to increase coral resistance and resilience in the face of climate change. Testing and implementing these novel approaches presents challenges related to uncertainty in their efficacy and risks. Additionally, there are likely to be multiple and potentially conflicting stakeholder objectives regarding desired coral reef outcomes. Decision frameworks provide a structure for informing management decisions under uncertainty and multiple objectives. Within such a framework, model-based projections inform decisions by indicating expected outcomes with uncertainty and increase learning through an adaptive management process of comparing expectations to realized outcomes. We describe a structured decision-support framework that can help identify when and where new coral intervention(s) are likely to be beneficial and navigate tradeoffs across management alternatives. To illustrate the utility and approach of the decision framework, we develop a simple dynamic reef-system model with implicit evolution in thermal tolerance. Our model explores the implementation of assisted gene flow and atmospheric shading, given expected risks and benefits to both, under different future climate scenarios and degrees of control over local stressors. With example results of our model, we illustrate the capacity of this approach to indicate (a) the conditions necessary for benefits to exceed risks to inform when and where to engage in each intervention, (b) the relative efficacy of different interventions to inform choices between them, and (c) the interaction between multiple interventions to inform simultaneous or sequential implementation. We place these example results in the larger structured decision-making and adaptive management process that includes stakeholder-driven problem formulation, implementation with sustained monitoring and evaluation, communication of progress to stakeholders, and updates to the management approach based on learning.

Virtual
Oral
A-1644

A Structured Decision-Making Approach to Guide Investment in Reef Restoration

Hardisty, P.[1], Anthony, K.[2], Mead, D.[1], Sivapalan, M.[3], Bowen, J.[3]
[1]Australian Institute of Marine Science, TOWNSVILLE, Australia
[2]Australian Institute of Marine Science, Brisbane, Australia
[3]Adaptus Ltd., Perth, Australia

p.hardisty[at]aims.gov.au

Abstract

At ICRS 2021, we argued that rescuing the world's coral reefs will require informed investment decisions. Nothing meaningful at the scales required will occur without money and an informed process for how it is spent. Traditional ad-hoc decision processes are unsuitable given the scale and complexity of the challenge, and the risk of failure either by acting or not. A formal structured decision-making approach involves four elements: 1) adopting an explicit decision hierarchy with lower order decisions nested within an overall top-down and bottom-up framework. 2) considering a broad range of options at each level of decision-making. 3) comparing options on a like-for-like basis through monetisation of economic, environmental and social costs and benefits, allowing trade-offs to be assessed and optima identified. And 4) involving stakeholders at each step to ensure decisions are understood, communicated, and implemented. Australia's Great Barrier Reef is facing the combined impacts of climate change-induced coral bleaching, and damage from cyclones, crown-of-thorns starfish, and sub-par water quality. Allocation of resources to the GBR, and among the different impacts, could be improved by such a structured process. At the highest level, we first identify the overall objective for the reef, and the level of investment Australia should commit compared with other national priorities. An optimal at-scale reef restoration and adaptation effort is one of the options. A level below, input from reef models help identify which specific reef restoration options, at which locations and scales best reach those optima, for the given investment. We seek to maximise benefits while reducing risk and considering uncertainty. Once the broader approach is established, next level decisions become more specific. For example, if deploying corals for assisted adaptation at a particular reef complex is part of an optimal approach, then we identify locations, species, densities, quantities, timing and delivery methods that maximise net benefits. Once interventions are in place, we shift to monitoring and adjusting interventions over time, as effectiveness is tracked. Choices exist which will result in optimal outcomes for coral reefs and the people who value them. Structured decision making will help ensure that we identify those choices, communicate them to stakeholders, and implement them.

Session 12D - From Thinking to Doing: What Does It Actually Take to Practice Ecosystem Based Management in Coral Reef Fisheries?

Conceptualized by: **Tauna Rankin**[1], **Supin Wongbusarakum**[2], **Juan J. Cruz-Motta**[3], **Nygiel B. Armada**[4]
[1] NOAA (Silver Spring, MD, USA)
[2] University of Hawaii (Honolulu, HI, USA)
[3] University of Puerto Rico (Mayaguez, Puerto Rico)
[4] USAID Fish Right Program (Philippines)

Chaired by: **Tauna Rankin**[1], **Juan J. Cruz-Motta**[3]

Oral
A-1524

Quantitative models to describe coral reef fisheries systems in the U.S. Caribbean as a necessary step to inform Fishery Ecosystem Plans.

Cruz-Motta, J.[1], Williams, S.[2], Seara, T.[3], Arnold, W.[4], Garcia-Moliner, G.[5], Tzadik, O.[6], Rankin, T.[7], Ortiz, A.[5], McCarthy, K.[8], Lopez-Mercer, M.[4], Faletti, M.[5], Stephenson, S.[4], Habtes, S.[9], Cruz-Rivera, E.[9]
[1]UPR-Mayagüez, Mayagüez, Puerto Rico
[2]ISER, Cabo Rojo, Puerto Rico
[3]University of New Haven, West Haven, United States
[4]NOAA National Marine Fisheries Service, St. Petersburgh, United States
[5]Caribbean Fisheries Management Council, San Juan, Puerto Rico
[6]The Pew Charitable Trust, Rincon, Puerto Rico
[7]Coral Reef program NOAA, Washington, United States
[8]NOAA National Marine Fisheries Service, Miami, United States
[9]USVI Department of Planning & Natural Resources, Red Hook, U.S. Virgin Islands

juan.cruz13[at]upr.edu

Abstract

The Caribbean Fishery Management Council (CFMC) has initiated the development of a fishery ecosystem plan (FEP) to guide and implement an ecosystem-based approach to fishery management in the federal waters of Puerto Rico and the U.S. Virgin Islands. To achieve this goal, the CFMC is using a protocol developed by the Lenfest Fishery Ecosystem Program task force, which considers five steps. This study dealt only with the first step of that process which included developing a general conceptual model of the fisheries systems in the region. The development of conceptual models (and the identification of associated indicators and threats) is a common procedure based on expert and stakeholder views and opinions. This process, however, rarely takes into consideration a quantitative analysis of existing data, which could help assess and guide the development of a final, more comprehensive model. In this study we developed a quantitative model that describes the status of the fishery ecosystems in the region. To this end, existing databases of three U.S. Caribbean Island platforms (Puerto Rico, St. Thomas/St. John and St. Croix) were compiled. These databases were grouped into three categories of data sources: a) response variables (fisheries independent data, landings, and trip interview program), b) predictive variables (environmental, habitat and anthropogenic stressors) and c) co-variables (socio-economic). For each data source, patterns of temporal and spatial variation were described using non-parametric multivariate analyses, to test for hypotheses related to consistent changes within each management area. Results of the response variables showed that temporal patterns of variation of the structure and composition of commercially exploited fish assemblages were not consistent across different locations within any of the island platforms. These results strongly suggest that the general conceptual models developed by stakeholders should be adapted for different locations and/or fishing regions within each island platform. With this information, and once all patterns of temporal variation of all components (response, predictive, and co-variable) are described, structural equation models will be used to develop a final quantitative model and assess the significance of specific relationships given the effects of other variables and their potential collinearities. In turn, this will help managers to prioritize interactions and threats in this fishery system.

Oral
A-1406

Where are the big fish at? Relative length distributions of commercially targeted reef fish species in Sudan using fishery-independent data

Kleiven, P.[1], Elamin, S. M.[2], Elamin, ,. E. M.[3], Saleh, A. M.[2], Iragi, M. A.[4], Olsen, E.[1], Kleiven, A. R.[1], Kolding, J.[5], Axelsen, B. E.[1], Johannessen, T.[1], Moland, E.[1, 6]
[1]Havforskningsinstittutet, Bergen, Norway
[2]Red Sea State University, Faculty of Marine Science and Fisheries, Port Sudan, Sudan
[3]Red Sea Fisheries Research Station, Port Sudan, Sudan
[4]Marine Fisheries Administration, Port Sudan, Sudan
[5]University of Bergen, Deparment of Biological Sciences, Bergen, Norway
[6]Centre for Coastal Research (CCR), Department of Natural Sciences, University of Agder, Kristiansand, Norway

pkleiven[at]hi.no

Abstract

The Sudanese coast of the Red Sea harbor an extensive coral reef ecosystem, but data on reef fisheries from this area is relatively scarce. Using data from both fishery-independent and fishery dependent sources, we compare the relative length distributions of several commercially-targeted species to assess the fishing pressure on these. Fishery-independent length data was collected based on stereo measurements from underwater visual census (UVC) using diver operated video (DOV) and baited remote underwater video (BRUV). These were deployed in 34 stations located on shallow (3-20 m depth) coral reef areas exposed to artisanal fisheries along the entire coast of Sudan in 2015, 2016 and 2017. Fisheries landings data was obtained from the Sigala central market and Suakin landing site in the same time-period.

Preliminary results indicate that similar sizes are observed for both fishery-dependent and -independent data for the highly valued primary target species Plectropomus aerolatus. For the jack Carangoides bajad and the lutjanid snapper Lutjanus bohar, both secondary target species, fishers are landing slightly bigger individuals than those observed visually. Differences in lengths and frequencies (using MaxN) were observed between northern and southern sites for the most sought after species. Differences in length distributions observed between methods underscore the importance of obtaining fishery-independent data when assessing the current state of reef fisheries.

Oral
A-1576

Building a fisheries-independent baseline for coral reef fish targeted in the artisanal reef fishery in Sudan's Red Sea State

Moland, E.[1], Nillos-Kleiven, P. J.[1], Elamin, S. M.[2], Elamin, E. M.[3], Mohamed, A. S.[2], Elhag, A. M.[2], Khalafalla, M.[2], Mukhtar, M. A.[3], Kleiven, A. R.[1], Kolding, J.[4], Olsen, E.[5], Elbashier, D. A. Y.[6], Ahmed, M. A. M.[6], Abaker, K. Y. I.[7], Yahya, O. A. M.[6]
[1]Norwegian Institute of Marine Research (IMR), His, Norway
[2]Red Sea University, Faculty of Marine Science and Fisheries, Port Sudan, Sudan
[3]Red Sea Fisheries Research Station, Port Sudan, Sudan
[4]University of Bergen, Department of Biological Sciences, Bergen, Norway
[5]Norwegian Institute of Marine Research (IMR), Bergen, Norway
[6]Marine Fisheries Administration, Port Sudan, Sudan
[7]Red Sea State University, Faculty of Marine Science and Fisheries, Port Sudan, Sudan

even.moland[at]hi.no

Abstract

Ecosystem-based fishery management (EBFM) and it's derivates constitute toolkits that can be used to achieve sustainable fisheries on the local and national level – even in data-poor settings. However, fisheries-independent information, when available, is highly valuable when assessing the impact of the prevailing fishing pressure. Visual census methodologies utilizing low-cost, off-the-shelf miniaturized video are increasingly being adapted for coral reef monitoring purposes. We introduced such technology in Sudan within a collaborative framework in partnership with academics and fisheries managers. Three 45-day surveys were conducted along the length of Sudan's Red Sea State coast in 2015, 2016 and 2017. During these, baseline data were collected using baited remote underwater video (BRUV) and underwater visual census using diver operated video (DOV) at 34 coral reef sites. Analyses of the resulting video recordings were initiated in a series of workshops in Port Sudan, in which representatives for all participating institutions took part. Here, we present features from the two resulting datasets and discuss the lessons learned from this endeavor. Visual sampling based on stereo video allowed collection of highly relevant data on coral reef fish available to the artisanal fishery throughout the Red Sea state coral reef ecosystem. Moreover, it proved to be a powerful educational tool, a valuable means of knowledge sharing and useful in engaging non-diving stakeholders with the ecosystem.

Oral
A-2106

Putting EBFM into Action for the U.S. Caribbean EEZ

Rankin, T.[1], Arnold, W.[2], Cruz-Motta, J. J.[3], Cruz-Rivera, E.[4], Garcia-Moliner, G.[5], Habtes, S.[6], Lopez-Mercer, M. d. M.[2], McCarthy, K.[7], Ortiz, A.[5], Seara, T.[8], Stephenson, S.[2], Tzadik, O.[9], Williams, S.[10]
[1]NOAA Fisheries, Coral Reef Conservation Program, Silver Spring, United States
[2]NOAA Fisheries, St Petersburg, United States
[3]University of Puerto Rico - Mayaguez, Mayaguez, Puerto Rico
[4]University of the Virgin Islands, St Thomas, United States
[5]Caribbean Fishery Management Council, San Juan, Puerto Rico
[6]USVI Department of Planning & Natural Resources, Frederiksted, United States
[7]NOAA Fisheries, Miami, United States
[8]University of New Haven, West Haven, United States
[9]The Pew Charitable Trusts, Rincon, Puerto Rico
[10]Institute for Socio-Ecological Research, Inc., Lajas, Puerto Rico

tauna.rankin[at]noaa.gov

Abstract

Effectively managing coral reef fisheries cannot be accomplished independent of the coral reef ecosystem upon which those resources depend. As such, the Caribbean Fishery Management Council (CFMC) is reorganizing its fishery management plans from species-focused to three island-based plans for Puerto Rico, St. Croix, and St. Thomas/St. John that recognize the management implications of the ecological, cultural, and socioeconomic differences among the island platforms. The CFMC has also embarked on the development of a fishery ecosystem plan (FEP) as a source document for incorporating ecosystem principles, goals, and policies into their current fishery management structure. FEPs can be used to provide context on the current state of and interaction within the ecosystems which the fisheries are managed, direct how that information should be used in relation to fishery management plans, and set priorities and effect policy to advance Ecosystem-Based Fisheries Management (EBFM), as described in the NOAA Fisheries EBFM Policy (NMFS 2016). Following a blueprint for building effective FEPs established by the Lenfest Fishery Ecosystem Program task force, the CFMC's EBFM Technical Advisory Panel (EBFM TAP) is working on developing the U.S. Caribbean FEP. The FEP development process takes into consideration five steps aimed at answering four key questions about the fishery system: Where are we now? Where are we going? How will we get there? Did we make it? The EBFM TAP is currently on steps one and two which includes data acquisition and visualization, creation of stakeholder-based conceptual models of the fishery ecosystem, goal setting, and a risk assessment. We provide an overview of the development process, progress to date, and lessons learned on how to operationalize EBFM for the U.S. Caribbean. Emphasis is made on the development of conceptual models by different stakeholders, including the public, advisory panels, and the CFMC's scientific and statistical committee, and the relationship of these models to a risk assessment of the U.S. Caribbean fisheries ecosystem. To date, the conceptual models are variable among stakeholders and among island platforms in the U.S. Caribbean not only in terms of the components of those models but also in terms of the relationships among those components. To ground truth this variability, we propose to validate those conceptual models and compare them with quantitative models constructed using other sources of data.

Poster
A-1594

Landings data: an invaluable source of information for management and conservation of coral reef fish in the Sudanese Red Sea

Ahmed, M. A. M.[1], Elamin, S. M.[2], Moland, E.[3]
[1]Marine Fisheries Administration, Port Sudan, Sudan
[2]Red Sea University, Faculty of Marine Science and Fisheries, Port Sudan, Sudan
[3]Norwegian Institute of Marine Research (IMR), His, Norway

mhmdiragi[at]yahoo.com

Abstract

Sudan's Red Sea state marine fisheries sector targets a wide range of coral reef fish species. The fishery is considered 'artisanal' to semi-industrial, consisting of a fleet of smaller vessels using handline, barrier nets and gillnetting. Since 2015, Sudan's Marine Fisheries Authority (MFA) has maintained a comprehensive fish landing sampling scheme and developed a fisheries statistics tool based on the Pasgear software. Landings are recorded at two landings sites, one of which is the Sigala central fish market in Port Sudan where the majority of landed fish are traded. The data allow analyses of annual and seasonal patterns in landings, thus providing essential information for management actions. Here, we present examples from the database for some primary target species of the Serranidae (*Plectropomus* spp.) and Lutjanidae (*Lutjanus* spp.) families over the period 2016-2017-2018. Throughout the period, the average (mean of means) length of landed *P. areolatus*, *P. pessuliferus*, *L. bohar* and *L. gibbus* were 66.0, 58.0, 54.5 and 35.5 cm; 38, 61, 48 and 33 cm; and 40, 64, 51 and 33 cm in 2016, 2017 and 2018 respectively. Landed biomass was estimated to 45, 51, 36 and 18 tons; 68, 24, 47 and 24 tons; and 69, 24, 48 and 25 tons in 2016, 2017 and 2018 respectively. These amounted to 6, 4, 3.3 and 1.9%; 5.7, 2, 3.5 and 2%; and 5.3, 1.9, 3.7 and 1.9% of total fish landings in 2016, 2017 and 2018 respectively. In each year, landings peaked in the month of May (2%) for *P. areolatus*, in March (0.8%) for *P.pessuliferus*, and in October (0.4%) for *L.bohar* and *L.gibbus*. We consider our fisheries statistics system an important step from a data-poor situation to a data-limited or data-rich approach to management of high value target species, within an ecosystem approach to fisheries management (EAFM) framework in the Red Sea state.

Poster
A-1593

Conservation status of some targeted species in the Sudanese Red Sea artisanal fishery evaluated from multiple data sources

Yahya, O. A. M.[1], Adam, A. M. S.[2], Moland, E.[3]
[1]Marine Fisheries Administration, Port Sudan, Sudan
[2]Red Sea University, Faculty of Marine Science and Fisheries, Port Sudan, Sudan
[3]Norwegian Institute of Marine Research (IMR), His, Norway

onisayahya[at]gmail.com

Abstract

In the Red Sea State, Sudan, an artisanal fishery is targeting a range of coral reef fish species – primarily by means of handline and harvesting occur throughout the year for both local and overseas consumption, with seasonal peaks in landings. Some are regarded as high value target species and prices are dictated by overseas demand. Since 2015, a new landings data collection system was developed through the project as part of the Norwegian funded UNIDO project “Building institutional capacities for the sustainable management of the marine fishery in the Red Sea State” (2015–2017). In the study presented here, the objective is to assess catch-per-unit-effort (CPUE) for different target species by using landings data from the Suakin landing site, where effort data has been recorded by fisheries inspectors from Sudan’s Marine Fisheries Authority (MFA) according to a randomized sampling scheme. Secondly, an interview-based stock assessment study has been initiated in local communities to evaluate fishers’ subjective experience regarding past and present availability of preferred target species as part of ongoing capacity building in ecosystem approach to fisheries management (EAFM). Preliminary findings indicate that fishers in some areas are experiencing declining catches compared to 5-10 years prior. The interviews also indicate along-coast differences in species presence/ catchability/ availability that seem to have prevailed over decades, suggesting differences in habitat suitability. So far, the results obtained suggest that Local Ecological Knowledge (LEK) is high, especially among older and often less educated fisherfolk, but represents an important source of information that should be incorporated in interview based assessment and management processes.

Virtual
Oral
A-2158

Implementation of Fishers Agreement on Groupers Fisheries in Karimunjawa National Park

Agustina, S.[1], Hartati, I. D.[1], Prasetia, R.[1], Tarigan, S. A.[1], Gunar, A. N. F.[1], Sumaryati, S.[2], Prihatinningsih, P.[2], Kartawijaya, T.[1], Holmes, K.[1], Yulianto, I.[1, 3]
[1]Wildlife Conservation Society-Indonesia Program, Marine Conservation and National Policy, Bogor, Indonesia
[2]Karimunjawa National Park Agency, Semarang, Indonesia, [3]IPB University, Bogor, Indonesia

sagustina[at]wcs.org

Abstract

The Karimunjawa National Park (KNP) is the central of small-scale and artisanal fisheries in Central Java Province, Indonesia. Coral groupers is one of the main fishery resources there, contributing incomes for local people within the park. However, recent condition showed that the coral groupers stock in the nature has been depleted due to a high-level of exploitation. In response to this condition, in 2011, few local group of fishers initiated an agreement to self-regulate fishing for people in the KNP. This agreement consists of regulations related to the restriction of speargun with hookah compressor, minimum allowable weight of fish caught, and period of fishing. Question then raised whether this local agreement is an effective way maintaining coral groupers stock in the KNP. We then compared the groupers stock condition prior to and after the establishment of local agreement. A time series data of fish-catch landing monitoring (2009-2020) was used to estimate the abundance, catch per unit effort (CPUE), mean fish' length, exploitation rate, and spawning potential ratio (SPR) for six coral groupers species (Epinephelus polypekadion, E. fuscoguttatus, Plectropomus leopardus, P.maculatus, P. oligacanthus, and P.areolatus). The data showed that after the agreement being established in 2011 there were positive impacts, including the increase of mean fish' length, abundance, and biomass. The use of spearfishing with hookah compressor also decreased from 2010 to 2020. The catch composition for the small-sized coral groupers (< 300 grams) decreased for about 1-2% from 2012 to 2020, for the three species (P. leopardus, P.maculatus, and P. oligacanthus). Moreover, after the establishment of local agreement, we found that the SPR was greater than the biological limit reference point (20%) for P. leopardus and P. oligacanthus. These findings indicate that the local agreement could effectively have a positive impact for groupers sustainability. This approach showed that fishers agreement can be used as a solution to support fisheries management, and can be replicated to other national parks.

Virtual
Oral
A-1983

Balancing ecological and socio-economic goals for the establishment of no-fishing zones in Jamaica

Palmer, S. E.[1], Campbell, D.[2], Hay, B.[3], Lee, S.[2], Lang, J. C.[4]
[1]The University of the West Indies, Department of Life Sciences, Kingston, Jamaica
[2]The University of the West Indies, Department of Geography and Geology, Kingston, Jamaica
[3]Caribbean Coastal Area Management (C-CAM) Foundation, Clarendon, Jamaica
[4]PO Box 549, Ophelia, United States

suzanne.palmer[at]uwimona.edu.jm

Abstract

Goals of the 18 Special Fishery Conservation Areas (SFCA), or no-fishing zones, on Jamaica's intensely overfished reefs are to create sustainable fisheries and improve reef ecosystem health. Within the Portland Bight Protected Area (PBPA) fishing activities are unregulated across its nearshore shoal and patch reefs. Ecological and socio-economic assessments were carried out in 2018-19 to determine suitable areas for locating a reefal SFCA in the PBPA. Five sites were assessed for reef condition with AGRRA fish and benthic surveys. Simultaneously, semi-structured interviews were conducted with 219 fishers at key landing sites regarding their fishing practices and perceptions of reef health and fisheries management. Stakeholder meetings with the wider fishing community provided further insight into the extent of local socio-cultural dependence on the PBPA reefs. The sites were in fair condition at the regional level in terms of coral cover (mean = 18%). Although fish density exceeded the recent regional average (107 vs. 58 /100m^2, N=561), the total fishable biomass was low (~3000 gm/m^2) and dominated by small parrotfish and other juveniles. Total macroalgal cover was high (about 52%) and herbivorous *Diadema* densities were low (< 0.5/m^2). The livelihood of fishers in the PBPA is highly dependent on reef fish and they mainly target snapper, parrotfish, grunt, doctorfish and jack. The findings illuminated important socio-demographic patterns with younger spearfishers primarily catching parrotfish, and older fishers typically fishing at night with nets. With only 19% of fishers unaware of the existing no-fishing zones, this unregulated reef fishing activity occurs without regard to the diminutive numbers or sizes, or whether any individuals are sexually mature, or spawning. Despite being coral reef-dependent for their livelihoods, the fishing communities have revealed support for no-take zones encompassing discrete reefal areas. Ecological priority for no-fishing zones were congruent with fisher's perceptions. However, their attitude towards protection varies according to sites visited, fishing techniques, and sociodemographic factors that should be accommodated to minimize socioeconomic trade-offs. Initial recommendations for a new SFCA, together with a locally adaptive ecosystem-based management plan including improved financial planning for coral reef-dependent families, are being prepared for submission to the Jamaican Government.

Virtual
Oral
A-2144

Over twenty years of MPA protection has benefitted fusiliers, but improved fisheries management is needed beyond the borders

Prasetia, R.[1], Agustina, S.[1], Muhidin, M.[1], Hartarti, I.[1], Pardede, S. T.[1], Tarigan, S. A.[1], Rimayanti, R.[1], Ripanto, R.[1], Jamaludin, J.[1], Kartawijaya, T.[1], Sulisyati, R.[2], Prihatinningsih, P.[2], Sumaryati, S.[2], Syaifudin, Y.[2], Mardhiah, U.[1], Holmes, K. E.[1], Yulianto, I.[3]
[1]Wildlife Conservation Society - Indonesia Program, Bogor, Indonesia
[2]Karimunjawa National Park, Semarang, Indonesia
[3]IPB University, Department of Fisheries Resources Utilization, Bogor, Indonesia

rprasetia[at]wcs.org

Abstract

The fusiliers (Family Caesionidae) are economically important reef fishes in Indonesia, and, as such, their populations are threatened across the country. Marine protected areas (MPAs) are projected to reduce this threat through protecting populations from being overfished. Karimunjawa National Park (KNP) is one of the oldest MPAs in Indonesia (established in 1999), with coral reefs providing habitats for many important fish, including fusiliers. In this context, KNP provides an opportunity for assessing how MPAs could maintain populations of these species. We have collected more than a decade of time-series data from underwater visual census (UVC) surveys (2005-2019) and fish-catch (FC) monitoring activities (2009-2020). We have assessed the abundance, biomass, catch per unit effort (CPUE), exploitation rate (F/M), and spawning potential ratio (SPR) for three key fusilier species (*Caesio caerulaurea, C. cuning,* and *C. teres*). UVC data reveal that both the mean abundance and biomass for these three species fluctuated between 2005 and 2019, with remarkable increases in a period from 2009 to 2012, and, again, from 2013 to the most recent survey conducted in 2019. However, the increases in 2019 were mostly for the small-sized class (fish length <20 cm). Noteworthy, the no-take areas of the park have maintained the fusiliers’ populations, where the abundance and biomass of the three species combined in 2019 were 2550.7 ind. ha^{-1} and 204.9 kg ha^{-1}, respectively, which are 2- to 9-fold higher than levels within the other zones where fishing is allowed. Hookah spearfishing is the dominant fishing method used to catch fusiliers. The mean CPUE for these fusilier species decreased significantly from 63.3 in 2009 to 2.9 kg $trip^{-1}$ in 2020. Moreover, the F/Ms and SPRs of the three fusilier species indicate that all three are overfished, with F/Ms of 4.17, 6.66, and 3.07, and SPRs of 0.21, 0.02, and 0.07 for *C. caerulaurea, C cuning,* and *C. teres*, respectively. KNP is effectively maintaining fusilier populations within the no-take areas, however, under the current fishing exploitation levels outside of these areas, it is insufficient to create the needed ‘spillover’ effect – supplying juvenile and adult individuals from the no-take areas to the fished areas – to curb overfishing. The use of unsustainable hookah spearfishing may need to be regulated in the future alongside community support needed for stricter regulations.

Virtual
Poster
A-2178

Ecosystems Approach to Fisheries Management (EAFM) in practice: insights from assessments in IndonesianFisheries Management Area 713

Nadiarti, N.[1, 2], Mary Moore, A.[3], Abu, N.[2], Ndobe, S.[4], Lukman, M.[5], Budiarto, A.[6]
[1]Universitas Hasanuddin, Fisheries, Makassar, Indonesia
[2]Universitas Hasanuddin, EAFM Learning Centre, Makassar, Indonesia
[3]Universitas Hasanuddin, Graduate School, Makassar, Indonesia
[4]Universitas Tadulako, EAFM Learning Centre Sulawesi Tengah, Palu, Indonesia
[5]GEF/FAO Indonesian Seas Large Marine Ecosystem (ISLME) Project, Gedung Mina Bahari II, Lt. 14, Jl. Medan Merdeka Timur No. 16, Gambir, Jakarta, Indonesia
[6]Ministry Marine Affairs and Fisheries, Directorate of Fisheries Resources Management, Directorate General Capture Fisheries, Gedung Mina Bahari II, Lt. 14, Jl. Medan Merdeka Timur No. 16, Gambir,, Jakarta, Indonesia

nadiarti[at]unhas.ac.id

Abstract

Indonesia is one of many countries that have officially adopted the Ecosystems Approach to Fisheries Management (EAFM). While EAFM approaches are expected to be applied primarily at the FisheriesManagement Area (FMA) level, EAFM assessments can be made and measures taken at many levels, e.g. province, city/regency or fishery/stock/taxon. The methodology set out in the Indonesian EAFM Assessment Guidelines assesses six Domains (Fisheries Resources, Habitat and Ecosystems, Fishing Technology, Social, Economy, and Governance) based on 32 indicators. FMA 713 includes the Makassar Strait and nearby waters, with rich fisheries resources. Several EAFM assessments have been conducted in FMA 713, including groupers and snappers (two reef-associated demersal fish groups heavily fished for the live reef fish trade andas fresh or processed fisheries commodities across the Coral Triangle) in East Kalimantan (study sites: Bontang and Balikpapan). In this and other assessments, data were collected through desk study and site visits. In this presentation we aim to share insights gathered during this and some other EAFM assessments in WPP 713, in particular with respect to the indicators, methods of assessment, and the drafting ofrecommendations on actions and policies to improve the EAFM status of the fisheries assessed.

Session 12E - How can scientists and managers identify optimum catchment management actions to improve downstream condition for reefs and people?

Conceptualized by: **Stacy Jupiter** [1], **Kim Falinski**[2], **Amelia Wenger**[3]
[1] Wildlife Conservation Society, Melanesia Program (Suva, Fiji)
[2] The Nature Conservancy (Arlington, VA, USA)
[3] The University of Queensland (Brisbane, Australia)

Chaired by: **Sebastian Ferse** [1], **Annette Breckwoldt** [1], **Marie-Lise Schläppy** [4], **Line Bay** [5], **Estradivari** [1]
[1] Leibniz Center for Tropical Marine Research (Bremen, Germany)
[4] UWA/AIMS (Crawley, Australia)
[5] Australian Institute of Marine Science (Townsville, Australia)

Oral
A-1775

Identifying adaptive management options for a Nassau grouper (Epinephelus striatus) spawning aggregation site using acoustic telemetry.

Kadison, E.[1], Nemeth, R.[1], Matley, J.[2], Jossart, J.[3], Wetherbee, B.[4], Shivji, M.[5]
[1]University of the Virgin Islands, Center for Marine and Environmental Studies, St. Thomas, U.S. Virgin Islands
[2]St. Francis Xaviet University, Aquatic Resources, Nova Scotia, Canada
[3]Southern Illinois University, Center for Fisheries, Aquaculture and Aquatic Sciences, Carbondale, United States
[4]University of Rhode Island, Department of Biological Sciences, Kingston, United States
[5]Nova Southeastern University, Halmos College of Natural Sciences & Oceanography, Dania Beach, United States

ekadiso[at]uvi.edu

Abstract

The Grammanik Bank, a mesophotic reef on the edge of the Puerto Rican shelf south of St. Thomas, US Virgin Islands, hosts one of the only remaining Nassau grouper (*Epinephelus striatus*) fish spawning aggregation sites left in the eastern Caribbean. This site is within a 1.5 km^2 area that is a seasonally protected from February 1 through April 30 each year. Acoustic telemetry was used to document spatial and temporal patterns of movement of Nassau grouper around the Grammanik Bank from 2007 to 2014. A receiver array covering an area of approximately 6km x 1.5km was deployed along the shelf edge in 2007, and 25 Nassau grouper were tagged with internal acoustic transmitters between 2007 and 2010. Acoustic telemetry data was analyzed investigating the influence of biological and environmental parameters on patterns of movement, and the level of protection offered by the seasonally protected area. All tagged fish were within or visited the array at least one year and up to a maximum of four years. Although some fish were determined residents of the array, the number of detections and individuals detected rose significantly during December thru May each year, specifically during the week after the full moon. Grouper showed consistent patterns in their monthly time of arrival and departure from the spawning site during these months, regardless of sex. Migration pathways were identified across the array to and from the protected area, as were staging areas and courtship arenas. Based on the frequency of detections, during the week after the full moon throughout the spawning season, the average daily residency within the protected area was ~75%, with fish generally there from late afternoon to midnight each day. The remaining time fish actively moved to and from this site (< 2km), suggesting that they set up temporary courtship and home sites near the spawning area, but outside of the marine reserve. This, along with the presence of Nassau grouper on the spawning bank from December through May, outside of the currently established seasonal closure, suggests that protection should be expanded both spatially and temporally on the Grammanik Bank to better protect this critically endangered species. The study illustrates the need for identifying migration pathways, seasonality and fish courtship and spawning behaviours to provide guidance in defining more effective boundaries for marine managed areas.

Virtual
Oral
A-1419

Confounded stressors: persistent high coral cover on subtropical reef despite sedimentation and low fish density

Falinski, K.[1], Conklin, E.[1], Minton, D.[2], Carr, R.[1], Sprague, J.[3], Sprague, R.[3]
[1]The Nature Conservancy, Honolulu, United States
[2]Minton Consulting, British Columbia, Canada
[3]Pulama Lana'i, Lana'i City, United States

kimfalinski[at]gmail.com

Abstract

Coral reefs and associated reef fishes of the sparsely populated island of Lānaʻi in the Hawaiian islands provide invaluable cultural and ecological benefits for nature and people. However, despite their importance, recent observations indicate that the health of these critical ecosystems is declining due to threats such as sedimentation and overharvest. In particular, denudation of the semiarid landscape over a century of grazing has led to excess sedimentation on to the reef. For managers looking to understand local stressors, there is a lack of data on reef resources and benthic structure, and on the extent of sedimentation on the reef flat.
To better understand the state of nearshore reefs and fisheries, and their potential response to sedimentation, we conducted SCUBA and snorkel-based reef surveys of approximately 125 sites along ~12 km of coastline in both shallow and deep areas of the reef complex. To survey nearshore coastal temperatures, salinity and turbidity, we used kayaks with attached physical water quality sensors to survey the priority area, and we established sediment traps for 48 hours, and measured total suspended sediments at 5 locations.
Results indicate that coral cover on these northeast Lana'i reefs is some of the highest in the main Hawaiian islands, especially on deep (>2 m) reef areas, where coral cover averages 55% cover and is routinely >75%, and sedimentation is lower than on shallow reef area. Kayak surveys revealed areas of very high turbidity, upwards of 100 NTU, while the sediment traps nearest to shore exceeded 3.0 g/cm2. The shallow benthic community shows evidence of these sediment impacts, including low coral cover, depressed coral recruitment, and shifts in coral species composition toward sediment-tolerant and weedy species. These impacts appear most pronounced near significant sediment inputs, and shallow reef areas distant from these inputs may represent remnants of the historical shallow reef community. Given the seemingly high quality of the deep reef area, the fish biomass is surprisingly low.
A relatively healthy coral reef ecosystem adjacent to degraded watersheds lacking fish certainly presents a unique case study in the effects of human impacts. Future work should consider the unique oceanographic conditions that may drive the success of the Lana'i windward reef system.

12E - How can scientists and managers identify optimum catchment management actions to improve downstream condition for reefs and people?

Virtual
Oral
A-1556

Informing coral reef conservation and management with geochemical sourcing of land-based sediment and contaminants: Olowalu, a Mission Blue Hope Spot

Takesue, R.[1], Deakos, M.[2], Falinski, K.[3], Hodges, A.[4], Storlazzi, C.[1]
[1]US Geological Survey, Pacific Coastal and Marine Science Center, Santa Cruz, United States
[2]Hawaiian Association for Marine Education & Research, Lahaina, United States
[3]The Nature Conservancy, Arlington, United States
[4]Maui Nui Marine Resource Council, Kahului, United States

rtakesue[at]usgs.gov

Abstract

Coral reef ecosystems are under increasing pressure from human activities and climate change, stressors that can introduce land-based sediment and contaminants to the coastal ocean and impair reef resilience. Mitigation of sediment and contaminant runoff requires knowledge about production functions, source areas, and/or transport pathways. These questions are being explored in the watersheds and reefs of Olowalu in leeward Maui, Hawaii, USA, chosen as a Mission Blue Hope Site for its high reef quality and role as a source of coral larvae for adjacent reefs, and identified as a priority restoration site after bleaching reduced live coral cover in the mid 2010s. The coral reefs off Olowalu face land-based pressures from sedimentation and contaminants produced by frequent wildfires and vehicular traffic on a major beach-front highway. Both could increase if future climate brings more weather extremes: droughts, wildfires, and floods. Population growth is also expected in Maui, and with it, increased chemical loads to the environment. This geochemical study aims to identify catchment sources of sediment accumulating on Olowalu and adjacent Ukumehame reefs. More specifically, geochemical sourcing aims to distinguish sediment originating from upper Ukumehame Gulch, which is extensively intruded by volcanic dikes, relative to basaltic sediment from lower Ukumehame and Olowalu Gulches, and from windward Kealaloloa Ridge, formed of young, more erodible alkalic lavas where many wildfires appear to originate. The study also aims to identify levels and sources of polycyclic aromatic hydrocarbons (PAHs, contaminants of concern) in watershed soil and reef sediment by using diagnostic ratios that distinguish PAHs produced by wildfires, vehicular traffic, and other human activities. Levels of anthropogenic metals in roadside soil and reef sediment also show potential ecological risk. An understanding of such land-based sediment sources, transport pathways, and contaminant sources from geochemical signatures can inform both strategic targeting of processes for catchment management and an integrated approach to coral reef ecosystem conservation, restoration, and management.

Session 12F - How can successful local reef management and restoration efforts be scaled up to achieve meaningful conservation results?

Conceptualized by: **Melanie McField**[1], **Lisa Carne**[2], **Anastasia Banaszak**[3], **Nadia Bood**[4]
[1] Healthy Reefs Initiative, Smithsonian Institution (Florida, USA)
[2] Fragments of Hope (Belize)
[3] National Autonomous University of Mexico (UNAM) (MC, Mexico)
[4] World Wide Fund for Nature (WWF) (Belize)

Chaired by: **Melanie McField**[1], **Anastasia Banaszak**[3], **Nadia Bood**[4]

Oral
A-1273

Replicating the Mexico reef insurance model in the U.S. – findings and recommendations based on a feasibility study

Bieri, T.[1], Hum, K.[2], Conklin, E.[2], Falinski, K.[2], Carr, R.[2], Braun, R.[3], Bertolotti, L.[3], Bowman, J.[3], Geselbracht, L.[3], Bergh, C.[3], Secaira, F.[4], Rogers, M.[5], Roberts, E.[6], Way, M.[7]
[1]The Nature Conservancy, California, United States
[2]The Nature Conservancy, Hawaii, United States
[3]The Nature Conservancy, Florida, United States
[4]The Nature Conservancy, Merida, Mexico
[5]The Nature Conservancy, Minnesota, United States
[6]The Nature Conservancy, Massachusetts, United States
[7]Formerly The Nature Conservancy, Virginia, United States

tamaki.bieri[at]tnc.org

Abstract

Coral reefs provide enormous coastal protection benefits by serving as natural submerged breakwaters. For example, the loss of just one meter of coral reefs could result in doubling of the costs from flood damage globally[1].

After multiple hurricanes devastated parts of the Yucatán Peninsula, local people realized that hotels and beaches protected by reefs suffered far less damage than those without. In response, the state and municipal governments and the tourism industry launched an initiative to manage and sustain the reefs. Fees paid by beach-front property owners for the use of the beach, which is federal property, are directed to a new trust fund for ongoing reef management and for purchasing an insurance policy to pay for reef repair in the event of another large-scale storm. The parametric insurance policy created, where the payout is triggered when wind speeds exceed 100 knots within a predefined area, enables swift payout and reef repair activities to commence within weeks of a storm event.

The reef insurance model implemented in Mexico is a compelling proof of concept for reef management and coastal protection globally. We conducted a feasibility study to explore the replicability of this model in Hawaii and Florida. In both states, the legal framework allows public and private entities to purchase insurance on a natural asset, and reef repair can be carried out with appropriate permits. While reefs can potentially be insured against sudden-onset and natural risks in addition to hurricanes such as marine heatwaves and stormwater runoff, gradual-onset and man-made risks such as ocean acidification, coral disease and ship groundings are not suitable for parametric insurance. Local stakeholders are supportive of the reef insurance model, and we are working to implement the first reef insurance policy in the U.S. in Hawaii. The presentation will focus on the many cross-sector collaborations that we established to investigate the legal, financial, and technical feasibility of reef insurance in Hawaii and Florida, as well as the partnerships developed to implement the reef insurance policy in Hawaii

1 Beck et al. The global flood protection savings provided by coral reefs. *Nat Commun* **9,** 2186 (2018)

Oral
A-1845

Scaling reef restoration with Iberostar's Wave of Change: leveraging existing capacity to explore commonalities in situ and land based nurseries

Calle Triviño, J.[1], Blanco, M.[2], Cortés Useche, C.[1], Galvan, V.[3], Harms, E.[3], Morikawa, M.[3]
[1]Iberostar Hotels & Resorts, Sustainability Office, Playa Paraíso, Mexico
[2]Iberostar Hotels & Resorts, Sustainability Office, Bavaro, Dominican Republic
[3]Iberostar Hotels & Resorts, Sustainability Office, Miami, United States

johanna.calle[at]iberostar.com

Abstract

Despite coral reef restoration efforts in different parts of the world, gaps still remain for performing restoration for ecosystem function at scale, a gap that is increasingly urgent to resolve in the declining reefs of the Caribbean. The private sector has been viewed as a potential candidate for providing investment and new solutions. Here, we present results of multi-species network of restoration programs across the Caribbean with "Wave of Change" Iberostar's movement to contribute to active programs in resilient reef restoration towards coastal protection where we operate by 2025. We have the capacity to have projects in our beach destinations, keeping alliances with local partners and developed with scientific bases for building diversity within species, between species and across locations to compare the same nurseries and experiments everywhere. In Dominican Republic currently we have an in situ coral nursery organized by genotype, with 50 structures capable of supporting an average of 30 fragments of coral each. We have a Coral Lab in the Bavaro Hotel land facilities with a genetic stock of 12 coral species and eight raceways individual control systems to simulate bleaching events where we have already begun to make our first thermal tolerance tests across different genotypes. In Aruba we are collaborating for the maintenance of a coral nursery *in situ* and are in the process of developing a second Coral Lab to house coral on land for additional research and outreach. In Mexico we have two in-water coral nurseries in Riviera Maya and Cozumel with 9 species of coral in each, within of the Iberostar Alliance-CINVESTAV and with the logistic support of Dressel Divers. In Jamaica we are also developing baseline studies on the ecosystems surrounding our properties in alliance with local partners, while developing appropriate restoration strategies for this destination. We have genetic stocks available in four countries for the development of different activities in education, research, technological innovation, recreation and tourism. At the regional level, the project will improve understanding of how to use coral reef restoration as a tool for adaptation to climate change, we will also present techniques that work in all four geographies, taking into account political environments, species biology and their local adaptations, so that we can provide models for long-term sustainable management, particularly in partnership with the private sector.

12F - How can successful local reef management and restoration efforts be scaled up to achieve meaningful conservation results?

Oral
A-1865

Scaling up MPAs, species conservation and policy engagement in Cambodia through community-led management and government collaboration.

Glue, M.[1], Duffy, H.[2]
[1]Fauna & Flora International, Phnom Penh, Cambodia
[2]Fauna & Flora International, Cambridge, United Kingdom

matt.glue[at]fauna-flora.org

Abstract

Marine ecosystems in developing nations are frequently exposed to a multitude of local and global stressors, to the detriment of both marine habitats and dependent local communities. In Cambodia, many of these stressors act as a roadblock to achieving effective coral reef conservation. For example, weak top-down governance, insufficient enforcement, high fisheries livelihood dependency and low awareness in local communities have historically disrupted marine conservation initiatives. Fauna & Flora International (FFI), in collaboration with the Royal Cambodian Government's Fisheries Administration (FiA), has worked closely with coastal communities at several sites for the past eight years. Capacity building, in the form of SMART patrol training, enforcement techniques, reporting of IUU fishing and funding for essential equipment has empowered coastal communities to effectively manage their reef resources. In conjunction to this site-based work, FFI is collaborating with government ministries to produce action plans for MPA management, IUU fishing and flagship marine species conservation. To promote the approach of co-management, FFI has also established stakeholder networks and facilitated workshops that bring together government ministries and help to reduce conflict. Through this combination of national and site-based interventions, there are early signs of improvement in biodiversity conservation and fisheries management in Cambodia. For example, incidences of IUU fishing near local communities within the Koh Rong Marine National Park (KRA-MNP) have declined since MPA proclamation and establishment of community patrols. Key biological indicators including fish biomass and abundance, hard coral cover and seahorse abundance have either remained stable or are showing signs of recovery. Building on the progress achieved in KRA-MNP, these approaches are being now being replicated in the nearby Koh Sdach Archipelago (KSA) with plans for other areas of the Cambodian marine seascape. The long-term goal of FFI and partners is to create a network of connected MPAs across the Cambodian coast which can work as a model for effective community-supported management elsewhere.

Oral
A-2056

Lessons from the Mesoamerican Reef: What's next when collaborative science and adaptive management still aren't achieving the desired results?

McField, M.
Healthy Reefs for Healthy People, Smithsonian Marine Station, Ft Lauderdale, United States

mcfield[at]healthyreefs.org

Abstract

The Mesoamerican Reef includes the largest barrier reef in the Atlantic and is a hotspot of ecological and cultural diversity. Ecological services provided by this reef were recently valued at almost US$ 4.5 Billion per year. By 2030, further declines in reef health could reduce this by $3.1 billion while improvements in reef health could increase it by $2.5 billion (by 2030), suggesting a new potential economic impact of improving reef health at $5.6 billion per year. *Healthy Reefs Initiative* (HRI) is a globally unique collaboration of over 70 coral reef-focused research, management and conservation organizations dedicated to safeguarding the Mesoamerican Reef using collaborative adaptive science-based management and restoration interventions. However, with a core team of only six people and an annual budget of <$420,000 our expenditure HRI represents a mere 0.008% of this value differential. The combined efforts of our partners budgets would still equate to less than 1% of value differential between improving and declining reef health. Clearly it makes economic and ecological sense to improve the health of the reef - yet the current expenditures in reef conservation are grossly inadequate. Part of the problem with scaling up conservation and restoration is simply that both are severely underfunded to achieve success. HRI's 2020 Report Card measured the first decline in reef health in 12 years of monitoring – after seeing slow but steady improvements up to this point in time. Likewise, the 2021 Eco-Audit, which evaluates the extent of implementation of 28 recommended reef management actions, measured some progress (66% vs versus 54% implementation in 2011). However, the pace of implementation decreased from 2% in 2016 to 0.8% per year in 2021, in direct opposition to our calls for urgency. Even one of the longest-standing recommendations - FULL protection of at least 20% of the territorial sea - has not made ANY substantial progress in the last 20 years, although partially protected areas have increased and also absorbed most of the funding, despite not demonstrating ecological benefits. The 2022 Report Card will be launched mid-2022, and will report further declines in reef health (details will be available in the presentation). We need marine conservation leaders to engage the power of the media and exert real social-political pressure in order to create a more powerful and dynamic basis for achieving lasting conservation results at scales that matter.

Poster
A-1600

Hyposalinity thresholds for stony corals Montastraea cavernosa, Porites astreoides, and Siderastrea siderea in Southeast Florida

Davis, H., Voss, J.
Florida Atlantic University Harbor Branch, Fort Pierce, United States

haleydavis2020[at]fau.edu

Abstract

Corals on Southeast Florida's coral reefs are often exposed to variable environmental conditions including dramatic changes in salinity due to their proximity to major watershed drainage zones such as Lake Okeechobee. One particularly vulnerable reef region is St. Lucie Reef (SLR), which marks the northernmost extent of Florida's Coral Reef (FCR) and may serve as an important northern refugia for Atlantic corals as equatorial waters continue to heat in the coming decades. Although some studies have examined sublethal effects of several drainage-associated stressors, lethal hyposalinity tolerance thresholds have yet to be determined for important scleractinian inhabitants of this region. This study selected three species of stony corals prominent to the region, each of which are found commonly at SLR and across FCR. For this study, coral colonies were collected from a nearby reef community that has been exposed to similar environmental conditions as those found on SLR. Using replicated, controlled ex situ experiments, this project aims to characterize lethal osmotic tolerances (*experiment 1*) and sub-lethal osmotic duration threshold (*experiment 2*) for each species. After an acclimation period, experimental tanks will have salinity reduced from control levels (35PSU) by 2 PSU/day until and LC50 is reached for each species (*experiment 1*). *Experiment 2* will then hold experimental tanks at that ISS until 50% mortality has occurred for each species. This presentation will focus on the LC50 salinity concentration found for each species *in experiment 1*, duration thresholds found for each species in experiment 2 and will introduce preliminary findings from visual health assessment data from across the experiments. This series of experiments is designed to contribute information on corals' responses to variable environmental conditions and provide threshold criteria to help inform freshwater management strategies for the Lake Okeechobee System and Southeast Florida overall.

Poster
A-1531

Coral Husbandry techniques as a tool for better reef restoration efforts and educational output in the Maldives

Kube, N.
Deutsches Meeresmuseum, Aquarium, Stralsund, Germany

nicole.kube[at]meeresmuseum.de

Abstract

In countries like the Maldives coral reefs play a major role in their citizen’s life, as the country is formed entirely by reef atolls. The main income is generated by fishing and tourism. Like everywhere else in the world coral reefs in the Maldives are impacted by coral bleaching, destruction and other influences, but little is known by the local people what happens under the water surface.
Mainly on touristical islands many coral reef restoration projects have been carried out in the archipelago. The German Oceanogrpahic Museum was contacted to help in some of these projects as often local protagonists lack experience about biology, husbandry and handling procedures of corals. Since 2015 aquarists from the Museum had been engaged in the Association “Coral doctors” to provide free 4-day workshops to help maximizing replanting success of corals: Theory lessons on general biology and ecology of coral reefs, coral propagation and husbandry methods were complemented with practical units at sea. We worked on seven different island, four of them hotel islands and in 2019 on three local islands. We quickly learned how effective these workshops are to rapidly raise peoples awareness for coral reefs. In these workshops more than 300 people were educated, ranging from local conservationists, tourist guides, dive centers, local communities including school classes and boy scout groups. On each island small coral restoration sites were implemented.
Since 2019 the team was enlarged, also by a partnership with the local NGO “Save the Beach“ on the island Villingili to support their efforts on reef restoration, rising awareness about plastic pollution and organising beach clean ups. It was recognized over the years that a education center would help to intensify the work necessary to protect Maldivian coral reefs. So Hassan Beybe, director of “Save the Beach” develop together with the European team plans for a Center for Marine Research and Education including a coral farm, school room and research lab. He managed to get a funding sponsors but then the pandemic put a hold on these activities. In March 2022 a new approach will be undertaken to help establishing this station so locals can learn about coral reefs on land and what they can do to protect them in every day life. We are also planning to enlarge coral restoration efforts by including step by step new developments in ex-situ coral reproduction. Results of these undertakings will be presented.

12F - How can successful local reef management and restoration efforts be scaled up to achieve meaningful conservation results?

Virtual
Poster
A-2167

Ecological status and trens in the epi-center of marine biodiversity - the Bird's Head Seascape, West Papua, Indonesia

Matualage, D.[1], Purwanto, P.[2], Andradi Brown, D.[3], Rumengan, I.[4], Maulana Arsyad, N.[5], Ahmad, A.[6], Ismu Hidayat, N.[7], Pada, D.[5], Monim, H.[4], Mambrasar, R.[5], Hamid, L.[8], Mulyadi, M.[8], Erdi Lazuardi, M.[9], N. Ahmadia, G.[3], Tuharea, S.[10]
[1]University of Papua, Mathematics and Natural Science, Manokwari, Indonesia
[2]CoralTriangle Center, Semarang, Indonesia
[3]World Wildlife Fund US, Washington DC, United States
[4]University of Papua, Manokwari, Indonesia
[5]Conservation International Indonesia, Sorong, Indonesia
[6]The Nature Conservancy, Sorong, Indonesia
[7]Conservation International Indonesia, Kaimana, Indonesia
[8]Cenderawasih Bay National Park, Manokwari, Indonesia
[9]conservation International Indonesia, Sorong, Indonesia
[10]UPTD BLUD Raja Ampat MPA, Raja Ampat, Indonesia

d.matualage[at]unipa.ac.id

Abstract

The Bird's Head Seascape (BHS) is located in West Papua, Indonesia has been identified as a crucial marine conservation priority because of its mega-biodiversity and high tourism value. The BHS contains over 600 species of coral and 1,600 species of reef fish. Tourism has also rapidly expanded within the seascape, with the annual number of tourists visiting Raja Ampat increasing from < 1,000 in 2007 to >25,000 in 2018. Since 2009 a network of Marine Protected Areas (MPAs) had been implemented to minimize local coral reef threats in the region, such as destructive fishing practices and overfishing. Currently, there are 18 MPAs established within the BHS, with 5 new MPAs under initiation. A regional reef health monitoring program was established in 2009 to track ecological changes on the reefs and evaluate MPA performance to inform adaptive management in the region. Hard coral cover and fish biomass have been measured every two or three years at 278 reef sites inside and at 30 reef sites outside 11 BHS MPAs from prior to MPA establishment (2009) to the present. Our results show over the past decade hard coral cover, commercially valuable reef fisheries biomass, and herbivore biomass have remained stable within the MPAs. While some no-take zones have high fish biomass, in general across the seascape no take zone do not outperform sustainable fisheries zones. Since 2012 management effectiveness has significantly increased in all BHS MPAs, with Raja Ampat MPAs performing most highly in World Bank Scorecard management assessments. Given reef fish biomass was generally high prior to MPA implementation, and the rapid expansion of tourism in the region, our results therefore suggest that the MPAs are generally performing well. However, continued coastal development and increases in tourism in the region are likely to exceed sustainable the sustainable carrying capacity for tourism and marine resource use, and need to be considered in future conservation management to continue to safeguard this region.

Virtual
Poster
A-2102

How effective is your MPA?: A Social-Ecological Network Framework and Indicators to evaluate Marine Protected Areas

Trialfhianty, T.[1, 2], Quinn, C.[1], Beger, M.[1]
[1]University of Leeds, Leeds, United Kingdom
[2]Universitas Pelita Bangsa, Bekasi, Indonesia

bstit[at]leeds.ac.uk

Abstract

The effort to maximize Marine Protected Area (MPA)'s performance has been studied around the globe including how to evaluate its efficiency. However, despite of a complex social and ecological condition and interactions within and outside the MPAs, our understanding of what aspects that can influence MPAs performance and what indicators to used to evaluate MPAs under heteregenous conditions is still lacking. This review aim to identify an adequate set of indicators for assessing MPA's effectiveness and understand how these indicators are interact. We reviewed 74 studies of MPA around the globe to explore a complex interaction within social-ecological network (SENs) and to syntheses set of indicators for assessing MPA's effectiveness drawn from IUCN's criteria. A total of 60 indicators have been identified to assess management, social-economic, output and environment attributes within MPAs and can be used to evaluate MPAs under heterogeneous conditions. SENs framework was built to understand how these indicators influence MPAs' outputs. This review deliver a significant outputs to contribute in building a good management strategies for an effective MPAs in the future.

Session 12G - How do Assessments of the Intergovernmental Panel on Climate Change Inform for change?

Conceptualized by: **Katja Mintenbeck**, **Elvira Poloczanska**
IPCC Working Group II TSU c/o AWI Bremerhaven (Bremen, Germany)

Virtual
Oral
A-1784

How to avoid the disappearance of coral reefs?

Hilmi, N.[1], Allemand, D.[2]
[1]Centre Scientifique de Monaco, MC, Monaco
[2]Centre Scientifique de Monaco, Science, Monaco, Monaco

hilmi[at]centrescientifique.mc

Abstract

About 500 *million people rely* on coral reefs for their livelihoods, coastal protection and food security (Burke et al., 2011). They provide ecosytems services like food provisioning, recreation and culture, and protection of coastal infrastructure, but also medicines, natural beauty and cultural and spiritual services (Hoegh-Guldberg, 2011). In some areas coral reefs are in better health than others. For example, Fine et al. (2019) considers that northern sections of the Red Sea are considered as coral reef refuges from global warming and acidification, at least for the coming decades. In French Pacific territories, some coral reefs are very healthy and far from local pollution sources (GCRMN 2018, Bambridge et al, 2019).
But usually, coral reefs are threatened ecosystems. The Intergovernmental Panel on Climate Change special report « Global Warming of 1.5°C » produced in the IPCC's Sixth Assessment Cycle found that if global warming reaches 2°C above pre-industrial levels, more than 99% of coral reefs are projected to decline. At an increase of 1.5°C, coral reefs are likely to decline between 70% and 90%. If they are degraded or if they disappear, it will be a loss for the whole humanity, which depends on them for their biological, environmental and socio-economic utilities.
Our paper aims at exploring to what extent scientific and technological knowledge (such as conservation and restauration) can preserve the coral reefs and how political agreements and protocols, and socio-economic and management tools can be solutions to change the trajectory predicted by IPCC for coral reefs in order to enhance human well-being and ocean sustainability.

Session 12H - How to design participatory processes to achieve transformations in reef management towards a sustainable future?

Conceptualized by: **Sebastian Ferse** [1], **Annette Breckwoldt** [1], **Heath Kelsey** [2]
[1] Leibniz Centre for Tropical Marine Research (ZMT) (Bremen, Germany)
[2] University of Maryland Center for Environmental Science (Cambridge, MD, USA)

Chaired by: **Sebastian Ferse** [1], **Annette Breckwoldt** [1]

Oral
A-1991

Participatory coral reef management to enhance socio-ecological resilience: case studies from Southeast Asia

Dunning, K.
Auburn University, College of Forestry and Wildlife Sciences, Auburn, United States

khd0008[at]auburn.edu

Abstract

This research asks how coral-reef dependent communities respond to man-made and natural stressors in ways that enhance socio-ecological resilience. Resilience is the ability of a coupled human-natural system (CHNS) to absorb change, and maintain essential features. To answer this question, this research examines 5 Southeast Asian case study communities in Indonesia and Malaysia, that underwent serious coral bleaching events between 2015-2017 during El Nino. In addition, tropical weather events resulted in further damage to reefs. When coupled with illegal fishing activity and the damage caused by large numbers of visitors to the reef, Southeast Asian reefs face a wide range of stressors.
This study employs participatory design whereby respondents co-created knowledge. Over 35 respondents were interviewed per community, and 30 additional respondents were surveyed in a mixed methods study. Coral reef tourism is the major source of livelihoods in the case site communities. This research examined several potential sources of resilience in communities, including community-based, participatory conservation efforts, cultural events tied to coral conservation, and governance structures to determine a model for enhanced resilience in reef communities. Findings are threefold. First, in communities where there is strong participatory component to conservation efforts (such as community-generated underwater sculptures or beach front exhibits) social and ecological resilience was enhanced. Cultural events tied to conservation (such as religious festivals) enhanced resilience by expanding awareness of norms that lead to reef stewardship, especially among youth. Finally, governance structures that are devolved, with more opportunities for stakeholder engagement and local participation enhanced resilience by fostering creativity and buy in among community members. Findings may be useful to multi-lateral institutions that fund community development projects, governments seeking to build socio-ecological resilience, and civil society organizations seeking to implement resilience-enhancing programs.

Oral
A-1985

Co-design of coral reef health status reports enables stakeholder engagement in local and global scale reef management

Kelsey, H.[1], Towle, E.[2], Donovan, C.[2], Kimball, J.[3], Fries, A.[1], Miller, N.[1], Koss, J.[2]
[1]University of Maryland Center for Environmental Science (UMCES), Cambridge, MD, United States
[2]National Oceanographic and Atmospheric Administration, SIlver Spring, United States
[3]California Ocean Protection Council, Sacramento, United States

hkelsey[at]umces.edu

Abstract

Coral reefs provide numerous benefits to local communities, including food, income from tourism and fishing, shoreline protection, and cultural value. These ecosystems are also under threat from numerous causes, at both global and local scales. Global scale threats are of critical importance, and include climate-related effects from temperature extremes, sea level rise, and ocean acidification. But focusing on these global issues at local scales may make it difficult to engage communities and stakeholders in discussions about effective coral reef management. Global scale threats are largely unaffected by local management actions and therefore are seen to be out of the purview of local management authority. Local-scale issues, however, are more relatable to local management activities and may provide entree into meaningful discussions about resource management issues. These include disease, coastal habitat destruction, land-based sources of pollution, overfishing, direct impacts from resource users, and boat groundings. We facilitated a process to co-design status reports on coral reef ecosystem health with local stakeholders in the U.S. Pacific, Caribbean, Florida, and Gulf of Mexico coral reef management jurisdictions. The process was designed to incorporate understanding of locally and culturally relevant issues and foster discussion about the interaction between global and local scale management. Interactions were premised on creating status reports that are based on standardized measurement and analysis methods for coral reef ecosystem health. The focus on developing a status report product created space for diverse stakeholders to discuss their views on reef ecosystem values and threats. The process resulted in a series of status reports that are scientifically-based, standardized to allow synthesis of results across jurisdictions, and relevant to local issues and needs. The co-design aspect of this project created opportunities for meaningful discussion among national-level management and local stakeholders with diverse views on coral reef importance, ecosystem health, management, and conservation. This two-way exchange of views allowed global and local issues and knowledge streams to be incorporated into the status reports. We envision that similar processes can be duplicated in other locations to engage stakeholders to foster exchange of views and integrate diverse knowledge streams in coral reef management.

Oral
A-2108

Customary Management of Coral Reefs & Fisheries by the Panglima Laot in Simeulue Island, Aceh, Indonesia

Turnip, I. N.[1], Youvan, T.[1], Dirgantara, R.[1], Erdiansyah, E.[1], Indra, I.[1], Duffy, H.[2]
[1]Fauna & Flora International, Indonesia Programme, Marine, Banda Aceh, Indonesia
[2]Fauna & Flora International, UK, Cambridge, United Kingdom

iiqbalnindo[at]gmail.com

Abstract

Traditional fisheries management through the Panglima Laot (Sea Commander) has a long history in Aceh, where the coastal waters support unique marine biodiversity including significant coral reefs. Fauna & Flora International (FFI) has worked with Aceh's coastal communities and government bodies for over 15 years, initially assisting in re-empowering the Panglima Laot and assessing the status of Aceh's coral reefs after the 2004 tsunami. Since then, FFI have worked with the Panglima Laot, the Acehnese government and local NGO partners to deliver coral reef conservation and fisheries management projects, with a current focus on PiSiSi MPA, on the offshore island of Pulau Simeulue, where FFI first engaged in 2011.

PiSiSi MPA was designated in 2006 and encompasses 26 village fishing grounds. However, the MPA was not operationalised, resulting in poor management and widespread illegal fishing in coral reef areas, particularly from compressor operators. This situation has been compounded by the shifting of marine management decision-making in Indonesia from district to provincial level, thus threatening to exclude local stakeholders in remote locations such as Simeulue. In order to address these issues, two locally managed marine areas (LMMAs), known as lhoks in Aceh, were designated following participatory mapping of community fishing grounds within PiSiSi. FFI has also supported community-driven monitoring and surveillance patrols to detect and deter illegal compressor fishing, and the Panglima Laot has carried out legal action against offenders through customary courts. In parallel, FFI and partners at Syiah Kuala University are carrying out regular monitoring of coral reef habitats in Simeulue, with survey data from 2018 showing signs of reef fish population recovery in community-managed reef areas. This work is currently scaling up across PiSiSi, with five more communities engaged in the early stages of LMMA design, and new reef baselines being established at other designated MPA sites around Simeulue Island. This talk will discuss the successes and challenges of this reef management approach, and will highlight best practice for collaboration between government, conservation NGOs, and traditional community institutions.

Oral
A-1857

Conservation incentives initiative to promote reef health and socio-economic well-being in Tun Sakaran Marine Park, Malaysia: progress and challenges

Wood, E.[1], Yusah, H. M.[2], Ng, J. V.[3], Mabustan, L.[2], Bin Ahmad, N.[4], Mapait, J. A.[4], Bavoh, E. M.[5]
[1]Semporna Islands Project, Hook, United Kingdom
[2]Semporna Islands Project, Semporna, Malaysia
[3]Semporna Islands Project, Kota Kinabalu, Malaysia
[4]Sabah Parks, Semporna, Malaysia, [5]Sabah Parks, Kota Kinabalu, Malaysia

ewood[at]f2s.com

Abstract

The Semporna area in Sabah (Malaysia) is recognised as a marine biodiversity hotspot within the Coral Triangle. It is also a highly important area for both commercial and artisanal fishing both around the coral reefs and in open waters. However, over-fishing and destructive fishing over many decades have inflicted serious and on-going negative impacts on reef health and productivity. The 350km^2 Tun Sakaran Marine Park was established in the area in 2004 and management to date has concentrated on protection of biodiversity, fishing restrictions and control of increasing tourism. Outreach and awareness programmes have resulted in considerable engagement with local communities but joint discussions, decision-making and action with regard to conservation and resource use strategies have largely been lacking. This marginalisation of MPA residents has been due in part to unresolved problems regarding land claims, native rights and the indeterminate status of many of the people living in the area. A complicating factor is that the overriding philosophy of the majority of fishers is that the sea will always provide and that success in bringing in a good catch depends on effort and good fortune rather than implementation of conservation and resource use strategies. This combination of management, social and cultural practices and beliefs has resulted in a situation where fishers are ambivalent about the MPA and are not particularly motivated to help look after the area because they are not actually benefitting from the Marine Park. A conservation incentive scheme is now being undertaken which entails development and implementation of a mutually agreed plan that will bring tangible and personal benefits to the MPA fishing community together with direct benefits for conservation and sustainability. The agreement will be between resource-users who agree to fish sustainably and collaborate in conservation efforts and the management authority that agrees to provide the compensatory benefits. This paper describes progress and challenges to date.

12H - How to design participatory processes to achieve transformations in reef management towards a sustainable future?

Virtual
Oral
A-1992

Participatory approaches to coral reef outreach and management: Lessons learned from coral reef monitoring stations the Wider Caribbean

Fletcher, P.[1], Hendee, J.[2], Serrano, X.[3], Jones, A.[4]
[1]Fabien Cousteau Ocean Learning Center, Ft. Lauderdale, United States
[2]National Oceanic and Atmospheric Administration, Atlantic Oceanographic and Meteorological Laboratory, Miami, United States
[3]National Oceanic and Atmospheric Administration, National Marine Fisheries Service, West Palm Beach, United States
[4]Caribbean Community Climate Change Centre, Atlantic Oceanographic and Meteorological Laboratory, Belmopan, Belize

pamela[at]fabiencousteauolc.org

Abstract

In 1997, the National Oceanic and Atmospheric Administration's Atlantic Oceanographic and Meteorological Laboratory in Miami, Florida initiated the Coral Reef Early Warning System (CREWS) Network. The network consists of oceanographic and meteorological monitoring stations installed at reef locations around the globe. Each station gathers near real-time data that is used for monitoring physical parameters and modelling local and regional conditions. The information can be used by resources managers as a first-alert to changes occurring in reef ecosystems, integrating with other datasets, and informing management actions for short- and long-term decision making. Since 1997, the network has expanded and the approach for selecting, installing, and maintaining the stations has been modified. Lessons learned over the past 25 years include improved collaboration and partnerships with local hosts. Collaboration, including participatory decision support in site selection resulted in strategic locations for long-term monitoring and ecosystem-based approaches to reef management. Additionally, a transdisciplinary approach has been used to increase outreach to build awareness and use of the data collected. More recently, the CREWS project team has grown to include not only coral researchers, but also resource managers and governmental and non-governmental organizations, and scientists working in fisheries, instrumentation, engineering, climate modelling and extension education. Formal and informal interactions among the project partners have revealed information needs in both content and delivery of data collected, and a broader group of end-users including formal education. Through the participatory approach, new ideas have been identified for implementation of public and private sensor networks with the goal of improving the understanding of the reef ecosystem for informed decision making in an uncertain future.

Session 12K - Resilient Reefs: What is the Evidence for and the Future of Resilience-Based Management?

Conceptualized by: **Elizabeth Shaver** [1], **Elizabeth Mcleod**[1], **Kenneth Anthony**[2], **Jennifer Koss**[3]
[1] The Nature Conservancy (Arlington, VA, USA)
[2] Australian Institute of Marine Science (Townsville, Australia)
[3] NOAA Coral Reef Conservation Program (Silver Spring, MD, USA)

Chaired by: Ian McLeod [1], David Mead [1]
[1] Australian Institute of Marine Science (Townsville, Australia)

Poster
A-2236

The forgotten tool: Fisheries benefits of combining no-take areas with regulated fisheries in an MPA

Sjahruddin, F.[1], Krueck, N.[2], Mumby, P.[1]
[1]University of Queensland, Brisbane, Australia
[2]University of Tasmania, Taroona, Australia

f.firmansyah[at]uq.edu.au

Abstract

The fact that 96% of Marine Protected Areas (MPAs) still allow fishing and many no-take marine reserves cover far less than 30% of fished habitat are thought to undermine the achievement of UN CBD and IUCN biodiversity targets. Yet having a small no-take marine reserve and larger regulated fishing zone within an MPA has been the most acceptable form of MPA design. What remains unclear is the extent to which combinations of no-take with regulated fisheries can achieve fisheries and biodiversity goals. To determine whether regulated fishing zones potentially can complement marine reserves within multiple use MPA management, we simulated multiple scenarios of coral reef fisheries. We show that increasing the area of no-take can help rebuild coral reef fisheries even when the modest Aichi Target of 10% is reached. But we also show that a variety of effort controls, including catch limits, can strongly complement the fishery when implemented outside no-take boundaries. We discuss the importance of these results in the context of setting global targets for MPA vs marine reserve cover.

Oral
A-1785

Adaptive management and resilient reefs in Bonaire, Dutch Caribbean

Eckrich, C.[1], Steneck, R.[2], Virdis, F.[3], Francisca, R.-L.[1], Bertuol, P.[1]
[1]STINAPA Bonaire, Kralendijk, Caribbean Netherlands
[2]University of Maine, School of Marine Science, Walpole, United States
[3]Reef Renewal Foundation Bonaire, Kralendijk, Caribbean Netherlands

nature[at]stinapa.org

Abstract

The coral reefs of Bonaire, Dutch Caribbean have been actively managed since 1969 through local conservation actions and regulations including a ban on spearfishing (1971), a permanent mooring system and ban on anchoring (1978), and self-financing of the Bonaire National Marine Park through user fees (1992). In 2003, a biennial monitoring program was initiated to follow resilience trends and the findings from this monitoring have led to the establishment of fish protected areas (2008) and the protection of all parrotfish (2010). Before lionfish invaded Bonaire waters, a community-based lionfish control program was developed, and lionfish densities have remained low since their arrival in 2009. Disturbing seawater quality findings were key to the establishment of a wastewater treatment facility (2015). In 2017 and 2019, resilience trends were documented including increased coral cover, an increase in juvenile corals, a decrease in macroalgal cover, and an increase in the abundance of large parrotfish. *Acropora cervicornis* and *palmata* at restoration sites have demonstrated high survivorship and have been observed spawning (2018, 2019) and several wild stands are expanding. Ecological restoration of the land-sea buffer zone in Washington Slagbaai Park is underway through the removal of feral goats from the park. After nine years, seawater quality monitoring has re-commenced and the implementation of a three-year coral action plan spearheaded by the national government began this year involving multiple local partners in the effort to safeguard Bonaire’s coral reefs.

Poster
A-1152

Incorporating water quality indicators in standard monitoring to assess the resilience of coral reefs

Capriati, A.[1, 2, 3], Leemput, I. v. d.[1], Becking, L. E.[3, 4]
[1]Wageningen University and Research, Aquatic Ecology and Water Quality Management, Wageningen, Netherlands
[2]Wageningen University and Research, Marine Animal Ecology, Wageningen, Netherlands
[3]Wageningen University and Research, Aquaculture and Fisheries, Wageningen, Netherlands, [4]Naturalis Biodiversity Center, Leiden, Netherlands

agustin.capriati[at]wur.nl

Abstract

More than half of coral reefs are degraded worldwide, urges scientists, governments, and conservation managers to monitor the remaining reefs and strengthen their resilience by reducing local stressors. One key local stressor that has received less attention is increased nutrient concentrations from land-based sources and activities. Nutrient enrichment poses a clear threat to coral reefs by enhancing the growth of algae and pathogenic microbes and preventing opportunities for recovery. A significant challenge is understanding how combined local environmental disturbances and other stressors will erode reef resilience. To fill the knowledge gaps, we are taking a multi-faceted approach with a combination of a systematic review, remote sensing analysis, empirical data collection, and qualitative modeling in the Indonesian Marine Protected Area (MPA). We focus on MPA in Maluku and West Papua. We will show preliminary data on how water quality, nitrogen signatures of sediments and macroalgae, microbial communities, and composition of coral reefs communities respond along a gradient of nutrient levels from land-based activities. Using our results, we will develop indicators of reef stress due to nutrient enrichment. Understanding the relations, interactions, and consequences of increased nutrients from land-based activities on reef resilience will allow us to provide input to the current reef health monitoring program for better MPA management.

Virtual
Oral
A-1648

A strategic approach for helping secure the world's coral reefs.

Hoegh-Guldberg, O.[1], Phua, C.[2], Beyer, H.[1], Kennedy, E.[1], Dove, S.[1], Tanzer, J.[2]
[1]University of Queensland, School of Biological Science, St Lucia, Australia
[2]WWF International, Ocean Practice, Brisbane, Australia

oveh[at]uq.edu.au

Abstract

A sober reality of the Paris Agreement (UNFCCC, Dec 2015) is that the global abundance of corals is likely to plummet by 70-90% even if warming is restrained to 1.5°C above the preindustrial period. While disheartening, we focus here on the 10-30% of corals that are likely to survive as part of a global strategic plan which aims to ensure the stabilization of reefs by the mid-to-late century. Hypothetically, this regeneration would be based on the remaining coral colonies acting as sources of tissue and gametes, from which corals and eventually coral reefs may flourish under a re-stabilizing climate. Identifying reefs that are least exposed to climate change is important for maximizing effectiveness as is reducing the impacts of non-climate related threats such as pollution and destructive fishing. Given the long timeframe, our conservation strategies are focused on developing a stable balance between local people, industry, and natural systems. We are also building a partnership between universities, communities, and non-government organizations to ensure that the ambitions of the project are underpinned by the appropriate scale and capacity. The strategy has three phases. The first is focused on identifying coral reef locations that were less exposed to climate change pressures such as extreme water temperatures and storms, as well as being well connected to surrounding reef systems. To do this, we convened a workshop of over 20 leading reef experts to identify key environmental variables likely to influence the mortality of corals. Once these variables had been defined, multiple locations (each 500 km² in size) were identified globally (i.e., bioclimatic units or BCUs). The second phase involved the use of modern portfolio theory to identify a balanced global portfolio (i.e., optimized for risk/return) of 50 BCUs least exposed to climate change. This BCU portfolio was published in Conservation Letters in 2018 (50 Reefs). The third phase of our plan involves a sustained and collaborative program of work on preserving the BCU portfolio via the related Coral Reef Rescue Initiative (ICRS). For this, we are developing comprehensive, high-level plans together with seven major ‘coral reef’ countries (Cuba, Fiji, Indonesia, Madagascar Philippines, Solomon Islands, and Tanzania) – helping develop a deepening set of conversations, coordinated actions, and partnerships among stakeholders including local communities, NGOs, businesses and government leaders.

Session 12L - What are the challenges, solutions and synergies at the interface of science and policy to successfully conserve coral reefs?

Chaired by: **Tina Dohna** [1], **Maya Pfaff** [2], **Laura Puk** [3]
[1] Zukunft-Umwelt-Gesellschaft (ZUG) gGmbH
[2] Deutsche Gesellschaft für Int. Zusammenarbeit (GIZ)
[3] World Wide Fund for Nature (Hamburg, Germany)

Oral
A-1699

Closing the gap between coral reef field monitoring, adaptive management, and national MPA policy

Andradi-Brown, D. A.[1], Estradivari, E.[2, 3, 4], Amkieltiela, A.[2, 5], Lazuardi, M. E.[2], Iqbal, M.[2], Veverka, L.[1], Ahmadia, G. N.[1]
[1]World Wildlife Fund, Washington DC, United States
[2]WWF-Indonesia, Bali, Indonesia
[3]Leibniz Centre for Tropical Marine Research (ZMT), Bremen, Germany
[4]University of Bremen, Bremen, Germany
[5]Katholieke Universiteit Leuven (KU Leuven), Leuven, Belgium

dominic.andradi-brown[at]wwfus.org

Abstract

With declining coral reef health globally, many nations have implemented Marine Protected Areas (MPAs) to both protect biodiversity and increase fisheries sustainability. MPAs, however, require substantial tailoring to local context which makes regular monitoring and evaluation essential – with these results feeding into adaptive management and policy. Here we review work in the Sunda Banda Seascape (SBS), eastern Indonesia, with a focus on linking field-based monitoring to improve MPA outcomes and inform regional MPA policy. Since 2012, WWF has built a long-term collaborative partnership with national, provincial, and local government to support establishment and effectiveness of 15 MPAs within the SBS, as well as regional MPA management capacity in Indonesia. A major component of this work has been identifying the impacts of the MPAs on coral reef health and communicating this to decision makers. We conducted coral reef surveys at 2-3-year intervals at 120 sites inside and outside MPAs across the SBS. Using state-of-the-art impact evaluation techniques, we adopted a quasi-experimental design that enabled causal effects of the MPAs to be identified. This approach allowed us to disentangle nuanced effects of MPAs on fish biomass despite changing regional pressures. To overcome obstacles in data cleaning, processing, and management, and to accelerate insights, we have helped design and adopted a new open-source web-based coral reef data collection platform. To communicate our results to policy makers we have collaborated with other researchers and NGOs to develop a series of ‘State of the Seascape’ dashboard reports that provide key indicators to inform regional decision making. Over the past year we have worked closely with the Ministry of Marine Affairs to co-design a national assessment of Indonesia’s MPA network that underpins the Government of Indonesia’s new 10 year vision for the future of MPAs. Our key lessons learned for effective information flow from field science to decision-makers include long-term commitments to supporting partners, collaborative projects involving decision-makers at different levels of government, and co-designing project outputs with decision makers to directly serve their needs.

Oral
A-1797

The impact of the Allen Coral Atlas, a global tool for mapping and monitoring coral reefs

Bambic, B.[1], Rivera-Sosa, A.[2], Lieb, Z.[1], Lyons, M.[3], Say, C.[3], Markey, K.[3], Alvarez, A. O.[4], Roelfsema, C.[3], Flynn, M.[5], Gerstner, P.[5], Asner, G.[5], Fox, H.[2]
[1]National Geographic Society, Mapping, Washington, United States
[2]Coral Reef Alliance, Oakland, United States
[3]University of Queensland, Brisbane, Australia
[4]Southern Cross University, Lismore, Australia
[5]Arizona State University, Tempe, Arizona, United States

brianna.bambic[at]gmail.com

Abstract

Coral reef managers and decision makers at multiple scales need information, in near real time, to react to the increasing threats facing reefs. However, more than three quarters of the world's coral reefs have never been mapped and lack monitoring. To address this knowledge gap and to support, inform, and inspire critical actions to manage and protect coral reefs, the Allen Coral Atlas (the Atlas) combines high resolution satellite imagery, machine learning, and field data to produce globally consistent benthic and geomorphic maps and monitoring systems of the world's coral reefs. The goal of the Atlas is to help stakeholders ranging from regional, national governments to local communities reach their conservation targets and improve their coastal resilience.

In our report, we demonstrate the impact of the Atlas and how it supports data-driven management, conservation, and restoration of coral reefs across multiple scales. With the support of many marine practitioners, the Atlas team has connected with more than 2,000 marine professionals. A subset of those marine professionals shared their stories of using the Atlas (n = 120 marine professionals, split into three main audiences: Marine and Coastal Managers (53), NGO Practitioners (31) and Researchers (36)). Stories of conservation impact ranged from marine spatial planning to site feasibility planning for restoration and coastal resilience analyses globally. We have also reached more than 2,000 people from 139 countries via an online course coordinated with key partners. Other outreach and engagement in relation to our monitoring systems (e.g large-scale bleaching or sedimentation events) further enhance the applicability and use of the Atlas. All has been possible due to the collaboration of wide networks of individuals and institutions worldwide. We hope to engage discussion on how collaborative marine networks can further science and conservation. Overall, we present a synthesis of the activities undertaken by the Atlas team, the conservation value observed linking science data to decision makers, user feedback gained in the process and actions to be taken to further global capacity for remote sensing tools for conservation impact.

12L - What are the challenges, solutions and synergies at the interface of science and policy to successfully conserve coral reefs?

Oral
A-2035

Climate-Smarting the Mesoamerican Reef Region

Bood, N.[1], Rohe, J.[2], Arkema, K.[3], Bartlett, R.[4], Del Mel, M.[5], Calzada, A.[6], Chevez, L.[7], Vasquez, P.[8], Porta, M. A.[9]
[1]World Wildlife Fund Inc, Mesoamerica, Belize, Belize
[2]World Wildlife Fund Germany, Hamburg, Germany
[3]Stanford University, Seattle, Washington, United States
[4]World Wildlife Fund Inc. US, Washington, DC, United States
[5]The Earth Science Institute, Columbia University, New York, New York, United States
[6]World Wildlife Fund Inc., Mexico, Merida, Mexico
[7]World Wildlife Fund Inc. (former), Mesoamerica, La Ceiba, Honduras
[8]World Wildlife Fund Inc., Mesoamerica, Guatemala, Guatemala
[9]World Wildlife Fund Inc, Mesoamerica, Guatemala, Guatemala

nbood[at]wwfca.org

Abstract

In a collaborative effort, a range of stakeholders from civil society, academia, government as well as communities are working together to mainstream climate-smart principles into marine protected area and coastal management in the Mesoamerican Reef region. The Mesoamerican Reef is the largest transboundary reef system in the world spanning the coastlines of Mexico, Belize, Guatemala and Honduras. The region is considered highly vulnerable to the effects of climate change, while the coastal-marine environment is under pressure from multiple anthropogenic impacts, such as coastal development, unsustainable fishing, and pollution.

Based on climate risk analyses and ecosystem service modelling (of fisheries, tourism, coastal vulnerability reduction, and sediment retention) the project has identified ecosystem-based adaptation measures with a view to improve the adaptive capacities of coastal communities in the region. The project is helping to enhance knowledge and capacities at local and national levels, contribute to marine protected areas management plans and national adaptation policies (such as the NDCs), pilot adaptation activities and increase education and awareness on climate change.

This contribution will present some key results from the project and reflect upon the collaborative process among the diverse stakeholders involved to distil key lessons, success factors as well as remaining challenges.

12L - What are the challenges, solutions and synergies at the interface of science and policy to successfully conserve coral reefs?

Oral
A-1668

NOAA's National Coral Reef Monitoring Program - Atlantic basin case studies in balancing a standardized program with emerging local management needs

Edwards, K.[1], Towle, E.[2]
[1]CSS, Inc. and NOAA, National Centers for Coastal Ocean Science, Beaufort, United States
[2]Lynker, Inc and NOAA, Coral Reef Conservation Program, Silver Spring, United States

kimberly.edwards[at]noaa.gov

Abstract

NOAA’s Coral Reef Conservation Program (CRCP) developed the National Coral Reef Monitoring Program (NCRMP) to standardize coral monitoring methodologies across US jurisdictions. The NCRMP framework collects sustained data on coral reef ecosystems across all US territories to report on the status of coral reefs at a large spatial scale and provide context for state/territorial management. Since the 2013 inception of NCRMP biological sampling in the Atlantic basin, state and territorial partners have requested additions to the standard monitoring program to address emerging local management and scientific needs. A recent example is the emergence of the novel Stony Coral Tissue Loss Disease (SCTLD) in Florida and the wider Caribbean. State and territorial partnerships are crucial to the success of NCRMP, so it behooves NCRMP to try to accommodate requested additions to benthic community surveys, if practicable and feasible. This poses a challenge to maintaining a standardized program, while still meeting the emerging needs of valuable state and territorial partners. This presentation will highlight these partnerships, some of the requests received over the past 6 years and how these requests were managed while striving to maintain the integrity of a standardized, long-term program. Change is inevitable in light of an ever-changing environment, and a static monitoring program is not a reality, but at a National scale, changes need to be strategically implemented. This presentation seeks to encourage dialogue on how to balance program changes over time, both politically with partners and programmatically within the national framework, to encourage partnership growth and development within the context of the standardized monitoring program.

Oral
A-1753

The Scuba diving industry at the interface of science and policy in islands

Nisa, Z.
World Maritime University, Global Ocean Institute, Malmo, Sweden

w1903547[at]wmu.se

Abstract

In the context of international coral reef policy, the Sustainable Development Goal 'Life Below Water' (SDG 14) includes a number of new commitments on ocean conservation and sustainability. Goal 14.7 specifically addresses Small Island Developing States (SIDS) and aims to increase economic benefits from the sustainable use of marine resources.

The coral reef economy in the fisheries, tourism and marine industry sectors in SIDS is directly linked to the health of coral reef ecosystems, which in turn is linked to supply chains. Coral reef-based industries and related policy discussions to facilitate economic benefits and management have now moved into the blue economy sector. For islands whose tourism generates 20 to 50 per cent of GDP and more than 30 per cent of jobs, coral reefs are the main attraction, with diving and snorkelling being the main tourism activities.The use of diving by commercial fishers for reef-based trade in seafood and fishery products is also of great national economic importance. Diving is an economically important industry, as evidenced by the number of SIDS that have just begun to incorporate this value into their blue economy policies.

SDG 8.9 states that policies should promote sustainable tourism that creates jobs. This session will discuss diving education platforms and diving industry tools that can be optimised in collaboration with policy makers and academia to develop cost-effective coral reef management strategies.

Case studies will be used to discuss the role of the diving industry in blue economy reform initiatives in SIDS and outline the requirements for industry engagement in evidence-based policy making. It will also highlight synergies and mechanisms for collaboration that are mutually beneficial to coral reef stakeholders.

The session will stimulate a discussion on evidence in the diving industry linking SDG 14 (life below water) with SDG 8 (productive employment and decent work for all) to support the development of SIDS.

Poster
A-1436

Restoration of Resilience of Nature and Society in the Caribbean Netherlands.

Dogruer, G.[1], Mücher, S.[2], Schellenberg, L.[3], Haas, A.[3], Becking, L.[4], Tonk, L.[5], van de Greest, M.[6], Daniels, F.[7], Meesters, E.[6]
[1]Wageningen University and Research, Wageningen Marine Research, IJmuiden, Netherlands
[2]Wageningen University and Research, Wageningen Environmental Research, Wageningen, Netherlands
[3]NIOZ Royal Netherlands Institute for Sea Research, Netherlands, Department of Marine Microbiology & Biogeochemistry, Texel, Netherlands
[4]Wageningen University and Research, Department of Animal Sciences, IJmuiden, Netherlands
[5]Wageningen University and Research, Wageningen Marine Research, Yerseke, Netherlands
[6]Wageningen University and Research, Wageningen Marine Research, Den Helder, Netherlands
[7]Wageningen University and Research, Wageningen Food & Biobased Research, Wageningen, Netherlands

gulsah.dogruer[at]wur.nl

Abstract

The Dutch Caribbean coral reefs are subjected to stressors of both local (e.g. tourism, erosion, pollution) and global (e.g. climate change) origins. Ecosystem services provided by coral reefs are the most significant economic resource for the Dutch Caribbean islands Bonaire, Sint Eustatius and Saba, meaning that restoring and regulating reef health is imperative for local communities. However, a recent publication indicates that coastal runoff adversely affects the health and diversity of coral reefs in Bonaire. This finding calls for better management of coastal runoff sources to not exceed the natural capacity of these precious ecosystems. Monitoring such land-sea interactions and local marine water quality followed by targeted interventions can increase the resilience of reef health and biodiversity. To achieve this, integrated approaches and strong local stakeholder involvement are key.
We aim to develop a sustainable, easily applicable and cost-effective approach for more predictive and proactive risk and conservation management by combining emerging scientific tools and integrating socio-ecological infrastructure. For this, we combine innovative tools (eDNA, metabolomics, remote sensing, AI-based data processing and underwater drones) with traditional methods (water quality parameters, passive sampling, isotope analysis, runoff modelling using digital evaluation models and bathymetry data) to evaluate how land-based human activities impact coastal water quality and coral reef health. The outcome will support 1) developing a local monitoring infrastructure for long-term marine water quality monitoring, 2) detecting early warning indicators for the adverse impact of environmental pollution on coral reef ecosystems, 3) integrating mechanistic knowledge within a local risk assessment framework. The interdisciplinary research design of our project and preliminary results will be presented.

Virtual
Oral
A-2162

What could hinder a National Park from being significantly improved? A case study of Taka Bonerate National Park, Indonesia

Muhidin, M.[1], Pardede, S.[1], Rahman, S.[2], Ronald, Y.[2], Agustiar, A.[2], Prasetia, R.[1], Holmes, K.[1], Madhiah, U.[1], Hutami, P.[1], Bachtiar, M.[3], Suprianto, A.[1], Fuadi, I.[1], Ardiansyah, I.[4]
[1]Wildlife Conservation Society, Bogor, Indonesia
[2]Taka Bonerate National Park, Selayar, Indonesia
[3]Diponegoro University, Semarang, Indonesia
[4]IPB University, Bogor, Indonesia

mmuhidin[at]wcs.org

Abstract

Management of coral reefs within Taka Bonerate National Park was strengthened since the beginning of evaluation process of the existing zoning system in 2015 along with efforts to ensure compliance with the zones' regulations. However, many ecological indicators are not yet showing significant improvements. Using time series of data from 2015-2021, we explore what may be hindering some sites within this MPA from performing better. We will assess 13 coral reef ecological indicators and address two key questions by comparing sites categorized in two ways: (1) sites that are far from inhabitants or villages (with lower human impacts) versus those close to inhabitants/villages; and (2) sites with clear management rules versus those with complicated management rules. We hypothesize that distance to the closest inhabitants/village might be an important factor with respect to the continued health of reefs in the park. Also, that simpler management rules, which might be more easily understood, accepted, and followed by community members, might help the community to comply, leading to improved reef health over time. All 13 ecological indicators will be scored and weighted to generate scores for reef health as well as scores for improvement since 2015. Site conditions will be asessed against both distance from populated areas as well as complexity of regulations using two-way Anovas and power analysis. Findings from this assessment will allow for adaptive management through providing recommendations for the next update to the zoning regulations for Taka Bonerate National Park.

12L - What are the challenges, solutions and synergies at the interface of science and policy to successfully conserve coral reefs?

Virtual
Oral
A-1220

Dark fishing fleets threaten highly diverse coral reef fish communities at Dongsha Atoll, South China Sea

Wen, C.[1], Heatwole, S.[2], Heard, J.[3], Price, N.[1], Ho, M.-J.[4], Chang, S.-K.[5], Chen, C.[6]
[1]Tunghai University, Department of Life Science, Taichung, Taiwan
[2]University of Wollongong, School of Earth, Atmospheric and Life Sciences, Wollongong, Australia
[3]The Hong Kong University of Science and Technology, Department of Ocean Science, Hong Kong SAR, Hong Kong SAR China
[4]Biodiversity Research Center, Green Island Marine Station, Marine Science Thematic Center, Taitung, Taiwan
[5]National Sun Yat-sen University, Institute of Marine Affairs, Kaohsiung, Taiwan
[6]Academia Sinica, Biodiversity Research Center, Taipei, Taiwan

ckcwen[at]thu.edu.tw

Abstract

The South China Sea is a biodiversity hotspot, however overfishing is a major threat to the coral reef ecosystems in the region. No-take marine parks have been established in some areas to combat overfishing. Illegal fishing activities, especially from large fleets without automatic identification systems persist. We evaluated the effects of illegal fishing activities on coral reef fishes in the Dongsha Atoll National Park. We conducted coral reef fish surveys throughout Dongsha Atoll to quantify fish abundance, species richness, biomass, species compositions, size distributions and size spectra. Coral cover and macroalgae cover were also quantified to determine the relative influence of habitat characteristics and fishing pressure on fish communities. Using data from coastal surveillance radar systems, fishing pressure was determined by the amount of fishing boats operating at each site. Fish abundance and biomass were lower in areas of high fishing pressure. Larger fishes were more prevalent in areas with less fishing pressure, although they were rarely observed across all sites. There were no clear differences in the size spectra and species richness across sites. Fishing pressure from these dark fleets, as well as macroalgae cover and reef profile appear to be the greatest influences on fish communities within Dongsha Atoll. Increasing and expanding the efficacy of enforcement is necessary to conserve the highly diverse reef ecosystems of Dongsha Atoll.

Virtual
Poster
A-1656

How scientific work can help policy makers: Trade in marine ornamental fishes - a perspective from Europe

Biondo, M. V.[1, 2], Burki, R. P.[3]
[1]Fondation Franz Weber, Research and Conservation, Bern, Switzerland
[2]University of Bern, Ecology and Evolution, Bern, Switzerland
[3]adsfg IT, Rosshäusern, Switzerland

monica.biondo[at]bluewin.ch

Abstract

an half of the known nearly 4,000 coral reef fishes, are traded internationally and demand is growing. About 40 million marine ornamental fishes are being sold annually. Many more are caught due to mortalities in the supply chain that represent a major concern. The biggest importers are the USA, EU, Japan, although hardly any data is available for Asia, Africa, Central and South America. Though the potential for overexploitation of some species is great and the fact that coral reefs are highly threatened, today there are no global systems in place to monitor this 1.5 billion US$ strong trade. Europe is a major importer of coral reef fishes, and monitors trade in live animals for disease prevention through the Trade Control and Expert System (TRACES). Our studies show that TRACES should be adjusted to gather compulsory information for the EU and worldwide. The database is not intended to record strict species-specific information about marine ornamental fishes, just the family level has to be provided mandatorily and information about the species is voluntary. Also, we analysed the IUCN Red List that shows that today almost half of the known coral fish species are not assessed and therefore their conservation status remains unknown.
We have created a list of species susceptible to overexploitation by trade. The species are ranked by a single score which is generated by number of traded specimens, trends in trade volumes according to TRACES and the IUCN Red List conservation status as well as vulnerability according to FishBase. Trade in species protected through the UN Convention on International Trade in Endangered Species (CITES) is monitored. But only very few species of marine ornamental fishes, namely all seahorses (hippocampus spp.), the napoleon wrasse (Cheilinus undulates) and the clarion angelfish (Holacanthus clarionensis), are listed under CITES. Very little is known about most other species. In August 2019 the conference of the parties (182 member states) to CITES voted in favour of a proposition to scrutinize the trade in coral fishes worldwide in order to evaluate the threat trade may pose to coral reefs. The decision was based on solid scientific work about the trade.

Session 12M - Do ocean literacy, governance, ecosystem services and blue economy have a key role for a successful marine conservation strategy and sustainable development?

Conceptualized by: **Anna Maria Addamo**[1,2], **Mariagrazia Graziano**[1], **Francesca Santoro**[3], **Thamasak Yeemin**[4], **Vo Si Tuan**[5]
[1] European Commission, JRC (Ispra, Italy),
[2] National Museum of Natural Sciences (Madrid, Spain)
[3] IOC, UNESCO (Venice, Italy)
[4] Marine Science Association of Thailand (Bangkok, Thailand)
[5] Institute of Oceanography Vietnam (Nha Trang, Vietnam)

Virtual
Oral
A-1843

Sustainable uses of coral communities on underwater pinnacles in the Western Gulf of Thailand

Yeemin, T.[1], Sutthacheep, M.[1], Hamanee, S.[2], Aunkhongthong, W.[1], Rangseethampanya, P.[1], Lawang, B.[1]
[1]Ramkhamhaeng University, Department of Biology, Bangkok, Thailand
[2]Sripatum University, School of Business Administration, Bangkok, Thailand

thamasakyeemin[at]yahoo.com

Abstract

Several hundred million people in coastal communities have benefited from coral reef ecosystems from fisheries, coastal protection, and tourist income. However coral reefs have been faced with increased negative impacts from natural and anthropogenic disturbances. Sustainable coastal development projects are required to protect coral reef ecosystems while meeting other economic needs. Diving tourism provides great benefits to the local and national economy as well as supports local employment and livelihoods. The growth of marine and coastal tourism, particularly diving business is an important aspect for the blue economy of many tropical countries worldwide. The degradation of coral reefs has been documented, particularly from coral bleaching, coastal development, and tourism impacts. This study applied a transdisciplinary approach to develop marine ecotourism in Mu Ko Chumphon, the Western Gulf of Thailand, to support sustainable uses coral reef ecosystems. The ecological and socio-economic surveys, particularly marine and coastal tourism, were conducted to gather relevant information for sustainable management. The results revealed that some coral communities on underwater pinnacles in Mu Ko Chumphon can be developed and promoted as new ecotourism sites to attract tourists from the main dive sites in Thailand, particularly Ko Samui, Ko Tao, Ko Phangan, Mu Ko Ang Thong and Pattaya in the Gulf of Thailand and Phuket in the Andaman Sea. Since the popularity of marine tourism in Mu Ko Chumphon is relatively low, tourism promotion, marketing as well as tourism infrastructure should be urgently developed. We also suggest that the ecotourism concept with local community collaboration should be applied to ensure the sustainability of ecological integrity and social-economic viability. This study provides integrated baseline information to support sustainable ecotourism management along with coral reef conservation in Thailand which can be applied at other coral communities in the Indo-Pacific region.

Virtual
Poster
A-1858

Biotechnological potential of soft-bottom polychaetes from coral reefs in the Western Gulf of Thailand

Jungrak, L., Yeemin, T., Sutthacheep, M., Chunhabundit, S., Phoaduang, S., Mue-suea, O., Wongnutpranont, A.
Ramkhamhaeng University, Department of Biology, Bangkok, Thailand

laongdow8853[at]gmail.com

Abstract

Coral reefs are the most diverse and productive marine ecosystems and provide a wide range of ecosystem services and goods, particularly food provision, coastal erosion protection, tourism income and drug candidates. The Polychaeta annelids occupy nearly every marine and coastal habitat and have potential for providing a wide array of natural products. However, studies on biodiversity and abundance of soft-bottom polychaetes from coral reefs are very limited. This study aimed to examine composition and abundance of soft-bottom polychaetes from coral reefs in the Western Gulf of Thailand for assessing biotechnological potential, particularly natural products. We investigated and collected polychaetes from soft bottom of coral reefs in Mu Ko Chumphon, the Western Gulf of Thailand. The diversity of soft-bottom polychaetes on the coral reefs was much higher than that of sandy beaches. Several polychaete taxa were found only on the coral reef ecosystems. Most soft-bottom polychaetes in this study were members of the families Spionidae, Nereidae, Pisiouidae, Amphinomidae, Syllidae, Magelonidae, Hesionidae, Capitellidae, Cirratulidae. These polychaetes showed potential for porphyrinoid pigments as photosensitizers, luminescent and fluorescent probes, eco-friendly pesticides and anti-foulants, painkillers and anaesthetics, anti-cancer therapy, anti-haemostatic and anticoagulant drugs, anti-inflammatory substances, antimicrobial properties, antivirals, adhesives and other bioproducts from symbiotic bacteria. This study also implies the application of polychaetes for bioindicators of environmental quality, and potential use in aquaculture.

Virtual
Poster
A-1852

Assessing carrying capacity of dive sites at an offshore island, Ko Losin, in the Gulf of Thailand

Pengsakun, S., Yeemin, T., Sutthacheep, M., Suebpala, W., Jaiharn, S., Rongprakhon, S.
Ramkhamhaeng University, Department of Biology, Bangkok, Thailand

marine_ru[at]hotmail.com

Abstract

Coral reefs are the most diverse and complex marine ecosystems. Ecosystem services provided by coral reefs to human including provisioning, cultural, regulating, and supporting services. Coral reef-based tourism, particularly diving, contributes high economic values to local and regional communities. Diving industry has been growing remarkably and has had negative impacts on coral reef ecosystems. The carrying capacity concept has been widely applied as an important management tool in many reef sites worldwide, particularly in marine protected areas to mitigate anthropogenic impacts on coral reefs. Carrying capacity provides the maximum number of divers that a dive site can be tolerated without any degradation happened. This study assessed carrying capacity of dive sites at an offshore island, Ko Losin, Pattani Province, in the Western Gulf of Thailand covering Psychological Carrying Capacity (PsCC), Physical Carrying Capacity (PCC), Facility Carrying Capacity (FCC) and Ecological Carrying Capacity (ECC). The surveys were conducted at three dive sites around Ko Losin. According to our analysis, all dive sites were below the carrying capacity. If a proper management plan is implemented at Ko Losin, the carrying capacity of dive sites is up to about 30,000 divers per year. This study provides baseline information on carrying capacity of dive sites at an offshore island in the Western Gulf of Thailand which is beneficial for further coral reef conservation, tourism management and establishing marine protected areas.

12M - Do ocean literacy, governance, ecosystem services and blue economy have a key role for a successful marine conservation strategy and sustainable development?

Virtual
Poster
A-1825

Assessing the potential for coral reef recovery after coral bleaching events at important tourist sites in the Gulf of Thailand

Sutthacheep, M.[1], Yeemin, T.[1], Ruangthong, C.[2], Dampupha, P.[2], Pengsakun, S.[1], Klinthong, W.[1], Chamchoy, C.[1]
[1]Ramkhamhaeng University, Department of Biology, Bangkok, Thailand
[2]Chumphon Marine National Park Operation Center 1, Department of National Parks, Wildlife and Plant Conservation, Chumphon Province, Thailand

msutthacheep[at]yahoo.com

Abstract

Coral reefs worldwide have been affected by climate change, especially more frequent and severe coral bleaching events. The mass coral bleaching events in the Gulf of Thailand occurred in the years 1998 and 2010. The capacity of coral ecosystems to respond to coral bleaching impacts or resilience depends on the ability to maintain and regain ecological functions following the bleaching events. Therefore, resilience-based management of coral reefs focuses on the maintenance of ecological processes to maintain ecosystem function and interventions for enhancing the persistence of coral reefs in the face of bleaching events. Coral recruitment is an important factor influencing the natural recovery of degraded reefs from coral bleaching and associated human activities. This study aimed to quantitatively examine diversity and abundance of juvenile corals from important tourist sites in the Eastern and Western Gulf of Thailand. The ecological surveys were carried out at reef sites in Mu Ko Samet, Rayong Province, Mu Ko Chang, Trat Province, the Eastern Gulf of Thailand, Mu Ko Chumphon, Chumphon Province, and Mu Ko Ang Thong, Surat Thani Province, the Western Gulf of Thailand. The highest density of juvenile corals was observed at a hotspot tourist site in Mu Ko Samet while the lowest one was recorded at a reef site in Mu Ko Ang Thong. All reef sites in Mu Ko Ang Thong showed low densities of juvenile corals. High densities of juvenile corals were recorded at important dive sites, such as Ao Lungdum and Ao Kiu Na Nok in Mu Ko Samet, Hin Gurk Ma, Ko Bai Dang and Ko Yak Yai in Mu Ko Chang and Ko Ngam Yai in Mu Ko Chumphon. The dominant juvenile corals were *Pocillopora*, *Porites*, *Favites*, *Fungia*, and *Turbinaria*. The high sediment load is suggested as an important factor controlling juvenile coral density in the Gulf of Thailand. We highlight the importance of management interventions for reducing the negative impacts of tourism development in the Gulf of Thailand. This study also provides necessary information for coral reef management plans and coral restoration projects in the Gulf of Thailand.

Session 12N - Communities of Practice - Do Learning Networks lead to better local management?

Conceptualized by: **Jason Philibotte** [1], **Petra MacGowan** [2], **Dana Wusinich-Mendez** [1], **Michael Lameier**[3], **Jennifer Koss** [1]
[1] NOAA Coral Reef Conservation Program (Silver Spring, MD, USA)
[2] The Nature Conservancy (Arlington, VA, USA)
[3] NOAA National Marine Fisheries Service (Silver Spring, MD, USA)

Chaired by: **Sebastian Ferse** [1], **Annette Breckwoldt** [1]
[1] Leibniz Center for Tropical Marine Research (Bremen, Germany)

Oral
A-1727

The Diversity of the Indo-Pacific Network (DIPnet): Capacity-building for marine biodiversity science in the tropical Indo-Pacific

Crandall, E.[1], Gaither, M.[2], Liggins, L.[3], Bird, C.[4], Toonen, R.[5], Riginos, C.[6]
[1]Pennsylvania State University, Biology, University Park, United States
[2]University of Central Florida, Biology, Orlando, United States
[3]Massey University, Natural and Computational Sciences, Auckland, New Zealand
[4]Texas A&M University, Corpus Christi, Life Sciences, Corpus Christi, United States
[5]University of Hawai'i, Hawai'i Institute of Marine Biology, Kane'ohe, United States
[6]University of Queensland, Biological Sciences, St. Lucia, Australia

ecrandall[at]psu.edu

Abstract

The Indo-Pacific is the largest biogeographic region in the world and encompasses the greatest concentration of marine biodiversity. Numerous challenges, such as the sheer size of the region and a lack of communication and collaboration among researchers, have impeded the development of comprehensive interdisciplinary biodiversity research programs that consider the region as a whole. Moreover, marine biodiversity in the Indo-Pacific is understudied in large part because developing countries across this region have reduced scientific infrastructure relative to countries like the United States and Australia. Founded in 2012, the **Diversity of the Indo-Pacific Network (DIPnet; diversityindopacific.net) was created to advance biodiversity research at both the species and genetic levels** in the Indo-Pacific by promoting capacity development, collaboration and best practices for reporting both occurrence and genomic data & metadata. Since its inception, DIPnet has held trainings in biodiversity informatics in Indonesia, the Philippines, South Africa and Fiji, reaching over 150 students and researchers from these and other developing countries. We have aggregated >36,000 mtDNA sequences from >230 species and >1,500 sampling sites into a searchable database from over 70 members around the world. These data were instrumental in the creation of the Genomic Observatories MetaDatabase (GEOME; geome-db.org), which aims to provide open and collaborative access to genomic resources for while protecting the rights of nations under the Convention on Biological Diversity. Moving forward, DIPnet is striving to advance our understanding of marine biodiversity at the genetic and species levels through true collaboration with researchers in developing Indo-Pacific countries, to connect graduate students in the United States with management agencies in the Indo-Pacific, and to enhance local capacity for Indo-Pacific countries to monitor their own biodiversity.

Oral
A-1183

Scaling up capacity and collaboration via peer learning networks: lessons learned from the Women Leaders Forum in the Coral Triangle region.

Djohani, R.[1], Widodo, H.[2], Gallardo, L.[3]
[1]Coral Triangle Center, Executive Director, Denpasar, Indonesia
[2]Coral Triangle Center, Senior Program Manager, Den Pasar, Indonesia
[3]Coral Triangle Center, Regional Communications Coordinator, Den Pasar, Indonesia

rdjohani[at]coraltrianglecenter.org

Abstract

Peer learning networks are increasingly important for maximizing sharing and learning, create support, and promoting collaboration across a wider geographic area to achieving conservation objectives at meaningful scales. The multi-national "Coral Triangle Initiative on Coral Reefs, Fisheries and Food Security" (CTI-CFF) launched the Women Leaders Forum (WLF) In 2014 to strengthen the role of women leaders in protecting the coastal and marine ecosystems in the Coral Triangle. The region is an epi-center for marine biodiversity including Indonesia, Philippines, Malaysia, Timor Leste, Papua New Guinea and Solomon Islands.

A group of fifteen women leaders from the Coral Triangle countries formed the WLF to strengthen the role of women in coastal and marine resource management in the region. The WLF, Coral Triangle Center and US Department of Interior implemented training and learning activities at both national and regional levels funded by USAID-RDMA with CTI-CFF and NGO partners from 2014-2019 . These activities included twelve small grants programs at the field level across the six countries to advance and leverage effective protection of coral reefs, associated habitats and species in marine protected areas (MPAs).

WLF expanded its program with the development of an Inter-Generational Leadership Learning Program providing a knowledge sharing platform for senior marine conservation women leaders who served as mentors to a younger generation of early career women. They applied their new skills in small-scale Conservation Challenge field projects that included coral mining, turtle protection, waste management in MPAs, and community education in marine resource management.

A participatory leadership competency model was developed by women leaders and trainers to elevate and scale up the role of women in preserving the Coral Triangle. To date, the WLF network has expanded to more than 200 members with links to national and global women's networks. The WLF supported the development of a Gender Equality and Social Inclusion (GESI) policy for the Coral Triangle Initiative which was adopted by all six countries in 2021.

The lessons learned from the CTI-CFF Women Leaders Forum activities such as the small grant program, inter-generational learning and the participatory leadership competency model provides a useful case-study for other multi-national initiatives that wish to achieve broad-scale coral reef conservation and sustainable fisheries objectives.

Oral
A-1828

Minimizing the competency gap for effective coral reefs management: lessons learnt from the Sunda Banda Seascape

Widodo, H., Suardana, N., Kasman, K.
Coral Triangle Center, Denpasar, Indonesia

hwidodo[at]coraltrianglecenter.org

Abstract

Amid the optimistic target to achieve 32.5 million hectares of marine areas protected for coral reefs, fisheries, and food security in Indonesia by 2030, a rapidly increasing number of marine protected areas have been established. However big a gap in human resources aspects appears to limit the ability of coral reefs in Indonesia to be sustained. Of the 140 marine protected areas (MPAs) assessed, 80% of those are lacking in dedicated personnel that has sufficient competencies in coral reefs science and management. An early assessment suggested that at least 2,800 competent personnel are required for managing the MPAs assessed. Other identified major gaps include the availability of in-country coral reef capacity development infrastructure, the current competency level of provincial personnel, and accessible training for community stakeholders who live inside the MPA. To date, efforts to minimize the gaps include 1) identifying sets of core competencies for MPA personnel, 2) establishing national standards for professional working competencies related to MPAs, 3) sporadic training delivery, 4) a project-based accreditation and certification process for marine and fisheries officers at provincial and district level, 4) a training curriculum and module development focusing on practical and actionable behavior. By carefully recording coral reefs conditions at three key MPA sites in the Sunda Banda Seascape, interviewing those involved in the capacity development process, and observing their involvement in coral reef conservation and management, we learned that a) at the provincial level; personnel of the coral reef management unit show significant knowledge increase and actively engage in facilitating coral reef conservation, b) at the technical management unit level; accreditation and certification processes trigger confidence and actionable behavior, and c) coral reef healthy index observations over a five year period indicate the target area remains in good quality.

Session 13A - Open Session: Interventions and restoration

Conceptualized and chaired by: **Sebastian Ferse**[1], **Ronald Osinga**[2]
[1] Leibniz Center for Tropical Marine Research (Bremen, Germany)
[2] University of Wageningen (Wageningen, The Netherlands)

Oral
A-1412

Reef Song: an ecosystem-based approach to enhancing reef resilience and restoration

Brooker, R.[1, 2], Barneche, D.[1, 2], Gilmour, J.[1, 2], Parsons, M.[1, 2], Pygas, D.[1, 2], Thomas, L.[1, 2], Meekan, M.[1, 2]
[1]Australian Institute of Marine Science, Perth, Australia
[2]UWA Oceans Institute, Perth, Australia

rohan.m.brooker[at]gmail.com

Abstract

The world's coral reefs are exposed to increasingly frequent and severe disturbance, limiting their time and opportunity for recovery. There is a clear need to explore new ways of enhancing coral health and resilience, to amplify recovery potential where possible. Ecosystem-based methods that take advantage of natural patterns and processes may prove particularly valuable, reducing the inputs required to establish recovery and promote resilience.

Coral reefs support complex networks of species interactions, one of the most conspicuous being the multifaceted relationships that exist between corals and fishes. A growing body of evidence suggests these relationships and the presence of fishes on reefs could support coral health via several pathways. However, additional work is required to determine if and how these relationships can be harnessed to improve coral reef resilience and recovery.

The Reef Song project, part the Australian Coral Reef Resilience Initiative (ACRRI), aims to address this issue. In a multi-year approach, Reef Song brings together novel research from Australia's east and west coasts to identify (a) how fishes influence coral growth and resilience, (b) how we can support coral-associated fish communities to enhance the positive effects of their presence, and (c) how this knowledge can inform practical, scalable solutions to improve coral recovery and restoration efforts.

In this talk, I will outline the justification and goals of the Reef Song project, provide an overview of key experiments, present a summary of our findings from the first year of research, and discuss the next steps. Finally, I will discuss links between Reef Song and other restoration and adaptation initiatives underway in Australia and elsewhere.

Oral
A-1684

Assisted gene flow using cryopreserved sperm in critically endangered coral

Hagedorn, M.[1, 2], Page, C.[3], O'Neil, K.[4], **Flores, D.**[5, 6, 7], Tichy, L.[8], Conn, T.[9], Chamberland, V.[5, 10, 11], Lager, C.[1, 2], Zuchowicz, N.[1], Lohr, K.[12], Blackburn, H.[13], Vardi, T.[14], Moore, J.[15], Moore, T.[15], Baums, I.[9], Vermeij, M.[5], Marhaver, K.[5]
[1]Smithsonian Conservation Biology Institute, Front Royal, United States
[2]Hawaii Institute of Marine Biology, Kaneohe, United States
[3]Mote Marine Laboratory, Summerland Key, United States
[4]The Florida Aquarium, Apollo Beach, United States
[5]Caribbean Research and Management of Biodiversity (CARMABI) Foundation, Willemstad, Curaçao
[6]University of Texas at Austin, Austin, United States
[7]University of Bremen, Bremen, Germany
[8]Raboud University, Nijmegen, Netherlands
[9]The Pennsylvania State University, University Park, United States
[10]SECORE International, Hilliard, United States
[11]University of Amsterdam, Amsterdam, Netherlands
[12]University of Florida, Gainesville, United States
[13]US Department of Agriculture, Fort Collins, United States
[14]NOAA Fisheries, Silver Spring, United States
[15]National Oceanic and Atmospheric Administration, St. Petersburg, United States

daisyfloresm3[at]gmail.com

Abstract

Assisted gene flow (AGF) is a genetic intervention to increase plants' and animals' ability to adapt to climate change. As a form of assisted migration, AGF aims to facilitate the adaptation of plant and animal populations to environmental change by importing genetic material (individual organisms or their germplasm) from elsewhere in a species' biogeographical range. Preservation of genetic diversity is of fundamental concern to conservation biology, as genetic diversity allows populations to evolve in response to change and increases population fitness. Reef-building corals are prime candidates for AGF because they are sessile, have severely declined in abundance, especially in the Caribbean, and are threatened by climate change. However, conducting AGF by translocating reproductively-mature corals is impractical because it places stress on the animals and creates a vector for the movement of diseases and invasive species. AGF paired with cryopreservation could be a more favorable intervention because it enables the movement of alleles between genetically isolated populations in greater numbers without any additional stress on the adults. Here, we report the first successful demonstration of AGF using cryopreserved sperm in corals. Using the critically-endangered Elkhorn Coral *Acropora palmata*, we successfully fertilized eggs from the Southern Caribbean (Curacao) with frozen-thawed sperm from genetically-distinct populations in the Northern Caribbean (Florida and Puerto Rico). Across five egg donors, average fertilization success was 91 to 99% for CUR x CUR (fresh sperm) crosses, 37 to 82% for CUR x CUR (frozen sperm) crosses, 3 to 19% for CUR FL (frozen sperm) crosses and 0 to 24% for CUR x PR (frozen sperm) crosses. Furthermore, we confirmed trans-regional parentage in the Curacao-Florida offspring using 19,696 single nucleotide polymorphism markers. This is the first direct evidence for reproductive compatibility of *A. palmata* across a recognized barrier to gene flow. Six-month survival of AGF offspring was high (42%), and yielded the largest wildlife population created from cryopreserved material to date. By successfully breeding this critically-endangered marine species across its biogeographic range without moving adults, we show that AGF using cryopreserved sperm is a viable tool for maintaining population-level genetic diversity to facilitate coral recovery and bolster reef resilience to global climate change.

Oral
A-1628

Coral restoration as a strategy to improve ecosystem services: international guidelines and perspectives from UNEP and ICRI

Hein, M.[1], Vardi, T.[2], Shaver, E.[3], Pioch, S.[4], Boström-Einarsson, L.[5], Ahmed, M.[6], Grimsditch, G.[6], McLeod, I.[7], Staub, F.[8]
[1]MER Research and Consulting, Monaco, Monaco
[2]ECS for NOAA Fisheries, New York, United States
[3]The Nature Conservancy, Arlington, United States
[4]Université Paul Valérie, Montpellier, France
[5]Lancaster University, Lancaster, United Kingdom
[6]UNEP, Nairobi, Kenya
[7]James Cook University, TropWATER, Townsville, Australia
[8]International Coral Reef Initiative, London, United Kingdom

margaux.hein[at]my.jcu.edu.au

Abstract

In 2019, the United Nations Environment Assembly requested that the United Nations Environment Programme (UNEP) and the International Coral Reef Initiative (ICRI) define best practices for coral restoration. With the start of the UN Decade on Ecosystem Restoration (2012-2030), the development of appropriate guidelines was essential. Guidelines led by the UNEP were prepared by a team of 20 experts in coral reef management, science, and policy to catalogue the best-available knowledge in the field and provide realistic recommendations for the use of restoration as a reef management strategy. Another report, led by ICRI, analysed the funding landscape for coral reef restoration. Here, we provide a synthesis of these guidelines. Specifically, we present (1) a case for the value of coral reef restoration in the face of increasing frequency and intensity of disturbances associated with climate change, (2) a set of recommendations for improving the use of coral reef restoration as a reef management strategy, tailored to goals and current methods, (3) latest findings showcasing specific funding gaps and needs, as well as recommendations to increase and improve future commitments and investments for coral reef restoration. We argue that coral reef restoration should not be seen as a “silver bullet” to address ecological decline and should be applied appropriately, with due diligence, and in concert with other broad reef resilience management strategies. However, coral reef restoration can be a useful tool to support resilience, especially at local scales where coral recruitment is limited, and disturbances can be mitigated. While there is limited evidence of long-term, ecologically relevant success of coral reef restoration efforts, ongoing investments in research and development are necessary to improve the scale, and cost-efficiency of current methods.

Oral
A-1371

The effect of coral prophylactic treatments on the microbiomes of Orbicella faveolata and Acropora palmata

Klinges, J. G.[1], **Craig, Z.**[2], Clark, A.[1, 3], Villoch, M.[1], Manfroy, A.[2], Merck, D.[2], Muller, E.[4]
[1]Mote Marine Laboratory, Coral Health and Disease, Summerland Key, United States
[2]Mote Marine Laboratory, Coral Restoration, Summerland Key, United States
[3]The College of the Florida Keys, Stock Island, United States
[4]Mote Marine Laboratory, Coral Health and Disease, Sarasota, United States

zcraig[at]mote.org

Abstract

Though bacterial pathogens and parasites can compromise coral health, coral microbiome research increasingly suggests a beneficial role for bacterial species living in coral tissue and mucus. Recent studies suggest the application of targeted antibiotic treatments, while inhibiting the growth of harmful bacteria, can also impact coral health by causing reduced photosynthetic efficiency of the coral's algal symbiont, increased susceptibility to pathogenic infection and increased mortality from bleaching. Land-based coral nurseries use prophylactic treatments such as Lugol's solution and KoralMD™ dip to reduce infectious agents as part of restoration best practices. These solutions often halt tissue loss, but the short- or long-term effects of these treatments on the coral microbiome is unknown. We conducted a controlled tank experiment to assess the effects of these broad-spectrum treatments on coral growth rates and microbial communities. Sixty individuals from each of two genotypes of the coral species *Acropora palmata* and *Orbicella faveolata* were treated with either Lugol's solution or KoralMD™. Coral tissue, mucus, and skeleton were sampled pre-treatment, during treatment, and 1 and 2 months after treatment to assess microbiome shifts and recovery. The V4 region of the bacterial 16S rRNA gene was sequenced for each sample to examine shifts in both beneficial and pathogenic microbial taxa. The impact of the two treatments on coral growth was assessed using surface area measurements from both 3D and 2D imagery. We found that *A. palmata* treated with Lugol's solution had significantly reduced growth rates compared with untreated controls. Study of the effects of these widely-used interventions may have significant repercussions on management and propagation strategies for corals reared in land-based nurseries. Furthermore, our findings may indicate which treatment strategy is more successful at mitigating microbiome-related health issues without long-term harmful effects.

Oral
A-1239

Pruning of dead branches as a new restoration technique to improve the population viability of the Mediterranean gorgonian Eunicella singularis

Mas, G.[1, 2], Serrano, E.[2], Bolivar, M.[2], Ribes, M.[3], Coma, R.[2]
[1]BIOSFERA Associació d'Educació Ambiental, Research and Conservation, L'Hospitalet de Llobregat, Spain
[2]Spanish National Research Council (CEAB-CSIC), Blanes, Spain
[3]Spanish National Research Council (ICM-CSIC), Barcelona, Spain

eserrano[at]ceab.csic.es

Abstract

The gorgonian *Eunicella singularis* is an engineering species from the Mediterranean Sea, threatened by recurrent mass mortality episodes linked to sea warming. In late summer 2018, we observed that prolonged high-water temperature conditions caused a mass mortality event of gorgonian populations in the Natural Park of El Montgrí, les Illes Medes i el Baix Ter (North-western Mediterranean). After the mass mortality event, the mean percentage of dead gorgonian colonies was 27%, whereas healthy colonies (i.e., <5% in partial mortality, PM) represented the 25% of the 481 examined colonies. The live colonies that showed any dead branches (48%) exhibited a mean PM of 24% (n=279). Most of the PM was located on the apical part of the colony branches (87%). Since previous studies have documented that gorgonians with a high incidence of PM have higher mortality rates and lower fecundity than healthy gorgonians, we decided to evaluate the effectiveness of pruning of the dead branches on improving the demographic parameters of the affected population. To conduct the assessment, permanent plots were installed in 2019 and annually monitored for two years. The pruning technique was applied in 2019 on the gorgonians of half of the plots, while the other plots were used as controls. Pruning was applied only on live gorgonians showing PM on the apical parts of the colony. The pruned colonies reduced the mean PM by 78%, leading to a mean PM of 5%, but increased to 9% in 2020 and 16% in 2021, whereas mean PM in the control colonies increased from 14% in 2019 to 18% in 2021; with no significant differences between pruned and control colonies in 2021 (One way-ANOVA, $p > 0.05$). The fecundity of the species diminished with increasing PM, so healthy colonies showed at least 4-folds higher gonadal production than severely affected colonies (>66-99% PM) for both males (0.14 ± 0.01 *vs* 0.03 ± 0.02 mm^3 $polyp^{-1}$) and females (0.21 ± 0.02 *vs* 0.001 ± 0.001 mm^3 $polyp^{-1}$). In this framework, in 2021, the fecundity of pruned colonies that remained healthy over the 2-years period was similar to that of control colonies for both males (0.15 ± 0.04 *vs* 0.17 ± 0.3 mm^3 $polyp^{-1}$) and females (0.28 ± 0.03 *vs* 0.28 ± 0.05 mm^3 $polyp^{-1}$). Ongoing monitoring of the permanent plots would contribute to elucidate the long-term pros and cons of using the pruning technique, especially in terms of colony mortality, and its potential recommendation for the management and conservation of threatened gorgonian forests.

Oral
A-2114

Use of a Coral Restoration Database for Tracking Coral Nursery Propagation and Restoration

Moulding, A.[1], Ross, L.[2], Escovar-Fadul, X.[3], Shaver, E.[3], Kramer, P.[2], Viehman, S.[4]
[1]NOAA Fisheries, St Petersburg, United States
[2]Atlantic & Gulf Rapid Reef Assessment Program, Big Pine Key, United States
[3]The Nature Conservancy, Washington DC, United States
[4]NOAA, Beaufort, United States

alison.moulding[at]noaa.gov

Abstract

As coral propagation and restoration is becoming more common and widespread, there is a need to track efforts to gauge their distribution and cumulative impact on population status. Through the Coral Restoration Consortium (CRC), a database was developed to compile nursery, restoration, and monitoring information from nursery practitioners. Information in the database includes location, species, number and size class of colonies, and area of reef restored. Monitoring information follows the Universal Monitoring Metrics identified in the CRC Coral Reef Monitoring Guide and includes survival, size class distribution, and amount of live tissue. Nursery and restoration site location is spatially depicted in an online GIS map on the CRC website, and we are working with The Nature Conservancy through their REEFhabilitation project to develop an online portal for data entry and download and to better visualize information in the database. The database can be used for a number of purposes such as to inform best management practices, increase partner collaboration, identify priority areas or gaps, or help with scaling up of restoration. The online portal will allow for easy data entry and searchable content and will perform a number of back end calculations like abundance, density, and live coral cover estimate that would allow users to visualize and download data for their own studies and management purposes. We will present data, maps, and capabilities we have developed to date.

Oral
A-1653

ReCoral by Ørsted™ – winds of change for coral reef restoration

Roberts, H.[1], Andersen, B.[2], Maria Secco de Oliveira, F.[2], Schrameyer, V.[3]
[1]Ørsted, Environment & Consents, London, United Kingdom
[2]Ørsted, Copenhagen, Denmark
[3]DHI Group, Copenhagen, Denmark

hywro[at]orsted.com

Abstract

Coral reef ecosystems are at risk due to global change and anthropogenic impacts, loosing species diversity and coverage at an unprecedented rate. The realization of large-scale coral restoration methods are still in their infancy, but they are urgently needed if active restoration is to keep pace with the decline of healthy coral reefs that the world is currently experiencing. It is within this context that we've embarked on a new project, ReCoral by Ørsted™, together with collaborators from the Penghu Marine Biology Research Centre in Taiwan.

In the latest coral reef restoration guide released by the United Nations Environment Programme, coral seeding is considered as 'potentially one of the most scalable methods for coral reef restoration'. Can coral seeding be applied at offshore wind farms in tropical waters to provide a lifeline for naturally occurring reef systems?

In deeper offshore waters where wind turbines are typically located vertical water column mixing creates temperatures that are relatively stable, and which therefore present a favourable coral growth environment vs the shallower nearshore waters that are home to many naturally occurring reef systems (esp. under global change conditions).

In summer 2021, a pilot experiment was conducted, where spawn slick was collected and reared in-vitro to reach competent larvae cultures. Competent larvae were subjected to settlement assays, testing three surface materials (steel, concrete, crushed oyster shell).

For the planned seeding of coral larvae on the offshore windfarm foundations in summer 2022, 1m^2 experimental seeding areas on 4 foundations positioned 1m below lowest astronomical tide level have been prepared. These experimental seeding areas comprise two evenly sized types of surface material (concrete and steel). Competent larvae culture, with a final density of 0.1 larvae per ml, will be released into pre-installed enclosures and left to settle.

Optimal artificial growth material, as well as settlement success and metocean conditions will be presented based on the findings from both the quayside pilot and the offshore field trial. The findings will be critically analysed and discussed, and information will be shared regarding: the potential to upscale the ReCoral approach; modelled reef connectivity enhancement and resulting net-positive biodiversity impact; and opportunities for facilitating large-scale reef restoration.

Oral
A-1598

Effect of fireworm corallivory in the performace of Acropora cervicornis restored populations

Santiago, P., Velazquez, J., Sanchez, J., Nevarez, J., Fonseca, J., Suleiman, S., Mercado, A.
Sociedad Ambiente Marino, San Juan, Puerto Rico

paola.santiago26[at]upr.edu

Abstract

The fireworm *Hermodice carunculata* is a widespread polychaete found in tropical and temperate marine ecosystems. In the Caribbean, it can be an aggressive predator that feeds upon many benthic species, including acroporids, gorgonians, and hydrozoans. Indeed, *H. carunculata* can cause significant damage to acroporids populations, especially when there is a sudden increase in their abundance. For instance, an outbreak of *H. carunculata* caused the extirpation of *Acropora cervicornis* hurricane-generated fragments in Jamaica. However, very few studies have focused on understanding the population level effects of the fireworm corallivory activity during non-outbreak periods. In this study, we used population metric models to determine whether predation by fireworm had a significant effect on the population growth rate (lambda) of *Acropora cervicornis* outplantanted populations in Puerto Rico. Results indicate that there was not a significant difference between coral growth and fireworm predation. We found that coral growth differed only by two percent between predated (**λ** = 0.97) and non-predated (**λ** = 0.99) populations. Elasticity analysis indicated that the most important transition rate for population growth was the probability of large size colony survival while remaining in large size class. However, this transition proved of most importance in the predated colonies, where the transition accounted for 83% of lambda value, potentially contributing to most changes in **λ** when compared to only 61% in non-predated coral colonies. Such difference resulted in a population trajectory varying moderately between populations. These results indicate that predation by fireworm may not be as damaging on in-between periods of previously reported H. carunculate outbreaks.

Oral
A-1232

Novel infrastructure for coral gardening and its implementation in the world's largest reefscaping project, Shushah Island, Saudi Arabia

Schmidt-Roach, S., Klaus, R., Al-Suwailem, A. M., Prieto, A. R., Hauser, C. A. E., Duarte, C. M., Aranda, M.
King Abdullah University of Science and Technology, Thuwal, Saudi Arabia

sebastian.schmidtroach[at]kaust.edu.sa

Abstract

Since 1950 corals have declined globally by an estimated 50%, and further dramatic declines are predicted by the end of this century. Although a global reduction of carbon emission is vital to prevent further loss, coral reef restoration has become imperative to maintain the ecosystem services coral reefs provide to humans at local scales. Most coral restoration or gardening efforts are expensive due to methods being labor intensive. Here we present a suite of technologies that increase scalability, efficiency and effectiveness of coral reef restoration and rehabilitation efforts. Our technologies streamline workflows in *in-situ* and *ex-situ* nurseries to reduce husbandry efforts, resolve transport issues of crops to outplanting sites, and allow rapid outplanting on natural or artificial substrates. Our approach can be applied to coral restoration and underwater landscaping, complemented by unique environmentally friendly structures for habitat expansion. Our platform integrates novel monitoring approaches that allow adaptive management, the application of assisted evolution approaches, and long-term monitoring. We discuss the application of our technologies as a crucial part of the conceptualization and planning of the world's largest coral reefscape at Shushah Island in NEOM in the Northern Red Sea, which aims to create a new 100 ha coral garden supported by an industrial scale coral nursery to improve sustainability and act as a biobank to preserve Red Sea coral diversity long-term.

Oral
A-1111

Enchancing Capacity for Coral Restoration in Indonesia by Implementing Scientifically Based Standards and Protocols.

Welly, M.[1], Djohani, R.[2], Mansell, P.[3]
[1]Coral Triangle Center (CTC), Marine Conservation Advisor, Denpasar, Indonesia
[2]Coral Triangle Center (CTC), Executive Director, Denpasar, Indonesia
[3]Mars Sustainable Solution, Indonesia Representative, Denpasar, Indonesia

mwelly[at]coraltrianglecenter.org

Abstract

Coral reef ecosystems provide an annual economic benefit estimated at $USD1.6 billion towards Indonesians from fisheries, marine tourism and other ecosystem services. With 2.5 million hectares of coral reefs, representing 18% of global coral cover, the coral reefs are a key ecosystem for coastal communities of Indonesia. However, Indonesian coral reefs are threatened by anthropogenic factors such as destructive fishing, pollution, and climate change.

Responses to these threats have led to multiple coral restoration projects as an effort to rehabilitate damaged coral reef ecosystems. Unfortunately, very few coral restoration projects in Indonesia follow rigorous scientific protocols, emphasize long-term monitoring to record progress or sustained viability of restored coral reef ecosystems.

A desktop study was conducted by Coral Triangle Center (CTC) on nine project sites and additional joint field assessment on five project sites in Indonesia with Mars Sustainable Solution (MSS) and Nusa Dua Reef Foundation (NDRF) on restoration using the Mars Assisted Reef Restoration System (MARRS) method from June – December 2021, which is the Reef Star. The total area repopulated covered 31,466.4 m^2 with 52,444 reef star structures positioned in select areas. The results of the study show that 64% of the completed restoration projects have been initiated and continue sustained long-term monitoring activity. Ecological, economic and governmental key indicators are continuing to be monitored.

As part of achieving the enactment of scientific standards in coral restoration, CTC worked in collaboration with MSS to develop an Indonesian coral reef restoration task force. The task force was provided training and technical assistance based on agreed scientific standards for coral restoration in Indonesia. Lessons from the task force experiences in assisting the local community, NGOs, and dive operators with coral restoration techniques show project failures occur from choosing inappropriate locations and methods, and an inadequate monitoring protocol.

Based on the CTC study, coral reef restoration projects in Indonesia would benefit from implementing scientific based standards; strengthening of human resource capacity; ensuring long-term monitoring mechanisms; and choosing a sustainable financing model for long-term coral reef restoration.

Poster
A-1190

International partnership for the restoration of coral reefs in the Arrecife de Puerto Morelos National Park (APMNP), Mexico.

Garmendia, M.[1], Padilla, C.[2], Gilliam, D.[1]
[1]Nova Southeastern University, Florida, United States
[2]Instituto Nacional de Pesca, Puerto Morelos, Mexico

pg710[at]nova.edu

Abstract

The Mesoamerican Reef system (MAR) is the second largest coral reef track in the world spanning approximately 1000 km offshore Mexico, Belize, Guatemala, and Honduras. The Arrecife de Puerto Morelos National Park (APMNP) has been a MAR marine protected area since 1998 and includes over 20 km of coral reefs. The APMNP supports the local community by sustaining tourism as well as the fishing industry. Stony coral populations in this area have declined due to both local and global anthropogenic stressors including increase sea temperatures and disease events. The recent significant losses associated with the Stony Coral Tissue Loss Disease (SCTLD) outbreak, first reported in the APMNP in June 2018, highlighted the need to expand restoration activities in the region. A collaborative project has been established to implement coral restoration activities in the APMNP using stony coral microfragmentation techniques. Microfragmentation is the developing reef restoration practice of cutting whole coral colonies into < 5 cm fragments, which optimizes growth, increases genetic diversity, and facilitates reproduction. This project is a partnership with Coralisma, a non-profit organization dedicated to the restoration, preservation, and education of coral reefs in the Riviera Maya, Mexico, the Mexican National Fishing Institute (INAPESCA), the National Fishing Research Center in Puerto Morelos (CRIAP), and the Coral Reef Restoration and Monitoring Laboratory (CRRAM) at Nova Southeastern University. In addition to promoting regional restoration efforts, this international collaboration will support education and advances restoration science through the exchange of ideas and expertise.

Poster
A-1601

Can Coral Restoration Combat Coral Losses to Stony Coral Tissue Loss Disease in the Northern Region of Florida's Coral Reef?

Pantoni, G.[1], Shilling, E.[1], Bell, S.[1], Hunt, J.[2], Sharp, W.[2], Muller, E.[3], Voss, J.[1]
[1]Florida Atlantic University, Harbor Branch Oceanographic Institute, Fort Pierce, FL, United States
[2]Fish and Wildlife Research Institute, Florida Fish and Wildlife Conservation Commission, Marathon, FL, United States
[3]Coral Reef Restoration Program, Mote Marine Laboratory, Sarasota, FL, United States

gpantoni[at]fau.edu

Abstract

Florida's Coral Reef has been heavily impacted by an outbreak of stony coral tissue loss disease (SCTLD). SCTLD first emerged off the coast of Miami, FL in 2014, appearing as lesions on susceptible coral species that causes tissue to slough off and reveal the white skeleton underneath. SCTLD has since spread through the entirety of Florida's Coral Reef, and throughout the Caribbean, causing massive coral die-offs and subsequent losses of ecologically and economically important reef habitats. In some regions, up to 60% of live coral tissue has been lost to SCTLD. Much of Florida's Coral Reef now exists as endemic zones, where most highly susceptible species have died, and subsequently SCTLD prevalence is now relatively reduced. Some research and management efforts have focused on treating diseased colonies *in situ* with the goal of preventing further coral loss. To determine the feasibility of outplanting SCTLD-susceptible coral species in endemic zones, a statewide collaborative project comprising the largest experimental coral reef restoration effort in Florida to date was developed with several regional partners. In May 2021, project partners across the reef tract outplanted 24 arrays with 1,152 coral colonies from three SCTLD-susceptible species- *Montastraea cavernosa*, *Orbicella faveolata*, and *Pseudodiploria clivosa*. Our team outplanted 192 of these colonies across two sites (48 colonies each) at St. Lucie Reef and two sites off West Palm Beach, both within the northern extent of Florida's reef tract. Each of these "colonies" consist of clusters of 5 genetically identical fragments in a cement base, with the intent that over time they will fuse together and grow over the base. These colonies at each of the four sites have been and will continue to be monitored and photographed monthly through October 2022. The percent of coral tissue lost to disease, predation, and other factors, such as algal overgrowth, are recorded based on the photos taken of the outplanted colonies each month. Preliminary survivorship data has shown a greater loss of live coral tissue and greater frequency of SCTLD on the outplant colonies at the West Palm Beach sites than the St. Lucie Reef sites. Additionally, image analysis software (ImageJ) will be used to quantify this tissue loss or growth. Outcomes of this project will inform and guide future coral restoration efforts across SCTLD endemic zones.

Poster
A-2193

ReCoral by Ørsted™ – a novel perspective for coral reef restoration

Roberts, H.[1], Andersen, B.[2], **Schrameyer, V.**[3]
[1]Ørsted, Environment & Consents, London, United Kingdom
[2]Ørsted, Copenhagen, Denmark, [3]DHI Group, Copenhagen, Denmark

hywro[at]orsted.com

Abstract

The realization of industrial-scale coral reef restoration methods are still in their infancy, but they could facilitate the rejuvenation of degraded reef sites by enhancing geneflow, thereby enhancing connectivity between reef systems and ultimately enhancing the resilience of coral reefs. Such enhanced resilience is needed to 'gear up' corals gene pools in order to help coral withstand the effects of climate change.
ReCoral by Ørsted™, is an initiative developed in collaboration with the Penghu Marine Biology Research Centre in Taiwan that attempts to address these needs.
If corals can be grown on the foundations of offshore windfarms in tropical waters, can these foundations become stepping-stones that enhance the connectivity of existing reef systems and that ultimately support the resilience that coral reefs have to the effects of climate change?
The subsea foundations of offshore wind turbines present a new growth area for corals. Vertical mixing within the relatively deep water column may present a thermal refuge. Utilising offshore windfarms, or other marine infrastructure in tropical waters, as a habitat for coral could present a promising strategy for combatting the effects of climate change.
Modifications to offshore wind turbine foundations that introduce settlement substrate in order to enhance settlement success will be presented. Future perspectives for upscaling opportunities will also be introduced.
We invite for a constructive discussion on ReCoral by Ørsted™, as a tool for supporting sustainable development, creating net-positive biodiversity outcomes, and facilitating natural reef restoration.

Virtual Oral
A-2216

Examining trade-offs between coral growth and heat tolerance using 3D models

Ferrari Legorreta, R.[1], Humanes, A.[2], Figueira, W.[3], Fabricius, K.[1], Pygas, D.[3], Martinez, H.[2], Edwards, A.[2], Bythell, J.[2], Sommer, B.[3], Chen, C.[3], Gonzalez-Rivero, M.[1], Golbuu, Y.[4], Guest, J.[2]
[1]Australian Institute of Marine Sciences, Cape Cleveland, Australia
[2]Newcastle University, Newcastle, United Kingdom
[3]University of Sydney, Sydney, Australia
[4]Palau International Coral Reef Center, Koror, Palau

r.ferrarilegorreta[at]aims.gov.au

Abstract

Tropical coral reefs have suffered catastrophic levels of mortality due to manmade global climate change. Although corals have the capacity to adapt to increasing temperatures, it is unclear whether rates of adaptation are sufficient to cope with
the current rate of change. Increased heat stress tolerance may come with potential risks to recipient population fitness due to resource trade-offs between traits, such as growth and fecundity. If there is a trade-off between heat tolerance and growth, selection for heat tolerant corals (artificial or natural) may mean reduced fitness during periods without heat stress; on the other hand, if no trade-off exists selection during heat stress may lead to more rapid adaptation than previously thought. Until recently, an important limitation in understanding such trade-offs has been the lack of precise and not invasive methods to measure coral
growth in situ. High-resolution 3D models can be used effectively to measure coral growth over time with millimetre precision and can robustly capture external structural change across complex morphologies. For instance, 3D models allow the measurement of surface area and volume, and potentially a number of other metrics of growth and morphology, such as space amongst branches.
This work will show case how 3D models can be used in situ to investigate the trade-off between heat tolerance and coral growth over time. We followed tagged colonies of corymbose corals (Acropora digitifera) over a year in the field and used 3D models to measure their growth. We then estimated heat tolerance of each colony by removing replicate nubbins and exposing them to heat
stress typical of a natural bleaching event under laboratory-controlled conditions. Preliminary results show no evidence of a trade-off between heat tolerance and growth of A. digitifera, however, more work is required to understand if trade-offs exist with other fitness traits (e.g. fecundity), during different life history stages or in other coral species. These results improve our capacity to measure the drivers underpinning ecosystem biodiversity, status and trajectory, thus informing potential management interventions such as coral restoration.

Virtual
Oral
A-1216

Using CoralPatchSim to Guide Coral Planting Decisions

McManus, J.[1], McManus, L.[2]
[1]University of Miami, Marine Biology and Ecology, Pembroke Pines, United States
[2]University of Hawai'i at Manoa, Hawai‘i Institute of Marine Biology, Honolulu, Hawai'i, United States

mcmanus.john[at]gmail.com

Abstract

CoralPatchSim is a user-friendly software tool to facilitate studies of resilience in coral communities. In most cases, the only required field work involves obtaining the horizontal diameters of corals and other benthos within quadrats, along with descriptions of species and growth forms. A simple log regression procedure is used to estimate rates of mortality and recruitment. Other inputs can be found in the literature and online databases such as the Coral Trait Database and that of the ReefBudget website. Simulations begin from a cleared portion of a coral community, generating projected profiles over time of bottom cover, living surface area, colony volumes, CaCO3 production, refuge volumes for fish of multiple size ranges, and other emergent properties. Disturbances such as coral bleaching and wave damage can be triggered during the simulations. A recent feature is the capacity to simulate the effects of adding planted corals of multiple species and sizes on resilience profiles. This provides users with a basis for determining if planting a given set of coral species in various abundances is likely to have a significant impact, and for selecting species to enhance community resilience. Coral parameters can be varied for scenario-testing in support of assisted evolution programs. This makes the tool useful for a variety of enhanced resilience purposes.

13A - Open Session: Interventions and restoration: Virtual Oral
A-2221

Restoring Herbivory Through a Multi-Pronged Approach in the Mesoamerican Reef

Soto, M.[1], McField, M.[2], Kramer, P.[3], Craig, N.[4], Drysdale, I.[5], Padilla, C.[6], Gutierrez, S.[6], Spadaro, J.[7], Carne, L.[8]
[1]Healthy Reefs for Healthy People Initiative, Puerto Morelos, Mexico
[2]Healthy Reefs for Healthy People Initiative, Fort Lauderdale, United States
[3]Atlantic Gulf Rapid Reef Assessment, Fort Lauderdale, United States
[4]Healthy Reefs for Healthy People Initiative, Belize City, Belize
[5]Healthy Reefs for Healthy People Initiative, Roatan, Honduras
[6]Mexican National Fisheries Institute, Puerto Morelos, Mexico
[7]Mote Marine Laboratory, Sarasota, United States
[8]Fragments of Hope, Placencia, Belize

soto[at]healthyreefs.org

Abstract
The largest change in coral reef health in the Mesoamerican Reef over the past 12 years has been the more than doubling of fleshy macroalgal cover across the entire region. Over-abundance of macroalgae is one of the main threats to corals, coral recruits, as well as coral fragments used in restoration programs. In order to address this issue, the Healthy Reefs Initiative (HRI) and key partners began with a focus on protection of herbivorous fish, which was successfully implemented through policy tools in Belize (2009), Bay Islands of Honduras (2010), Guatemala (2015) and Quintana Roo, Mexico (2019). But, while parrotfish and surgeonfish are key reef herbivores, their grazing may not be sufficient enough to counter the overwhelming increases in macroalgae experienced on many reefs. Therefore, HRI conducted pilot projects to elevate herbivory on local reefs by increasing the density of large herbivorous crabs (*Maguimithrax spinosissimus*) in Mexico and Belize. Adult crabs were translocated onto two protected reefs in late 2018, in order to test their potential to reduce harmful algae. Mexico had a stronger reduction in turf algae, while Belize had a decrease in both turf and fleshy macroalgae. In both sites, a significant increase in crustose coralline algae was observed, all changes that are considered beneficial for reef health. In 2019, based on these positive results, new projects were designed to rear crab juveniles for placement onto protected reefs undergoing active restoration. Mariculture and aquaculture methods from other regions of the Caribbean are being adapted in Mexico and Belize with promising preliminary results. Late 2021, a cohort of young crabs were introduced in coral restoration reef patches and the associated benthic composition is monitored to determine optimum density and crab sizes to obtain best restoration impacts. Once these techniques are established, HRI will helps transfer this knowledge to local communities to rear crabs for harvest in their fishing areas and support coral restoration programs, working as a “seed bank”. The end goal of these projects is to improve reef health by increasing herbivory, while also involving local communities with these innovative restoration initiatives.

Virtual
Poster
A-1175

Establishing baselines for coral reef communities prior to large-scale island restoration efforts

Wright, R.[1], Benkwitt, C.[2], Williams, G.[3], Ford, H.[3], Wedding, L.[1]
[1]University of Oxford, School of Geography and the Environment, Oxford, United Kingdom
[2]Lancaster University, Lancaster Environment Centre, Lancaster, United Kingdom
[3]Bangor University, School of Ocean Sciences, Bangor, United Kingdom

rosalie.wright[at]ouce.ox.ac.uk

Abstract

Multiple interacting stressors affect ecological patterns and processes on reef ecosystems world-wide. It is therefore important to document the composition and spatial distributions of coral reef communities to provide benchmarks for continued monitoring. Such baseline data can present valuable information with which to assess the long-term impacts of ecological restoration efforts and resource management interventions. This study focuses on the remote atoll of Tetiaroa, French Polynesia, where a large-scale island restoration program has recently been established. We collected baseline data on benthic reef habitats inside the lagoon to understand the impacts of a management intervention on reef communities. The intervention involves the removal of invasive rats from each of Tetiaroa's *motus* (islets) with the intention of supporting recovery of cross-ecosystem nutrient subsidies, vectored by seabirds. The ecological baselines reported here will be used to monitor impacts of restored land-sea nutrient cycles on coral reef community composition and spatial distributions of benthic reef organisms.

We conducted diver-operated digital imaging surveys of hard-bottom reef habitat at lagoonal sites adjacent to the *motus*. With the imagery data obtained from these georeferenced video-transects, we examined relative coral abundance and benthic community composition. This data enabled us to produce an ecological baseline of benthic communities at fine (m) spatial scales, prior to the atoll-wide eradication program. Results also reveal the spatial patterns of dominant benthic organisms and identify relationships with structural rugosity and environmental conditions, such as site exposure and adjacent island seabird population density. This information provides critical insight into the spatial structure and distribution of Tetiaroa's benthic reef communities; an important dataset against which future change can be detected. This will address knowledge gaps in our understanding of cross-ecosystem dynamics and land-sea management interventions.

Session 13B - Can Coral Reef Restoration Increase Coastal Protection?

Conceptualized by: **Curt Storlazzi**[1], **Shay Viehman**[2], **Mike Beck**[3]
[1] U.S. Geological Survey (Santa Cruz, CA, USA)
[2] NOAA (Beaufort, NC, USA)
[3] University of California, Santa Cruz (Santa Cruz, CA, USA)

Chaired by: **Curt Storlazzi**[1], **Shay Viehman**[2]

Oral
A-1337

Rigorously Valuing the Coastal Hazard Risk Reduction Provided by Coral Reef Restoration in Florida and Puerto Rico

Storlazzi, C.[1], Reguero, B.[2], Cumming, K.[1], Cole, A.[2], Shope, J.[3], Viehman, S.[4], Gaido, C.[2], Beck, M.[2]
[1]U.S. Geological Survey, Pacific Coastal and Marine Science Center, Santa Cruz, United States
[2]University of California at Santa Cruz, Santa Cruz, United States
[3]Rutgers University, Department of Environmental Sciences, New Brunswick, United States
[4]National Oceanic and Atmospheric Administration, National Center for Coastal and Ocean Science, Beaufort, United States

cstorlazzi[at]usgs.gov

Abstract

The restoration of coastal habitats, particularly coral reefs, decreases the exposure of coastal communities to flooding hazards. Hurricanes Irma and Maria in 2017 caused widespread damage to the State of Florida and the Territory of Puerto Rico's coral reefs. Here we combine engineering, ecologic, geospatial, social, and economic tools to provide a rigorous valuation of where coral reef restoration could decrease the hazard faced by Florida and Puerto Rico's reef-fronted coastal communities. We follow risk-based valuation approaches to map flood zones at 10-m^2 resolution along all 980 km of Florida and Puerto Rico's reef-lined shorelines for three potential coral reef restoration scenarios and compare them to the flood zones without coral reef restoration. We quantify the coastal flood risk reduction provided by coral reef restoration using the latest information from the U.S. Census Bureau, U.S. Federal Emergency Management Agency, and U.S. Bureau of Economic Analysis for return-interval storm events and in terms of their 'Annual Expected Benefits', a measure of the annual protection provided by coral reef restoration. These data provide stakeholders and decision-makers with spatially-explicit, rigorous valuation of how, where, and when coral reef restoration in Florida and Puerto Rico will increase critical coastal storm flood reduction benefits. The overall goal is to ultimately reduce the risk to, and increase the resiliency of, Florida and Puerto Rico's coastal communities.

Oral
A-2173

Coral restoration design to reduce wave-driven flooding of tropical coastlines

Viehman, S.[1], Storlazzi, C.[2], Familkhalili, R.[3], Cheriton, O.[2], Nemeth, M.[4], Cumming, K.[2]
[1]NOAA, National Centers for Coastal Ocean Science, Beaufort, United States
[2]US Geological Survey, Pacific Coastal and Marine Science Center, Santa Cruz, United States
[3]CSS, Inc., Fairfax, United States
[4]NOAA, Restoration Center, Aguadilla, United States

shay.viehman[at]noaa.gov

Abstract

The continued degradation of coral reefs coupled with the effects of climate change increase the vulnerability of coastal infrastructure to storm wave-driven flooding. Coral restoration is an increasingly promoted strategy to mitigate flooding and protect coastal property. Although coral restoration can address numerous goals from ecological to socioeconomic, few applications yet exist at the large-scale (kms) needed for coastal risk reduction, and many questions about optimal design remain. We first examine characteristics of a degraded coral reef in Puerto Rico offshore of high-value coastal infrastructure. We then simulate coral restoration design scenarios through numerical modeling to determine how these different scenarios lead to changes in reef characteristics that reduce wave breaking and coastal inundation. We use the XBeach numerical model calibrated and validated on field data collected on Isla Verde reef, Puerto Rico, USA. Results presented here show how changes in coral restoration design, such as change in reef friction and depth at various locations across the reef profile, could reduce risk for coastal flooding. These results can inform designs and implementation of large-scale coral restoration done to reduce coastal hazards and protect coastal infrastructure.

Virtual Oral
A-1571

Quantifying the Effectiveness of a Coral Reef Restoration Approach for Wave Attenuation

Geldard, J.[1], Lowe, R.[1], Draper, S.[1], Ghisalberti, M.[1], Westera, S.[1], Ellwood, G.[1], Cuttler, M.[1], Smith, D.[2], McArdle, A.[3]
[1]The University of Western Australia, Oceans Graduate School, Crawley, Australia
[2]MARS inc., London, United Kingdom
[3]MARS inc., Cairns, Australia

justin.geldard[at]research.uwa.edu.au

Abstract

Extreme surface waves associated with storm systems generate coastal flooding and erosion that can impact coastal populations and infrastructure. The large roughness of healthy coral reefs has the potential to significantly attenuate this wave energy prior to reaching the shoreline through the drag forces coral roughness exerts on the water column. The magnitude of the forces experienced by corals is dependent on the complex geometries of the colonies that interact with the wave-driven oscillatory flow. A detailed physical modelling study was conducted to investigate wave attenuation over an 8 m long reef of 1:3 scaled MARS inc. reef stars within a 54 m long and 1.5 m wide wave flume at the University of Western Australia Coastal and Offshore Engineering Laboratory. Wave heights were measured along the reef to quantify rates of wave dissipation by the coral canopy for a range of incident wave conditions, offshore water levels and three different coral covers (representing temporal changes in coral reef development). In addition, horizontal and vertical force time series were obtained for each coral cover on a representative reef star in isolation, as well as within the full reef, using a 3-axis load cell. Using these results we parameterise the drag forces due to complex coral canopies in oscillatory flow and develop and validate a model to predict wave attenuation over arrays of MARS inc. reef stars. The model can be used to improve reef restoration and conservation by assessing the effectiveness of complex coral reef structures in providing coastal protection at different site locations (wave conditions and reef depths), as well as over varying time scales of restoration and coral growth.

Session 13C - Creating coral reefs waiting: Can we harness heterogeneity in phenotypic-stress response to optimize coral reef restoration?/ How can we leverage advances in evolutionary ecology to maximize adaptive potential of restored coral populations?

Conceptualized by: **Ilsa B. Kuffner**[1], **Joanie A. Kleypas**[2], **Les Kaufman**[3], **Lisa J. Rodrigues**[4], **Iliana Baums**[5], **John Parkinson**[6], **Sarah Davies**[3], **Sheila Kitchen** [5], **Margaret Miller**[7]

[1] U.S. Geological Survey (St. Petersburg, FL, USA)

[2] National Center for Atmospheric Research (Boulder, CO, USA)

[3] Boston University (Boston, MA, USA)

[4] Villanova University (Villanova, PA, USA)

[5] Pennsylvania State University (State College, PA, USA)

[6] University of South Florida (Tampa, FL, USA)

[7] SECORE International (Hillard, OH, USA)

Chaired by: **Ilsa B. Kuffner**[1], **Joanie A. Kleypas**[2], **Lisa J. Rodrigues**[4], **Iliana Baums**[5], **John Parkinson**[6], **Sarah Davies**[3], **Margaret Miller**[7]

13C - Creating coral reefs waiting: Can we harness heterogeneity in phenotypic-stress response to optimize coral reef restoration?/ How can we leverage advances in evolutionary ecology to maximize adaptive potential of restored coral populations?

13C - Creating coral reefs waiting: Can we harness heterogeneity in phenotypic-stress response to optimize coral reef restoration?/ How can we leverage advances in evolutionary ecology to maximize adaptive potential of restored coral populations?

Oral
A-2230

Biological processes impacting the persistence of the threatened Acropora palmata coral in Dry Tortugas National Park

Chapron, L.[1], Kuffner, I.[2], Stathakopoulos, A.[2], Bartlett, L.[2], Lyons, E.[2], Grottoli, A. G.[1]
[1]Ohio State University, Columbus, United States
[2]St. Petersburg Coastal and Marine Science Center, St. Petersburg, United States

chapron.3[at]osu.edu

Abstract

Coral reefs have declined globally over the past half century due to anthropogenic
activities. Of particular concern in the western Atlantic is the precipitous loss of the reef building coral Acropora palmata. Once a dominant reef framework building coral throughout the Caribbean, this coral is now listed as threatened. However, ongoing research shows that A. palmata has higher survivorship and calcifies faster in the Dry Tortugas National Park compared to their clones at other sites in the Florida Keys. We hypothesize that greater incorporation of heterotrophically derived carbon (i.e., zooplankton) and/or more favorable oceanographic conditions in the Dry Tortugas facilitate the faster growth and higher survival rates of A. palmata. To test this hypothesis, 50 colonies of five nursery-raised genets of A. palmata (two ramets from each per site) were transplanted to five sites along the Florida Keys reef tract, including two sites in the Dry Tortugas. Total lipids, cholesterol (which is derived heterotrophically), chlorophyll (a proxy for photosynthetic health), and isotopic composition (which can reveal the proportionate contribution of photoautotropically and heterotrophically derived carbon to coral tissues) of the A. palmata ramets can will be used to determine the proportionate contribution of heterotrophic and autotrophically derived carbon to coral tissues. Preliminary lipid, chlorophyll, calcification and survivorship data will be presented along with assessments of the zooplankton abundance, temperature, and flow regimes at each of the sites. These findings will enable us to better identify the environmental conditions or biological traits that enhance A. palmata fitness, and which genetic strains of A. palmata are best suited to each site in the Florida Keys. These results will provide valuable information for effectively restoring A. palmata on a regional scale and enhancing the ecosystem function and services this species provides by protecting coastal communities and delivering economic stability through reef fisheries and tourism.

Oral
A-1787

Exposing Orbicella faveolata to projected ocean conditions and disease suggests genetic diversity is critical for resilient-reef restoration

Eaton, K.[1, 2, 3], Banister, R.[4], Klepac, C.[5], Petrik, C.[5], Hall, E.[3], Muller, E.[3]
[1]Cooperative Institute for Marine and Atmospheric Studies, University of Miami, Miami, United States
[2]National Oceanographic and Atmospheric Administration (NOAA) Atlantic Oceanographic and Meteorological Laboratory, Ocean Chemistry and Ecosystems Division, Miami, United States
[3]Mote Marine Laboratory, Sarasota, United States
[4]Florida Institute of Technology, Melbourne, United States
[5]Mote Marine Laboratory, Summerland Key, United States

kre31[at]miami.edu

Abstract

Florida's Coral Reef (FCR) has experienced a substantial decline in live coral cover over the last several decades with no signs of natural recovery. Three stressors that have primarily contributed to this decline are ocean warming, ocean acidification, and infectious disease outbreaks. Because these threats are likely to continue unabated, preferentially selecting and outplanting corals that are resilient to these stressors is critical for the restoration of FCR. Here, we exposed different genotypes of the Caribbean coral *Orbicella faveolata* to increased temperature (31.5˚℃), reduced pH (7.7), and disease through a series of wetlab experiments. First, we exposed six replicates of twelve genotypes to increased temperature and reduced pH for two months within Mote Marine Laboratory's Climate and Acidification Ocean Simulator (CAOS) using a fully-factorial design. The physiological response of each coral was assessed by quantifying the photochemical parameters using PAM fluorometry, change in buoyant weight, net photosynthesis and respiration via oxygen evolution methods, and instant calcification via the alkalinity anomaly technique. After the two month exposure to increased temperature and reduced pH, three replicates of each genotype from each treatment were then exposed to wild corals showing signs consistent with stony coral tissue loss disease (SCTLD) under similar environmental treatment conditions. Disease incidence rates of each fragment were recorded for four weeks post exposure. Additionally, we characterized the bacterial community and Symbiodiniaceae for each genotype used in this study. Although there were two *O. faveolata* genotypes resistant to all three stressors, most genets showed stress-specific resistance. Additionally, previous exposure to increased temperature and reduced pH did not influence the relative risk of disease. Coral genotypes that were the most disease susceptible had less of the algal symbiont, *Durusdinium*, compared with more disease resistant genotypes. The results of this study emphasize the need for genetic diversity within restored populations.

13C - Creating coral reefs waiting: Can we harness heterogeneity in phenotypic-stress response to optimize coral reef restoration?/ How can we leverage advances in evolutionary ecology to maximize adaptive potential of restored coral populations?

Oral
A-1786

Exploiting Local Variation in Thermal Tolerance to Trial Managed Relocation of Corals and Build Climate Resilience in SE Florida

Johnson-Sapp, K.[1], Wen, A. D. E.[1], Yeager, E.[1], Karp, R. F.[1], Bremer, R.[1], O'Banion, J.[1], Mendoza-Routt, B.[1], D'Alessandro, M.[1], Bartels, E.[2], Hanson, G.[3], Moura, A.[4], Reckenbeil, B.[5], Lirman, D.[1], Muller, E.[2], Gilliam, D.[3], Levy, J.[4], Maxwell, K.[5], Moulding, A.[6], Cunning, R.[7], Baker, A. C.[1]
[1]University of Miami, Miami, United States
[2]Mote Marine Laboratory, Sarasota, United States
[3]Nova Southeastern University, Fort Lauderdale, United States
[4]Coral Restoration Foundation, Key Largo, United States
[5]Florida Fish and Wildlife Conservation Commission, Marathon, United States
[6]National Oceanic and Atmospheric Administration, St. Petersburg, United States
[7]Shedd Aquarium, Chicago, United States

kej31[at]miami.edu

Abstract

Local thermal heterogeneity in reef environments presents an opportunity to test the intervention strategy of using corals from warmer habitats to build the thermal tolerance of populations at cooler restoration sites. This approach, referred to as Local Managed Relocation (LMR), is best suited to areas where strong temperature gradients occur over relatively small geographic scales, but assumes that corals retain at least some of their thermal tolerance if moved to another location. We tested this assumption by measuring changes in thermal tolerance in ~80 genets of the threatened Caribbean staghorn coral Acropora cervicornis that were reciprocally exchanged among five Florida nurseries and propagated alongside native nursery stocks for 12 months. Using a Coral Bleaching Automated Stress System (CBASS), we rapidly quantified differences in the thermal tolerance to assess the relative contribution of fixed effects (e.g., coral genet) vs. acclimatization effects (e.g., nursery environment) in determining thermal tolerance. We quantified the thermal tolerance of each unique nursery-by-genotype combination (n=268) and found that, independent of coral genet, nursery had a strong effect on thermal tolerance, with translocated genotypes in more northern (Miami-Dade and Broward Counties) nurseries exhibiting higher thermal tolerance compared to the same genotypes from southern nurseries (Monroe County). Moreover, changes in thermotolerance depended heavily on the origin/destination combination of translocated colonies, with corals from southern nurseries gaining thermotolerance when moved to more northern ones, and vice versa. Overall thermal performance was not explained by warmer nursery environments, but instead correlated with decreases in symbiont to host (S/H) cell ratios. These results align with previous work demonstrating that lower S/H ratios can increase thermal tolerance, and we hypothesize the decrease in S/H ratios is driven by an increase in host cells reflecting greater metabolic reserves and a higher capacity to deal with oxidative stress. Although there are likely additional genetic mechanisms at work, we conclude that the thermotolerance of A. cervicornis in Florida can be strongly modulated by nursery environment and that the extent to which the outplant environment resembles that of the nursery may further influence the eventual thermotolerance of restored populations.

Oral
A-1315

Acropora cervicornis Data Coordination Hub, an open-access tool for aligning datasets and evaluating genotype-specific performance

Kiel, P.[1, 2, 3], Formel, N.[2, 3], Jankulak, M.[2, 3], Baker, A.[1], Cunning, R.[4], Gilliam, D.[5], Kenkel, C.[6], Langdon, C.[1], Lirman, D.[1], Lustic, C.[7], Maxwell, K.[8], Moulding, A.[9], Moura, A.[10], Muller, E.[11], Schopmeyer, S.[12], Winters, S.[10], Enochs, I.[3]
[1]University of Miami, Marine Biology and Ecology, Miami, United States
[2]Cooperative Institute for Marine and Atmospheric Science, Miami, United States
[3]NOAA Atlantic Oceanographic and Meteorological Laboratory, Ocean Chemistry and Ecosystems Division, Miami, United States
[4]John G. Shedd Aquarium, Daniel P. Haerther Center for Conservation and Research, Chicago, United States
[5]Nova Southeastern University, Halmos College of Arts and Sciences, Dania Beach, United States
[6]University of Southern California, Department of Biological Sciences, Los Angeles, United States
[7]The Nature Conservancy, Florida Keys Office, Big Pine Key, United States
[8]Florida Fish and Wildlife Conservation Commission, Florida Fish and Wildlife Research Institute, Marathon, United States
[9]NOAA National Marine Fisheries Service, Southeast Regional Office, Protected Resources Division, St. Petersburg, United States
[10]Coral Restoration Foundation, Tavernier, United States
[11]Mote Marine Laboratory, Sarasota, United States
[12]Florida Fish and Wildlife Conservation Commission, Florida Fish and Wildlife Research Institute, St. Petersburg, United States

patrick.kiel[at]noaa.gov

Abstract

Chronic declines in coral cover across the Florida Reef Tract and the Caribbean have prompted propagation of the threatened coral, *Acropora cervicornis*. Numerous studies have found significant differences in stress responses between genotypes, representing a potential means of tailoring restoration towards particular stressors. Most of these studies, however, have been conducted at limited spatial and temporal scales, precluding comprehensive comparisons of genet performance. To this end, we created the *Acropora cervicornis* Data Coordination (AcDC) Hub, a web-accessible relational database that uses an open-source implementation of MySQL combined with a user-friendly interface developed in R. AcDC facilitates the comparison of genotypes by assessing the full range of biological variability and compiles genotype-specific reports to quickly ascertain where a given genotype stands relative to the entire population. Transparent data standardization techniques and the inclusion of all metadata ensure consistency and accountability. To date, 212 genotypes and 26 metrics are included from 28 collaborators. Of these, 89 (42%) genotypes are shared in more than one study, and 25 (12%) are shared in four or more studies. The standardized data has identified genets with consistently heightened growth rates and bleaching resistance. As propagation and outplanting operations continue to scale up, so too must we scale the coordination and assessment of stock performance. AcDC serves the restoration community by aligning disparate datasets and guiding practitioners towards making better-informed restoration decisions.

13C - Creating coral reefs waiting: Can we harness heterogeneity in phenotypic-stress response to optimize coral reef restoration?/ How can we leverage advances in evolutionary ecology to maximize adaptive potential of restored coral populations?

Oral
A-1677

Coral-reef restoration and Kintsugi, the art of repairing cracked pottery

Kuffner, I.[1], Kaufman, L.[2], Baums, I.[3], Grottoli, A.[4], Kleypas, J.[5], Banaszak, A.[6]
[1]U.S. Geological Survey, Saint Petersburg, Florida, United States
[2]Boston University, Boston, Massachusetts, United States
[3]Pennsylvania State University, University Park, Pennsylvania, United States
[4]Ohio State University, Columbus, Ohio, United States
[5]National Center for Atmospheric Research, Boulder, CO, United States
[6]National Autonomous University of Mexico, Puerto Morelos, Mexico

ikuffner[at]usgs.gov

Abstract

Kintsugi is the Japanese art of repairing cracked pottery, wherein the cracks between the broken pieces are filled with gold or other precious metals, arriving at a work of art that is regarded in higher value than the original, unbroken vessel. Coral-reef restoration cannot return reefs to a pre-anthropogenic state. Yet, as the scientific community considers the challenging future of coral reefs, we must ponder what level of resources is reasonable to invest in restoring reefs, where to focus our efforts, and to what end. Natural selection is occurring constantly as environmental changes unfold, but can humans play a deliberate role in speeding up or guiding this natural process? The amount of heterogeneity in response to environmental stress that is apparent in many observational and experimental studies to date offers hope that we can do so. Here we present evidence to support the idea of creating through restoration “seedbank” reefs in strategic locations to increase local genetic diversity and success of sexual reproduction, and “stepping-stone” reefs to increase connectivity among extant, vestigial populations of corals threatened by heat stress, disease, and other pressures. We propose that gradients (both natural and man-made) in temperature regime, exposure to diseases, water quality, access to heterotrophy, etc., can be exploited to create a network of restored reefs with the explicit goal of increasing the probability of natural-reef reassembly on a regional scale; thus, taking a *Kintsugi*-like approach by connecting the remaining fragments of functioning reef assemblages with the “gold” of knowledge and successes gained through science and focused, deliberate restoration efforts.

Oral
A-1889

Symbiotic flexibility in early life stages of corals could allow rapid adaptation to a warming climate: a promising tool for reef restoration

Nietzer, S.[1], Moeller, M.[1], Hume, B.[2], Voolstra, C.[2], Schupp, P.[1]
[1]University of Oldenburg, ICBM, Environmental Biochemistry, Wilhelmshaven, Germany
[2]University of Konstanz, Department of Biology, Konstanz, Germany

samuel.nietzer[at]uni-oldenburg.de

Abstract

Our rapidly changing environment requires coral reef ecosystems to rapidly adapt in order to sustain their existence. In addition to protecting existing reef ecosystems, active restoration measures are an important tool to strengthen coral communities. Non-genetic adaptive mechanisms such as symbiotic and developmental plasticity, which are most pronounced in the early life stages, are likely to play an important role for the survival of scleractinian communities. Both symbiotic and developmental plasticity are believed to correlate with environmental conditions, hence enabling the developing holobiont to adjust to prevailing environments. Species acquiring their symbionts via horizontal transfer are assumed to be more flexible in their associations.
Here, we tested this presumption in long-term exposure experiments, which revealed that recruits of the spawning corals *Acropora digitifera* and *A. hyacinthus* engaged in symbioses with different Symbiodiniaceae than their parents when reared under elevated temperatures (ambient, + 1 °C, + 2 °C). After one year, corals reared at 31 °C exclusively hosted *Durusdinium* spp*.,* whereas recruits in 29 °C also hosted *Cladocopium* spp.. No differences in survival were found, although recruits exposed to 31 °C grew significantly less. In juveniles of the two brooding species, *Leptastrea purpurea* and *Pocillopora damicornis,* we did not detect differences in their symbiont community compositions compared to their parents. In both spawning species, the temperature-mediated development of their symbioses may represent a strategy to adapt to changes in prevailing thermal regimes. Alternatively, it could indicate the breakdown of the host's ability to maintain a beneficial and stable association with partners other than *Durusdinium.* By contrast, the unchanged Symbiodiniaceae composition of the brooding corals may either represent a more thermally stable association, or an inability to modify their association. These mechanisms and the reproductive mode of corals should be considered in reef conservation and restoration efforts.

Session 13D - Effectiveness of regional coral reef restoration approaches - what can we learn from the Caribbean and Eastern Tropical Pacific?

Conceptualized by: **Edwin A. Hernández-Delgado**[1], **Samuel E. Suleimán-Ramos**[1], **Elisa Bayraktarov**[2], **Phanor Montoya-Maya**[3]
[1] Sociedad Ambiente Marino (San Juan, Puerto Rico)
[2] The University of Queensland (Brisbane, Australia)
[3] Corales de Paz (Santiago de Cali, Colombia)

Chaired by: **Elisa Bayraktarov**[1], Camilo Cortés-Useche[2]
[1] The University of Queensland (Brisbane, Australia)
[2] Iberostar Group (Playa Paraiso, Mexico)

Oral
A-1589

Testing the effect of multispecies outplanting on coral growth and survival in the face of multiple stressors

Cobleigh, K., Bestrom, N., Arrington, B., Quetel, J., Mele, D., Dade, L., Brandt, M.
University of the Virgin Islands, Center for Marine and Environmental Science, St Thomas, U.S. Virgin Islands

kathryncobleigh[at]gmail.com

Abstract

Caribbean coral restoration efforts have primarily focused on acroporid corals, a species group that experienced significant regional population declines and has seen little recovery due to continued impacts from disease, predation pressure, storm damage, and other local and global anthropogenic stressors. However, restoration efforts have started to expand outside of this genus, in part due to recent declines in bouldering coral populations that are susceptible to the highly virulent and transmissible stony coral tissue loss disease (SCTLD). The bouldering coral *Orbicella annularis* is susceptible to SCTLD but is also a known alternative prey for corallivores that prefer acroporids. Other weedy species like *Porites astreoides* are resistant to SCTLD and predation and may therefore represent pathogen sinks through heterotrophic feeding and/or predation barriers. This project aimed to test the effect of co-outplanting multiple species which may support different indirect benefits to each other's growth and survival. While optimizing *Acropora cervicornis* growth was the primary focus of this project, this multispecies outplanting effort incorporated multiple genotypes of *A. cervicornis*, SCTLD-susceptible *O. annularis* as an alternative corallivore prey for acroporid predators, and *Porites astreoides* as a potential disease sink. Experimental plots were installed in St. Thomas, U.S. Virgin Islands. Six treatments across five genotypes of *A. cervicornis* were applied, including: 1) Low density of *A. cervicornis* (single colony), 2) Single genotype but high density (three colonies of *A. cervicornis*), 3) Multi-genotype of *A. cervicornis* (three colonies each originating from a different genotype), 4) Alternative corallivore host (one *A. cervicornis* colony with two *O. annularis* lobes), 5) Disease alternate (one *A. cervicornis* colony with two *P. astreoides* colonies), and 6) Multispecies (One *A. cervicornis colony*, one *O. annularis* lobe, and one *P. astreoides* colony). Initial 3-dimensional measurements and coral health assessments were recorded at the time of outplanting and repeated quarterly. Two-dimensional experimental plot photos were taken monthly and processed using ImageJ, calculating changes in coral cover as a proxy for coral growth. Data analysis is currently under way; however, we expect that growth per each *A. cervicornis* colony will be greater in multi-species and multi-genotype treatments.

Oral
A-1891

Towards restoration of the biodiversity of coral reef fish assemblages in the Mexican Caribbean

Cortés-Useche, C.[1, 2], Reyes-Gamboa, W.[2], Cabrera-Pérez, J. L.[2], Calle-Triviño, J.[1], Cerón-Flores, A.[3], Raigoza-Figueras, R.[3], Yathiraj, R.[4], Arias-González, J. E.[2], Blanco Pimentel, M.[5], Galvan, V.[6], Harms, E.[6], Morikawa, M.[6]
[1]IBEROSTAR GROUP, Sustainability Office, PLAYA PARAISO, Mexico
[2]CINVESTAV, Laboratorio de Ecología de Ecosistemas de Arrecifes Coralinos, MERIDA, Mexico
[3]Acuario XCARET, Playa del Carmen, Mexico
[4]Nature Seychelles, Centre for Environment & Education, Mahe, Seychelles
[5]IBEROSTAR GROUP, Sustainability Office, Bavaro, Dominican Republic
[6]IBEROSTAR GROUP, Sustainability Office, Miami, United States

camilo.cortes[at]iberostar.com

Abstract

Multiple global and local disturbances, combined with lack of regulation, are increasing and have negative impacts on coral reef biodiversity. In this context, active strategies with a more interventionist approach have been proposed, promoting the restoration of coral reef communities, including severely decreased reef fish communities.
Here, we propose a proof-of-concept for enhancing fish populations on reefs using: (1) postlarvae capture, (2) aquarium culture, and (3) release to reef sites. We conducted field studies in the Mexican Caribbean to analyze for the first time, the possibility of using the capture and aquarium culture of postlarvae fish species and release of juveniles as a tool for the potential recovery of reef biodiversity resilience. We tested the potential of postlarvae capture using two distinct night light traps (BOX and collect by artificial reef ecofriendly traps, C.A.R.E.) in three sampling sites with different distances from shoreline and depth. We collected 748 postlarvae reef fishes from eight orders, 20 families, and 40 species. Acanthuridae, Pomacentridae, Monacanthidae, and Tetraodontidae comprised the highest species number of postlarvae families.
Individuals of bicolor damselfish (*Stegastes partitus*) were conditioned to artificial structures simulating the reef habitat in *ex situ* aquariums, during the post-larval development period. After this period, the individuals were released near the areas where they were collected, conserving the artificial reef structures to which they were associated in the aquariums. We present the results of the pilot release experiment with *S. partitus*, showing that there is a positive effect in survivorship during the capture (80%) and release (76–100%) procedures into suitable habitat and good chance that more studies will bring novelty to the field. Although trials carried out with more species relevant to restoration will be needed. The use of these techniques can be a great opportunity to improve the research of restoration efforts in the Caribbean region with fish-depleted coral reefs with vulnerable food webs, especially at local scales and supporting other management strategies.

Oral
A-1730

A comparison of micro-fragmenting propagation techniques for the endangered stony coral species, Acropora palmata

Mele, D.[1], Carne, L.[2], Vaughan, D.[3], Brandt, M.[1]
[1]University of the Virgin Islands, St. Thomas, U.S. Virgin Islands
[2]Fragments of Hope, Placencia, Belize, [3]Plant a Million Corals, Summerland Key, United States

danmele87[at]gmail.com

Abstract

At the forefront of coral restoration techniques is the coral gardening approach, which utilizes a nursery phase where corals are propagated before outplanting to a degraded reef. *Ex-situ* water table nurseries have opened the door for the use of micro-fragmentation, where corals are cut into just a few centimeter pieces, as these small fragments can be grown in a highly controlled environment that is conducive for health and growth. Other techniques involve directly transplanting coral fragments to a degraded reef, thus bypassing the nursery phase.

However, these techniques have mainly been practiced with larger coral fragments. Few studies have examined the efficacy of using micro-fragmentation techniques commonly used in an *ex-situ* nursery with direct outplanting. Here, we compare direct outplant micro-fragments of *Acropora palmata* with two phases of water table grown

micro-fragments 1) nursery phase and 2) outplanting phase, over two sequential 12-week studies. The 2 studies' fragments were collected from 16 distinct *A. palmata* colonies split between two locations; Stumpy Bay, and Fortuna Bay, U.S. Virgin Islands. Study 1 consisted of 16 direct outplant arrays (array = 5 micro-fragments) compared against 15 water table grown arrays. Study 2 involved outplanting the water table arrays from Study 1 and comparing them to an additional subset of 15 direct outplants arrays. Each array of direct outplants had a matching array of water table micro-fragments originating from the same parent colony. Both Study 1 and Study 2 showed a clear trend favoring water table arrays over direct outplant arrays. Water Table arrays consistently outperformed direct outplant arrays concerning growth and survival (WT = 100% survival in Study 1 and 97% survival in Study 2). However, direct outplants still performed exceptionally well, showing 91% survival in Study 1 and 85% survival in Study 2.

Poster
A-1289

Stony Coral Microfragment Outplanting in Southeast Florida, USA

Alfirevich, J., Garmendia, M., Hayes, N., Gilliam, D.
Nova Southeastern University, Dania Beach, United States

ja2397[at]nova.edu

Abstract

Microfragmentation was developed to promote increased growth of slow-growing massive stony coral species for active restoration. The purpose of this study was to understand the value of moving microfragments into an *in situ* nursery prior to outplanting to reef. *Montastraea cavernosa* (1 colony; 15 microfragments), *Pseudodiploria clivosa* (2 colonies; 160 fragments), *Solenastrea bournoni* (5 colonies; 183 fragments), and *Siderastrea siderea* (6 colonies; 317 fragments) were collected in southeast Florida, USA in March 2021. A diamond band saw was used to cut colonies into 2-4 cm diameter microfragments resulting in a total of 698 fragments. These fragments were housed in an *ex situ* nursery at Nova Southeastern University for up to five months, with an overall survival rate of 97%. In November 2021, 106 fragments were placed on a mesh table in an *in situ* nursery, and the remaining 569 fragments were outplanted in two arrays 30 m apart at one reef site off southeast Florida. Monitoring efforts occurred for both sites (nursery and outplant) after one week and monthly for three months. Monitoring consisted of survival and condition data for each fragment, where mortality was defined by complete tissue loss. Instances of missing fragments was not included with mortality. Nursery and outplant survival were similar for *M. cavernosa* and *S. siderea*. *Solenastrea bournoni* outplants had greater survival while *P. clivosa* had greater survival in the nursery. Identifying causes of partial mortality in microfragments is challenging due to their small size, but tissue loss visually consistent with predation and/or disease was recorded for all species in the nursery and outplants. Microfragment dislodgment (missing) from the nursery table or the reef substrate after outplanting was not a major issue for any species. These data indicate that the value moving microfragments into an *in-situ* nursery prior to outplanting is species specific. These types of studies provide information that can be used to promote greater success and efficiency in coral nursery-related restoration activities.

Poster
A-1530

Scaling up techniques for coral restoration interventions using coral sexual recruits

Banaszak, A.[1], Guendulain, S.[2], Mendoza, S.[3]
[1]Universidad Nacional Autónoma de México, Unidad Académica de Sistemas Arrecifales, Puerto Morelos, Mexico
[2]Universidad Autónoma Metropolitana, Doctorado en Ciencias Biológicas y de la Salud, Mexico City, Mexico
[3]SECORE International, Puerto Morelos, Mexico

banaszak[at]cmarl.unam.mx

Abstract

Currently, the capacity to outplant corals, as fragments or as sexual recruits, cannot keep pace with the loss of coral cover. Therefore, more attention is now being placed on scaling up´restoration efforts. Over the last 12 years, our focus has been to produce corals derived from sexual reproduction to improve genetic diversity in restoration sites as a means of enhancing the ability of the population to face global change. To date three reefs have sexual recruits outplanted on them, and some of these colonies have reached sexual maturity. A variety of scaling techniques have been applied and tested. First, we work at up to eleven sites along the Mexican Caribbean during the spawning season to increase the probability and volume of spawn capture and to use a large pool of parent colonies. Second, we collect coral spawn from an array of species (*Acropora palmata, Diploria labyrinthiformis, Orbicella faveolata, O. annularis and Psuedodiploria strigosa*) to extend the period during which we can collect spawn and to increase the number of species that we can culture to the settlement stage. Third, we have designed mobile laboratories such that spawn collection and early-stage (embryo and larval stage) culturing can be conducted at remotes sites, where most coral reefs are located, without the need for a well-established laboratory facility. Fourth, we have developed an automated culturing facility to handle large quantities of developing embryos and larvae with enough space for large numbers of artificial settlement substrates. Fifth, we collaborate with national and international organizations and researchers to test innovative designs and ideas such as *in situ* culturing systems, self-attaching substrates and a variety of materials and coatings. Sixth, we train professors, students and practitioners, via hands-on workshops and postgraduate courses during the summer months, which coincide with coral spawning, to encourage more organizations to develop independent assisted fertilization and larval propagation projects. Taken together, these techniques can significantly improve the number of sexual recruits out-planted onto restoration sites.

Poster
A-1520

2bRAD Sequencing as a Tool for Predicting Coral Restoration Success in a Multi-Species South Florida Coral Restoration Experiment

Bell, S.[1], Shilling, E.[1], Pantoni, G.[1], Hunt, J.[2], Sharp, W.[2], Muller, E.[3], Voss, J.[1]
[1]FAU Harbor Branch Oceanographic Institute, Biological Sciences, Fort Pierce, United States
[2]Florida Fish and Wildlife Conservation Commission, Fish and Wildlife Research Institute, Marathon, United States
[3]Mote Marine Laboratory, Coral Reef Restoration Program, Sarasota, United States

sydneybell2021[at]fau.edu

Abstract

No other coral disease has been as widespread and detrimental as SCTLD which has devastated Florida's reefs with a 30% decline in coral density and a 60% decrease in live tissue cover over the past 7 years. Among the 25 susceptible species are many primary reef-builders and massive coral species, which contribute in large part to reef calcification and growth. SCTLD has spread across Florida's Coral Reef (FCR) since 2014 and today there are regions where the disease is no longer observed at epidemic prevalence. These endemic zones presented an opportunity to assess the efficacy of restoring SCTLD-susceptible corals in areas that may or may not still be vulnerable to SCTLD. Currently, little is known regarding the effectiveness or risks of outplanting coral colonies for restoration purposes in SCTLD-endemic regions. Additionally, very few studies have outplanted and long-term fate-tracked massive coral species in northern FCR locations. This project utilized three SCTLD-susceptible massive coral species on FCR: *Montastraea cavernosa, Orbicella faveolata,* and *Pseudodiploria clivosa.* In May 2021, 1,152 five-fragment clusters from 75 donor colonies were outplanted across six regions throughout FCR including: Martin/Palm Beach County, Broward County, Miami-Dade County, the upper Florida Keys, the middle Florida Keys, and the lower Florida Keys. This collaborative project comprises the largest experimental coral outplanting and restoration project in Florida to date. The coral outplants have been and will continue to be monitored monthly for survival, disease susceptibility, and growth. Before the outplanting of these fragment clusters onto the reef, tissue samples were collected from all 75 donor colonies for subsequent molecular studies. Using a type IIB restriction-site associated DNA sequencing approach (2bRAD), this project identified single nucleotide polymorphisms (SNPs) and evaluated SNPs or genotypes potentially associated with SCTLD susceptibility or general restoration fragment performance and survival. The growth and survivorship success of the coral genotypes in situ will be assessed across all the six outplant regions of this project. Results from this study will inform the feasibility of future coral restoration efforts in SCTLD endemic zones and identify any disease-resistant coral genotypes if they indeed occur. Targeting disease-resistant coral genotypes as candidates for outplanting may be a vital tool in repopulating FCR.

Poster
A-1566

Stabilization and Associated Benthic Community Recovery of Ship Grounding Sites after Boulder Deployment

Wever, S., Gilliam, D., Jones, N.
Nova Southeastern University, Marine and Environmental Science, Dania Beach, United States

swever[at]nova.edu

Abstract

Ship groundings are acute disturbances that alter benthic biological community composition and the physical structure and function of coral reefs. In 2006, two >170m commercial shipping vessels ran aground on the inner reef near Port Everglades offshore Fort Lauderdale, Florida, USA. These groundings crushed and displaced corals, reduced rugosity, and created areas of loose reef rubble. Three- and four-years post grounding, site assessments showed limited biological recovery and the persistence of unconsolidated rubble in and around the bow scar areas. In 2015, Florida's Department of Environmental Protection deployed limestone boulders on portions of the grounding sites to stabilize unconsolidated reef rubble and restore rugosity. This study examined the change in benthic biological community composition from 2016 to 2022 at permanent sites within stabilized (boulder) and un-stabilized (rubble) grounding areas and adjacent un-impacted reef areas. Belt and photo transects were used to collect species-specific demographic data for both adults and juveniles and taxa-specific cover data. Our results found stabilized sites had higher recruitment and inter-annual survival of stony corals than un-stabilized sites after seven years. In that same time, stony coral species richness increased two-fold at stabilized sites while fluctuating annually at un-stabilized sites. Other key taxa, including gorgonians and the giant barrel sponge (*Xestospongia muta*), had limited recruitment to stabilized and un-stabilized sites. Results from this study suggest boulder deployment may promote stony coral recovery following ship groundings, creating habitat more similar to un-impacted reef than unconsolidated rubble. This study also demonstrates the value of long-term restoration monitoring to better understand reef succession after disturbance events.

Virtual
Oral
A-2104

Effectiveness of regional coral reef restoration approaches - what can we learn from the Caribbean and Eastern Tropical Pacific?.

Rodríguez-Troncoso, A. P.[1], Tortolero-Langarica, J. J. A.[2], Rodríguez-Zaragoza, F. A.[3], Morales-de-Anda, D. E.[1], Cupul-Magaña, A. L.[1]
[1]Centro Universitario de la Costa, Universidad de Guadalajara, Laboratorio de Ecología Marina, Puerto Vallarta, Mexico
[2]Tecnológico Nacional de México, Instituto de Bahía de Banderas, Nayarit, Mexico
[3]Universidad de Guadalajara, Centro Universitario de Ciencias Biológicas y Agropecuarias, Laboratorio de Ecología Molecular, MIcrobiología y Taxonomía, Jalisco, Mexico

pao.rodriguezt[at]gmail.com

Abstract

Due to the increased live coral cover loss worldwide, several coral restoration programs have been implemented in the last decade. Different protocols have been implemented with different techniques for enhancing the live coral cover (LCC), but without considering a long-term monitoring program that evaluates its effects at the community level to identify if intervened sites can be considered rehabilitated. During 2014, a coral-restoration program was established in Islas Marietas National Park (MNP), using the direct propagation technique for *Pocillopora* spp., the genus with the highest coverage in Eastern Tropical Pacific Region. Over 4,000 healthy fragments were planted from 2014 to 2019, and every two months, the MNP was monitored to determine changes in LCC, fish, echinoderm, and benthic habitat structure. Results showed differences in LCC among restored sites (19.4%) and no-intervention sites (8.9%). Restored sites showed an increase in echinoderm abundance. Fish assemblage also showed a significant change, mainly at the functional-entity level. Likewise, fish omnivores and invertivores presented a higher species richness and biomass. Finally, fish functional redundancy, equity, and originality were also related to restoration. The results show that after a six-year coral restoration program, the coral ecosystem was considered rehabilitated, as LCC increased despite the influence of thermal anomalies of El Niño 2015-2016 event, and also an increase in key groups is evidenced. This emphasizes the relevance that a rehabilitation program must have a constant monitoring program that evidences the changes in ecosystem ecological succession.

Virtual
Oral
A-1737

Enhancing herbivore populations: A more holistic approach to improving coral reef restoration

Williams, S. M.
Institute of Social and Ecological Research Inc., Lajas, Puerto Rico

stcmwilliams[at]gmail.com

Abstract

Most Caribbean coral reefs have lost their capacity to recover from these disturbances and have undergone long-term shifts from coral to an algal-dominant state. Even more so, rare algal groups like peyssonnelids are increasing in abundance on shallow-water coral reefs. In particular, *Ramicrusta* spp., a member of the peyssonneliacean family (Rhodophyta), is spreading throughout the Caribbean islands. In Puerto Rico, *Ramicrusta* is the dominant substrate (>63% cover) on many coral reefs on the east coast (Culebra, Fajardo, Vieques). *Ramicrusta* presence poses a real threat to coral reefs as it can smother corals by overgrowing their living tissue. Also, the rapid growth of *Ramicrusta* not only reduces the area of suitable substratum for coral settlement but hinders active coral restoration.

So, how can we decrease the cover of algae, specifically *Ramicrusta*, to allow for a healthier reef state for restoration activities? Most peyssonnelids and some macroalgae (*Dictyota* spp.) are chemically defended against fish herbivores. However, sea urchins have been observed eating these nuisance algae in the laboratory and the field. Since 2015, over 4,000 long-spined sea urchins, *Diadema antillarum*, have been restocked to different coral reefs around Puerto Rico. The Puerto Rico *Diadema* Restoration Project takes a novel approach by collecting post-larval settlers (0.4 mm to 1.0 mm test diameter) of *Diadema* from the wild. The settlers are reared in the laboratory to a size sufficient to reduce mortality (2.0 cm to 4.0 cm test diameter) when restocked to algal-dominated reefs.

The results show significant changes in the benthic structure occur during the first week after *Diadema* is restocked. Substantial reductions of fleshy macroalgae (*Dictyota* spp.) and thick turf mats with sediments, both unsuitable substrates, contribute to this change. Also, restocking *Diadema* significantly reduced the cover of *Ramicrusta* spp. By two months of urchin restocking, the abundance of fleshy macroalgae decreased by a maximum of 90% and *Ramicrusta* and turf mat with sediments by 61% and 92%, respectively. Pavement ("clean substrate"), crustose coralline algae (CCA), and filamentous turf algae increased between one to two orders of magnitude in experimental plots with *Diadema*. The restoration of native sea urchins is a non-invasive and useful approach to aid in the mitigation of algae, especially potentially dangerous alga like *Ramicrusta*.

Virtual
Poster
A-2115

Use of Acropora Iron Reef (AIR) Modules in reef rehabilitation on the Port Royal Reefs, Jamaica, West Indies

Green, C.[1], Palmer, S.[1], Charpentier, B.[2], Ross, A.[3]
[1]The University of the West Indies, The Department of Life Sciences, Kingston, Jamaica
[2]Duwatech Inc., Ontario, Canada, [3]Seascape Caribbean, Montego Bay, Jamaica

chaunieg[at]gmail.com

Abstract

Coral reefs in Jamaica are considered to be amongst the most degraded in the Caribbean Region due to the loss of rugosity, biodiversity, and fish biomass. However, several rehabilitation efforts, together with no-take zones, seek to replenish coral communities and improve overall reef health and reef fisheries. The interventions have largely been limited to the north coast of Jamaica and their effectiveness is not extensively reported. Modified versions of the Acropora Iron Reef (AIR) module were installed across areas of the Port Royal Barrier reef that have historical records of *Acropora cervicornis* thickets. The experimental area covers ~1,000m² at 8-10m depth and encompasses 4 adjacent spurs (800m² as direct intervention sites and 200m² as a control site). To determine the effectiveness of the AIR modules as a medium for coral growth 144 *Acropora cervicornis* fragments (5cm length) were harvested from six donor colonies and attached to the AIR modules using cable ties. Over a 12-month period the coral fragments were monitored *in situ* monthly for survivorship (percentage of live coral tissue and coral health), and quarterly for coral growth (total linear extension). The ability of the AIR modules to facilitate natural recruitment was assessed by comparing spurs with installed modules with coral attached, spurs with modules (no coral), and a control spur (no intervention). The presence and percentage of cover by corals and other encrusting species was assessed over time through image analyses of the modules. The presence of the AIR modules to influence the behavior of urchins and fish was explored through roving diver surveys and mounted GoPro cameras across all spurs. Preliminary findings indicated 96.5% survivorship of *Acropora cervicornis* fragments that are attached to the AIR modules with evidence of new coral tissue overgrowing the modules. Natural settlement of *Agaracia agaricites* and *Favia fragum* was observed across multiple modules. The design of the AIR modules, originally developed by The University of the West Indies, Discovery Bay Marine Laboratory, imitates the growth form of wild *Acropora cervicornis* colonies and can return three-dimensional properties to flattened reefscapes. This study aims to provide a case study for practitioners to gain insight into the effectiveness and applicability of the AIR module as a locally sourced, low technology, low-cost tool for restoring habitat functionality.

Session 13E - How can interventions and restoration help coral reefs survive the next few decades?

Conceptualized by: **Tom Moore**[1], **Tali Vardi**[1], **Petra Lundgren**[2]

[1] NOAA Restoration Center (St. Petersburg, FL, USA)

[2] Great Barrier Reef Foundation (Brisbane, Australia)

Chaired by: **Tali Vardi**[1]

Oral
A-1616

Modeling interventions to increase the resilience of coral reefs in the Maldives

Akiona, A.[1], Chancellor, K.[1], Lubarsky, K.[1], McNamara, D.[2], Vardi, T.[3], Williams, Z.[4], Zgliczynski, B.[1], Sandin, S.[1]
[1]Scripps Institution of Oceanography, UCSD, La Jolla, CA, United States
[2]University of North Carolina Wilmington, Wilmington, United States
[3]ECS for NOAA Fisheries Office of Science & Technology, Silver Spring, MD, United States
[4]NOAA Fisheries, Beaufort Laboratory, Beaufort, NC, United States

aakiona[at]ucsd.edu

Abstract

Coral interventions are being developed as tools for scientists and reef managers to mitigate the effects of climate change on coral reefs. Understanding how corals and benthic functional groups may respond to potential interventions should help managers protect and restore coral reefs as the climate effects (particularly bleaching) become more frequent and more severe. Here, we use an empirically grounded, spatially explicit cellular automata model to assess potential interventions for the Republic of the Maldives, an island nation which depends heavily on coral reef related tourism and which has recently embraced reef restoration. We draw on extensive Maldives survey data from the 100 Island Challenge, a large-scale effort to describe variation in coral reefs from across the globe, to model different intervention scenarios, including business as usual and coral outplanting. When forced with projections for sea surface temperatures and no interventions, we find that future coral reef states vary dramatically depending on whether coral mortality is morphology-specific or random. Additionally, we find that by assuming corals have already adapted somewhat to warm water events, the projection models offer a more precise representation of previous thermal stress and thus more optimistic projections of future coral cover. Finally, we show that larval outplanting helps to mitigate some of the predicted coral mortality under projected temperature scenarios. Our model predicts that coral adaptation and human intervention will be crucial for the future health of reefs in the Maldives.

Oral
A-1954

Assisted gene flow of corals to exploit thermal heterogeneity over small spatial scales: Implications for sexual and asexual restoration programs

Baker, A.
Rosenstiel School of Marine and Atmospheric Science, University of Miami, Department of Marine Biology and Ecology, Miami, United States

abaker[at]rsmas.miami.edu

Abstract

Managed relocation of corals has been proposed as a strategy for increasing coral thermotolerance, but is accompanied by risks such as the introduction of pathogens or invasive species. A pragmatic way of minimizing these risks is to identify thermal heterogeneity over small spatial scales and use corals from locally warmer conditions as source populations for restoration. Another way of minimizing some risks is to consider managed breeding of individuals over somewhat larger spatial scales, and use the offspring of these crosses for outplanting efforts. We have begun these efforts in Florida, and are now scaling up attempts to introduce and/or breed corals from nearby sites outside Florida as part of efforts to both increase the genetic diversity of threatened stocks (e.g., the elkhorn coral *Acropora palmata*) and increase thermal tolerance of restored populations (e.g., the staghorn coral, *Acropora cervicornis*). These pilot efforts join a suite of additional interventions (such as algal symbiont manipulations, probiotics, and assisted reproduction) that have been brought together under the Southeast Florida Coral Reef Restoration Hub. More recently, as part of the Defense Advanced Research Projects Agency (DARPA) “Reefense” program these interventions (and others) have been incorporated into a broader effort to: (1) develop hybrid engineered and biological reef-mimicking structures that provide immediate protection from wave impacts, coastal flooding, erosion, and storm damage; (2) Engineer ecological communities that promote coral growth and enhance recruitment to enhance the capacity of these structure to self-build and self-repair; and (3) Identify, test, and deploy novel technologies to improve the adaptive capacity of corals and increase the long-term resilience of these hybrid reef structures. This new project represents an effort to meet or exceed ambitious targets in all three areas over a 5-year timeframe. While building coastal resilience through the deployment of hybrid reef structures is not a long-term solution to sea level rise, these “**X-reefs**” (ne**X**t generation hybrid **reefs** that incorporate advanced materials, ecological engineering, and adaptive biology), have the potential to become essential components of managed retreat strategies in low-lying tropical and subtropical areas. Their development represents an opportunity for critical research and testing to help meet the parallel challenge of helping reef corals survive the climate crisis.

Oral
A-2157

Pre-exposure to a variable temperature treatment improves the response of Acropora cervicornis to acute thermal stress

DeMerlis, A.[1, 2], Kirkland, A.[3], Kaufman, M.[1], Mayfield, A.[2, 4], Formel, N.[2, 4], Kolodziej, G.[2, 4], Manzello, D.[5], Lirman, D.[1], Traylor-Knowles, N.[1], Enochs, I.[2]
[1]University of Miami Rosenstiel School for Marine and Atmospheric Sciences, Miami, United States
[2]NOAA Atlantic Oceanographic and Meteorological Laboratory, Miami, United States
[3]The University of New Orleans, New Orleans, United States
[4]University of Miami Cooperative Institute for Marine and Atmospheric Sciences, Miami, United States
[5]NOAA Center for Satellite Applications and Research, College Park, United States

allyson.demerlis[at]rsmas.miami.edu

Abstract

Widespread mortality events due to thermal bleaching and disease have led to dramatic declines in coral cover, resulting in a loss of reef ecosystem services. Restoration driven by coral nurseries and outplanting is imperative, yet challenges remain in maximizing success. Of particular concern is the sustained viability of reintroduced coral fragments that are potentially subject to the same stressors that previously compromised natural populations. To this end, various stress-hardening techniques have been explored in conjunction with genotype performance evaluation in order to confer a degree of resilience to restored populations and increase the efficacy of restoration efforts. Previous field studies have demonstrated that corals from environments with greater thermal variability have higher thermotolerances, and it is possible that this phenomenon can be exploited to artificially enhance resilience. We exposed six genotypes of the Caribbean staghorn coral *Acropora cervicornis* to dynamic temperature treatments in the laboratory, where they experienced punctuated thermal stress events (31 °C) twice daily for a period of roughly three months. Following, treated corals as well as control fragments held in static conditions (28 °C) were subjected to a rapid bleaching assay (32 °C). Coral health during this stress test was assessed daily using color categorization, as well as pulse amplitude modulation (PAM) fluorometry. Both stress-hardened and control corals experienced disease and bleaching during the 32 °C thermal challenge. Corals initially exposed to variable thermal conditions, however, showed decreased disease susceptibility and survived significantly longer under sustained high temperature stress compared to control corals. Preliminary findings suggest a benefit of this stress-hardening methodology in increasing the resilience of reared coral fragments. Further work, however, is needed to identify the underlying mechanisms, as well to determine how long this conferred resilience is sustained.

Oral
A-1390

Efficiency and success of coral mariculture can be improved through grazing by herbivorous fish

Knoester, E. G., Rizzi, E., Murk, A. J., Osinga, R.
Wageningen University and Research, Marine Animal Ecology, Wageningen, Netherlands

ewoutknoester[at]hotmail.com

Abstract

Restoration is an emerging tool for coral reef conservation, yet despite small-scale successes there are concerns about high costs and ecological setbacks. A closer integration between reef ecology and restoration could help address such concerns. A prime example is the use of grazing herbivores to reduce coral nursery cleaning costs. However, the relation between herbivore biomass and cleaning benefits remains unquantified. This study aimed to measure the link between fish biomass, grazing pressure and coral nursery performance. Six study sites were selected in southern Kenya (-4.700, 39.396), equally divided across three levels of fisheries management (fished < reserve < no-take). From November 2017 to March 2018, remote underwater videos were used to record grazing pressure exerted on coral nurseries (n = 8) and accumulated fouling density and coral growth were measured. Grazing pressure was tenfold higher and fouling density fourfold lower in the marine reserves and no-take zones compared to fished areas. Reduced fouling correlated strongly with increased coral growth, which doubled in the marine reserves and tripled in the no-take zones. Across study sites grazing was dominated by bristletooth tangs (*Ctenochaetus spp.*), except where these were uncommon or outcompeted by territorial damselfish. These results show that improved coral nursery performance in protected areas can be partially linked to higher grazing pressure, which in turn is determined by both fish biomass and local species composition. We recommend placing coral nurseries in areas with high biomass of key grazers to facilitate the removal of fouling and increase coral growth.

Oral
A-1279

Maximising restoration outcomes: a framework for guided intervention and monitoring

Mead, D., Ortiz, J., Anthony, K., Bainbridge, S., Radford, B., Robson, B., Poutinen, M., Gibbs, M.
Australian Institute of Marine Science, Townsville, Australia

d.mead[at]aims.gov.au

Abstract

Global capability to deploy innovative interventions to restore and adapt coral reefs is rapidly increasing. With this comes a need to guide deployments, forecast benefits and risks, and monitor impact. The deployments invariably occur at specific sites within a reef, where ideally the benefits spread over time to the adjacent parts of that reef and to other reefs. Well-selected sites have the potential to generate impact many orders of magnitude greater than the direct deployment benefits.

Before any deployment can commence, key decisions are required: site location(s), species, quantities, deployment densities, timing. Efficient and targeted monitoring is needed to help guide intervention and to evaluate impacts. Making these decisions optimal is a function of many complex physical and ecological processes, while predicting impact and monitoring for that impact adds further complexity and cost. Being able to make robust decisions and then to measure the impact of these decisions is a fundamental part of implementing intervention strategies.

The Australian Institute of Marine Science and partners (including the Reef Restoration and Adaptation Program) are developing a suite of technologies and models that, when combined, create a simple cost-effective information and decision-support framework and associated workflow to achieve these goals. The workflow starts with characterising the targeted reef, runs a suite of models and decision-support frameworks to establish an intervention design and strategy (including deployment sites), and produce forecasts of impacts. It further refines the deployment in real time and concludes with technologies and a design to monitor impact over time, and to guide continual improvement of the guidance system.

This workflow will be presented along with examples of its application and guidance on how it could be more broadly utilised.

Oral
A-2105

Iberostar's Wave of Change as the tourism sector's first comprehensive program in coral conservation restoration

Morikawa, M.[1], Blanco, M.[2], Calle, J.[3], Cortes, C.[3], Galvan, V.[4], Harms, E.[5], Fluxa, G.[6]
[1]Iberostar Hotels & Resorts, Miami, United States
[2]Iberostar Group, Bavaro, Dominican Republic
[3]Iberostar Group, Cancun, Mexico
[4]Iberostar Group, Miami, United States
[5]Iberostar Group, Washington DC, United States
[6]Iberostar Group, Palma, Spain

megan.morikawa[at]iberostar.com

Abstract

Coral reefs need bold new interventions in order to survive as humanity knows them. The tourism, a primary beneficiary, is rapidly adopting practices in responsible tourism, yet a large gap remains between their sustainability initiatives
and comprehensive coral reef conservation and restoration. Iberostar Hotels & Resorts is a spanish-based, privately owned, 4th generation family owned company with 120 properties in 19 countries worldwide, with 80% of its properties coastal and 80% of coastal properties protected by reefs. Iberostar's Wave of Change is its bold commitment to the oceans through 3 lines of action: embracing a circular economy, implementing a responsible consumption of seafood, and promoting coastal health through the discovery, protection, and restoration of the coral reef, seagrass, and mangrove ecosystems where it operates. All within our vision to have resilient Caribbean reef restoration and/or protection in the reefs where we operate by 2025, we present first findings from Iberostar's Coral Lab in the Dominican Republic, methodologies for multi-species in-water restoration programs in Aruba, Dominican Republic, and Cozumel, Iberostar's first fish sanctuary in Jamaica, and synergies between work on drastically reducing plastics, sourcing responsible seafood, and waste water management for coral reefs. Through this burgeoning comprehensive marine conservation program directly within the hotel's operation, we hope to provide a model for other groups to
provide catalytic solutions for scaling coastal protection across unique geographies while leveraging strengths in the tourism sector's longstanding history in human connection.

Oral
A-1567

Hybrids in coral restoration: A comparison of growth and survival among Caribbean acroporid species and their hybrid in a coral tree nursery

VanWynen, C.[1], **Hightshoe, M.**[1], Fogarty, N.[2], Dahlgren, C.[3], Gilliam, D.[1]
[1]Nova Southeastern University, Department of Marine and Environmental Sciences, Dania Beach, United States
[2]University of North Carolina Wilmington, Center for Marine Science, Wilmington, United States
[3]The Perry Institute for Marine Science, Waitsfield, United States

mh2120[at]nova.edu

Abstract

In response to the severe population declines of Caribbean acroporids, *Acropora* coral restoration efforts have been implemented throughout the region with the goal to maintain genetic diversity and promote recovery of these critical reef framework builders. Current methods primarily target *Acropora cervicornis* and *A. palmata*, two species of branching corals that can mate to form a hybrid, *A. prolifera*. Using interspecific hybrids with higher fitness than one or both parental species has gained traction as a novel restoration technique. For this study, three in-situ coral tree nurseries were established around Great Stirrup Cay, The Bahamas, to compare the growth and survival among Caribbean acroporid taxa. A minimum of three 15 cm fragments from six putative genotypes of each acroporid taxa were collected from colonies around New Providence, The Bahamas, and transported to Great Stirrup Cay in June 2018. One fragment from each genotype was transported to each nursery site, cut into three sections (apical, middle, and basal), and suspended from PVC coral trees (n=157). Survival and total linear extension (TLE) were collected monthly for each fragment for 12–13 months. Nursery site significantly affected fragment survival, while taxon, fragment section, and genotype did not. Whole fragment mortality for all taxa was 29.3% in the first month but decreased to 0–5% for the remainder of the study. Taxon, nursery site, and fragment section were identified as important factors affecting TLE. *A. prolifera* average linear growth after 12 months (102.5 mm +/- 14.4 SE) and average growth rate per month (8.3%) was significantly greater than *A. cervicornis* (35.6 mm +/- 7.9 SE, 2.7%) and *A. palmata* (47.4 mm +/- 7.2 SE, 4.3%). Furthermore, apical *A. prolifera* fragments at site N3 had a greater average growth compared to all other taxa and fragment sections. This study highlights the rapid growth rate of hybrid corals and suggests that fragment sections have equivalent survival and growth. Consequently, these results suggest that coral restoration managers may benefit from using fast-growing hybrids for outplanting to degraded reefs and increasing the scale of nursery projects.

Poster
A-1330

Enhancing the recovery of Diadema antillarum on coral reefs in the Caribbean using urchin recruiting, generating, and housing sytems (URGHs)

Ballard, A., Rohwer, F., Baer, J.
San Diego State University, Biology, San Diego, United States

aballard3083[at]sdsu.edu

Abstract

The transition of Caribbean and Western Atlantic coral reefs from coral to macroalgal dominance has been a pressing issue for nearly four decades. The alteration in community structure on these reefs experienced the most dramatic shift following the 1983-1984 epizootic-driven mass mortality event of the keystone herbivore, the long-spined sea urchin (*Diadema antillarum*). Since the event, there has been limited recovery of the species which has led to its functional extinction in most areas of the Caribbean and Western Atlantic. With the reduction in grazing pressure on macroalgae, there has been an increase in coral disease and decrease in coral recruitment and survivorship which has resulted in loss of habitat complexity.

Due to this, an area of focus within recent years has been developing ex situ methods to rear *Diadema antillarum* and then using the developed urchins to restock reefs. However, challenges in late-stage development and early post-larval settlement persist with these methods. Here we describe a novel in situ urchin recruiting, generating, and housing system (URGHs) that will establish an ecologically effective and self-sustaining *Diadema antillarum* population. We hypothesize that refuge availability at multiple life stages using URGHs will increase the survival of *Diadema antillarum* from the larval to adult life stage. Design parameters of URGHs will optimize oxygenation, refuge, and diet throughout development, as well as provide suitable benthos for larval settlement and metamorphosis. To enhance metamorphosis, URGHs will be seeded with assays of metamorphosis associated contractile structures which are released from the marine bacterium *Pseudoaltermonas luteoviolacea.* Preliminary results show that the effector protein, Mif1, found within the tube lumen of the contractile structures induce 56% metamorphosis of urchin larvae.

Once built, the URGHs will be deployed onto natural and artificial reefs in St. Thomas, US Virgin Islands. The goal of URGHs is to create networks of locally high densities of adult *Diadema antillarum* that will serve as centers of larval dispersal to colonize nearby reefs and ultimately reefs throughout the Caribbean and Western Atlantic. Repopulation of *Diadema antillarum* will prevent further overgrowth of corals by algae, create suitable benthos for coral recruits, improve the survivorship of newly recruited and juvenile corals which will increase refuge availability and settlement cues for *D. antillarum*.

Poster
A-1608

Demonstration of Coral Reef Arks in Vieques, Puerto Rico: providing the best step forward for coral reef restoration at a US Navy cleanup site

Carilli, J.[1], Baer, J.[2], Hartmann, A.[3], Chadwick, B.[4], Rosen, G.[1], Rohwer, F.[2]
[1]Naval Information Warfare Center Pacific, Energy and Environmental Sciences, San Diego, United States
[2]San Diego State University, Department of Biology, San Diego, United States
[3]Harvard University, The Department of Organismic and Evolutionary Biology, Boston, United States
[4]Coastal Monitoring Associates, San Diego, United States

jcarilli[at]spawar.navy.mil

Abstract

Vieques is a small island located east of the main island of Puerto Rico, and was the site of a former US Navy live-fire training and testing range. The training range closed in 2003, and portions of the land were transferred to several different agencies; the majority of the island is now a National Wildlife Refuge administered by the Department of the Interior. Much of the former training range is now a priority cleanup site under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), which provides the framework for the Vieques Environmental Restoration Program. As part of the Vieques cleanup, underwater munitions will be located and safely removed; corals growing on these items, or within the area that would be impacted by the removal, would be translocated by scientific divers as described in the Programmatic Biological Opinion on the Underwater Investigation and Removal/Remedial Activities in UXO 16, Vieques, Puerto Rico from the National Marine Fisheries Service (consultation OPR-2017-00026).
To maximize the beneficial outcomes of the underwater cleanup for coral reef restoration in Vieques, the US Naval Facilities Engineering Command (NAVFAC) Atlantic, which manages the cleanup program, invited the Coral Reef Arks project team to carry out a demonstration of their novel coral reef restoration technology at Vieques. Coral Reef Arks aim to provide an ideal environment for translocated corals to thrive. Arks are mid-water-column artificial reefs that are seeded with both translocated corals, as well as cryptic reef diversity that is captured by Autonomous Reef Monitoring System (ARMS) units, providing a more holistic artificial reef environment compared to transitional methods. Coral Reef Arks are envisioned as a stepping-stone approach to provide healthy conditions for corals and associated reef organisms to live, which can then re-seed adjacent natural reefs with larva, and/or can be translocated back to adjacent natural reefs when site conditions (including local and global-scale impacts) are healthy enough to allow reefs to re-establish. This presentation will present initial results of the Coral Reef Arks demonstration in Vieques, which began in November 2021 with additional support from the NOAA Restoration Center and the Puerto Rico Department of Environment and Natural Resources.

Poster
A-1957

Thermal stress resistance of wild/ farmed Orbicella faveolata corals, and their response to shade as a mitigation strategy during cumulative heating.

Coelho, V.[1], Vaughan, D.[2], Bayles, B.[1]
[1]Dominican University of California, San Rafael, CA, United States
[2]Plant A Million Corals, Summerland Key, FL, United States

vania.coelho[at]dominican.edu

Abstract

We compared how *Orbicella faveolata* wild and aquacultured corals differed regarding their resistance to thermal stress, as well as their response to the use of shade to mitigate coral bleaching during extended periods of high temperature. A total of 259 coral fragments from four wild colonies; with at least 60 fragments per colony, were used in this experiment. We also examined 342 coral fragments from three aquacultured lineages with distinct genotypes, with a minimum of 85 coral fragments per genotype. The wild corals were rescued colonies kept at the Key West Harbor in Florida, United States, and the aquacultured specimens have been farmed for over a decade, and were also originally from other rescued colonies kept in the same location as the wild corals used in this experiment. Corals were subjected to three lab treatments during a four-week period: 1) controls at low temperature (26.5 degrees Celsius) and high light intensity (20 moles of quanta per square meter per day), 2) high temperature (31.5 degrees Celsius) and high light intensity (HTNS), and 3) high temperature and low light intensity (5 moles of quanta per square meter per day, HTS). Stress was measured by color changes, evaluated using a standardized reference card, as a proxy for decreases in symbiont density and chlorophyll a content (i.e. bleaching). Our results showed that this species is generally resistant to thermal stress but sensitive to high light levels. No difference between controls and HTS corals was observed, but HTNS corals did not perform as well as the other two treatments. Aquacultured corals were more sensitive to thermal stress than wild colonies in the HTNS treatment, however a statistical comparison among all seven different genotypes showed that only one aquacultured genotype was more sensitive than all other six; wild or farmed. We concluded that using this species in coral reef restoration is a particularly good choice because of its resistance to thermal stress and strong response to shading as a mitigation strategy. However, thermal resistance experiments should be conducted prior to those efforts, in order to identify and avoid genotypes that are more sensitive to heat, taking into account the expected increase in the frequency of high temperature periods due to climate change, and consequent greater probability of bleaching episodes.

Poster
A-1237

Understanding Global Perceptions of Coral Reef Restoration

Collins, S.
Newcastle University, Natural and Environmental Sciences, Newcastle Upon Tyne, United Kingdom

s.collins4[at]newcastle.ac.uk

Abstract

Ecological Restoration and rehabilitation are now commonly used strategies to halt the global decline of coral reefs, yet the value of such techniques is still widely debated within the scientific community. The increasing need for active management solutions in the face of global coral decline has prompted an explosion in both reef restoration projects and restoration ecology research. Various restoration techniques continue to be implemented across multiple sites worldwide, yet the effectiveness of these strategies is unclear. Despite some notable successes at local scales, coral reef restoration has been referred to as a ‘band-aid solution’, unable to be implemented at the scale of the disturbance, resulting in an expensive and temporary fix. Critics further argue that the emphasis on restoration distracts from mitigating the root cause of the issue - climate change. In the worst case, restoration may be used as an excuse for environmental damage. However, local management efforts do not prevent continued action in climate mitigation, thus one needn’t inhibit the other. Restoration initiatives have various associated positive outcomes, including increasing the genetic diversity and preventing the extinction of coral species. More recently, studies reporting the socio-economic outcomes of restoration have shown multiple benefits, especially to local communities. Enhanced stewardship, increased job opportunities and revenue from tourism are a few such benefits that may not be replicated in these coastal communities without the emphasis on active restoration. Despite a clear variation in opinions of coral restoration, there is limited discussion of this in scientific literature, especially from the perspectives of coral restoration practitioners who offer a unique insight into the value of coral restoration. This study aims to synthesise the opinions of both academics within coral science and restoration practitioners to establish the current perspectives on the value of coral reef restoration. This will be achieved through the thematic analysis of semi-structured interviews with a cohort of interviewees across a global scale. This research hopes to determine what is perceived to be the current benefits and limitations of coral reef restoration and the justification behind such opinions. Furthermore, valuable insight will be provided into the areas of alignment and areas of contestation among academics and practitioners regarding coral reef restoration.

Poster
A-1039

Characterizing Carbonate Chemistry of Corals Across Hong Kong's Environmental-urbanization Gradient for Optimal Coral Restoration and Propagation

King, T., Wyatt, A.
Hong Kong University of Science and Technology, Ocean Science, Kowloon, Hong Kong SAR China

tbking[at]connect.ust.hk

Abstract

Coral reefs are globally important ecosystems that are increasingly threatened by changing ocean conditions. Hong Kong's waters boast relatively high coral biodiversity despite a marginal environment for coral growth. These corals survive over strong gradients of environmental conditions and human-mediated impacts. In recent decades, highly urbanized areas have experienced significant coral decline, suggesting that preserving and restoring these reefs should be a high priority. However, the effectiveness of restoration efforts is dependent upon proper site selection, with coral growth and survival tied to local environmental gradients. Hong Kong's waters are characterized by higher coral cover and diversity in the east, with increasing degradation occurring westward due to the impacts of urbanization, including eutrophication stemming from the Pearl River Estuary. It has been difficult to prioritize coral recovery and propagation sites across this gradient due to a lack of understanding of variations in ecosystem function, especially potential net ecosystem calcification (NEC) rates and relationships between environmental parameters and coral growth and survival rates around Hong Kong.

The purpose of this project is to measure ecosystem function and identify sites expected to support higher rates of both NEC and net ecosystem production (NEP). In order to better optimize coral restoration and propagation efforts, we need to first understand the relationship between environmental parameters, NEP, and NEC across Hong Kong's environmental-urbanization gradient. Data on the spatial variation in rates of NEC and NEP, measured based on vertical gradients in dissolved oxygen and pH, will be presented in the context of optimizing coral nursery site selection. Comparison of growth rates across this spatial range will be used to demonstrate the optimal range of environments in which corals may be successfully restored in Hong Kong, which has broader implications for optimizing coral restoration efforts globally based on understanding of the links between environmental dynamics and ecosystem function.

Poster
A-1926

Targeted research to support reef grazer and staghorn coral population enhancement in the Florida Keys

Patterson, J.[1], Henry, J.[1], Lohr, K.[2], Pilnick, A.[3], O'Donnell, K.[4], O'Neil, K.[5]
[1]University of Florida, Fisheries and Aquatic Sciences, Apollo Beach, United States
[2]National Marine Sanctuary Foundation for NOAA Office of National Marine Sanctuaries, Silver Spring, United States
[3]University of Florida, School of Natural Resources and Environment, Apollo Beach, United States
[4]NOAA National Marine Fisheries Service, St. Petersburg, United States
[5]The Florida Aquarium, Apollo Beach, United States

joshpatterson[at]ufl.edu

Abstract

Active reef restoration in Florida and the wider Caribbean comprises an increasingly diverse species portfolio and efforts are focused on building capacity to meet reef-scale restoration targets, enhance genetic diversity of outplanted populations, recover lost herbivory, and increase the proportion of sexually propagated corals used in restoration. Hypothesis-driven research has an important role in answering questions related to these broad goals. Such research is particularly important for staghorn coral *Acropora cervicornis*, which remains an important species cultured for restoration efforts in the Caribbean. For example, *A. cervicornis* represents 20% of all coral outplants prescribed for the first phase of Mission: Iconic Reefs, an ecosystem-level restoration effort that is set to occur across a diverse set of Florida Keys reefs over the next 20+ years. Mission: Iconic Reefs also calls for restocking the long-spined sea urchin, *Diadema antillarum*, a species with the potential to provide sorely missed herbivory. Over the last several years, we have conducted a series of experiments contributing to the goals of improving *A. cervicornis* restoration strategies and developing the ability to culture *D. antillarum* at scale. Coral studies in the Florida Keys have revealed that 1) nursery growth is not predictive of outplant performance and other phenotypes must be developed for systematic monitoring; 2) outplanted corals at fore reef and inshore environments are differentially affected by major hurricane disturbance; and 3) direct-outplanting ex-situ sexually propagated colonies is feasible yet return to an ocean-based nursery improves survival and growth. Aquaculture techniques for *D. antillarum* are showing promise and over 1,000 juvenile urchins have been produced to date, with a recent initial experimental release in Florida Keys National Marine Sanctuary. Altogether, this work provides ideas and information for managers when considering the future roles of *A. cervicornis* and *D. antillarum* in the broader restoration context.

Virtual
Oral
A-2155

Buying Time in the Face of Climate Change: Developing a New Coral Reef Restoration Paradigm to Accelerate Natural Adaptation and Recovery Processes

Bowden-Kerby, A.
Corals for Conservation, Sigatoka, Fiji

abowdenkerby[at]gmail.com

Abstract

The widespread demise of coral reefs due to climate change is now a certainty, as mass bleaching threatens even the best managed and most pristine of coral reefs. To invest time and funds to carry out restoration without facing this stark reality risks losing vital ground in what should become a coordinated and multipronged effort to prevent the demise of coral reef systems. If we fail to address mass bleaching in our coral restoration efforts all progress will be swept away within decades as the ocean warms.
A new paradigm for coral restoration is proposed, not based on numbers of corals planted or area covered, but rather on helping corals adapt to rising temperature, maintaining natural reproduction, enhancing coral recruitment, and encouraging sharing of resistant symbionts, while ensuring that as many coral species as possible survive locally over time.
In our ongoing program, with pilot sites in six Pacific Island nations, effort is invested in translocating heat adapted corals, from near-shore hot pockets with summer temperatures of >32C, to cooler offshore reefs with less stress. Gene bank nurseries of bleaching resistant corals are thus created in a more secure environment, helping prevent the death of heat-adapted corals of multiple declining species into the future as extreme heat stress events increase. Unbleached corals of targeted species are also selected during severe bleaching events for inclusion in the nurseries, securing them from over-abundant predators post bleaching.
From the gene banks, second-generation coral colonies are harvested for use in creating patches of genetically diverse climate adapted corals, which become reproductively, ecologically and biologically viable at reef scale. Rather than restoration using large numbers of small fragments, this strategy, modelled on tropical forest restoration, seeks to restore dense patches of more complete communities, replete with protective fish and invertebrates. Thes animals in turn increase coral and substratum health and enhance natural larval based recovery processes, jump-starting natural recovery. We hypothesize that incoming coral recruits are also inoculated by heat adapted algal symbionts which leak from the coral patched, facilitating the adaptation processes on the wider reef.
With global emissions out of control, the most we can hope for is to buy precious time for coral reefs, by saving coral species and coral diversity that will not likely survive unassisted.

Virtual
Poster
A-1352

Cement modules as coral restoration tools on degraded reefs

Hixon, M., Dilley, E., Brush, E., Jones, R.
University of Hawaii, School of Life Sciences, Honolulu, United States

hixonm[at]hawaii.edu

Abstract

Reefs that have suffered major coral mortality and lost their physical structure typically become covered by macroalgae, creating the dilemma of how to attract herbivorous fishes and macroinvertebrates to recolonize a degraded reef and subsequently facilitate a phase shift back to dominance by coral. Cubic-meter cement modules with abundant holes of various sizes deployed by our lab in the Virgin Islands and the Bahamas had proven effective in attracting many fish and eventually corals, so we deployed the same kind of modules on a degraded reef off Waikīkī Beach, O‘ahu, Hawai‘i. Compared to control structures with no holes, modules providing physical shelter were colonized by more herbivorous fish, resulting in marginally less benthic algae. However, there was no significant indirect positive effect of physical shelter on colonizing dominant corals of the genera *Monitpora*, *Pocillopora*, and *Porites* in terms of recruitment, survival, or growth within 4 years of deployment. We then tested whether “corals of opportunity” that had naturally detached at the same site would survive and grow when attached to the modules. To date, transplanted colonies of *Pocillopora meandrina* have thrived, whereas those of *P. grandis* have done so only when colonized by *Trapezia* guard crabs, which apparently defend colonies from corallivorous cushion stars (*Culcita novaeguineae*). We are currently testing whether *Tripneustes gratilla* urchins outplanted from a state nursery will survive and grow when released onto the modules, and if so, whether urchins will increase herbivory to a level that more clearly benefits coral colonization.

Session 13F - How can we apply sexual propagation to restore resilient coral reefs at significant scales?

Conceptualized by: **Peter Harrison** [1], **Dirk Petersen** [2]
[1] Southern Cross University (Lismore, Australia)
[2] SECORE International, Inc. (Bremen, Germany)

Chaired by: **Peter Harrison** [1], **Dirk Petersen** [2], **Aric Bickel** [3]
[1] Southern Cross University (Lismore, Australia)
[2] SECORE International, Inc. (Bremen, Germany)
[3] SECORE International (Miami, USA)

Oral
A-1920

Capacity Building and Technology Development for Large Scale Coral Restoration via Larval Propagation

Bickel, A.[1], Chamberland, V.[2], Latijnhouwers, K.[2], Mendoza, S.[3], Banaszak, A.[4], Petersen, D.[5], Miller, M.[1]
[1]SECORE International, Miami, United States
[2]SECORE International, Curacao, Curaçao
[3]SECORE International, Puerto Morelos, Mexico
[4]UNAM, Puerto Morelos, Mexico, [5]SECORE International, Bremen, Germany

a.bickel[at]secore.org

Abstract

Current outplanting methods for coral restoration require labor-intensive manual transplantation of each coral-substrate-unit using adhesives, nails or cable-ties; these labor-intensive methods significantly raise the cost and time needed to restore reefs at the needed scale. To increase restoration efficiency, our organization is leading a collaboration to develop technologies and implement partnerships that reduce labor and costs, allow application of techniques in remote areas, and expand the spectrum of species restored. We primarily use larval propagules that are settled on self-stabilizing substrates ("seeding units") that are 'sowed' on the reef, without artificial attachment. Based on experiments with multiple shapes and materials, we have designed a set of substrates that improve survival of recruits, retention of seeding units, and can be in-expensively mass-produced. To facilitate large-scale restoration at locations remote from land-based infrastructure, we have developed technology to conduct the rearing and settlement process in situ with specially designed floating "pools" that are deployed prior to a coral spawning event. Fertilized eggs resulting from in situ gamete collection and in vitro fertilization are placed directly into the pools containing seeding units to complete larval development, settlement, and potentially a post-settlement nursery period with minimal labor. Our upscaling work is also being facilitated by a comprehensive capacity building program, where organizations are invited to enter a 5-year training program aimed at enabling them to sustainably implement a larval propagation program. Selected organizations are provided the necessary materials, mentorship, and tailored training to build the skills and knowledge to develop a successful restoration program. In this manner, we intend to build a community of practice that is prepared to adopt, adapt, and improve developed technologies and methodologies.

Oral
A-2057

Using sexual propagation technique to restore a resilient reef in Thailand: possibility for a larger scale ?

Chavanich, S.[1], Viyakarn, V.[1], Lin, C.[2], Fujita, T.[3], Iwao, K.[4], Omori, M.[4]
[1]Chulalongkorn University, Marine Science, Bangkok, Thailand
[2]National Museum of Marine Biology and Aquarium, Pintung, Taiwan
[3]National Museum of Nature and Science, Zoology, Ibaraki, Japan
[4]Akajima Marine Science Laboratory, Okinawa, Japan

suchana.c[at]chula.ac.th

Abstract

In Thailand, sexual propagation technique has been developed and applied to restore a reef in the upper Gulf of Thailand since 2010. More than 3,000 juvenile corals were produced from sexual propagation and raised in a hatchery. At present, 5 year-old post-settlement colonies were detected to be reproductively mature and subsequently spawned every year since 2013. From our long-term studies, more than 50% of adult colonies reached a maturity stage and reproduced gametes. Our finding also showed that sexual propagation not only maintained and increased genetic diversity, but also may help corals to cope with the changes of environment such as high temperatures. Our juvenile corals tended to be more resilient to the increase of temperatures than other natural ones. However, to serve as an efficient restoration tool and for a large scale, some factors need to be considered. Those factors included production cost, maintenance cost, and knowledge availability. In this study, we will share from our long-term experience on benefits, limitations, and challenges of using coral sexual propagation technique to restore a resilient reef in the upper Gulf of Thailand, and the possibility to extend and expand in a large scale.

Oral
A-1717

PROJECT CORAL – A synopsis of ex situ broadcast coral spawning research; potential applications to research and up-scaling reef restoration practises.

Craggs, J.[1, 2], Guest, J.[3], Davis, M.[4], O'Neil, K.[5], Sweet, M.[6]
[1]Horniman Museum and Gardens, London, United Kingdom
[2]University of Derby, School of Natural & Environmental Sciences, Derby, United Kingdom
[3]Newcastle University, School of Natural & Environmental Sciences, Newcastle upon Tyne, United Kingdom
[4]Horniman Museum and Gardens, Aquarium, London, United Kingdom
[5]The Florida Aquarium, Center for Conservation, Tampa, United States
[6]University of Derby, Aquatic Research Facility, Environmental Sustainability Research Centre, Derby, United Kingdom

jrkcraggs[at]gmail.com

Abstract

While brooding corals commonly release planula in aquaria, broadcast spawning in closed systems have historically been rare and highly unpredictable. Broadcast spawning correlates strongly with a number of environmental signals, (seasonal temperature, solar irradiance, lunar and diel cycles) however few robust experimental studies have examined the role of these putative cues in triggering spawning. In 2012 an innovative research programme commenced, developing techniques to predictably induce broadcast coral spawning events *ex situ*, utilising a bespoke mesocosm design that accurately replicated environmental spawning cues. To date, we have been able to spawn 35 species of coral, followed by successful *in vitro* fertilisation to produce F1 and in one case, F2 generations.

We are now using this platform for broader research purposes, focused in three areas; 1) understanding reproduction at a fundamental level, 2) developing methods to enhance post settlement survival and 3) utilising the unique opportunity that *ex situ* spawn management provides such as phase shifted spawning at various temporal scales to produce multiple reproductive events within a single year, and therefore increasing access of gamete material for experimentation.

A synopsis of techniques developed over the past ten years will be presented, along with results of this cutting-edge research.

Oral
A-1517

Onset of zooplanktivory and optimal water flow rates for prey capture in newly settled polyps of ten Caribbean coral species

Geertsma, R.[1], Tim, W.[1], Latijnhouwers, K.[2, 3, 4], Chamberland, V.[2, 3, 4]
[1]Wageningen University, Marine Animal Ecology, Wageningen, Netherlands
[2]SECORE International, Hilliard, OH, United States
[3]CARMABI Foundation, Willemstad, Curaçao
[4]University of Amsterdam, IBED Freshwater and Marine Ecology,, Amsterdam, Netherlands

robbert-jan.geertsma[at]wur.nl

Abstract

Zooplanktivory is an important source of nutrients in corals. However, little is known about coral zooplanktivory shortly after larval settlement and metamorphosis. In most species it is unclear if, when and under which conditions newly settled polyps are able to capture and ingest prey. This remains a critical knowledge gap, as zooplanktivory could allow coral settlers to replenish energy reserves shortly after metamorphosis, possibly improving settler condition during one of their most vulnerable life stages. Here, we documented the onset of prey (*Artemia salina* nauplii) capture in ten Caribbean coral species and assessed optimal water flow rates (WFR) for prey capture in five of these species. All symbiotic and aposymbiotic species initiated zooplanktivory within six days following metamorphosis, with the exception of *Acropora palmata* which was never observed capturing nauplii during our 20-day study. Optimal WFR for prey capture varied among species, with *Favia fragum* displaying maximum prey capture rates in zero flow and *Diploria labyrinthiformis* most effectively capturing nauplii under WFR of 5 to 20 cm s-1. Under each species' optimum WFR, prey capture abilities varied considerably, with *F. fragum* capturing up to one nauplius every two minutes compared to one nauplius every nine minutes in *Colpophyllia natans*. Using these findings, we make species- specific recommendations to optimize early husbandry practices for these ten coral species and further discuss applications to increase the effectiveness and scale of coral restoration using sexually-derived coral larvae.

Oral
A-1514

A comparison of coral recruit rearing methods: effects of settlement substrate type and rearing investment on coral recruit survival and growth

Gutting, A.[1], Lillis, A.[2], Nixon, E.[3], Cook, S.[3]
[1]The Nature Conservancy, Christiansted, U.S. Virgin Islands
[2]Sound Ocean Science, Christiansted, U.S. Virgin Islands
[3]Scripps Institution of Oceanography, San Diego, United States

a.n.gutting[at]tnc.org

Abstract

To address coral reef decline and aid coral population recovery from myriad disturbances, larval propagation has emerged as a promising method to increase genetic diversity and restoration scalability. For a restoration project to be truly scalable, methods must be developed to maximize the ratio of success (e.g., outplant survival and growth) to time and financial costs. This study compared survival and growth of *Diploria labyrinthiformis* and *Pseudodiploria strigosa* recruits one year after settlement across different levels of rearing effort (time and financial investment) and on different settlement substrates. Gamete bundles were collected from wild parent colonies and combined for fertilization and subsequent larval rearing. Larvae were settled onto three substrate types - ‘tetrapods’ (designed by SECORE), ‘stars’ (designed by SECORE), and natural substrate (coral skeleton) collected from the beach. Two weeks post-settlement, the number of settlers on each substrate was scored, and one-third of each substrate type was assigned to each of three treatments representing different levels of investment (n=9): 1) high investment – substrates were kept in a raceway in a land-based nursery, and raceways and individual substrates were cleaned approximately monthly; 2) medium investment – substrates were kept on a PVC table in a field-based nursery, and tables were cleaned approximately every three months; 3) low investment – substrates were directly outplanted to a reef adjacent to the field-based nursery, and no cleaning was conducted. After one year, the number of recruits on each substrate was scored, and the diameter of each surviving recruit was measured. Percent survival for each substrate was calculated, and a two-way ANOVA was used to compare recruit percent survival and mean recruit diameter at one year across investment treatments and substrate types. The highest survival rates were found in the field-based nursery, and the highest growth rates were found in the field-based nursery and on tetrapods. This determination of the recruit rearing method that yields the highest success (survival and growth) with the lowest time and financial costs is critical to inform the effective application of sexual propagation restoration efforts at a larger scale.

Oral
A-1643

Mass Coral Larval Production and Supply for Large Scale Coral and Reef Restoration

Harrison, P.
Southern Cross University, Faculty of Science and Engineering, Lismore, Australia

peter.harrison[at]scu.edu.au

Abstract

Increasing loss of foundation reef corals is threatening the integrity of coral communities and reef ecosystems in many regions globally. Coral populations are naturally resilient but loss of breeding corals depletes larval supply, diminishing natural recruitment rates that are essential for maintaining or recovering coral populations. Synchronous coral spawning events provide access to trillions of gametes that can be used for mass production of genetically diverse larvae, which can then be used for settlement on degraded reefs that are able to be restored. This presentation highlights the results from recent larger-scale collaborative and multidisciplinary larval restoration projects on damaged reefs in the Great Barrier Reef and Philippines. Larval restoration initially involves capture of large volumes of spawned gametes and embryos from surface slicks using innovative floating spawn catchers for mass rearing of coral larvae *in situ* on reefs. Larvae are reared in floating larval pools within protective fine mesh nets until they are competent to settle. Larvae can be settled onto settlement substrata within larval pools before being released onto target reefs, or millions of larvae can be released directly onto damaged reef areas with low live coral cover. Larval release and settlement can be achieved using various fine mesh containment nets and larger-scale controlled larval cloud techniques including autonomous technology to increase settlement and recruitment. Reef trials have consistently demonstrated significantly higher larval settlement in experimental plots supplied with coral larvae, compared with control plots relying on low natural larval supply. Rapid growth of some surviving corals results in re-establishment of breeding populations within two-three years, and increased fish abundance. These results demonstrate the potential for further scaling up of mass larval production and supply to rapidly increase larval settlement and recruitment for future large-scale larval restoration of resilient coral communities on degraded reefs.

Oral
A-1012

First steps towards folding ex situ reared sexually propagated corals into restoration programs: experimental results and considerations

Henry, J.[1], O'Neil, K.[2], Pilnick, A.[1], Patterson, J.[1]
[1]University of Florida, Gainesville, United States
[2]The Florida Aquarium, Tampa Bay, United States

josephhenry86[at]gmail.com

Abstract

Hard coral cover in the Western Atlantic has decreased by more than 80% in the last 40 years. While it is clearly imperative to address the global and regional stressors that led to this decline, active coral restoration has grown in importance as a management tool and is now central to the Mission: Iconic Reefs project in South Florida. To date, the vast majority of coral outplanting in Florida has employed asexually propagated ramets derived from wild donor colonies. Strategies involving sexual reproduction combined with land-based ex situ propagation could help to increase the genetic diversity of restored coral populations and ultimately improve restoration outcomes. However, achieving high coral recruit survival ex situ is difficult and results are highly variable. Furthermore, questions regarding how these corals will perform once placed back into the dynamic marine environment must be considered. A set of experiments was designed to address how to achieve high

post-settlement survival while minimizing labor and how to best ensure survival after release to the ocean and in outplanting. In 2017 and 2018, we collected *Acropora cervicornis* gametes from broodstock corals held in the Coral Restoration Foundation (CRF)'s ocean nursery and resulting larvae were transported to an ex situ facility. An initial experiment recorded high post settlement survival ex situ and identified an herbivorous snail species that improved coral rearing success by controlling algae proliferation. In 2019, in situ experiments began with outplanting both year classes of sexually propagated corals at a back reef and an inshore patch reef in the Florida Keys, plus return to the CRF nursery where gametes originated. After a 480-day monitoring period, major findings were 1) high survival rates (~73%) across all 160 outplants, 2) significant differences in survival between outplanting locations and coral recruit year class, and associated method of attachment, and 3) very high survival of sexually propagated corals returned to the ocean based nursery (~89% overall), with 40-fold greater growth than direct-outplanted colonies. We suggest that ex situ propagation offers a scalable and effective opportunity to meet the need for increased genetic diversity in coral restoration. Our work offers options for managing the high input of novel genotypes into coral restoration systems and suggests additional research to maximize the adaptive potential of restored coral populations.

Oral
A-1921

Feeding of coral settlers in large in situ mesocosms greatly increases their long-term survival

Latijnhouwers, K.[1, 2, 3], Ter Horst, L.[1], Schneider, J.[1], Van Duijnhoven, J.[1], Miller, M.[1], Vermeij, M.[2, 3], Chamberland, V.[1, 2, 3]
[1]SECORE International, Hilliard, Ohio, United States
[2]CARMABI Foundation, Willemstad, Curaçao
[3]University of Amsterdam, IBED, Amsterdam, Netherlands

k.latijnhouwers[at]secore.org

Abstract

Larval propagation techniques are becoming increasingly popular to enhance coral abundance and genetic diversity in depauperate coral communities. Recently, SECORE International developed the coral rearing in-situ basin (CRIB), allowing large-scale larval rearing through to settlement. However, cohorts of settled larvae often still suffer drastic mortality rates (>95%) once outplanted, limiting the effectiveness of this technique. Here we aimed to promote the health, growth, and long-term survival of coral settlers by optimizing conditions within this CRIB for a two-week period after larval settlement. We used settlers of two Caribbean coral species to (i) co-culture with juvenile herbivorous urchins to reduce competition from neighboring algae on artificial substrates, (ii) fed settlers with zooplankton, and (iii) inoculated them with algal symbionts. Settlers of *Favia fragum* (which already possess symbionts inherited from their maternal colony) were co-cultured with 0.5- to 2.0-cm-diameter *Diadema antillarum* and/or fed with *Artemia* nauplii (~300 nauplii/L). Settlers of *Diploria labyrinthiformis* were also fed with *Artemia* nauplii and/or inoculated with Symbiodiniaceae (110 cells/mL) extracted from adult conspecifics. After two weeks, *F. fragum* settlers cultured with urchins were six times less likely to survive than those reared without, likely due to incidental grazing. In contrast, fed settlers of both species had grown up to double the size of unfed conspecifics right before outplanting and were two to three times more likely to survive on the reef three to four months after outplanting. In addition, survival of *D. labyrinthiformis* settlers inoculated with Symbiodiniaceae was twice as high three-months after outplanting compared to untreated settlers. CRIB treatments no longer had an effect on the survival of *F. fragum* recruits after 18 months, and neither did the *Symbiodinium* inoculation for the survival of *D. labyrinthiformis* recruits. However, feeding *D. labyrinthiformis* settlers for only two weeks prior to outplanting while in a CRIB resulted in a six times higher density of successfully established juvenile colonies on the reef. We conclude that feeding coral settlers of certain species benefits the effectiveness of ocean-based nursery settings as a readily applicable and low-cost technique to drastically increase the overall success of large-scale larval-based coral restoration efforts.

Oral
A-2200

Coral Larvae Exhibit Material Composition- and Texture-Based Settlement Preferences

Levenstein, M. A.[1], Tichy, L.[2], Quinlan, Z. A.[3], Tholen, H.[1], Vermeij, M. J. A.[4], Marhaver, K. L.[4], **Wagoner Johnson, A. J.**[1]
[1]University of Illinois at Urbana-Champaign, Urbana, United States
[2]Radboud University, Nijmegen, Curaçao
[3]San Diego State University, San Diego, United States, [4]CARMABI Foundation, Willemstad, Curaçao

ajwj[at]illinois.edu

Abstract

Coral juvenile recruitment and survival remain bottlenecks to reef recovery. Restoration efforts that focus on this stage of development typically settle larvae onto a limited range of ceramic and concrete substrates in controlled environments for later outplanting. However, few substrate formulations have been tested for restoration, and little is known about how materials characteristics (e.g. composition and texture) affect settlement choices. Here, we approach reef restoration via larval settlement from a materials science perspective. We designed a series of novel substrate formulations based on lime mortar comprising a primary carbonate component (principally $CaCO3$) mixed with various additives intended to support juvenile attachment, calcification, and growth. We also produced these new carbonate formulations in a range of millimeter-scale textures and compared their performance to other potential restoration materials, such as ceramic, limestone, and several plastics. Coral larvae from two Caribbean broadcast-spawning species (Diploria labyrinthiformis and Acropora palmata) demonstrate significant preferences for subsets of substrate materials, additives, and textures. Larvae preferred substrates with millimeter-scale textural features, such as ridges, and carbonates with silica-based additives. D. labyrinthiformis larvae also displayed preferences for substrates containing the alkaline earth carbonate, strontianite ($SrCO3$), in addition to calcium. The sensitivity of larvae to the concentration of a substrate additive was also investigated. Larvae that were offered carbonate substrates with concentrations of glass additives between 5% and 20% by mass were able to distinguish among differences as small as 5%. This work demonstrates that coral larvae exhibit materials-based settlement preferences, even with relatively small changes in substrate formulation, and in the absence of typical biological settlement cues such as coralline algae. Engineering the composition and texture of settlement substrates has the potential to significantly improve juvenile settlement and survival during reef restoration projects and may support increases in natural coral recruitment to human-built structures in coastal areas.

Oral
A-1423

Sustainable coral restoration by establishing in situ “artificial spawning hotspots” -2. Protection of adult corals against serious disturbances-

Nakamura, S.[1], Tamura, K.[1], Suzuki, G.[2], Yonezawa, Y.[3], Kanyama, T.[4], Nakase, S.[5], Yamazaki, M.[5]
[1]ECOH CORPORATION, Tokyo, Japan
[2]Fisheries Technology Institute, Ishigaki, Japan
[3]KOKUSAI KOGYO CO.,LTD., Tokyo, Japan
[4]Fisheries Infrastructure Development Center, Tokyo, Japan
[5]Ministry of Agriculture,Forestry and Fisheries, Tokyo, Japan

s-nakamura[at]ecoh.co.jp

Abstract

We report the technical developments required for enhancing larval supply in Part I. In this part, we focus on technologies for maintaining a sustainable larval supply. In other words, we aim to establish "artificial spawning hotspots" that harbor conspecific adult colonies densely and protect them from disturbances. For scleractinian corals, especially the genus Acropora, fatal disturbance factors include outbreak of COTS, large-scale bleaching, and storm surge. Protection against these are crucial for establishing sustainable "artificial spawning hotspots".

Providing shade to "artificial spawning hotspots" is a better counteraction against bleaching at high temperatures, since shading is easily achievable compared to cooling, although both high water temperature and strong light are known to damage corals and symbiotic algae. We explored the effectiveness of providing shade to the "artificial spawning hotspots" to establish a concrete operation system when bleaching is predicted. We report insights from shading experiments conducted in the field and an aquarium.

To avoid COTS predation, bottom-raising is an effective method. In fact, during a COTS outbreak in 2011, only corals put on a 50 cm bottom-raised rack survived the outbreak within a bay. Hence, we established the optimal thickness of platform legs in artificial reef required to prevent climbing of COTS to "artificial spawning hotspots".

At present, we are constructing a prototype of artificial reef for "artificial spawning hotspots" that is durable against storm surge, rearing approximately 400 colonies of five-year-old Acropora tenuis as a larval source. We would touch upon it during the presentation. In addition, the optimum arrangement of "artificial spawning hotspots" for effective coral restoration, considering a range of fertilization and larval behaviors, is under investigation.

Oral
A-1953

Beyond the Bank: Repeated broadcast spawning in an ex situ population of the threatened Atlantic pillar coral, Dendrogyra cylindrus.

O'Neil, K.[1], Serafin, R.[1], Williams, E.[1], Lewis, C.[2], Neely, K.[3], Patterson, J.[4], Craggs, J.[5, 6]
[1]The Florida Aquarium, Center for Conservation, Apollo Beach, United States
[2]Keys Marine Laboratory, Long Key, United States
[3]Nova Southeastern University, Dania Beach, United States
[4]Institute of Food and Agricultural Sciences, University of Florida, Program in Fisheries and Aquatic Sciences, School of Forest Resources and Conservation, Gainesville, United States
[5]Horniman Museum and Gardens, Forest Hill, London, United Kingdom
[6]University of Derby, Aquatic Research Facility, Environmental Sustainability Research Centre, Derby, United Kingdom

koneil[at]flaquarium.org

Abstract

As coral reefs continue to decline across the globe, an increased interest in *ex situ* gene banking and propagation has developed. In Florida, an ongoing disease outbreak and declining population numbers have rendered the local population of *Dendrogyra cylindrus* at risk of local extinction. Large distances between remaining colonies make *in situ* spawn collection difficult with limited historical success. The formation of a living *ex situ* genetic bank beginning in 2015 has allowed for the preservation of genetic diversity that has been lost in the wild. The limited number of surviving wild genotypes and lack of documented natural recruitment would ordinarily point to a bleak future for the species in Florida. However, using the methodology developed by Project Coral at the Horniman Museum and Gardens, this species spawned synchronously for three consecutive years in 2019-2021 after fully inducing the gametogenic cycle of corals that had been living *ex situ* for 1-2 years using artificial light and temperature cues. The resulting larvae and coral settlers have 21 contributing parents that were originally collected from a distance of over 100 km apart from one another. The repeated availability of large numbers of larvae resulted in increasing success in post-settlement rearing and survival. The predicted and well-synchronized *ex situ* spawning events show that long-term living genetic banks can be used to preserve coral genotypic diversity in the face of severe wild declines and small *ex situ* populations can be used to produce offspring for future restoration activities. By combining diverse parent colonies from a wide area in a single aquarium, assisted gene flow and managed breeding activities can be conducted without cryopreservation and with minimized risk of disease transmission.

Oral
A-2046

Developing intensive aquaculture of the long-spined sea urchin Diadema antillarum as a tool for coral reef restoration

Pilnick, A.[1], O'Neil, K.[2], Patterson, J.[3]
[1]University of Florida, School of Natural Resources and Environment, Apollo Beach, United States
[2]The Florida Aquarium, Apollo Beach, United States
[3]University of Florida, School of Forest, Fisheries, and Geomatics Sciences, Apollo Beach, United States

apilnick[at]ufl.edu

Abstract

The long-spined sea urchin *Diadema antillarum* was once an abundant reef grazing herbivore throughout Caribbean coral reefs. Benthic surveys conducted in the Florida Keys during the 1960-70s revealed average densities of 5-10 individuals per square meter. In 1983-1984, an unidentified disease affecting *D. antillarum* appeared on the east side of the Panama Canal and spread with prevailing currents, causing 93-100% mortality on Caribbean coral reefs. Widespread population reductions from this event resulted in a sudden lack of reef herbivory and increase in macroalgae cover and contributed to an ecological phase shift from hard coral dominated to macroalgae dominated reef systems in many areas. *D. antillarum* population recovery since 1983-1984 has been slow or nonexistent. Attempts to restore resilient coral reefs at significant scale would benefit from restoring lost herbivory via establishment of sexually propagated *D. antillarum*. A critical first step in this direction is the ability to reliably produce *D. antillarum* from gametes. Investigations into *D. antillarum* aquaculture have been occurring for almost 30 years with limited success due to the difficulty and length of the larviculture process. The purpose of this study is to refine methodology for reliable *ex situ* reproduction and larval rearing of *D. antillarum* in closed recirculating aquaculture systems (RAS), which would improve the viability of experimental population enhancement. A novel 1800-L RAS incorporating unique 40-L circular larviculture vessels was developed to perform replicated trials aimed at investigating culture bottlenecks and critical phases of larval development. Initial investigations examined the effects of microalgae diet cell densities and diet species combinations on larval morphometrics and development. Larvae reared on microalgae diets containing the cryptomonad microalgae *Rhodomonas lens* exhibited greatly improved growth and survival over 21- and 42-day long trials. Rudiment appendage development was also observed in a higher proportion in larvae reared on diets containing *Rhodomonas lens*. Additional data including appropriate larval densities and water quality parameters will be presented. The novel RAS successfully produced juvenile *D. antillarum* and current efforts are focused on scaling up production to reef-relevant levels.

Oral
A-1463

Science to inform coral seeding: lessons learnt from five field trials on the Great Barrier Reef

Randall, C.[1, 2], Page, C.[1], Whitman, T.[1, 2], Jurriaans, S.[1], Giuliano, C.[1], Hoogenboom, M.[2], Severati, A.[1], Sims, C.[1], Bickel, A.[3], Miller, M.[3], Webster, N.[1], Abdul Wahab, M.[1], Heyward, A.[1], Negri, A.[1]
[1]Australian Institute of Marine Science, Townsville, Australia
[2]James Cook University, Townsville, Australia
[3]SECORE International, Hilliard, United States

c.randall[at]aims.gov.au

Abstract

Renewal of coral populations through natural recruitment is declining as oceans warm. One aim of reef restoration is to augment natural recruitment by seeding sexually produced coral larvae and juveniles onto degraded reefs. Yet upscaling restoration with coral propagules will require overcoming inherently low rates of post-settlement survival, particularly on degraded reefs, and improving our understanding of the context-specific drivers of this mortality. To inform coral seeding techniques, we undertook a series of trials on the Great Barrier Reef (GBR) to investigate ecological and methodological questions, including: (i) the effect of conditioning duration, (ii) the role of herbivory, (iii) the effect of microcrevice structure and seeding-device design, (iv) the role of receiving community composition, and (v) the effect of species and genotype on coral survival. The key findings from these trials suggest that protection from herbivory is paramount, that survival is highest in microrefugia within the devices but that many microrefugia designs work, and that receiving community and genotype both significantly influence survival success. These results improve our understanding of context-specific drivers of success or failure in coral seeding, and can be fed into decision support tools to guide future restoration.

Oral
A-2118

Sustainable coral restoration by establishing in situ "artificial spawning hotspots" -1. Enhancement of larval supply utilizing "larval cradle"-

Suzuki, G.[1], Tanita, I.[1], Tashiro, S.[1], Suhara, Y.[2], Komatu, T.[3], Kanyama, T.[4], Nakase, S.[5], Sasaki, M.[5]
[1]Fisheries Technology Institute, Ishigaki, Japan
[2]ECOH Corporation, Tokyo, Japan
[3]KOKUSAI KOGYO Co.,Ltd., Tokyo, Japan
[4]Fisheries Infrastructure Development Center, Tokyo, Japan
[5]Ministry of Agriculture, Forestry and Fisheries, Tokyo, Japan

gosuzu[at]affrc.go.jp

Abstract

Coral reef degradation, increasingly common in recent times, has escalated significantly due to pandemic bleaching events during 2015-2017 that caused severe damage to coral communities worldwide. Preservation of these coral communities that function as fisheries grounds and nurseries is crucial for ensuring sustainable utilization of fisheries resources in tropical coasts. Coral transplantation is known to be a positive restoration method. However, large-scale transplantations require a great deal of labor. Even if it succeeds once, the transplanted corals are vulnerable to extermination by only a single disturbance such as bleaching events and outbreak of crown-of-thorns starfish (COTS). Hence, sustainable large-scale coral restoration requires enhanced annual larval recruitment, which could be ensured by amplifying reproduction in corals. This can be approached by considering two key factors crucial for sustainable coral restoration. First, initial survivability could be improved by collecting eggs and sperms at spawning and rearing larvae until settlement. Second, "artificial spawning hotspots" that consist of a densely populated conspecific adult colonies and protect these from disturbances should be subsequently established. In this slot, we report novel techniques that can suppress initial mortality in corals by ensuring high fertility at spawning and settling larvae steadily on artificial substrates. For this, a special larval collector called "larval cradle" was developed that can consistently perform bundle collection, fertilization, and larval rearing in the field, which allowed us to produce more than 10 million larvae per collector without effort. We tried to seed these larvae directory onto seafloor by moving "larval cradle" itself. In addition, we have devised a short square mortar tube, called "mortar square hollow section (mSHS)", as a substrate to enhance larval settlement and survival rates. By combining these techniques, we expect to introduce an efficient, large-scale coral rearing method in the field with a thousand-fold higher rate of survival compared to nature.

Oral
A-1650

Longer nursery duration improves growth and survivorship of coral juveniles: implications for selective breeding interventions

van der Steeg, E.[1], Humanes, A.[1], Bythell, J.[1], Edwards, A.[1], Miller, M.[2], Guest, J.[1]
[1]Newcastle University, Newcastle upon Tyne, United Kingdom
[2]SECORE International, Miami, United States

e.van-der-steeg2[at]newcastle.ac.uk

Abstract

High rates of early post-settlement and post-transplant coral mortality can result in bottlenecks to natural recovery and successful large scale reef restoration. Several studies have shown that fish exclusion leads to increased juvenile coral survivorship. However, most studies to date use techniques, such as cages or specially designed substrates, that exclude almost all fish or that alter abiotic factors, such as water flow and light levels. This makes it hard to separate out the effects of large grazer exclusion from these other factors. In addition, settlement plates with very young corals (< 1 month old) are often used and not much is known about other early life history stages (e.g., juveniles >2 cm diameter). This study tested the effects of deterring large fish grazers on the survivorship and growth of *Acropora digitifera* juveniles reared from eggs in Palau. Juvenile corals were outplanted at six months old with a mean diameter 2.2 ± 0.2 cm. A minimally invasive approach was designed to selectively exclude larger grazing fish (e.g., parrotfish) while minimising abiotic changes such as light and water flow. This involved metal spikes arranged around outplanted corals to act as fish grazing deterrents. Long and short (mean protrusion 7.1 cm and 5.1 cm respectively) spikes were arranged around juvenile corals at approximately 0.8 cm distance, creating 5 treatments to mimic different degrees of grazer deterrence: 1) 4 long, 2) 4 short, 3) 2 long, 4) 2 short and 5) a control with no spikes. The mean survivorship of all fish grazer deterrent treatments was significantly higher compared to the control seven months after outplanting. The two treatments of 4 long and 4 short spikes had the highest survivorship (72.5% and 70.0% respectively), almost double that of the control treatment with no spikes (37.5%), suggesting a strong effect of excluding larger grazers on six-month-old juvenile corals. This study demonstrates the dramatic effect of large fish grazing on juvenile coral survivorship and early outplant mortality, highlighting the need to develop substrates for sexual coral propagation that will protect corals from large grazers.

Oral
A-1794

Starting them young: Ecophysiological benefits and trade-offs of manipulating algal symbiont communities in threatened Caribbean coral recruits

Williamson, O.[1], Allen, C.[2], Hardy, K.[1], Dennison, C.[1], Miller, M.[3], Williams, D.[4], Cunning, R.[5], Baker, A.[1]
[1]University of Miami's Rosenstiel School of Marine and Atmospheric Science, Marine Biology & Ecology, Miami, United States
[2]University of Melbourne, Melbourne, Australia
[3]SECORE International, Miami, United States
[4]NOAA Southeast Fisheries Science Center, Key Biscayne, United States
[5]Shedd Aquarium, Chicago, United States

omw10[at]rsmas.miami.edu

Abstract

Intervention strategies to create “climate smart” corals for restoration include manipulating the association between corals and their algal endosymbionts (Family Symbiodiniaceae). In adult Caribbean corals, controlled bleaching and recovery can shift symbiont assemblages in favor of thermally-tolerant *Durusdinium trenchii* and increase bleaching thresholds by 1-2°C. However, the implications of hosting *D. trenchii* during the early life stages of Caribbean corals remain largely unknown. Since most coral larvae are not supplied with Symbiodiniaceae, there is a window during early ontogeny when potentially diverse algal symbionts may be acquired. Establishing an environmentally-appropriate symbiont community may underpin survival and fitness during the first few months of a coral’s life. Here, we tested methods to experimentally boost the proportion of thermotolerant *D. trenchii* in newly-settled, aposymbiotic juveniles of six Caribbean species, and examined the resulting ecophysiological benefits and trade-offs. Recruits of all species were found to acquire *D. trenchii*, but to different extents; significant interactions were found between coral species and symbiont source (coral fragments vs. algal cultures). In a heat stress experiment, *O. faveolata* recruits hosting predominantly *D. trenchii* survived twice as long as those hosting other taxa. In addition, when exposed to stony coral tissue loss disease (SCTLD), *M. cavernosa* recruits hosting *D. trenchii* were significantly less susceptible to infection than those hosting *Breviolum*. However, *O. faveolata* recruits hosting predominantly *D. trenchii* were an average of 50% smaller in size than those with other symbiont types, indicating possible trade-offs between stress tolerance and growth. Although such drawbacks are important to consider, the advantages of hosting *D. trenchii* may outweigh the risks in the face of rapidly warming oceans and deadly disease outbreaks. Together, our findings suggest that *D. trenchii* (and possibly other symbiont types) can be intentionally introduced in the coral sexual propagation pipeline, and may help researchers and practitioners evaluate early symbiont community manipulation as a tool for reef restoration. The simplicity and potential scalability of these methods present a relatively low-cost, efficient opportunity to enhance Caribbean coral resilience during early life stages prior to outplanting on the reef.

Oral
A-1228

Promoting coral larval settlement using natural hydraulic lime substrates with inorganic additives.

Yus, J.[1], Noriega, J.[1], Lovrich, E.[1], Levenstein, M. A.[1], Nixon, E.[2], Quinlan, Z. A.[2], Wegley Kelly, L.[2], Bennett, M.-J.[3], Vermeij, M. J. A.[3, 4], Marhaver, K. L.[3], Espinosa-Marzal, R. M.[1], Wagoner Johnson, A. J.[1]
[1]University of Illinois at Urbana-Champaign, Urbana, United States
[2]Scripps Institution of Oceanography, University of California San Diego, San Diego, United States
[3]CARMABI Foundation, Willemstad, Curaçao
[4]University of Amsterdam, Department of Freshwater and Marine Ecology, Institute for Biodiversity and Ecosystem Dynamics, Amsterdam, Netherlands

jyus[at]illinois.edu

Abstract

Providing suitable habitats for natural coral growth is an important area of research in coral restoration. We designed and produced engineered substrates with a combination of inorganic additives and tested them for their ability to enhance larval settlement, with the ultimate goal of further aiding in the post-settlement growth, mineralization, and defense of juvenile corals. This work complements current larval propagation practices, which typically rely on the biochemical effects of settlement induction by marine biofilms and/or crustose coralline algae. Building upon our previous work [1], we extended our studies to a calcium carbonate-rich substrate material, natural hydraulic lime (NHL). This is an inexpensive material that can be easily processed by 3D printing or molding without requiring complex equipment and which has a higher durability than the non-hydraulic lime mortar that we investigated previously. We hypothesized that the presence and/or controlled release of Mg, Sr and Ca ions from the substrate materials could help cue the complex search behavior of the larvae during this crucial stage in the life, and thus promote the initiation of settlement and metamorphosis. To test this hypothesis, we investigated NHL-based substrates into which we incorporated $SrCO_3$, $MgSO_4$ and $MgCO_3$-based additives with concentrations ranging between 5% and 20% by mass. The settlement induction of these substrates was then investigated in three Caribbean broadcast-spawning species (*Colpophyllia natans*, *Diploria labyrinthiformis* and *Orbicella faveolata*). We found that larvae exhibit different preferences for a subset of the substrate compositions in a species-specific manner. In general, larvae of all three species showed a preference for NHL with lower silicate content. In addition, *C. natans* and *D. labyrinthiformis* showed a preference for NHL containing a combination of Mg and Sr carbonates. In ongoing work, we are investigating how these additives influence the skeletal composition of settled juvenile corals.

[1] Mark A. Levenstein et al., Composite Substrates Reveal Inorganic Material Cues for Coral Larval Settlement, ACS Sustainable Chemistry & Engineering (2022) (accepted) DOI:10.1021/acssuschemeng.1c08313

Virtual
Oral
A-2085

Growth of a Ten-Month Old Caryophyllid Coral, Euphyllia glabrescens, (Chamisso and Eysenhardt, 1821) in Concrete Tank

Ayop, A.[1, 2]
[1]University of Northern Philippines, CAS-Academic, Vigan City, Philippines
[2]University of San Carlos, Biology Department, Cebu City, Philippines

antonio.ayop[at]unp.edu.ph

Abstract

Larval dispersal and settlement of corals have been given more attention in research, especially in the recruitment period and growth of the juveniles. Studies on sexually produced juveniles show slow and fast growth in some species of corals. Hence, growth is a vital characteristic of post-settlement juveniles to withstand any physical disturbance that might occur. This study was conducted to determine the growth of the *Euphyllia glabrescens* in two different plates (cement and red clay) if there is a significant difference. Cement and red clay plates were used since these materials were relatively cheaper and easy to fabricate. The monitoring of growth was every month for a period of ten months, from June 2015 to March 2016. Using the Geometric Mean Diameter (GMD) of the corallite cup of all settled juveniles in both the red clay and cement plates was measured under a stereoscope. Results revealed that the average larval-juvenile growth development of *E. glabrescens* in the monthly growth rate of cement was 0.28 mm mo^{-1}, and the red clay plate was 0.31 mm mo^{-1}, and there was no significant difference. The mean accumulated diameter growth over ten (10) months was in slow growth in both red clay plates with 3.73 ± 0.43 mm, and 3.53 ± 0.74 mm for cement plates. In accumulated growth in both plates, there was no significant difference. However, during observation, the red clay produces tiny particles (pulverize) that cause prone dislodgement of juveniles, and for those juveniles in the cement, the juveniles were firmly attached. The slow accumulated growth in both plates was due to the presence of the fast-growing green algae such as *Ulva* sp. and turf algae that outcompete nutrients and light. Therefore, in the mass production of *E. glabrescens* juvenile for future use in the restoration aspect, highly recommended the cement plate with dimensions of 2.5 cm x 2.5 cm x 1 cm to minimize surface area for algal encroachment and easy to locate the juveniles.

Session 13G - What methods and techniques can scale-up coral reef restoration?

Conceptualized by: **Sarah Frias-Torres** [1], **Tom Moore**[2]
[1] Vulcan Inc. (Seattle, WA, USA)
[2] NOAA Restoration Center (St. Petersburg, FL, USA)

Chaired by: Elisa Bayraktarov [1], Tali Vardi [2], Nicole Kube 3
[1] Griffith University (Nathan, Australia)
[2] NOAA Restoration Center (St. Petersburg, FL, USA)
[3] Deutsches Meeresmuseum (Stralsund, Germany)

Oral
A-1414

Motivations, success, and cost of coral reef restoration

Bayraktarov, E.[1], Saunders, M.[2], Frias-Torres, S.[3, 4]
[1]Griffith University, Digital Solutions, EcoCommons Australia, Nathan, Australia
[2]CSIRO Oceans and Atmosphere, St Lucia, Australia
[3]Project Drawdown, San Francisco, United States
[4]Smithsonian Marine Station, Fort Pierce, United States

e.bayraktarov[at]griffith.edu.au

Abstract

Coral reef restoration is an increasingly important part of tropical marine conservation. Information about what motivates coral reef restoration as well as its success and cost is not well understood but is needed to inform restoration decisions. This is crucial if we want to scale up coral reef restoration interventions to meaningful ecological, socio-economic and spatial scales. First, we systematically reviewed and synthesized data from mostly scientific studies published in peer-reviewed and gray literature on the motivations for global coral reef restoration, the variables measured, outcomes reported, the cost per hectare of the restoration project, the survival of restored corals, the duration of the project, and its overall spatial extent depending on the restoration technique employed. According to published literature, the main motivation to restore coral reefs for the projects assessed was to further our ecological knowledge and improve restoration techniques, with coral growth, productivity, and survival being the main variables measured. The median project cost was 400,000 US$/ha (2010 US$), ranging from 6,000 US$/ha for the nursery phase of coral gardening to 4,000,000 US$/ha for substrate addition to build an artificial reef. Restoration projects were mostly of short duration (1-2 years) and over small spatial extents (0.01 ha or 108m2). Median reported survival of restored corals was 60.9%. Second, to overcome publication bias and fill the gap between academia and work done by practitioners, we interviewed 12 coral reef restoration projects from five Latin American countries and found that most of them used direct transplantation, the coral gardening method, micro-fragmentation or larval propagation. Median annual total cost from all projects was $93,000 USD (range: $10,000 USD - $331,802 USD) (2018 dollars) and intervened a median spatial area of 1 ha (range: 0.06 ha - 8.39 ha). The median project duration was 3 years; however, projects have lasted up to 17 years. We conclude by sharing 'bright spots' in marine restoration across different ecosystems by highlighting examples of projects which were large in extent, cost-effective compared to other projects, persisted over long durations, expanded rapidly in area, and generated social and economic benefits.

Oral
A-1095

Effect of substratum structural complexity of coral seedlings on the settlement and post-settlement survivorship of coral settlers

Fujiwara, S.[1], Kezuka, D.[2], Hagiwara, K.[3], Ishimori, H.[2], Tabata, H.[4]
[1]IDEA Consultants, Inc., Institute of Environmental informatics, Tsuzuki, Yokohama, Japan
[2]IDEA Consultants, Inc., Okinawa Branch, Naha, Okinawa, Japan
[3]Okinawa Environmental Research Co., Ltd., Naha, Okinawa, Japan
[4]IDEA Consultants, Inc., Setagaya, Tokyo, Japan

fjw20240[at]ideacon.co.jp

Abstract

The substratum structure used by coral seedlings is critical for facilitating settlement and for increasing the survivorship of coral spats. However, knowledge of substratum complexity remains largely unknown. In this study, we examined the effect of substratum structural complexity on the settlement and post-settlement survivorship of coral larvae using 4 types of substrata: Coral Settlement Device (CSD, 4.5 cm φ × 2.5 cm H, top-shaped), Ceramic Plate (CP, 29.5 cm L × 3.1 cm W × 0.9 cm H, unglazed ceramic plate), Coral Net (CN, 30 cm × 60 cm, mesh size 19 mm, plastic net), and Scallop Shell (SS, 11.0 cm in shell length) . The structural complexity obtained from the ratio of the surface area to the vertical projected area of the substrata was CSD: 3.77, CP: 2.65, CN: 2.00, and SS: 2.00. The substrata sets were installed at each of the 14 sites, by June of each year between 2012 to 2014, around the Ryukyu Islands of Okinawa. This is the simultaneous spawning season of the dominant *Acropora* corals. After about 2 and 6 months of spawning, a certain number of each type of substrata was sampled and the number of coral spats, by taxa, which settled on them, was counted . The larval settlement rate (= number of substrata settled / number of substrata installed × 100) in the first set of samples and the survivorship (number of colonies on each substrata in the second sampling / number of settlers on each substrata in the first sampling × 100) of coral spats in the second set of samples were estimated. The mean settlement rate was CSD (37.3%), CP (29.3%), CN (30.2%), and SS (33.0%), and the mean survivorship was CSD (51.7%), CP (33.0%), CN (7.0%), and SS (25.4%), for the three-year period. A positive correlation was found between substratum structural complexity, mean settlement rate, and mean survivorship. Our results show that substratum complexity of coral seedlings influences the settlement of coral larvae and the survivorship of coral spats.

Oral
A-1607

Turning Restoration Sites into Nurseries Using Cuttings from Outplants to Exponentially Increase the Restoration Footprint and the Number of Corals

Griffin, S.[1], Nemeth, M.[1], Rodriguez, P.[2], Irizarry, E.[2], Flynn, K.[2], Ruiz, H.[3]
[1]NOAA Restoration Center, Aguadilla, Puerto Rico
[2]Sea Ventures Marine Response Unit, Fajardo, Puerto Rico
[3]HJR Reefscaping, Cabo Rojo, Puerto Rico

sean.griffin[at]noaa.gov

Abstract

One of the main challenges to current coral restoration efforts is how to significantly scale up techniques by increasing production while reducing costs and diver interaction time with corals. Many groups around the world are propagating corals in nurseries. In the nursery, we can take one colony, cut it into several fragments, grow those out and then repeat the process to produce tens of thousands of corals that are available to help reseed and repopulate reefs. These corals are then outplanted which usually involves transporting corals to another site and divers reattaching corals one by one. What we have been doing so far is relatively slow, time intensive and relatively expensive. It requires a lot of diver interaction time. What if each of our restoration/ outplant sites can become additional nurseries. We can take cuttings from previous outplants once they have grown to exponentially increase the numbers of corals and the size of the restoration footprints. After a few years, many transplants have multiple branches. We can harvest some of these branches and use them for expansion. Results from Puerto Rico presented here show that this method works. Donor colonies heal within a few weeks, and the cuttings survive well. A few years after the first outplanting, the number of corals at these sites and the restoration footprints were increased by a scale of magnitude. This method reduces the costs per coral and diver interaction times while exponentially increasing production. There are also no structures or plastic involved in this method. If the site can't be maintained due to lack of funding or other issues, nothing is lost. The "nursery" mimics a natural ecosystem.

Oral
A-1281

3D Printing and Fabrication for Sustainable and Eco-Friendly Coral Restoration

Hauser, C., Bilalis, P., Albalawi, H., Khan, Z., Valle-Pérez, A., Alrashoudi, A., Ponce de León, E. H.
King Abdullah University of Science and Technology, Biological and Environmental Sciences and Engineering, Thuwal, Saudi Arabia

charlotte.hauser[at]kaust.edu.sa

Abstract

Coral reef degradation is a key area of concern, mainly caused by the spread of coral diseases, overfishing, pollution and marine heat waves. There is a pressing need to develop scalable methods for effective, cost-efficient restoration of coral ecosystems. While current approaches attempt to address this issue, they often rely on the use of synthetic non-natural materials, which could release toxic compounds in the long-term, and are severely limited in scalability. Hence, our goal is to provide novel eco-friendly and sustainable coral restoration methods. We developed a multi-step fabrication process, named 3D CoraPrint, which involves reverse engineering of live coral structures, fabrication of 3D coral replicas with eco-friendly inks, and propagation of live coral samples by micro-fragmentation. Our in-house developed Calcium Carbonate Photoinitiated ink (CCP) is environmentally friendly and tolerates harsh conditions in terms of temperature, salinity and pH without signs of degradation. Our method exploits 3D printing technology to fabricate artificial natural-based coral skeletons, expediting the growth rate of live coral fragments and quickening the reef transplantation process while minimizing nursery costs. In addition, it allows for flexibility and customization thus establishing a scalable model for coral fabrication to boost restorative efforts around the globe. Departing from a baseline on the current state-of-the-art technology for 3D printing of coral skeletons, we provide here a number of steps toward pushing the boundaries of 21st century coral reef restoration processes, and through 3D printing and fabrication aim to develop a more eco-friendly and sustainable process in the future.

Oral
A-1823

The Value of Integrating Community Groups into Restore with Resilience Efforts

Hughes, K., Caruso, C., Hancock, J., Drury, C.
Hawaii Institute of Marine Biology, Kaneohe, United States

kirawa[at]hawaii.edu

Abstract

The decline of coral reefs has prompted multiple stakeholder groups to get involved, but the scale of the problem is extensive and diffused. Coral restoration is a validated and essential tool to restore viable coral populations. Research suggests that a significant amount of coral must be restored to improve climate tolerance, so it is critical that efforts include local community groups in the design and implementation of restoration efforts to reach the scale needed to make a lasting impact. Given the widespread negative impacts of recent ocean warming events, this *Restore with Resilience* project promotes a change from conventional restoration to "proactive restoration" to account for future conditions. Community involvement enhances perception, stewardship and attachment, thereby reinforcing healthy human-coral reef relationships beyond the initial active, hands-on engagement. For the first time, this project aims to combine selective propagation of thermally tolerant corals with community efforts. The efficacy of this approach will be determined with a focus on the methodologies, materials, and logistics for collecting corals of opportunity, testing resilience, outplanting, and monitoring. The overarching goal is to develop best practices that translate across regions and among stakeholder groups.

Oral
A-1554

Cost-Efficiency and Scalability of Larval Propagation Technologies through Engineering

McGonigle, M.[1], Bickel, A.[1], Petersen, D.[2]
[1]SECORE International, Miami, United States
[2]SECORE International, Bremen, Germany

m.mcgonigle[at]secore.org

Abstract

The majority of current coral restoration projects are one hectare or smaller. While many are effective at this local scale, the quantity of divers, labor, and infrastructure, etc. needed to increase the size of restoration effort casts doubt on their applicability at larger scales. Recognizing this, SECORE International has approached this challenge by incorporating engineering expertise, both internally and externally, to address bottlenecks as we look to scale restoration operations. An example of this approach is the extrapolation of design requirements for artificial larval seeding units with knowledge of corals' ecological requirements for settlement and post-settlement survival, such as surface texture, surface area, mass, size, shape and microhabitats. Our original units were fabricated out of concrete, by hand, using cast molds. These units are functional and provide adequate settlement results at a modest economic point, but have room for improvement. When considering increasing production from hundreds to tens of thousands of units, the amount of manual effort required to manufacture and handle each unit in this manner is untenable. By breaking down and defining our knowledge into specific design requirements and specifications – materials to create a specific surface texture to support larval settlement and dissuade predation and fabrication modes to create desired sizes, shapes and microhabitats to support larval settlement, handling, and retention on the reef – that are written in a language which manufacturers and industry can understand and incorporate. Gamete collection, larval rearing, and coral outplanting are further examples of areas where we have applied this perspective and techniques. By taking a process level approach considering design, fabrication, and logistics while leveraging interdisciplinary support, we allow our research team to focus on overcoming biological constraints while the engineering team focuses on the bottlenecks of scaling our solutions for coral reef restoration.

Oral
A-1398

Increasing exsitu coral nursery productivity by optimizing seawater temperature

Merck, D.[1], Petrik, C.[2], Manfroy, A.[1], Muller, E.[3]
[1]Mote Marine Laboratory, Coral Reef Restoration, Summerland Key, United States
[2]Mote Marine Laboratory, Summerland Key, United States
[3]Mote Marine Laboratory, Coral Reef Restoration, Sarasota, United States

dmerck[at]mote.org

Abstract

Ex situ coral propagation for reef restoration is a fairly new and evolving field, especially when conducted on a macroscale. Production rates of cultured corals can be optimized by slight changes in environmental parameters. However, while in cultured facilities, corals are also subjected to associated pests such as stinging hydroids, infectious diseases, and cyanobacterial blooms. Therefore, reducing ex situ residency time by altering environmental parameters can lead to greater survivorship and faster biomass production of cultured corals. Studies indicate that some species of coral display parabolic tissue growth in association with water temperatures, where growth increases with increasing temperatures until their threshold is exceeded, which leads to bleaching, reduced growth, and potential mortality. To maximize coral biomass production in Mote Marine Laboratory's ex situ facility, we tested the effect of two water temperature treatments (control: 25.2 ± 0.08 °C; high temperature: 29.5 ± 0.03 °C) on four coral species commonly used in reef restoration during a 7 month grow-out period with the goal of increasing growth rates without exceeding temperature thresholds. We used four replicate clones of three genotypes of Acropora palmata, Montastraea cavernosa, Orbicella faveolata, and Pseudodiploria clivosa. ImageJ software was used to record two-dimensional tissue area and survival rates were determined via visual observations. Results suggest that M. cavernosa had faster growth rates in the high temperature treatment in contrast to the control treatment, whereas A. palmata had faster growth in the control treatment in contrast with the high temperature treatment. Survival of these two species was equal regardless of the treatment . P. clivosia and O. faveolata had faster growth in the high temperature treatment compared to the control treatment, however, both of these coral species experienced near complete mortality within the first 4 months due to an unknown tissue loss event. The loss of two coral species during their grow-out period highlights the challenges associated with maintaining optimal health of coral within land-based systems. The results also suggest that temperature preferences are present among coral species within ex situ systems and restoration practitioners should consider species-specific temperature regimes to maximize ex situ coral growth rates during the planning and operations of land-based coral nurseries.

Oral
A-1028

Toward improved retention of unattached coral seeding units

Miller, M.[1], McGonigle, M.[1], Haus, B.[2], Severati, A.[3], Rojas, C.[4], Nguyen, M.[5, 6], Bickel, A.[1]
[1]SECORE International, Miami, United States
[2]University of Miami, Rosenstiel School of Marine and Atmospheric Sciences, Miami, United States
[3]Austrailan Institute of Marine Science, Reef Restoration and Adaptation Program, Townsville, Australia
[4]Engineering for Change, Panama City, Panama
[5]Columbia University, New York, United States
[6]Engineering for Change, New York, United States

m.miller[at]secore.org

Abstract

The step of attaching coral propagules to the reef surface is among the most costly in most coral restoration pipelines. One solution is to obviate the attachment step completely by ‘sowing’ or wedging propagules. Coral larval seeding units (SUs) are artificial substrates that can be designed with specific characteristics to foster efficient handling, self-stabilization, and favorable habitat for coral recruits. In order to improve the retention of unattached SUs, we tested the stability/movement of SUs with different morphologies under controlled hydrodynamic forcing in the SUSTAIN (SUrge-STructure-Atmosphere Interaction) laboratory at the University of Miami. A standardized bottom surface with (ridged) rugosity features was placed on the bottom of the wave simulation tank. Along with seeding unit devices that are in current use in larval propagation programs (7-10 cm in maximum dimension) we devised several series of SU test models, each isolating a particular characteristic (e.g., mass, size, number of arms, asymmetry of arms, etc). Tests on these SUs were performed under four graded conditions of current and wave forcing. A ranked score was assigned to each device under each set of forcing conditions according to its observed stability or movement. Factors that had unexpectedly high influence on stability included the profile/surface area and the distribution of mass within the unit. These factors will be considered in future SU design iterations, within the constraints imposed by other factors crucial to upscaling efficiency including recruit habitat quality, handling efficiency, and manufacturing cost.

Oral
A-2103

Printing 3D coral models that fish like

Oren, A.
Ben-Gurion University, Eilat, Israel

asaoren[at]gmail.com

Abstract

Natural live coral and coral skeletons are harvested for a range of applications including the aquarium trade, decoration, souvenirs, education, and science. 3D printed corals can take their place in many of these applications. Although lacking live tissue, the printed structure can be identical to a coral, and the models can be printed from different materials, colors, and manipulated to suit specific needs. We used 3D printed corals to examine fish preferences in shelters. 3D printed coral models, based on a *Stylophora pistillata* skeleton, were manipulated and printed in different materials and colors. Next, they were set on a natural coral reef to determine fish's response. 3D printed corals recruited multiple fishes of 8 species. Examining fish preference, the most preferred a yellow color Poly-Lactic Acid (PLA) shelter, which was preferred over the original skeleton as well as over live corals. Other materials and colors had fewer interactions. For example, models made from gypsum had no interactions observed at all during the entire test. The yellow PLA was then used in printing 15 models which were structurally manipulated out of the original coral structure. The larger structures showed higher amount of fish interactions, especially the largest structure (200% larger than the original size) which had a 100% increase in species richness and 500% in fish interaction abundance as compared to the original printed model. It should be noticed that all of the artificial models showed higher species diversity and richness as compared to control live corals and natural coral skeletons. It is also worth noticing that *Chromis viridis* fish even laid eggs, and protected them all the way to hatching, on some of the models. This study is another step in developing 3D printed models to replace corals harvested from the sea.

Oral
A-1243

Is fertilisation success of small outplanted coral patches even achievable? Density-dependent effects of fecund adult colonies on coral reproduction.

Ricardo, G.[1], Doropoulos, C.[2], Babcock, R.[2], Mumby, P.[1]
[1]Univeristy of Queensland, School of Biology, St Lucia, Australia
[2]CSIRO, Brisbane, Australia

g.ricardo[at]uq.edu.au

Abstract

As coral reefs face an uncertain future under climate change, recovery and restoration programs are now being adopted in many places globally, investigating multiple possible interventions that aim to assist coral reefs through a warmer world. Many interventions involve translocating or outplanting corals to a degraded reef to maintain ecosystem functions, facilitate reseeding, or introduce genes that improve heat-tolerance. However, an underlying assumption for the success of these interventions is that introduced small-scale patches of coral will eventually reproduce and cross-fertilise. Yet even larger natural populations can suffer from Allee effects during fertilisation, whereby insufficient sperm concentrations lead to poor fertilisation success, especially when substantial dispersive forces (such as wind and currents) coincide with the spawning event.

We conducted a manipulated field experiment using two common broadcasting *Acropora* species to assess if small populations of translocated coral can successfully fertilise. The patches were isolated from conspecifics by a unique ‘ponding effect’ that occurs at low tide within the main lagoon at One Tree Island Reef, Great Barrier Reef. On the main night of spawning, which presented relatively calm hydrodynamic conditions, eight colonies of *Acropora tenuis* spawned with an average intercolonial distance of 2.0 m, whereas 15 *Acropora digitifera* spawned with an average intercolonial distance of 1.1 m. For *Acropora tenuis*, observed fertilisation success was mainly attributed to a single replicate (~25% fertilisation), the only sample above the self-fertilisation rate of ~2%. In *A. digitifera*, half the replicates had an observed level of fertilisation success above the self-fertilisation rate (0%). *In situ* sperm concentrations ranged from $0 – 2.2 \times 10^3$ (*A. tenuis*), and $9.6 \times 10^1 – 1.3 \times 10^3$ (*A. digitifera*), with the upper range at concentrations known to cause successful fertilisation in laboratory experiments.

Our results indicate, for the first time, that small-scale patches of outplanted corals are capable of fertilising under relatively calm hydrodynamic conditions, but outplant interventions require considerations to the patch size and density, in addition to the likely prevailing hydrodynamic conditions, at the time of spawning.

Oral
A-1172

Antifouling coatings can reduce algal growth in coral aquaculture

Röpke, L. K.[1], Brefeld, D.[1], Soltmann, U.[2], Randall, C. J.[3], Negri, A. P.[3], Kunzmann, A.[1]
[1]Leibniz Centre for Tropical Marine Research, Bremen, Germany
[2]Gesellschaft zur Förderung von Medizin-, Bio- und Umwelttechnologien e.V., Dresden, Germany
[3]Australian Institute of Marine Science, Townsville, Australia

lisa.roepke[at]leibniz-zmt.de

Abstract

Early coral recruits can be overgrown and outcompeted by algae, reducing survival in coral aquaculture and the supply of recruits for restoration programs. Here we investigated a suite of antifouling (AF) coatings for their fouling inhibition efficacy on aragonite surfaces (plugs) in aquaria and tested coral larval settlement as an indicator of potential toxicity of the AF coatings. Uncoated plugs became heavily fouled with only 4-8% bare substrate remaining on upper surfaces after 37 days. During this period, the encapsulated dichlorooctylisothiazolinone (DCOIT)-coating was most effective (51% of bare substrate), with the antiadhesive and CeO_{2-x} nanoparticle (NP) coatings being less effective (23% and 2.4% bare substrate, respectively). Average settlement of *A. tenuis* larvae on the AF-coated plugs did not statistically differ from settlement on the uncoated controls. However, settlement on the NP-coating was generally the highest and was significantly higher than the lowest settlement found on the antiadhesive coating. On partially AF coated plugs, larval settlement on control and NP-coated areas was significantly higher than settlement on the antiadhesive and DCOIT coatings. Our results suggest that AF coatings can reduce fouling intensity while preserving coral settlement, a first step towards controlling fine-scale competition with other benthic organisms in coral aquaculture.

Oral
A-1639

Choral reef conservation: Turning bioacoustics knowledge into practical solutions to protect, monitor and restore reef communities

Simpson, S.[1], Lamont, T.[2], Nedelec, S.[3], McCormick, M.[4], Meekan, M.[5], Radford, A.[6]
[1]University of Bristol, School of Biological Sciences, Bristol, United Kingdom
[2]University of Lancaster, Lancaster, United Kingdom
[3]University of Exeter, Exeter, United Kingdom
[4]University of Waikato, Hamilton, New Zealand
[5]Australian Institute of Marine Science, Crawley, Australia
[6]University of Bristol, Bristol, United Kingdom

s.simpson[at]bristol.ac.uk

Abstract

Over the last 20 years, we have discovered that the larvae of many reef organisms, including fish, molluscs, crustaceans and corals themselves, can cue into acoustic cues generated by reef residents. This sensory information can help larvae find coastlines, guide directional swimming, inform microhabitat selection and alter settlement behaviour. But during the same period, we have become acutely aware of the negative impacts of anthropogenic noise pollution in the ocean. On reefs, motorboat noise can be prevalent, masking cues, deterring larvae from settling, elevating stress levels, changing fish behaviour (sometimes with fatal consequences) and reducing reproductive success. Sadly, some of the most pristine reefs we first worked on have been reduced to rubble fields, with overfishing, bleaching and cyclones causing devastating mortality that is reflected in the soundscapes at our study sites. The diverse and dynamic sound of this bustling reef orchestra is no more. We are, quite literally, changing the soundtrack of the Anthropocene.

It is therefore time to turn our knowledge into solutions to restore reef communities. By listening to reefs, we realise we can hear the health of the reef community, including nocturnal and cryptic animals that evade the attention of visual surveys. We are developing metrics that will allow managers to map the health of reefs in pristine, degraded and recovering sites, and offer financiers and insurers objective metrics of recovery to support further investment. Through a range of field-based experiments, some spanning entire breeding seasons, we have developed simple management approaches to limit the negative impacts of motorboat noise. By combining spatial, temporal and technological mitigation strategies, we can increase the likelihood of larval settlement to focal sites and increase natural breeding success. Finally, applying our knowledge of acoustically mediated settlement to reef restoration sites, we are starting to call fish into new sites to accelerate recovery and maximise the chances of these reefs developing into preferred coral-dominated communities. With recently-gained bioacoustics knowledge and the opportunities and determination to "think big", we can conserve our Choral Reefs for future generations.

Oral
A-1545

Novel methods to increase scalability and foster colony development of restored Acropora cervicornis

Unsworth, J., Hesley, D., D'Alessandro, M., Carrick, J., Kaufman, M., Rivas, N., Lirman, D.
University of Miami Rosenstiel School of Marine and Atmospheric Science, Marine Biology and Ecology, Miami, United States

jdu13[at]miami.edu

Abstract

Recent years have seen a rapid global expansion of efforts to restore and sustain declining coral populations. Driven by the dire state of reefs around the world, restoration practitioners now outplant 10,000s of nursery-raised coral fragments every year; however, widely used coral attachment methods limit the number of corals that can be outplanted per day, representing a substantial bottleneck in the coral restoration process. To continue to scale up, new methods are needed that allow programs to grow their restoration footprint while reducing costs. Cement has long been used as a coral attachment tool and has potential as a more cost- and time-efficient technique, but research is needed to understand its effects on coral survivorship and develop best practices for its use. We tested 45 different cement mixes in a three-stage elimination format to determine the most effective mixture for outplanting *Acropora cervicornis* and compared this new method to two commonly used attachment techniques. The resulting cement mixture yielded equal survivorship to other methods, is twice as fast to execute, and has one-tenth of the material cost of the other methods. Using this methodology, we then tested the ability of novel outplanting arrangements to foster the development of large, sexually mature *Acropora cervicornis* colonies, a primary goal of coral restoration. We outplanted dense clusters containing multiple small fragments spaced 1-2cm apart and compared them to large fragments planted individually. We further investigated the effect of intraspecific diversity by combining multiple genotypes within a subset of clusters. Dense clusters demonstrated equivalent growth and higher survivorship than large individuals, and performance of single-genotype clusters did not differ from that of polyclonal clusters. Our findings support outplanting small fragments from multiple genotypes in high-density arrangements as a favorable alternative to outplanting large fragments individually. This technique not only allows practitioners to forgo the time and effort required to grow large fragments, but also yields polyclonal colonies that may be more resilient to thermal stress. Finally, our findings highlight cement as a cheap, effective, and underutilized coral attachment tool. While not a silver bullet, this technique will greatly expand the number of corals that can be outplanted per year, allowing coral restoration efforts to reach ecologically significant scales.

Poster
A-1427

Coral Restoration in the Maldives: opportunities and challenges of upscaling restoration efforts

Dehnert, I.[1, 2], Saponari, L.[3], Galli, P.[1, 2], Montano, S.[1, 2]
[1]Università degli Studi di Milano-Bicocca, Department of Earth and Environmental Sciences (DISAT), Milano, Italy
[2]MaRHE Center (Marine Research and High Education Center), Magoodhoo Island, Faafu Atoll, Maldives
[3]The Centre for Environment & Education, Nature Seychelles, Mahe, Seychelles

inga.dehnert[at]unimib.it

Abstract

The low-laying archipelago of the Maldives, a country that highly depends on healthy coral reefs and the services they provide, is on the forefront of experiencing the adverse effects of climate change. As coral reefs are degrading, the need for comprehensive coral restoration projects, as part of a broader conservation management strategy, is accelerating. While the Maldives have not yet explored their full restoration potential, the unique geographical and socioeconomic situation found here provides ample opportunities for local coral restoration projects on the 188 inhabited and 159 resort islands. In particular, the luxury tourism industry could be encouraged to provide the necessary resources for restoration projects of scale, given that many resorts already employ marine biologists for educational purposes, including coral frame projects. This research assesses the application of ‘coral gardening’ for upscaled coral restoration efforts in the Maldives, by providing the necessary regional validation and useful insights into the various opportunities and challenges of this technique. First, we evaluate the suitability and performance measures of mid-water coral nurseries across different atolls and islands (i.e., resort and local island) and farming habitats (i.e., lagoon and reef environment), using a common monitoring protocol. We report regional benchmark results for *Acropora, Pocillopora* and *Porites* fragment survival and growth as well as investigating ecological interactions such as mutualistic fauna and predator associations of farmed and transplanted corals. Outplanting success of nursery-grown corals is reviewed in terms of the wider ecological footprint, indicating significant benefits to the degraded reef environment by increasing fish abundance and diversity along with natural coral cover. Our research further documents some of the challenges of the coral gardening approach, by quantifying the negative impacts of unmitigated coral disease occurrence in coral nurseries and highlighting the risks of interrupted monitoring and maintenance protocols for restoration projects, resulting from the COVID-19 pandemic. Overall, this work hopes to provide a scientific baseline for future coral gardening projects in the Maldives that can guide restoration practitioners towards efficient and scaled-up coral conservation work.

Poster
A-1091

Developing propagation techniques for Dendrogyra cylindrus using in-sit and ex-situ methods

Moura, A.
Coral Restoration Foundation, Tavernier, United States

amelia[at]coralrestoration.org

Abstract

The few colonies of the morphologically unique *Dendrogyra cylindrus* (pillar coral) that remain in the Florida Keys are heavily diseased and unable to reproduce sexually, rendering the local wild-population reproductively extinct. Efforts have been made to preserve the species through a series of collection events during which fragments of live colonies were taken into coral nurseries for long-term care. This effort, known as the Pillar Rescue project, was coordinated across multiple Florida-based restoration organizations. Due to a novel bacterial disease spreading rapidly throughout Florida, Stony Coral Tissue Loss Disease, another coordinated effort was made to collect tissue from all remaining genetically unique *D. cylindrus* individuals in 2020 and 2021, known as the Coral Rescue project. These combined efforts have resulted in fragments of every known Florida-originating genotype represented in a nursery setting, yet many colonies have not yet been fragmented and stock levels remain static.

Launched by NOAA in December 2019, the Mission: Iconic Reefs plan is a 20-year, multi-organizational initiative designed to restore seven reefs in the Florida Keys. This long-term restoration plan prioritizes the restoration of other faster growing species in the first 10 years, but emphasis shifts to several more diverse species in the second half of the plan. *D. cylindrus* is one of those species, and to meet the restoration outplanting goals outlined, the number of fragments must increase. As the first step towards this goal, propagation techniques to generate hundreds to thousands of fragments must be developed specific to this delicate species. Here, we present the results of one of the first attempts to generate over new fragments of *D. cylindrus*. This effort has been incredibly successful, with over 200 fragments generated in just one year from only 35 original colonies. Methods used were a combination of in-situ and ex-situ fragmentation techniques, and newly generated fragments were attached to various substrates to understand which promoted the fastest growth in an offshore nursery environment. The success of this pilot project provides a baseline understanding of how to promote growth and minimize loss of such a delicate species in an offshore nursery environment so as to produce the amount of tissue necessary for large-scale restoration programs.

Poster
A-1522

Mineral accretion–supported coral restoration: In situ experiment to test effects of cleaning and electrification regimes on four hard coral species.

Pezin, J.[1], Wong, J.[1], Zora, A.[2], Allahgholi, A.[1]
[1]Coralive.org, Zürich, Switzerland
[2]Fregate Island, Conservation & Sustainability, Fregate Island, Seychelles

julie[at]coralive.org

Abstract

Active coral restoration experiments have shown that using Mineral Accretion Technology (MAT) significantly increases the growth, health and survival of transplanted coral fragments. This study investigates the capacity of MAT to support coral growth, health and subsequent survival *in situ*, of four different species of corals, *Acropora muricata (AM), Acropora austera (AA), Acropora vermiculata (AV) and Pocillopora meandrina (PM)*, under different maintenance cleaning and electrification schedules chosen to represent different potential real-world restoration scenarios. The experiment was deployed on Fregate Island, Seychelles in April 2021 and will run for 12 months. Here we present the results of the monitoring campaign conducted 10 months after deployment. Overall, MAT had a positive effect on coral fragment attachment and survival, with 96.8% (SD 17.21) of fragments alive after ten months on electrified structures, compared to 89.8% (SD 30.11) on not electrified structures. Cleaning did not confer additional benefits to coral growth, potentially due to the low algal fouling at this site, suggesting that cleaning can be reduced or eliminated at this site without detrimental effects on coral growth. The growth rate differed between species, with consistently higher growth rate for *AM,* followed by *AV, AA* and *PM.* MAT was beneficial to the growth of some species more than others. *AM* had the highest growth under 12hrs electrification at night, which was significantly higher compared to the 24hrs electrification treatment, though it was not significantly different from the not electrified treatment. The growth of *PM* was higher under the not electrified treatment, suggesting that it does not benefit and may be negatively affected by MAT. A total of 35 new colonies of *PM* naturally established on the experimental structures. These new colonies had a clear preference for not electrified structures, followed by 12hr electrification and then 24hr electrification structures. Additionally, we observed an overall increase in fish abundance and diversity since the beginning of the experiment. After ten months, these results suggest that, even though MAT confers clear benefits to coral fragment attachment and subsequent survival, the scheduling of electrification and maintenance cleaning could be optimized for a better growth and recruitment.

Poster
A-1928

Toxicity and Effectiveness of a New Two-Part Underwater Adhesive for Coral Restoration

Rojano, M., Renegar, A.
Nova Southeastern University, Dania Beach, United States

mr2752[at]nova.edu

Abstract

Epoxy is widely used in coral restoration, both to attach corals to substrates and as an applied firebreak to halt the advancement of disease on a coral. However, putty-type epoxies have several drawbacks; they have to be mixed by hand, and tend to have low substrate adhesion and extended hardening times. To address these issues and provide a safe and effective alternative for coral restoration activities, a new two-part mixed adhesive has been developed. This new adhesive can be dispensed underwater using a caulk-type applicator gun and static mixing tips, and has a short hardening time of approximately ten seconds. However, before it could be used in coral restoration activities, it was necessary to assess the performance and effectiveness of the adhesive and any potential aquatic toxicity.

Four 48 h static renewal dose-response assays were used to examine the potential toxicity of 1) adhesive Part A, 2) adhesive Part B, 3) the mixed adhesive and 4) the mixed adhesive when in direct contact with coral tissue. The target species for these experiments, *Acropora cervicornis*, was chosen due to its widespread use in coral restoration and the known sensitive nature of this species to aquatic contaminants. Exposure effects were evaluated using a semi-quantitative physical condition scoring metric (which included bleaching, polyp extension/retraction, tissue swelling/distension, and mucus production), mortality, and changes in photosynthetic efficiency.

Poster
A-1139

Effect of Cement Tile Composition on Coral Larval Settlement and Post-Settlement Growth

Stickley, M. G.[1], Baker, A. C.[1], Miller, M. W.[2], Williamson, O. M.[1], Hardy, K. M.[1], Suraneni, P.[3]
[1]Department of Marine Biology and Ecology, Rosenstiel School of Marine and Atmospheric Science, University of Miami, Miami, United States
[2]SECORE International, Miami, United States
[3]University of Miami, Civil and Architectural Engineering, Miami, United States

mgs152[at]miami.edu

Abstract

Coral restoration projects worldwide are increasingly focusing on sexual reproduction to boost genetic variation, particularly after disturbances. However, the success of these efforts can be variable, due to challenges inducing settlement and maximizing post-settlement survival. Many restoration projects typically use small ceramic settlement tiles or ‘plugs’ as recruitment or grow-out substrates in ex situ facilities, but the composition of these tiles is rarely investigated as a means of accelerating or promoting the growth of these early-settlers. To test whether different cementitious materials might increase settlement or promote growth, we created tiles (3x3x1 cm) using nine different cementitious mixes. After the tiles were conditioned for two weeks in a flow-through tank system, we conducted a settlement choice assay with larvae of the Caribbean species Orbicella faveolata. One tile of each type was placed in a plastic bin with approximately 10,000-15,000 embryos for one week. Settlement varied across the cementitious mixes, with 51.8% of total living settlers attaching to FA60 (28.5% Portland cement, 43% fly ash, 28.5% water) tiles while the next closest mixture (SL60: 28.5% Portland cement, 43% slag, 28.5% water) had only 13.5% of total settlers. The least successful tile type in the settlement experiment was AAS1 (67% slag, 7% sodium hydroxide, 26% water) with only 1% of total living settlers. Next, we conducted a longitudinal analysis to test whether the chemical compositions of the tiles affected the growth rates of O. faveolata recruits over four months. Pictures were taken of individual polyps biweekly under a dissecting microscope and area measurements calculated using ImageJ software. Preliminary results suggest that recruits on FA60 tiles also grew fastest among all tile types (2.2x faster than the group mean of nine treatments) and that recruits on the AAS1 tiles grew the slowest (showing an 18% reduction in size due to major skeleton and tissue loss). We hypothesize the FA60 mix (and potentially other related mixes) may change the water chemistry in the boundary layer surrounding these cementitious settlement materials, therefore enhancing larval settlement and growth, with potential applications for reef restoration efforts.

Poster
A-1606

Chimerism and reskinning of large Orbicella faveolata in the wake of SCTLD

Wheeler, A.[1], Figueiredo, J.[2], Walker, B.[2]
[1]Nova southeastern university, Marine science, Dania, United States
[2]Nova southeastern university, Halmos College of Arts and Sciences, Dania, United States

aw2060[at]nova.edu

Abstract

Stony corals (order Scleractinia) are a critically important group of species that engineered the foundation of Florida's Coral Reef (FCR) over 10,000 years ago. The FCR serves as a natural breakwater for extreme weather events and an economic well for the south Florida tourism and fisheries. Recently, numerous biotic and abiotic anthropogenic stressors have combined to dramatically reduce the health and ecosystem function of these organisms. Stony coral tissue loss disease (SCTLD) has proved to be especially damaging given its high transmission rate and interspecies lethality.
Southeast Florida is home to over 100 live large (>2m length), reef-building *Orbicella faveolata* (OFAV) corals that have survived all natural and anthropogenic pressures in the last hundred years. However, in the past 8 years, many have lost considerable live tissue from SCTLD and 13 have died completely. Once a colony dies, its surface becomes colonized by other organisms and bioerosion of the structure is accelerated. Restoring these large corals with live coral tissue will replace their lost ecosystem function, stave off bioerosion, and allow them to grow and continue providing habitat.
A main goal of coral restoration is to increase the chances for successful sexual coral reproduction. This requires different genotypes to spawn simultaneously in close proximity. To attain faster reproductive size of outplanted corals, restoration practitioners place coral fragments of the same genotype together to promote fusion. However, it may be possible to further increase chances of success through creating chimeras, corals that contain more than one genotype. Natural instances of the fusion of corals forming chimeras have been observed from the larval to the adult stage and due their proximity of the different genotypes during spawning, it will likely increase chances of cross fertilization.
Monthly monitoring of 100 large corals has provided an opportunity to collect loose fragments from these resilient individuals that would normally die and use them to restore other structures. Currently, fragments from 10 colonies/genotypes are planned to create 550 microfragments to outplant. This study aims to test if fusion among genetically distinct OFAV coral fragments is possible by outplanting different genotypes side by side. The study will allow us to determine which genotypes are compatible to fuse, i.e. form chimeras. These chimeras could be used to reskin recently dead OFAV skeletons.

Virtual
Oral
A-1379

Research on Key Technologies of Coral Biobank

Chen, H.
Hainan South China Sea Institute of Tropical Ocean, Coral Laboratory, Sanya, China

chenhong68[at]vip.163.com

Abstract

After 2 years of research on the key technologies of coral biobanks in Hainan Province, China, the construction of indoor and field banks of corals has been completed, The indoor biobank is built in the Hainan Institute of Tropical Oceanography, and the outdoor biobank is located in the waters of Phoenix Island in Sanya City and Quanfu Island in Yongle Atoll,A total of 50 species of Hermatypic coral in the first phase, The main species are porites , acropora, golasea, monipora, etc ,In addition, there are more than 100 coral species to be added to the library.And seedling cultivation technology of multicellular tissues of corals has been created, the development of coral seedlings. Rapid reproduction and large-scale production provide valuable germ plasm resources for the ecological restoration of coral reefs.Tissue culture technology of coral has pushed the amputation asexual reproduction technology to a new height, and combined with the sexual reproduction to form a comprehensive technical system.In this study, 30,000 new seedlings of newly propagated coral were used for ecological restoration in the South China Sea, which is currently growing continuously.

This study also created the molecular biology identification technology of corals. Since morphological identification of coral seedlings is difficult in the early stage, we made use of primers of coral mitochondria to amplify DNA fragments to identify the nascent coral species. Histiocytes in seawater to rapidly identify the distribution of coral species in this sea area. Establishing a coral biobank is equivalent to building a Noah's Ark for coral resources, which are of great significance for the protection and restoration of the South China Sea and on global coral reefs.

Virtual
Oral
A-2171

A viable coral reef recovery model in the Philippines:A tool for climate change resilience that supports food security

Maypa, A.[1], Baird, M.[2], Raymundo, L. J.[3], Catitig, R. O. G.[4], Bayron, Jr., R.[5], Neri, F.[6], Estacion, J.[6], White, A.[4], Maaño, D. E.[7]
[1]Jose Rizal Memorial State University - Main Campus, Office of the Vice President for Research, Development and Extension, Dapitan City, Philippines
[2]USAID - SIBOL Project, Siargao Island, Surigao, Philippines
[3]University of Guam Marine Laboratory, Mangilao, Guam, United States
[4]Coastal Conservation and Education Foundation, Cebu City, Philippines
[5]Office of the Provincial Agriculturist-CRM Section, Larena, Siquijor Province, Philippines
[6]Silliman University - Institute of Environmental and Marine Sciences, Dumaguete City, Philippines
[7]DENR-Biodiversity Management Bureau, Diliman, Quezon City, Philippines

aileenmaypa2019[at]gmail.com

Abstract

Climate change negative impacts in the Philippines include increased frequency of strong typhoons that have decimated extensive areas of coral reefs in previously sheltered locations. Typhoons in 2011-2012 triggered coral-to-macroalgae phase shifts in many of the 30 Marine Protected Areas (MPAs) and adjacent fished reefs assessed immediately after these storms. Declines in reef fish biomass was up to five times lower. Diversity losses from species to family levels were also recorded. Fisher perception surveys, livelihood and income losses estimated fish catch declines up to 75% in some areas. This prompted the development of an assisted coral reef recovery (ACRR) model that included aspects of ecological and human-community resilience, MPA management and biodiversity protection, coastal law enforcement (CLE) and governance, and livelihood recovery and ecotourism. Our tool kit included a passive ACRR which utilized CEPA and capacity building. We also strengthened coastal law enforcement, simultaneously applying top-down and bottom-up protection of areas identified as “resilient reefs,” protection of small pelagic fish populations and their habitats, establishment of multi-habitat MPAs and livelihood skills trainings. Active ACRR initiatives included the development of a low cost and community-friendly substrate and coral fragment stabilization protocols and reef fish recovery tools specific for rubble-dominated typhoon-damaged areas. We tested these protocols and tools in eight MPAs in Siquijor Island, central Philippines from 2013 to 2019. Coral and reef fish parameters were compared across and within MPAs where control and experimental stations were established. In poached MPAs, algal blooms were linked to fish herbivore fluctuations. Target fish biomass was significantly associated with MPA Effectiveness Assessment Tool (MEAT) enforcement score (p = 0.025, R^2 = 13.3%). Strengthening MPA enforcement and CLE in general directly contributes to fishery stocks improvement, among other factors, thus, to food security. In municipal to regional scale of coral reef damage then, local governance bodies play a very important role in assisting coral reef recovery and, in both ecological and community resilience. ACRR in both its active and passive forms is not well understood in the Philippines. We also aim to contribute in the formulation of science-based policies for coral reef restoration in the Philippines.

Virtual
Oral
A-1729

Differential Effects of Substrate Type and Genet on Growth of Microfragments of Acropora palmata

Papke, E., Wallace, B., Hamlyn, S., Nowicki, R.
Mote Marine Laboratory, Summerland Key, United States

eringpapke[at]gmail.com

Abstract

Global decline of coral reefs has led to a widespread adoption of asexual propagation techniques for coral restoration, whereby coral colonies are fragmented and allowed to re-grow before being returned to the reef. While this approach has become increasingly popular and successful, many questions remain regarding best practices to maximize restoration speed, efficiency, and survival. Two variables that may influence growth and survival of asexually fragmented colonies include coral genet and growth substrate. Here, we evaluate the effects of genet and substrate (commercially available ceramic vs. in-house made cement) on the survival and growth of 221 microfragments of elkhorn coral *Acropora palmata* over 193 days. All corals survived the experimental period, and doubled their initial size in 45 days, with an average growth of 545% over the study duration. Growth was generally linear, though the growth of some corals more closely matched logistic, logarithmic, or exponential curves. Both genet and substrate had significant effects on coral growth, though the two factors did not interact. Genet had a stronger influence on coral growth than substrate, with the fastest genet growing at 216% the rate of the slowest genet. Corals on cement substrate grew at 111.9% the rate of those grown on ceramic. This represents both a significant cost savings and elimination of logistical challenges to restoration practitioners, as the cement substrate ingredients are cheap and globally available. Our work shows that both genet and substrate should be considered when undertaking asexual restoration of *Acropora palmata* to maximize restoration speed and efficiency.

Virtual
Oral
A-1681

Corallivory and genotype drive Orbicella faveolata micro-fragment survivorship and growth during restoration

Raker, C.[1], Olmeda-Saldaña, M.[2], Williams, S.[2], Weil, E.[3], Prada, C.[1]
[1]University of Rhode Island, Biological and Environmental Sciences, Kingston, United States
[2]Institute for Socio-Ecological Research, Inc, Lajas, Puerto Rico
[3]University of Puerto Rico at Mayagüez, Department of Marine Sciences, Mayagüez, Puerto Rico

ceraker[at]uri.edu

Abstract

As coral reefs face increasing threats from stressors such as global warming, overfishing, eutrophication, coastal development and ocean acidification, coral restoration has become an important tool to aid coral populations. A novel strategy for restoring boulder corals is microfragmentation, which enhances coral growth by at least five times, partially solving the “slow growth” issue of culturing massive corals. However, mortality rates are still significant during the early weeks after transplanting microfragments to impacted areas. Here we examined the effects of predation after transplanting fragments by caging *Orbicella faveolata* microfragments and testing if, after an acclimation period under field conditions, survival rates would increase. We tracked the health and growth of ten genotypes across different acclimation periods from a control group of no acclimation (0 months) to full acclimation (4 months). After four months, we presented a mix of acclimated and unacclimated corals to predators on reefs. Coral survivorship was highest in acclimation cages (near 100%) compared to the field ($p < 0.001$), with significant growth differences across genotypes ($p < 0.001$). Corals also grew more in acclimation cages ($p < 0.001$), with rates slowing down in the first two months after being planted into the substrate. These results suggest caging fragments boost coral survival during coral initial stages of restoration by > 50% and increase the persistence of transplanted fragments. Results also highlight the importance of testing the performance of genotypes before major outplanting efforts, and prioritize genotypes with high survival and growth rates. Beyond coral restoration, results demonstrate the possible negative ecological effects of corallivores, on recent transplants of fragments to open substrate, which attract attention particularly of parrotfishes. Further investigation is needed on whether fish herbivores in unhealthy ecosystems may hamper coral restoration.

Virtual
Poster
A-2128

Grazing effects of sea urchin Diadema savignyi onalgal abundance and coral recruitment processes

Dang Do Hung, V.[1, 2, 3], Yoko, N.[2], Fong, C.-L.[1, 2], Shiu, J.-H.[2]
[1]National Taiwan Normal University, Department of Life Science, Taipei, Taiwan
[2]Academia Sinica, Biodiversity Research Center, Taipei, Taiwan
[3]Institute of Marine environment and Resources, Vietnam Academy of Science and Technology, Haiphong, Vietnam

vietbio310[at]gmail.com

Abstract

Herbivores control algae and promote coral dominance along coral reefs. However, the majority of previous studies have focused on herbivorous fish. Here we investigated grazing effects of the sea urchin *Diadema savignyi* on algal abundance and coral recruitment processes. We conducted an in situ cage experiment with three density conditions of *D. savignyi* (0, 8, 16 indiv. m^{-2}) for three months during the main coral recruitment season in Taiwan. Results demonstrated a strong algal control by *D. savignyi*. At the end of the experiment, average algal cover was 95% for 0 indiv. m^{-2}, compared to 47% for 8 indiv. m^{-2} and 16% for 16 indiv. m^{-2}. Average algal biomass at 8 indiv. m^{-2} declined by one third compared to 0 indiv. m^{-2} and almost zero at 16 indiv. m^{-2}. On the other hand, a negative grazing effect of *D. savignyi* was observed on coral recruitment processes. Notably, at 16 indiv. m^{-2}, the density of coral recruits declined and mortality of small coral fragments (proxy of coral juveniles) increased. Our results confirm findings of previous studies and indicate the need to balance both positive (strong algal control) and negative (physical damage) influences of *Diadema* grazing to facilitate the coral recruitment process.

Virtual
Poster
A-1707

Handbook of coral reef restoration technology by sexual reproduction

Yamazaki, M.[1], Fudo, M.[1], Okada, W.[2], Tamura, K.[2], **Kanyama, T.**[3], Suzuki, G.[4], Yonezawa, Y.[5], Komatsu, T.[5], Kayanne, H.[6], Kakuma, S.[7], Omori, M.[8]
[1]Ministry of Agriculture, Forestry and Fisheries, Tokyo, Japan
[2]Ecoh Corporation, Tokyo, Japan
[3]Fisheries Infrastructure Development Center, Chuo-ku, Japan
[4]Seikai National Fisheries Research Institute, Ishigaki, Japan
[5]Kokusai Kogyo CO.,LTD., Tokyo, Japan
[6]The University of Tokyo, Tokyo, Japan
[7]Okinawa Deep-sea-water Research Center, Kumejima, Japan
[8]Tokyo University of Fisheries, Tokyo, Japan

t-kanyama[at]fidec.or.jp

Abstract

Coral reefs are now rapidly decreasing by local and global stressors such as repeated mass bleaching events. In the face of this crisis with catastrophic projection in the future, only conservation and management are not regarded as effective measures to sustain coral reefs in the future. Recently, active restoration and intervention measures have been proposed from genetic to ecosystem scales, while few have been validated in field. In Japan, Akajima Marine Science Laboratory pioneered to develop breeding technology of corals since 1990s, and published a handbook in 2014. Expanding its technology, Fisheries Agency of Japan has conducted reef restoration project mainly Okinotorishima, the southernmost remote island in Japan. Coral juveniles were hatched in aquarium tanks in Okinawa from adult colonies transported from Okinotorishima, and the 114,000 corals were successfully returned to Okinotorishima and outplanted on natural knolls and artificial foundations. In addition, a practical method aimed at a lower cost was developed. With this scheme, we have developed a special device called “larval cradle” that can consistently perform bundle collection, fertilization, and larval rearing in the sea area. These techniques can settle larvae steadily on artificial substrates by ensuring over 90% fertilization late at spawning and over 90% survival rate of larvae at 4 day-old.
A series of the technologies are compiled as “Handbook of Coral Reef Restoration Technology by Sexual Reproduction” in 2019 as toolkits for not only researchers but also local managers and fishermen to apply coral breeding in their sites. Based on this handbook, we now apply, extend and validate this technology for restoration of coral reefs in Ishigaki Island, which were severely damaged by COT outbreak in 2010 to 2011 and bleaching in 2016. The table of contents of the handbook are listed below. We will distribute this handbook at poster presentation.

Chapter 1 Introduction
1. Coral and coral reefs
2. Strategy for restoration technology
Chapter 2 Upscale restoration by sexual breeding of corals
1. Outline of the technology -Breeding, rearing on nursery, outplanting to rocks-
2. Mass production of corals by sexual breeding in aquarium tanks on land
3. Collecting, rearing, and seeding coral larvae in situ -Development of a special larval collector called “larval cradle”
References

Session 13H - Can coral climate resilience be enhanced via assisted evolution?

Conceptualized by: **Madeleine van Oppen** [1], **Sarah Frias-Torres**[2], **Manuel Aranda**[3], **James Guest**[4]
[1] The University of Melbourne (Parkville, Australia)
[2] Vulcan Inc. (Seattle, WA, USA)
[3] KAUST (Thuwal, Saudi Arabia)
[4] Newcastle University (Newcastle, UK)

Chaired by: **Manuel Aranda**[3], **James Guest**[4]

Oral
A-2191

Pre-conditioning three generations of Pocillopora acuta to explore mechanisms underpinning coral acclimation to climate change stress

Cantin, N.[1], Stephenson, S.[1], Drury, C.[2], Majerova, E.[2], Roper, C.[1], van Oppen, M.[3]
[1]Australian Institute of Marine Science, Townsville, Australia
[2]Hawaii Institute of Marine Biology, Kaneohe, United States
[3]University of Melbourne-Parkville, Parkville, Australia

n.cantin[at]aims.gov.au

Abstract

Repetitive severe coral bleaching events on the Great Barrier Reef and throughout the tropics from 2014-2017 have escalated the concern that climate change is rapidly overwhelming the capacity of reef-building corals to adapt and survive.

Successful restoration in a warming ocean will require biological techniques that go beyond coral fragmentation and juvenile recruitment. In a long-term study we tested the role of genetic and epigenetic mechanisms underpinning the long-term

acclimation capacity of reef-building corals to temperature and acidification stress within and across generations. We exposed parental (P) colonies of Pocillopora acuta and raised two generations of offspring (F1 and F2) under experimental present day, 2050 and 2100 climate scenarios (400 ppm pCO_2 x ambient temperature (0.95°C-weeks, accumulated heat stress), 685 ppm pCO_2 x +1.5°C (2.5°C-weeks, accumulated heat stress) and 900 ppm pCO_2 x 2.0°C (5.0°C-weeks, accumulated heat stress)). This chronic stress exposure over a three-year period identified sensitive and tolerant genotypes within the experimental population. Several physiological traits were measured during three realistic summer heat stress events under future ocean acidification conditions (rates of metabolic respiration, photosynthesis, and calcification, tissue biomass, symbiont type and density and bleaching sensitivity, recovery and survivorship) to quantify phenotypic patterns of tolerance within and between generations. Rates of survivorship and maximum photosynthetic capacity were higher under the 2050 (+1.5°C) scenario (57% F1 survivorship) compared to the present day (51% F1 survivorship) and 2100 (+2.0°C; 39% F1 survivorship) scenarios. Analyses of the microbiome community composition (Symbiodiniacea and bacteria), combined with DNA methylation analyses across the treatments and between generations will be used to explore the genetic and epigenetic mechanisms underpinning the observed variability in tolerance.

Oral
A-1353

Can novel conservation interventions help coral reefs survive the climate crisis?

Guest, J.[1], Humanes, A.[1], Bythell, J.[1], Edwards, A.[1], Palmowski, P.[1], Lachs, L.[1], Wass, E.[1], van der Steeg, E.[1], Golbuu, Y.[2], Martinez, H.[1]
[1]Newcastle University, Newcastle upon Tyne, United Kingdom
[2]Palau International Coral Reef Center, Koror, Palau

james.guest1[at]ncl.ac.uk

Abstract

Efforts to manage coral reef ecosystems have largely focused on local management of fishing pressure and water quality, however, even well managed reefs are vulnerable to large scale climate change disturbances. In addition to tackling climate change directly, there is now increased interest in restoring damaged areas and actively assisting corals to adapt to anticipated environmental conditions via assisted evolution (AE). AE may involve deliberate genetic, epigenetic and microbiome changes to the coral holobiont. Many of the proposed approaches are being tested under laboratory conditions, and only the most promising of these would be combined with field-based ecological restoration to introduce more resilient corals onto vulnerable reefs. For AE to have a conservation benefit, corals reared in the lab must be outplanted to reefs in sufficiently large numbers and in a cost-effective way. Furthermore, they must survive until reproductive maturity and pass any beneficial traits to their offspring. Clearly, huge challenges remain before AE can be successfully implemented as a conservation method. A series of experiments were carried out to assess the feasibility of coral selective breeding, one of the key techniques proposed for AE, using the corymbose species *Acropora digitifera* in Palau as a model. Our aims were to a) examine the extent of intrapopulation variability in holobiont heat tolerance, b) determine the extent of trade-offs between heat tolerance, growth and fecundity, c) estimate heritability of heat tolerance, and d) improve cost effectiveness of outplanting selectively bred corals. We found remarkable intrapopulation variation in coral heat tolerance, with the most tolerant corals able to withstand an additional 4.8 °C-weeks of heat stress compared to the least tolerant corals. There was no evidence of a trade-off between adaptive traits, and heat tolerance was not associated with Symbiodiniaceae or bacterial microbiome community structure. We found evidence of heritability for heat tolerance in embryos, larvae and 1- year old juveniles of selectively bred corals. Finally, an innovative method to outplant corals to the reef resulted in a two-fold increase survivorship and significantly reduced outplant times. While considerable research is still needed before selective breeding can be implemented on reefs, our research provides promising evidence of its potential as a novel conservation tool.

Oral
A-2003

Within population selective breeding in Acropora digitifera: evidence for heat tolerance maternal effects on early life history stages

Humanes, A.[1], van der Steeg, E.[2], Martinez, H.[2], Lachs, L.[2], Golbuu, Y.[3], Bythell, J.[2], Edwards, A.[2], Guest, J.[2]
[1]University of Newcastle, Newcastle upon Tyne, United Kingdom
[2]Newcastle University, Newcastle Upon Tyne, United Kingdom
[3]Palau International Coral Reef Center, Koror, Palau

adriana.humanes-schumann[at]newcastle.ac.uk

Abstract

Selective breeding as a method to restore degraded reefs and increase their resilience has mainly focused on breeding individuals from different populations with distinct temperature regimes. In contrast, the potential of within population phenotypic variability has rarely been explored to support selective breeding treatments. This approach has several advantages as it avoids costly movement of individuals between populations and mixing of genetically distinct populations. Here we perform selective breeding crosses utilizing heat tolerance variability within an *Acropora digitifera* population in Palau. To determine the heat tolerance of the adult population, bleaching and mortality responses were assessed over a 36-day temperature stress experiment under mesocosm controlled conditions on fragments from 66 adult colonies. From these, eight colonies with contrasting heat tolerances (low and high) were identified. During the annual mass spawning event, gametes were collected from these eight colonies and cross-fertilized to produce 4 types of crosses: high sire × high dam, high sire × low dam, low sire × high dam, and low sire × low dam. Four-hour post-fertilization embryos from the resulting crosses were exposed to +3°C heat stress for 30-hours after which their survivorship and settlement success were estimated. Heat stress had a significant negative effect on embryo survivorship and larval settlement only in crosses with low-tolerant dams (high sire × low dam & low sire × low dam), suggesting maternal phenotype may be important in governing heat tolerance of offspring. Our results have two important implications for coral assisted evolution: 1) in large healthy Acropora populations, there appears to be sufficient phenotypic variation in heat tolerance to provide material for selective breeding; and 2) heat tolerance of the mother appears to be the main influence on that of the offspring, suggesting that selective breeding could enhance overall population-level heat tolerance if these effects are seen throughout the life span of the individual. While these early results are encouraging, further research is needed to a) determine whether adult offspring show a similar heat tolerance response, b) estimate the feasibility of out-planting large numbers of selectively bred corals, and c) to examine potential trade-offs between heat stress tolerance, growth, survivorship and fecundity throughout the life span of a coral colony.

Oral
A-1053

Expanding the suite of heat-evolved Symbiodiniaceae through experimental evolution under increased temperatures

Scharfenstein, H.[1, 2], Alvarez-Roa, C.[2], Peplow, L.[2], Buerger, P.[1, 3], Yan Chan, W.[1], van Oppen, M.[1, 2]
[1]The University of Melbourne, School of BioSciences, Parkville, Australia
[2]Australian Institute of Marine Science, Townsville, Australia
[3]Macquarie University, Applied BioSciences, Sydney, Australia

hscharfenste[at]student.unimelb.edu.au

Abstract

Dinoflagellates in the family Symbiodiniaceae commonly form endosymbioses with scleractinian corals, providing vital photosynthate to their host. This symbiotic relationship is sensitive to higher than usual temperatures and/or irradiance, which are the primary causes of large-scale coral bleaching events. Whilst evolutionary adaptation may enable species to overcome stressful conditions and persist in the long-term, the long sexual generation times of corals (3-5 years or longer) make it likely that genetic adaptation would occur too slowly relative to the pace of climate change. Assisted evolution refers to a series of bioengineering approaches with the aim to accelerate natural adaptative processes and the evolution of specific traits that will enhance coral bleaching resilience. Since coral bleaching resilience is partly dependent on the thermal tolerance of the intracellular Symbiodiniaceae communities, one assisted evolution strategy consists of accelerating the evolution of Symbiodiniaceae thermal tolerance through exposure to elevated temperatures *in vitro* (i.e. experimental evolution). In the present study, we used this approach to increase the thermal tolerance of Symbiodiniaceae strains spanning the genera *Symbiodinium*, *Cladocopium*, *Durusdinium* and *Fugacium*. The *in vitro* thermal tolerance of these strains was assessed after 4.6-5 years of experimental evolution via a reciprocal transplant experiment to ambient and elevated temperatures. Growth and photosynthetic performances, oxidative stress levels and nutrient usage were measured to compare thermal tolerance between strains. Overall, the heat-evolved strains displayed improved physiological performances under elevated temperature compared to their wild-type counterparts. This study advances our understanding of the *in vitro* physiological responses of Symbiodiniaceae to elevated temperatures and expands the suite of heat-evolved Symbiodiniaceae strains available for coral reef restoration efforts, if found to confer improved thermal tolerance *in hospite*.

Virtual
Oral
A-2210

Experimental evolution of algal endosymbionts can enhance coral thermal tolerance

Buerger, P.[1], Oakeshott, J. G.[2], Owain, E. R.[2], van Oppen, M. J. H.[3, 4]
[1]Macquarie University, Applied Biosciences, North Ryde, Australia
[2]CSIRO, Land & Water, Canberra, Australia
[3]University of Melbourne, School of BioSciences, Parkville, Australia
[4]Australian Institute of Marine, Science, PMB #3, Townsville, Australia

patrick.buerger[at]mq.edu.au

Abstract

Coral reefs have suffered severe bleaching and mass mortality from high seawater temperatures over recent decades. With the aim to enhance coral thermal tolerance, we performed experimental evolution on cultures of the coral algal endosymbiont *Cladocopium goreaui* (ITS2 type C1). Twelve sub-cultures were derived from the same monoclonal culture, two of which were maintained at ambient temperature (27ºC; i.e., wild-type strains) while ten were subjected to a stepwise temperature increase to 31ºC (i.e., heat-evolved strains). After 6 years of exposure to 31ºC (~200 asexual generations), all ten heat-evolved algal strains had lower levels of secreted reactive oxygen species, stable photosynthetic performance and positive growth under elevated temperature *in vitro* compared to the wild-type strains. When the heat-evolved strains were reintroduced into coral larvae, three of the ten holobionts resisted bleaching during seven days of experimental heat stress at 31ºC, while the other seven and the wild-type holobionts bleached. RNA sequencing suggested lower photosynthetic rates and higher carbon-fixation rates are among the mechanisms responsible for the enhanced thermal tolerance. Microalgal locus-specific mutations clustered on several scaffolds and distinguished the respective strain from another. Finally, bacterial 16S rRNA metabarcoding indicated that bacteria might have a contributing effect on the *C. goreaui* thermal tolerance, at least *in vitro*. Our findings show that coral stock with increased bleaching tolerance can be developed through experimental evolution of the microalgal symbionts.

Session 14 - Open Session: Outreach and education

Chaired by: **Carin Jantzen**[1], **Christian Wild**[2], **Michelle Calvert** [3]
[1] SECORE International (Hilliard, OH, USA)
[2] University of Bremen (Bremen, Germany)
[3] Horniman Museum and Gardens (London, UK)

Oral
A-1780

Virtual Reality of Coral Reefs: Exploring Psychological Distance after Two Immersive Virtual Experiences

Bambic, B.[1], Karutz, C.[2], Won, A. S.[3]
[1]National Geographic Society, Mapping, Washington, United States
[2]Receipts, Co-Founder, Bend, United States
[3]Cornell University, Department of Communication, Ithaca, United States

brianna.bambic[at]gmail.com

Abstract

Adverse impacts of climate change, overfishing, and marine pollution are jeopardizing recent gains of marine protected areas in our global oceans. As stewards and managers of the ocean, humans need to better communicate these issues to the general public in order to achieve a sustainable future. Accordingly, knowledge of conditional changes of the underwater marine environment is vital to create awareness that in turn drives environmental concern and pro-environmental behaviors.
To explore these issues, we looked to new cutting-edge technologies that can simulate a direct experience of the ocean and may make temporal changes more apparent.

This research examined the effectiveness of using an immersive virtual environment (360-degree video) in a real-world context (museums and aquariums) to increase connectedness to nature and willingness to take action. Participants from coastal and inland communities were exposed to virtual reality (VR) footage of a marine ecosystem showing coral reef degradation (Lighthouse reef, Belize). Participants were shown one of two conditions; “temporal change,” which included both archival and present-day footage to highlight shifting baselines; or “present-only,” which included present-day footage alone. In a pilot study with high rates of survey non-completion, we found an interaction between conditions and pretested environmental attitude scores on completion rates. In a second, pre-registered study, redesigned to reduce non-completion rates, we found that participants who watched the footage showing temporal change reported reduced psychological distance in some cases; however, reactions were affected both by participant location as well as their pre-reported levels of environmental concern.

This presentation will discuss the value of VR as a community engagement tool to decrease psychological distance and increase awareness and connectedness to nature. It will also highlight the challenges of using VR in real-world settings. This information is intended to illustrate how VR experiences may enable powerful mediated experiences of marine environments and promote place bonding. Thus, has the potential to successfully communicate to local communities and government agencies the advantages of navigating funds to mitigate pollution, improve monitoring of resources, and incentivize renewable energy practices.

Oral
A-1308

Bringing coral to the classroom: using VR and live-streaming to engage children across the world

Buchanan-Dunlop, J.
Encounter Edu, London, United Kingdom

jamie[at]encounteredu.com

Abstract

Coral reefs are some of the most beautiful, abundant, and important ecosystems on the planet. They are of enormous value not just to those millions relying on them directly for life and livelihoods, but on a global level.

As part of a global drive to increase ocean literacy in formal education, coral reefs are finding more prominence in the classroom through mentions in curriculum programmes of study and exam specifications. While those whose work is focused on the reef, its wonder and complexities may feel normal, but for most teachers brought up on a diet of biology lessons focused on hedgerows and foxes, or exotic geography locations tied to terrestrial case studies such as the Amazon rainforest, teaching about coral reefs poses more of a challenge.

Over the past ten years, Encounter Edu has been developing the Coral Oceans component of AXA Ocean Education, with the vision of making coral education mainstream as part of a young person's education wherever they are. This started with providing outreach for the XL Catlin Seaview Survey, with their project of creating a 360-degree photo baseline of reef systems across the world. Since 2012, Coral Oceans comprises a backbone of 30 lessons on coral for students ages 7 to 16, including over 150 classroom resources, and 100s of photos, videos, and activities. Classes can use these in conjunction with the immersive 360-degree imagery. To date, these resources have been downloaded over 50,000 times, with an estimated student reach of 1.7 million.

The classroom resources are being offered in more languages, with translations into German, French, Spanish, Bahasa Indonesian, Italian, Poland, and Portuguese.

Added to this has been a suite of live-streamed lessons that have brought coral science direct from field stations and projects to over 110,000 students around the world, and featured the work of 20 coral scientists. These live lessons have been broadcast from the Great Barrier Reef, Timor-Leste, Bermuda, and their current home at CARMABI in Curacao. With live lessons having become a feature of education during the pandemic, they have a renewed power to make the faraway nearby.

We look forward to a world where an appreciation of the coral reef and its futures is widespread and look forward to working with more partners across the globe.

14 - Open Session: Outreach and education

Oral
A-1306

Engaging, Educating, and Empowering the Future

Danser, N.
ScubbleBubbles, Noord, Aruba

nichole[at]scubblebubbles.org

Abstract

I will share the story of a teacher and a group of teenagers who started diving for fun and grew into a thriving NGO with multiple reef restoration projects.
We are currently the only organization in our country with government permission to carry out coral restoration activities.

They say you cannot feel protective of something you do not love, and you cannot love something without knowing it. So I get young people scuba diving and in love with the ocean, especially reefs.
Once they have been on a couple of dives, they cannot help but love the ocean. This is when we educate them as to what is happening to the reefs, and why corals are dying. We share with them what we are doing and how they can help.
Finally we empower them to make a positive impact in the world. We train them to be part of restoration projects, reef surveys, and reef clean ups. We give them the responsibility of organizing events, completing applications for government approval or projects, and training new volunteers. This not only empowers them, but it makes them feel a greater responsibility to spread awareness to their friends and family.
The young volunteers also do presentations for the community, both for adults and for school children.

I hope our story will help others find a way to educate and empower younger generations to help protect and restore the reefs.

Oral
A-1265

The Importance of Educating Youth to Inspire the Next Generation of Coral Reef Stewards

Heemsoth, A.[1], Thompson, E.[2]
[1]Khaled bin Sultan Living Oceans Foundation, Education, Annapolis, United States
[2]Khaled bin Sultan Living Oceans Foundation, Annapolis, United States

heemsoth[at]livingoceansfoundation.org

Abstract

Fostering youth education is an essential component of coral reef conservation. Awareness and knowledge about coral reefs are vital to managing and protecting this vulnerable ecosystem. Education is a tangible way to create awareness, instilling a sense of responsibility and influencing behavior change to generate coral reef stewardship and citizenship. If well educated, the next generation of environmental stewards will understand the environmental issues that coral reefs face and create solutions to address these challenges. This presentation will disclose three different programs that use various strategies to effectively educate teachers and youth about the marine environment, particularly coral reefs. These programs are as follows: 1) Corals in the Classroom, a teacher professional development workshop, introduces a set of classroom-ready activities from the *Coral Reef Ecology Curriculum.* Educating youth has to begin with providing resources and training for teachers that is reliable and can be easily incorporated into their classes. Teachers that are more confident teaching students about coral reefs are more likely to incorporate this information in classroom instruction. 2) The Science without Borders® Challenge is an annual international art contest, which inspires students ages 11-19 to be creative while learning about important ocean and coral reef conservation issues. A multi-disciplinary approach is used to incorporate art and science reaching youth that may not be science-minded, motivating them to create artwork that not only educates the artist, but also raises awareness and inspires viewers to conserve the ocean. 3) The Mangrove Education & Restoration program is an immersive, yearlong education experience that engages secondary students and teachers to learn about, restore, and monitor mangroves in the Caribbean and their connectivity to coral reefs. The program utilizes place-based and project-based learning strategies and includes professional development for teachers, experiential learning, field experience, and program evaluation. Through these education programs, we have identified a number of ways to effectively educate students about coral reefs and inspire the next generation of ocean stewards. The lessons learned from these educational programs, as well as the programs themselves, can be easily replicated and applied broadly to coral reef conservation efforts around the world.

Oral
A-1746

Citizen Science for Social Change: Evaluating the Impact of Coral Restoration as a Vehicle for Public Stewardship

Hesley, D., Kaufman, M., Joos, A., Lirman, D.
University of Miami RSMAS, Miami, United States

djh43[at]miami.edu

Abstract

Coral reefs have experienced dramatic declines worldwide over the past several decades due to both local and global stressors, prompting the implementation of projects aimed to protect remaining populations, accelerate recovery, and increase social action. One such effort is the development of coral restoration programs. While programs around the world now grow 1,000s of corals and outplant 10,000s of colonies onto reefs annually, the cost, labor, and impact of these activities continue to be limiting factors.

To address these limitations, we developed the University of Miami's Rescue a Reef (RAR) program, a coral restoration citizen science project designed to build community and coastal resilience through experiential learning opportunities for participants. Since creation in 2015, >800 RAR participants have outplanted >7,000 corals, showing that citizen scientists can advance coral restoration efforts. Importantly, corals outplanted by RAR participants showed the same survivorship as those outplanted by scientific experts. However, scientific consensus is that the long-term success of reef restoration and coral recovery will depend on social action to mitigate local and global stressors.

To formally assess RAR's impact on this front, a program evaluation was conducted to identify potential changes in participant knowledge levels, attitudes, and/or behaviors dependent on how they engaged RAR. An anonymous, voluntary survey was distributed to program followers and participants to allow us to reflect on program activities and evaluate impacts. Survey responses showed significant increases in self-reported knowledge levels on coral reefs, threats, and tools for conservation after program engagement. Additionally, majority of respondents reported pro-environmental behavior changes since interacting with RAR. Furthermore, results showed that these impacts correlated with the length of time and way (i.e., outreach vs. citizen science) they engaged the program.

By coupling coral restoration with meaningful community engagement, we demonstrated that citizen science can go beyond just data collection to the advocacy and stewardship of these critical marine resources. The direct benefits of using citizen science for restoration are greatly enhanced when these educational and social impacts are considered. Thus, the growing field of reef restoration should use its platform as a vehicle to raise public awareness, support, and action on coral conservation.

Oral
A-1097

Teaching coral reef ecology: how a science comic can engage kids worldwide

Jantzen, C.[1], Ney, L.[1], Rising, K.[2], Löschke, S.[3]
[1]SECORE International, Bremen, Germany
[2]SECORE International, Derby, United Kingdom
[3]SECORE International/IPCC, Schneehohl, Germany

c.jantzen[at]secore.org

Abstract

Coral reefs are declining worldwide, not only putting many millions of people's livelihood at risk, but also heralding the ecological disaster when whole ecosystems are wiped out.

Coral reefs are among the most fascinating marine ecosystems, home to a diverse community of sometimes bizarre creatures and they may even be compared in their functioning to a kind of super organism working in concert with all its parts. Aside from the fact that these features may provide various appealing themes for teaching, few is known about corals and their ecosystems among a broader audience. This may be because it is an ecosystem far away–below the water surface and along the tropical belt. Additionally, corals themselves may not be the cuties kids can identify or adults may feel emphatic with.

Educating coastal communities along the tropical belt, as well as people from industrial nations, and especially the next generation, including future stakeholders and decision makers—the children—is essential to create awareness and curiosity, thus setting the stage for implementing measures for reef management and enhancement sustainably.

We took up the challenge and created Coral Heroes—a science magazine and an actual comic at the same time. In the leading roles are four young corals, using artistic freedom to let them walk around and speak like typical comic characters. The comic itself is underlain with anecdotal facts, funny remarks and the Coral Heroes interact lively on their journey through the secret world of the fictional Towabonga reef. The comic is lovingly drawn by German illustrator Bernhard Speh and filled with vibrant colors.

The first two language versions of the comic were German and English, respectively. Driven by inquiries for further translations, we created Spanish, Indonesian, French, Dutch, Papiamento and Italian versions of our Coral Heroes with the help of volunteer translators. Our goal is to take our Coral Heroes on a journey around the world to teach as many kids as possible!

Oral
A-1173

Changing perspectives in coral reef exhibits to improve knowledge transfer– insights into an innovative and flexible exhibition module

Lahl, R.[1], Havlik, P.[2], Höfling, C.[2], Loreit, F.[3], Merkt, M.[3], Roßmanith, E.[2], Voigt, L.[2], Wagner, E.[2]
[1]Leibniz Centre for Tropical Marine Research (ZMT), Office for Knowledge Exchange, Bremen, Germany
[2]Senckenberg Society for Nature Research (SGN), Leibniz Institution for Biodiversity and Earth System Research, Frankfurt, Germany
[3]German Institute for Adult Education, Leibniz Centre for Lifelong Learning, Bonn, Germany

rebecca.lahl[at]leibniz-zmt.de

Abstract

How can we exert fascination and support learning about coral reefs with exhibits? Which methods and contents reach different audiences? Are there special forms of presentation that encourage the audience to take action for reef conservation? These are guiding questions in the BMBF-funded project TemPe (“Temporary Permanence”). For this purpose, a highly flexible and innovative exhibition module is developed – the TemPe-transformer. It is being tested as a prototype in the permanent exhibition “Tropical Coral Reef” that opened in July 2021 in the Senckenberg Natural History Museum Frankfurt. The research museum addresses a diverse audience of all age groups as a place of education, communication and knowledge transfer. It seeks to support societal discourse and direct exchange between science and society. However, for the museum it can be challenging to incorporate current issues into permanent exhibitions. Here comes the TemPe-transformer into play: It introduces current socio-politically relevant information and research results in the reef exhibition, combining analogue, digital and participatory elements. It is seen as an add-on commentary level, which provides interactive elements promoting the exchange with visitors. Within the project, we are extensively investigating the effect of different communication approaches to instigate reflection processes in the audience. Therefore, the transformer successively stages information provided by three different perspectives: Society, art and science. The focus of the perspectives is developed in a participatory process to ensure that it corresponds to the interests of the visitors. Knowledge transfer objectives for the exhibition module include: (1) Reefs have an immense value, both material and non-material, (2) Reefs are at extreme risk from human activities; climate change is the greatest threat, (3) There are goal-oriented measures for reef protection that anyone can support individually. We are evaluating the general visitors’ experience of the transformer and the knowledge transfer of its three perspectives. In addition, we are exploring methods to evaluate a change of attitude or behaviour towards sustainability, climate change and reef conservation. The aim of this iterative development of the prototype throughout the three-year-long project is an optimised exhibition module adaptable to other venues and presentation formats.

Oral
A-1431

Advanced 3D technologies applied to coral skeletons structures for generating an open science archive « Corallum fabrica »

Rigot, E.[1, 2], Tribouillois, D.[1], Foncy, J.[1], Barbareau, G.[1], Zanon, C.[1], Libourel, J.[1], Larré, J.-M.[1], Domart-Coulon, I.[3], Castelin, M.[3], Duru, P.[4], Bramanti, L.[5], Lartaud, F.[5], Planes, S.[6], Malaquin, L.[1], Vieu, C.[1, 7]
[1]LAAS-CNRS, Centre national de la recherche scientifique, Micro Nano Bio Technologies, Toulouse, France
[2]LLA-CRÉATIS, Université de Toulouse, Toulouse, France
[3]Muséum national d'Histoire naturelle, ISYEB, UMR 7205 CNRS MNHN SU EPHE UA, Paris, France
[4]Université de Toulouse, INPT, UPS, Institut de Mécanique des Fluides, Toulouse, France
[5]Sorbonne Université, CNRS, LECOB, UMR 8222, Observatoire Océanologique, Banyuls-sur-Mer, France
[6]PSL Research University, EPHE, UPVD, CNRS, USR 3278 CRIOBE, Perpignan, France
[7]INSA, Université de Toulouse, Toulouse, France

erigot[at]laas.fr

Abstract

Coral biodiversity and viability are markers of various environmental changes caused by anthropic disturbances. The numerous reports on coral mortality after periodic warming events strongly suggest that many coral species are at risk of local extinction. The posture of scientists tackling this urgent issue is important and both cultural and scientific.
As a trans-disciplinary community gathering physicists, biologists, taxonomists, environmental scientists, and designers, we propose the use of 3D technologies and engineering science in a project avoiding any techno-solutionism drift such as eco-engineering to promote a scientific posture of mediators of coral's reef memory. Indeed, by applying advanced 3D technologies to coral skeletons structures visualization and reconstruction, we have initiated an open science archive named « *Corallum fabrica* » to publicize biodiversity and facilitate science in constructing an accessible coral reef 3D repository.
The objective of this project is the sharing and digital preservation of these specimens for future generations and research. The ambition of the project is to preserve the common cultural heritage embedded in coral's skeleton art of building.
We have addressed this challenge by using x-ray micro-tomography (EasyTom XL) to image and numerically encode the 3D architecture and to render 3D inner cavities, porosities, and micro-structures of coral's skeleton from National Museum of Natural History in Paris and personal scientist collections. Reconstructed 3D models exhibit a typical spatial high resolution of 4-50 microns, depending on size and morphology. A dedicated Virtual Reality Tool (oculus quest 2, Unity software) with hand tracking technology has been designed for public dissemination. It allows an immersion inside the details of the micro-structures and the discovery of a large panel of morphologies which characterize the different species. Moreover, we reproduced (1-100X) fantoms of these structures by 3D printing methods involving stereolithography and large-scale printing by clay extrusion.
The dual impact of the project is both cultural and scientific. The virtual reality experience and the sculptures is used for scientific mediation and public outreach in museums, schools and sensibilization events. The open-access archive is used by the scientific community interested in coral mineralization and growth modelling.

Oral
A-1292

What works? Lessons learned from ten years communicating coral reef science around the world.

Thompson, L., Carlton, R., Heemsoth, A.
Khaled bin Sultan Living Oceans Foundation, Annapolis, United States

thompson[at]lof.org

Abstract

The Global Reef Expedition (GRE) is a scientific research mission that circumnavigated the globe studying the health and resiliency of coral reefs. From 2011-2015, we traveled to 15 countries, completing 22 month-long research missions at some of the most remote and understudied coral reefs on the planet. However, collecting scientific data was not our only goal of this endeavor. We realized that in order to make an impact, we not only needed to convey scientific knowledge, we also needed to inspire citizens and local leaders to act to protect and preserve their coral reefs. As a result, outreach and education were deemed critical components of each research mission. On the GRE, we brought along award-winning filmmakers and photographers to showcase the wonders of coral reefs and the threats they face, hosted blogs and webcasts to connect people with scientists in the field, and brought teachers on the expeditions to share knowledge of coral reefs with students. Once the field research was complete, we focused on communicating our findings to stakeholders so they could make informed decisions on how to manage their marine environment. Throughout it all, we shared our progress and scientific findings on social and digital media, collected metrics, and tracked the performance of our messages over time. We summarized the data collected on our outreach and communications efforts to determine which messages on coral reef science and conservation best resonated with our audience and garnered the most engagement. In this session, we will discuss lessons learned, present our assessment of which communications tools and types of media (i.e., film, blogs, social media, email, publications) were the best investment of our limited time and resources, and share our data on what messages performed best for each audience. Learn from our experience what worked (and what didn't) from ten years communicating coral reef science around the world.

Oral
A-1484

Climate Change Curriculum for Higher Education in the U.S. Affiliated Pacific Islands: iBooks

Wetzell, L.
University of Hawaii at Manoa, Kewalo Marine Laboratory, Honolulu, United States

lwetzell[at]hawaii.edu

Abstract

Climate change impacts are of great concern and the Pacific Island regions and many are already feeling the effects through seawater intrusion into limited aquifers, increased rates of coastal erosion, coastal inundation events, coral bleaching events, changes in rainfall patterns, and changing tracks of typhoons. As such, communities in these regions are in critical need for studies on ecosystem responses and adaptations. In lieu of a geographical and culturally relevant textbook and opportunities for experiential learning for students in higher learning, a series of iBooks were developed for five community colleges: American Sāmoa Community College–ASCC, the College of Micronesia-FSM, the College of the Marshall Islands–CMI, Northern Marianas College–NMC, and Palau Community College–PCC. The iBook provides an interactive approach to learning to students with varying learning abilities. Its flexible design allows the faculty and students to navigate their depth of knowledge by connecting with online stories and videos, scrolling through regionally-based photographs and examples, and accessing widgets (tools) that provide quantitative exercises and qualitative practices. The iBooks house a glossary, key terms/concepts, and culturally resilient activities. The fundamental design of the iBook is to serve as a template for the faculty and students to modify with current events, scientific data, and media inputs. Each island is affected differently by climate change and will vary in response from technological to traditional approaches. The idea behind the iBook collection is to serve as a geographical and culturally relevant educational tool that educates, engages, and empowers students and their communities to become resilient to climate change impacts. The project was funded by the National Science Foundation's Partnership for Advanced Marine and Environmental Science Training for Pacific Islanders (NSF ATE) grant project and will become part of the Teaching Oceania Series, published by the Center of Pacific Studies with the University of Hawaii at Mānoa.

Oral
A-1550

Building Relationships Between Hawai'i's Coral Reefs, Local People, and Visitors

Woo, S.
Hawai'i Institute of Marine Biology, Coral Resilience Lab, Kaneohe, United States

sarahwoo[at]hawaii.edu

Abstract

While Hawaiʻi's economy is dependent on a multi-billion dollar tourism industry, the resources for our island chain are finite. We struggle to support Kama'āina (residents), let alone the millions of international and national visitors that travel to the islands each year. *Encouraging Visitors to Mālama I Ke Kai* is a new partnership between the Coral Resilience Lab at the Hawaiʻi Insitute of Marine Biology and The Kahala Hotel & Resort (KHR), formed to encourage both Kama'āina (residents) and visitors to engage in place-based activities to better understand coral reefs and Hawaiian culture. Locally, this program takes the first steps toward creating more of a balance among visitors and Kama'āina. Globally, our access to such diverse visitors allows us to use local examples to spread awareness much farther. We encourage everyone to take the steps necessary to understand and protect coral reef ecosystems, regardless of where they call home.

Ma ka hana ke ʻike is a Hawaiian proverb that roughly translates to "through doing one learns". We feel hands-on engagement allows outreach efforts to make a lasting and meaningful impression. The *Encouraging Visitors to Mālama I Ke Kai* program provides participants with a variety of activity options to target multiple learning styles and make environmental stewardship both personable and achievable. Activities include participating in community organization workdays, an educational video, touch tank experiences, ocean-themed art classes, and research seminars.

Over the first 6 months of the program, 650 individual ranging from locals to international visitors, ages 5 to 80 years old, have participated in the program. We are establishing best practices to encourage others within the Hawaiʻi hospitality industry to expand *Encouraging Visitors to Mālama I Ke Kai* and make an even broader impact. We strive to normalize conversations surrounding reciprocity to create, instill, and perpetuate the value in taking care of our natural resources. We are interested in learning more about how programs with similar missions have been successful in other parts of the world.

Poster
A-1030

Can the mobilization and training of citizen scientists aid in data collection, the management of coral reef ecosystems, and policy making?

Hewlett, J.[1], Mattone, D.[2]
[1]Finger Lakes Community College, Canandaigua, United States
[2]Muskegon Community College, Muskegon, United States

hewletja[at]flcc.edu

Abstract

The local, regional, and global threats to coral reefs have allowed for the creation of a citizen army able to monitor and play a critical role in the adaptive management of coral reefs. Groups like Reef Check, the citizen-based survey methods of the Atlantic and Gulf Rapid Reef Assessment (AGRRA), and institutions of higher education have all contributed to marine conservation efforts around the world. Data collected by these citizen and student scientists have led to the creation of marine protected and marine managed areas, a broader public understanding of climate change's effect on reef health, and have encouraged more students to pursue marine science and conservation as an educational pathway.

In the United States, Finger Lakes Community College (New York) and Muskegon Community College (Michigan) have been involved in coral reef monitoring efforts since 2003. Students learn about the science of coral reefs (biology, chemistry, geology) in a college course and receive training in Reef Check and AGRRA monitoring protocols. These skills and concepts are applied during a two-week field study in the Caribbean. Our work has been acknowledged by the Nevis Fisheries Ministry for providing data used to help establish marine protected areas around St Kitts and Nevis. Data generated from these efforts have contributed to the establishment of marine managed areas around the island of Montserrat, and damage assessment reporting in Dominica following hurricanes Irma and Maria in 2017.

The continued use of citizen scientists to gather vital data on reef health is a valuable and necessary tool in the effort to manage reefs and monitor how reefs worldwide are adapting to climate change.

Poster
A-1712

From Science to Awareness and Management: Virtual Reality for Coral Reef Sustainability

Reuter, H.[1], Zachmann, G.[2]
[1]Leibniz Centre for Tropical Marine Research (ZMT), Theoretical Ecology and Modelling, Bremen, Germany
[2]University Bremen, Department for Computer Science, Computer Graphics Group, Bremen, Germany

hauke.reuter[at]leibniz-zmt.de

Abstract

Life underwater is beautiful, complex, and largely unknown. This is particularly true for tropical coral reefs which provide major services for over 500 million people. However, tropical reefs face dire challenges, such as global temperature increase causing frequent deadly bleaching events, and local impacts resulting from intensive use and pollution. Therefore, easy-to-handle and intuitive tools for awareness building and for sustainable management are highly desirable.

Science has accumulated a large body of knowledge about the dynamics of coral reefs and the effects of harmful impacts. However, such knowledge often remains inaccessible for management authorities, ecosystem users, and the general public. This gap can be closed through the combination of scientifically-sound simulation models with new presentation, visualization, and gamification technologies such as virtual reality (VR). Ultimately, such technologies could provide users with a “virtual twin” of the ecosystem. Immersing non-specialists in such a virtual environment that lets users experience the extrapolations of the simulated reef like a real one will create a high degree of presence in the simulation and, hence, foster increased awareness and even lead to change towards a more environmentally sustainable behavior. This facilitates comprehension of complex forecasts even by non-experts working in political, societal, and economic sectors.

Our presentation will give an overview on how agent-based simulation models of coral reefs serve as “virtual laboratories” to analyze coral reef developments under different environmental and use conditions. We will present techniques to generate 3D virtual environments automatically in real-time based on these models, allowing for a full immersive experience. This innovative approach for underwater modeling provides an interactive and dynamic framework to test different scenarios and outcomes on reef development. This contributes to awareness building for threats to fragile ecosystems through serious games and aims at a well-informed management and the general public.

Virtual
Oral
A-1385

Long term effects of an informal education program on tourist environmental perception

Machado Toffolo, M.[1, 2], Simoncini, G.[1], Marchini, C.[1, 2], Meschini, M.[1, 2], Caroselli, E.[1, 2], Franzellitti, S.[2, 3], Prada, F.[1, 2], Goffredo, S.[1, 2]
[1]University of Bologna, Department of Biological, Geological and Environmental Sciences, Bologna, Italy
[2]The Inter-Institute Center for Research on Marine Biodiversity, Resources and Biotechnologies, Fano Marine Center, Fano, Italy
[3]University of Bologna, Department of Biological, Geological and Environmental Sciences, Ravenna, Italy

mariana.machado2[at]unibo.it

Abstract

Tourism is one of the most important economic sectors worldwide, with significant overarching impact on the environment, including negative effects caused by tourist inappropriate behavior while on vacation. By providing informal educational activities, tourism also has an educative role that leads to positive learning outcomes and beneficial environmental effects. Here we present the short- and long-term outcomes of a project for environmental education (Glocal Education) carried out in three travel destinations, aimed at promoting sustainability variables (knowledge, attitude, and awareness) in participating tourists. Since psychological components can affect learning outcomes, we also considered tourist satisfaction in participating in the project and identification with its values, as well as the intention to travel with the hosting tour operator again in the future. Tourists were asked to compile evaluation questionnaires three times: before Glocal Education activities, right after activities (i.e., while still on vacation), and after at least one year from initial project participation. Short- and long-term learning outcomes were tested, and possible relations between these variables and psychological components (satisfaction, identification, and intention) of the learning experience were verified. Overall, knowledge, attitude and awareness increased in the short term, while in the long term, knowledge and attitude decreased, and awareness remained constant. In most cases, psychological components showed positive relation with sustainability variables, which suggested their important role in structuring and carrying out environmental education activities. This study suggests that informal environmental education activities can be advantageous for tourism stakeholders in terms of customer loyalty, while promoting environmentally friendly tourist action.

Virtual
Oral
A-2170

Building citizen science networks for coral reef conservation in Indonesia

Senen, B.[1], Kadir, R.[1], Gani, F.[1], Sjahman, E.[1], Rapp, L.[2], Cichocki, J.[2], Madduppa, H.[3], Dias, J.[4], **Huhn, M.**[2, 5]

[1]Fisheries College Hatta-Sjahrir, Banda Naira, Indonesia
[2]Luminocean, Jakarta, Indonesia
[3]Agricultural University Bogor (IPB), Department of Marine Science & Technology, Bogor, Indonesia
[4]University of Southern Mississippi, Hattiesburg, Indonesia
[5]Ruhr-University Bochum, General Zoology and Neurobiology, Bochum, Germany

mareike[at]luminocean.com

Abstract

As climate change is threatening coral reefs worldwide, the mitigation of local stressors that additionally weaken coral reef resilience is becoming increasingly urgent. The Indonesian archipelago is home to some of the world's most biodiverse reefs. On the one hand, due to a rapid human population growth and an increasing demand for marine resources even the fringing reefs of remote islands are facing growing threats from local sources. On the other hand, Indonesia is a popular scuba diving destination, and the coral reefs attract millions of visitors every year, adding a significant economic value. This has led to a dense network of dive centers in the archipelago. These could be a valuable source of information for i) visitors and local communities to change their behavior towards a more sustainable interaction with the marine environment, ii) Indonesian researchers and research institutions to collect scientific data without having to travel to remote locations. The Indonesian NGO Luminocean is focusing on growing a network of dive centers, divers, underwater enthusiasts, national and international students, and scientists. The aim is to provide a flow of information and awareness from the scientific community towards divers and local communities and a flow of data from divers, dive centers and communities towards Indonesian researchers. The network is grown and maintained by providing monthly bi-lingual (English and Indonesian) marine biology webinars, as well as through social media and newsletters. Furthermore, the network has initiated two pilot projects involving community and citizen science. The first is a project called "Marine Bioinvasion Monitoring Indonesia" in the platform iNaturalist for sharing information on potential introductions of non-native species and for building baseline datasets on marine taxa that are known for their invasion potential. The second is a project to test the suitability of the larval propagation technique for coral restoration, to be conducted with the involvement of local authorities and students. This project points out how coral restoration efforts can sometimes do more harm than good, and tests - at the Banda Islands - how larval propagation can be conducted with locally available knowledge and resources. We will present the outcome and outlook of these two projects and hope to reach out to experts that could act as scientific supervisors within the growing network of dive centers, divers, and students.

Virtual
Poster
A-2139

Vive el arrecife, a travelling exhibition on coral reefs in Mexico

Medina-Rosas, P.
Universidad de Guadalajara, Puerto Vallarta, Mexico

pedromedinarosas[at]gmail.com

Abstract

Communicating scientific knowledge to different groups of the society is an important part of the scientific work, allowing people to understand nature and applying information to everyday life. One way of transmitting knowledge is through museum exhibitions, as they make visitors become active agents, with a new perspective of the topic. The purpose of the project was to communicate the main elements of the coral reefs, as well as relevant information on these marine environments and their inhabitants, by creating a museum exhibition on coral reefs of Mexico and the world. The exhibition entitled “Vive el arrecife” (Live the reef, in Spanish) is a didactic and interactive experience that immerses visitors into the coral reef environment, awakening their senses towards exploration, providing data of interest and scientific rigor on the socio-cultural, economic and biological importance of the ecosystem. For its elaboration, a team of scientists, members of the Mexican Coral Reef Society, was integrated with a team of communicators, educators and designers. The exhibition contains eighteen displays and modules, where visitors can learn what coral reefs are and how are they built, diverse aspects of the environment and current problems due to climate change, and fundamentally, how to raise awareness and participate in coral reef conservation, even if they live in a city faraway from the ocean. The exhibition opened in January 2018 and has been in venues of science museums of three Mexican cities, where more than 100,000 persons have visited it. The exhibition was planned to travel to other cities in Mexico, to receive at least half million visitors, and additionally other visitors on-line through the web site www.viveelarrecife.com and social networks, as well as printed publications. According to written comments, the change in people awareness about coral reefs and marine organisms is evident in the visitors.

Session 15A - Open Session:
New theories and future projections

Conceptualized and chaired by: **Arjun Chennu** [1]**, Emma Kennedy** [2], **James Robinson** [3]
[1] Leibniz Centre for Tropical Marine Research (Bremen, Germany)
[2] University of Queensland (Brisbane, Australia)
3 Lancaster University (Lancaster, UK)

Oral
A-1332

A spark in the dark – first insights into red fluorescence in coral dwelling gall crabs

Bähr, S.[1], Laetz, E. M. J.[2], Van der Meij, S. E. T.[2, 3], Benzoni, F.[1]
[1]King Abdullah University of Science and Technology, Red Sea Research Center, Division of Biological and Environmental Science and Engineering, Thuwal, Saudi Arabia
[2]University of Groningen, Faculty of Science and Engineering, Groningen Institute for Evolutionary Life Sciences, Groningen, Netherlands
[3]Marine Biodiversity Group, Naturalis Biodiversity Center, Leiden, Netherlands

susanne.bahr[at]kaust.edu.sa

Abstract

Coral reefs are among the most colourful marine ecosystems. In shallow-water reefs, blue-green light is dominating at depths below 10m and the vivid colouration is lost due to the rapid attenuation of long wavelengths from downwelling sunlight. Fluorescence may reintroduce colour by absorbing short-wavelength light and re-emitting it at longer wavelengths. This mechanism is utilized by various marine taxa. In scleractinian corals, for instance, it is thought to be involved in photoprotection and acclimation. In reef fish, red fluorescence is particularly widespread and its supposed functions associated to camouflage, prey detection and intraspecific communication. However, for most marine organisms the presence, role and function of fluorescence remain scarcely studied. Recently, red fluorescence was recorded in a coral-dwelling gall crab (Cryptochiridae) for the first time, sparking interest in reef-associated decapods as a new target for fluorescence research. Co-evolution patterns between gall crabs and their coral hosts make these crustaceans an interesting model taxon for studying the evolutionary background and host-related intraspecific variation of fluorescence. To start investigating the presence and functional role of fluorescence in gall crabs we focused on its occurrence and the location of the associated fluorophore in cryptochirids inhabiting the central Red Sea (Saudi Arabia). We imaged them *in situ* and sampled for examination under the fluorescent stereomicroscope with subsequent histological analysis. Furthermore, we analysed fluorescence patterns across carapace regions and body parts in different taxa using multiple correspondence analysis (MCA). We recorded fluorescence in seven out of nine gall crab genera. Intensity and appearance of fluorescence patterns were highly variable. The MCA suggested the presence of distinct fluorescent morphotypes. Histology work allowed us to ascertain that the commonly used fixative formalin (4%) leads to degradation of red fluorescence. Histological examination of ethanol-fixed specimens, however, indicated that the fluorophore(s) might be organised in cell-like structures with high morphological similarity to crustacean and reef fish chromatophores. Future research stemming from these results will include other reef-associated decapods to address the evolutionary background of fluorescence and the potential ecological role and function of this phenomenon.

Oral
A-1995

Disentangling key drivers of nutrient concentrations in coral reef fish to achieve food and nutrition security

Maire, E.[1], Graham, N.[1, 2], MacNeil, A.[3], Robinson, J.[1], Bodin, N.[4], Hicks, C.[1, 2]
[1]Lancaster Environment Centre, Lancaster University, Lancaster, United Kingdom
[2]Australian Research Council, Centre of Excellence for Coral Reef Studies, James Cook University, Townsville, Australia
[3]Ocean Frontier Institute, Department of Biology, Dalhousie University, Halifax, Canada
[4]Sustainable Ocean Seychelles, Mahé, Seychelles

e.maire[at]lancaster.ac.uk

Abstract

Fish are particularly rich in micronutrients essential to human health and development, and deficiencies in these micronutrients result in over a million deaths annually. However, considerable variation exists in micronutrient availability within and between species. It has recently been established that diet, thermal regime, and energetic demand significantly affect the nutrient content of marine fish globally. More specifically, species from tropical thermal regimes contain higher concentrations of calcium, iron, and zinc; species from cold thermal regimes or those with a pelagic feeding pathway contain higher concentrations of omega-3 fatty acids; and smaller species are richer in calcium, iron, and omega-3 fatty acids. However, the nutrient content of only a few coral reef species is effectively quantified and we still lack a generalizable understanding of which species are most able to address pressing nutritional needs in tropical coastal countries. Here, we analyze the concentrations of calcium, iron, selenium, zinc, vitamin A, and omega-3 fatty acids in ~20 species of coral reef fish across 10 locations in the Indo-Pacific, and integrate contemporary scientific knowledge regarding the environmental, ecological, and physiological drivers shaping the nutritional value of fish to predict nutrient content among global reef fish communities. We find that size, feeding pathway, and benthic habitat quality shape the quantity and diversity of micronutrients in fish species. Importantly, we identify suites of species, that are both rich in micronutrients important to human health and that have the potential to substantially meet the dietary requirements for several key nutrients. Our findings also emphasize that shifts in reef fish communities caused by coral habitat changes can ultimately alter the nutritional outcomes provided by coral reef fisheries. Projecting the nutritional compositions and yields of predicted future coral reef configurations and associated fisheries will be essential to sustain the nutritional needs of some of the most vulnerable food insecure human populations in the near future.

Oral
A-1875

A mechanism for top-down control of crown-of-thorns outbreaks in coral reef ecosystems

Meekan, M., Lester, E.
Australian Institute of Marine Science, Crawley, Australia

m.meekan[at]aims.gov.au

Abstract

It is widely acknowledged that the dynamics of populations of crown-of-thorns starfish (*Acanthaster planci*) are likely to be driven by both bottom-up and top-down processes. Although there is a well-documented mechanism by which bottom-up processes can act to encourage outbreaks (via high nutrient loads that enhance larval survival and recruitment), there is only circumstantial evidence for any role of top-down factors such as predation in population regulation. Importantly, we lack any convincing mechanism by which predation might influence recurrent outbreaks of these starfish. Here, I review recent field and experimental evidence that suggests that the removal of large mesopredatory fishes restructures both the abundance and trophic role of smaller mesopredators on coral reefs. Relaxation of the fear of predation and/or competition allows smaller mesopredators to feed higher in the water column and to access more energy-rich prey such squid and fishes. In turn, smaller mesopredatory fishes reduce their consumption of benthic invertebrates, including asteroids. Studies show that this change in diet occurs across at least three families of reef fishes, and potentially the entire guild of mesopredators. This idea that the removal of predation pressure by mesopredatory fishes, particularly on smaller size classes of crown-of-thorns might contribute to outbreaks is consistent with long-term data sets on the incidence of outbreaks gathered from the Great Barrier Reef and other localities.

Oral
A-1125

Bayesian estimation of community dynamics parameters reveals largely individualistic dynamics in a high-diverse reef fish assemblage

Ruiz-Moreno, A.[1, 2], Emslie, M. J.[2], Connolly, S. R.[1, 3]
[1]James Cook University, Townsville, Australia
[2]Australian Institute of Marine Science, Townsville, Australia
[3]Smithsonian Tropical Research Institute, Panama City, Panama

alfonso.ruizmoreno[at]my.jcu.edu.au

Abstract

Understanding biodiversity on coral reefs is crucial as millions of people's livelihoods depend on them. Reef fishes play vital roles on coral reefs, and identifying what mechanisms drive the dynamics of fish populations is critical to ensure biodiversity maintenance. Species-to-species and species-to-environment interactions are considered key drivers of community dynamics. However, disentangling these drivers in species-rich assemblages, like coral reefs, is challenging due to the high number of potential interacting species. To address this issue, we developed a process-based model that can quantify how intra-specific competition, interspecific interactions, and species' covarying responses to environmental fluctuations jointly drive temporal community dynamics. To reduce the dimensionality of the model we implemented a factor analysis approach and a shrinkage prior within a Bayesian framework. Here, we fitted the model to time series of abundances on 41 reefs of the Great Barrier Reef. We found that most reef fish species are, on average, weakly positively correlated in their responses to environmental fluctuations, with considerable variability in the magnitude of species pairwise correlations. However, interspecific interactions are negligible, whereas intraspecific interactions are strongly density dependent. Among species, there are strong, detectable differences in both overall average and magnitude of temporal fluctuations in intrinsic growth rates, as well as intraspecific density dependence; however, within species, there is no detectable among-reef variation in these parameters in the model. These findings reveal largely individualistic species dynamics, and strong geographically consistent niche structure in reef fish communities, on the Great Barrier Reef.

Poster
A-1210

Exploring historical dynamics to support adaptive management on Hawaiian coral reefs

Rahnke, S., McManus, L.
Hawaiʻi Institute of Marine Biology - UH Mānoa, Kāneʻohe, HI, United States

srahnke[at]hawaii.edu

Abstract

Evaluating the effectiveness of coral reef management interventions requires a thorough understanding of historical ecological dynamics to avoid consequences of “shifting baseline syndrome”. Marine historical ecology generally points to long term declines in marine ecosystems as the result of human interactions. In Hawaiʻi, however, it has been demonstrated that traditional forms of land and sea management enhanced the health of reef ecosystems and promoted recovery. Here, we developed a coral reef community model that can explore the historical dynamics of a reef in the Main Hawaiian Islands and simulate ecological responses to human activity. We first quantified a historical baseline using data from archeological deposits, anecdotal descriptions, as well as modern fisheries data. We then assessed the impact of varied levels of apex predator removal on the relative abundances of corals, herbivorous fish, and predators. For specific levels of apex predator removal, the abundance of herbivorous fish was increased through a mechanism of mesoconsumer release. However, complete removal of apex predators from the system led to a lower relative abundance of herbivores. Our results demonstrate the value of historical ecology in the evaluation of coral reef management, and illustrate important scenarios of human harvesting that may enhance coral reef systems. Future work will use this framework to further explore the implications of various management interventions across historical, present, and future social-ecological conditions.

Virtual
Oral
A-2098

Effects of climate change on the distribution of a keystone sea urchin in the tropical Atlantic

Principe, S. C.[1], Acosta, A. L.[2], Lotufo, T. M. C.[1]
[1]Universidade de São Paulo, Instituto Oceanográfico, São Paulo, Brazil
[2]Universidade de São Paulo, Instituto de Estudos Avançados, São Paulo, Brazil

silasprincipe[at]usp.br

Abstract

Climate change is leading to shifts in the distribution of organisms, triggering profound modifications on ecosystem functioning through the disruption of key processes. Herbivory is especially critical in maintaining coral reefs, as the increase in macroalgal growth may lead to phase-shifts. Hence, we modeled the current and future distribution of *Lytechinus variegatus*, a major grazer in tropical Atlantic reefs, considering presence data obtained in the OBIS/GBIF databases and through an extensive literature survey. We employed a Log-Gaussian Cox Process (LGCP), which is suited to model presence-only data, and a novel method that consider barrier (e.g. islands, coastal features) models to assess spatial effects that are not accounted by covariates. Bayesian hierarchical models were fitted using INLA (Integrated Nested Laplace Approximation) considering a set of environmental variables: mean salinity, maximum sea surface temperature (MaxSST), pH and Chl-a concentration. After selection, the final model (which included salinity, MaxSST and the spatial effect) was projected in the current period and in 3 Shared Socio-economic Pathway scenarios (SSP1, SSP2 and SSP3). LGCP results are interpreted as relative probability of occurrence. Today, *L. variegatus* have a potential distribution from ~27.5°S up to 35°N, with a higher probability of occurrence on Florida and in the northeast of Brazil, including the Abrolhos region. Changes in the probability of occurrence of *L. variegatus* are expected in all scenarios. In the SSP1 there is an overall decrease in probability of occurrence, but some areas will have an increase (consistent with a poleward shift). On the SSP2 and SSP3 scenarios there is a higher decrease in probability of occurrence on the northeast of Brazil (but lower in the SSP3), with increase in probabilities in the south of Brazil and on the north of Florida. Considering a future scenario in which the current distribution is kept (species is unable to track climate shift), we assessed how the mean sea surface temperature of each locality (sample of 1000 points) will diverge from the optimal temperature for the species. In the current period, most sampled points have mean temperatures below the optimum. However, in the SSP3 scenario, localities will be in general 2.5°C hotter than the optimal temperature. All these results are of concern considering the importance of the species in the functioning of Atlantic reefs.

Session 15B - How will tropical fisheries respond to climate changes on coral reefs?

Conceptualized by: **James Robinson** [1], **Alice Rogers**[2], **Kirsty Nash**[3], **Shaun Wilson**[4]
[1] Lancaster University (Lancaster, UK)
[2] Victoria University of Wellington (Wellington, New Zealand)
[3] Institute for Marine and Antarctic Studies (Hobart, Australia)
[4] Department of Biodiversity, Conservation and Attractions (Australia)

Chaired by: **James Robinson** [1]

Oral
A-1715

Climate impacts alter fisheries productivity and turnover on coral reefs

Hamilton, M.[1], Robinson, J.[1], Benkwitt, C.[1], Wilson, S.[2, 3], MacNeil, A.[4], Ebrahim, A.[5], Graham, N.[1]
[1]Lancaster University, Lancaster Environment Centre, Lancaster, United Kingdom
[2]Department of Biodiversity, Conservation and Attractions, Perth, Australia
[3]University of Western Australia, Oceans Institute, Crawley, Australia
[4]Dalhouse University, Department of Biology, Halifax, Canada
[5]Seychelles Fishing Authority, Victoria, Seychelles

mark.hamilton[at]lancaster.ac.uk

Abstract

Following coral bleaching, the alteration of benthic reef habitats leads to changes in fish assemblages, including those targeted by fisheries. In addition to abundance and biomass, the rates at which fish biomass is produced and replenished (productivity and turnover) are relevant to sustaining fisheries. Yet the responses of these metrics on reefs following bleaching are largely unknown. Here, we use data from Seychelles spanning >20 years to examine fish productivity and turnover trends after mass coral bleaching events, on reefs that were recovering to coral-dominated habitats or had regime-shifted to macroalgae-dominated. We found that the productivity of fish assemblages increased after bleaching on all recovering reefs, resulting in similar levels of productivity on fished and protected reefs 19 years after bleaching. Over the same period, productivity on regime-shifted reefs remained stable at 1994 levels on fished reefs, with higher levels observed on protected reefs. Net turnover was generally higher on fished regime-shifted reefs compared to recovering reefs for the whole fish assemblage and for all diet groups, suggesting fish biomass is more readily replenished on macroalgal reefs. Increases in productivity on fished recovering reefs were observed for all diet groups, particularly herbivore-detritivores including scraping and excavating parrotfish, which appeared to drive biomass accumulation through increased fish abundance. On macroalgal reefs, productivity of browsers increased 16-fold on protected reefs and 10-fold on fished reefs which, combined with invertivores, maintained post-bleaching productivity. After accounting for management and reef state, reef structural complexity was a positive predictor of fish productivity for all diet groups. These findings indicate that post-bleaching fish productivity is strongly influenced by the benthic recovery trajectories of reefs and demonstrates the importance of herbivore and invertivore species in sustaining small-scale inshore fisheries following climatic disturbances. The differences in fish productivity between reef habitats has implications for communities that rely on these fishing grounds for their livelihoods and as a source of nutrients.

Oral
A-1260

Modeling the effects of climate change and management strategy on nearshore fisheries in Hawai‘i

Innes-Gold, A.[1, 2], Carvalho, P.[3], Correa-Garcia, S.[1], Marcoux, S.[4], McManus, L.[1, 2], Oleson, K.[2], Stokes, K.[1, 2], Madin, E.[1, 2]
[1]Hawai'i Institute of Marine Biology, Kaneohe, United States
[2]University of Hawai'i at Manoa, Honolulu, United States
[3]University of California, Santa Cruz, United States
[4]Division of Aquatic Resources, Honolulu, United States

ainnesgo[at]hawaii.edu

Abstract

Small-scale fisheries provide food security and support livelihoods for hundreds of millions of people globally. The recreational and artisanal coral reef fisheries surrounding the main Hawaiian Islands exemplify the importance of these fisheries as they support food and economic security, create social bonds, and maintain traditional knowledge and practices. However, the history of post-colonial overexploitation in Hawai‘i, combined with rising ocean temperatures, has led to a dramatic decline in reef fish populations. In an effort to protect nearshore marine resources, the Hawai‘i Division of Aquatic Resources developed the Holomua: Marine 30x30 Initiative to designate 30% of nearshore waters as marine management areas by 2030. However, the composite effects of management and climate change on target reef fish populations remains uncertain. The goal of this study was to test the effects of different management strategies and sea temperatures on herbivorous fish stocks (one of the most commonly targeted group in the non-commercial fisheries) and fisher success on O‘ahu, Hawai‘i. To do this, we created a bioeconomic model representing O‘ahu’s non-commercial fishery for herbivorous reef fishes and included temperature-dependent fish population growth. We tested management strategies, including bag limits and marine reserve implementation, and quantified fish population (biomass) and success of fishers (total harvest and market-equivalent revenue) as response variables. In addition, we modeled various climate change scenarios under the same management restrictions to test the robustness of these management scenarios under potential impacts of climate change. The results will help guide managers as they work towards of their goal of sustainable resource management in Hawai‘i.

Oral
A-1186

The impact of a mass coral bleaching event on reef fish assemblage size spectra

Moule, T.[1], Richardson, L.[1], Robinson, J.[2], Williams, G.[1]
[1]Bangor University, School of Ocean Sciences, Bangor, United Kingdom
[2]Lancaster University, Lancaster Environment Centre, Lancaster, United Kingdom

tcmoule[at]gmail.com

Abstract

Climate-driven bleaching is rapidly transforming coral reef ecosystems. Marine heatwave events and associated coral mortality are consequently collapsing habitat structure, and such loss of reef complexity is expected to alter the composition and diversity of reef fish communities. However, how reef fish size distributions vary amongst distinct coral habitats and how these relationships respond to a large-scale thermal disturbance remains unclear. Recent advances in reef fish size-spectra analyses indicate habitat degradation and human threats disproportionately affect certain groups of fish. Specifically, degraded habitats impact small-bodied fishes due to reduced refugia, and fishing pressure reduces carnivorous fish biomass. Whilst this provides important insight into how reef fish community structure can change, the impact of a large-scale thermal disturbance on the size distribution of functionally important fish groups remains uncertain. Here, we use empirical data on reef habitat composition, cross-scale structural complexity, and fish abundances at Lizard Island before (September 2015) and after (October 2016) a mass coral bleaching event to explore the effect of habitat structure on predator and herbivore fish size distributions, and how those size-spectra may change across a mass coral bleaching event. By understanding how reef fish body-size assemblages are determined by the composition of coral-dominated reefs and the differential impacts of climate-induced loss of live habitat, we can better understand how mass coral bleaching events will alter reef fish communities. Moreover, with climate change disturbances forecast to increase, understanding the likely function of future coral reefs is vital for management in conserving the provision of reef services.

Oral
A-1438

Nutrient productivity of coral reef fisheries

Robinson, J.[1], Daring, E.[2], Maire, E.[1], Hamilton, M.[1], MacNeil, A.[3], Hicks, C.[1], Graham, N.[1]
[1]Lancaster University, Lancaster, United Kingdom
[2]Wildlife Conservation Society, New York, United States
[3]Dalhousie University, Halifax, Canada

james.robinson[at]lancaster.ac.uk

Abstract

Ocean warming is expected to impact reef fisheries production by inducing habitat turnover and restructuring fish assemblages. Climate-driven shifts in fisheries productivity threaten the supply of nutritious seafood in tropical coastal nations, and yet our understanding of both fish production and fish nutrient content on degraded reefs is limited. Here, we integrate reef fish nutrient concentrations into a fish production framework to estimate the nutrient productivity of coral reef fishes. Nutrient productivity is a new metric that combines ecological theory with fisheries management and aspects of human health, can be estimated with freely-available data on fish growth and nutrient content, and provides information for understanding ecosystem services from future coral reefs. We use underwater survey data from seven Indo-Pacific countries to show that low trophic level fishes are the most nutritious and productive species. These species will likely become increasingly important sources of nutritious seafood from climate-impacted reefs, owing to their resilience to both coral declines and fishing pressure. We also quantify the nutrient productivity of reef fishes across habitat regimes and management zones, finding that coral cover and protection from fishing are key predictors of nutrient production in the Indo-Pacific. Our results suggest that reef fisheries will continue to support tropical food and nutrition security, if exploitation of low trophic level species can be managed within sustainable limits.

Session 15C - Models as synthesis tools in coral reef research - How to identify drivers, facilitate projections, and aid management?

Conceptualized by: **Hauke Reuter** [1], **Jaap Kaandorp**[2]
[1] Leibniz Centre for Tropical Marine Research (Bremen, Germany)
[2] University of Amsterdam (Amsterdam, The Netherlands)

Chaired by: **Hauke Reuter** [1]

Oral
A-1036

Coral reef refugia at a smaller scale: A global map of tidally-generated internal waves and their impact on temperature variability

Bachman, S.[1], Kleypas, J.[2]
[1]National Center for Atmospheric Research, Climate & Global Dynamics, Boulder, United States
[2]National Center for Atmospheric Research, Climate & Global Dynamics, BOULDER, United States

kleypas[at]ucar.edu

Abstract

The hunt for thermal refugia for coral reefs - ideally the identification of sites that experience lower temperatures than surrounding regions, high temperature variability, and high food supply – has remained elusive. Internal gravity waves (IGWs) are tidally-driven oscillatory subsurface disturbances that are known to entrain cooler and/or nutrient-rich subsurface waters into reef environments, with the potential of creating refugia for reefs during warming events. Despite their potential importance to coral reefs, however, IGWs generate conditions that are typically small scale (< 5 km) and subsurface, so they usually remain unseen or unresolved by remote sensing and oceanographic models. To shed light on where IGWs are likely to impact temperature conditions within coral reef regions, we present an analysis of hourly data from the LLC4320, a massive high resolution (1/48º; <2.5 km) numerical global ocean simulation using the Massachusetts Institute of Technology General Circulation Model. The analysis consists of isolating changes in heat content due to internal processes in the IGW frequency band.

Based on the results, we present a global map of potential thermal refugia for corals reefs, which reveals strong regional differences in their distribution. Assuming 10-m depth as the nominal reef depth, reef regions likely to benefit from IGW-induced cooling occur in SE Asia and the Coral Triangle, the Galápagos, and potentially along the Pacific shelf of Central America. Such refugia are rare within the Atlantic reef sector. The analysis also illustrates that the seasonality of these conditions is an important consideration, as the depth of high temperature variability may not coincide with actual reef depth year-round. This raises the question of whether corals that experience even seasonal temperature variability are better adapted to bleaching events, given the exposure to high temperature variability and/or higher food supplies. Our study provides a first mechanistic look at IGW-induced refugia, as well as a recipe for identifying such refugia for coral reefs and other marine ecosystems under the threat of climate change.

Oral
A-1399

Modeling the impacts of long term warming and marine heatwaves on reef fish habitat

Clarke, T., Cheung, W.
The University of British Columbia, Institute for the Oceans and Fisheries, Vancouver, Canada

t.clarke[at]oceans.ubc.ca

Abstract

Coral reefs and coral reef fishes are particularly vulnerable to long term warming and the increasing frequency, magnitude and intensity of marine heatwaves. Warming increases the metabolic rate and oxygen demand of fishes, forcing trade-offs between oxygen demanding processes that can change the productivity and distribution of reef associated species. Correlative species distribution modeling is the most common approach taken to model the impacts of climate change on marine species due to its low data requirements, yet it may not perform very well under novel climates. While modeling the physiological mechanisms driving these species distribution shifts improves the accuracy of projections, this approach cannot be broadly applied due to high data requirements. Hybrid species distribution models based on generalized biological principles that define how marine ectothermic organisms relate to their environment may improve future projections while keeping data requirements low. We apply a hybrid species distribution model through the application of the Aerobic Growth Index (AGI) to analyze the impacts of long-term warming and marine heatwaves on reef fishes. AGI integrates growth theory, metabolic theory, and the Gill-Oxygen Limitation Theory to compute an eco-physiological-based indicator of habitat viability. We expect to produce global habitat loss projections for reef fish under long term warming and marine heatwaves.

Oral
A-1212

Conservation for evolving coral populations

McManus, L.[1], Forrest, D.[2], Tekwa, E.[3], Schindler, D.[4], Colton, M.[5], Fox, H.[5], Webster, M.[6], Essington, T.[4], Palumbi, S.[7], Mumby, P.[8], Pinsky, M.[9]
[1]University of Hawaii at Manoa, Hawaii Institute of Marine Biology, Kaneohe, HI, United States
[2]University of British Columbia, Institute for Resources, Environment and Sustainability, Vancouver, BC, Canada
[3]University of British Columbia, Department of Zoology, Vancouver, BC, Canada
[4]University of Washington, School of Aquatic and Fishery Sciences, Seattle, WA, United States
[5]Coral Reef Alliance, Oakland, CA, United States
[6]New York University, Department of Environmental Studies, New York, NY, United States
[7]Stanford University, Hopkins Marine Station, Pacific Grove, CA, United States
[8]University of Queensland, School of Biological Sciences, Queensland, Australia
[9]Rutgers University, Department of Ecology, Evolution, and Natural Resources, New Brunswick, NJ, United States

mcmanusl[at]hawaii.edu

Abstract

While reducing emissions is critical to the continued persistence of reefs, local conditions have been shown to interact synergistically with climate change to negatively impact coral cover and overall reef health. Effectively managed marine protected area (MPA) networks must therefore address both local and global threats. In particular, these networks should aim to reduce stressors locally while harnessing natural environmental variation to facilitate evolutionary rescue at the regional scale. To that end, we used an eco-evolutionary model to test the efficacy of various spatial arrangements of MPAs in three major coral reef regions, the Caribbean, Southwest Pacific, and the Coral Triangle, to identify strategies that best support evolving coral populations under projected warming. At the network scale, we found that all MPA strategies were similarly effective in terms of overall coral cover, although the best-performing strategies depended on the region and focal time period, namely during decline and recovery. While protecting cold sites or refugia led to the highest cover during decline, protecting hot sites led to the highest cover at the end of the simulations. Randomly selecting sites maintained coral cover through time and avoided stark trade-offs during the decline and recovery periods that were evident in other strategies. This is likely because the random or strategy supports reefs across a range of temperatures, in addition to protecting both sources and sinks of coral larvae. In doing so, a random network maintains multiple adaptation adaptation pathways: local adaptation, demographic rescue, and evolutionary rescue.

Oral
A-1025

SDMs & Phylogenetic Analyses to predict changes in richness, phylogenetic and functional diversity of Atlantic coral assemblages under climate change

Rodríguez, L.[1], Tuya, F.[2], Martínez, B.[3]
[1]Universidad Las Palmas de Gran Canaria, Las Palmas de Gran Canaria, Spain
[2]Universidad de las Palmas de Gran Canaria, Las Palmas de Gran Canaria, Spain
[3]Universidad Rey Juan Carlos, Móstoles, Spain

laura.rdz.garcia[at]gmail.com

Abstract

Climate change is altering corals distributions worldwide. The use of climatic projections, via Species Distribution Models to predict coral distributional shifts, can identify threaten species and help to set priority areas of conservation.
In this study, we predict future distributional changes of 45 Atlantic reef-forming corals (scleractinian) and assessed if these distributional shifts, and the main environmental variables driving their distributions, correlated with their phylogeny and/or their functional traits; i.e. whether expected contractions and expansions affected specific clades or traits. Additionally, we estimated the potential loss and/or gain of species richness, phylogenetic diversity (PD), and phylogenetic structure (PD_{SES}: clustering, overdispersion or randomness) of the Atlantic coral communities under a future climate scenario (A2-IPCC-2100) compared to current conditions.
According to our results, approximately 69% of the coral species under study will increase their total suitable habitat by the year 2100, while 31% will decrease it; most of them (85%) will suffer any range contraction somewhere in the Atlantic. The potential loss of Atlantic corals in the future will be randomly distributed across their phylogeny, i.e. potential extinctions will not only affect one section of the phylogeny, therefore alleviating an inordinate loss of evolutionary history. Nearly all current and future communities presented a random phylogenetic structure. Environmental variables also did not show a significant correlation with the phylogeny, neither with the coral's functional traits. Predicted changes in species Richness and PD varied across the Atlantic; certain areas displayed large evolutionary diversity losses, highlighting their conservation relevance. Species belonging to isolated clades (high evolutionary distinctiveness) contribute to quantitative increases or decreases of PD becoming crucial species for conservation.
These findings highlight the importance of combining SDMs and phylogenetic metrics to develop conservation strategies to protect the future of coral reefs.

Oral
A-1358

How do climate change and connectivity drive coral reef fish abundance in the Western Indian Ocean?

Warmuth, L.[1], Bonsall, M.[1], Head, C.[1, 2]
[1]University of Oxford, Department of Zoology, Oxford, United Kingdom
[2]Institute of Zoology, Zoological Society London, London, United Kingdom

laura.warmuth26[at]gmail.com

Abstract

Coral reefs worldwide are facing more risks than ever before and the Western Indian Ocean (WIO) harbours about 16 % of the global coral reefs with highly reef-dependent communities. Coastal protection and food security depend on efficient conservation management, which requires understanding of connectivity and prediction of fish abundance. This research aimed to explore how functional reef fish groups are impacted by their environment and if they respond differently to climate change stressors and connectivity. We created generalized additive models for the three trophic groups “grazers and detritivores”, “large excavators and bioeroders” and “corallivores” across 53 sites in the WIO. This is the first study to combine ecological models with oceanographic connectivity between coral reefs for this region. The models show that different metrics of connectivity and chlorophyll *a* seem to be more important than sea surface temperature for all three groups. Our designed metric to characterize modelled connectivity based on particle tracking was the most important predictor for abundance of grazers and detritivores – a group highly important for reef resilience by feeding on algal turf and limiting the number of algae. Interestingly, their abundance peaked at low and high levels of connectivity which indicates that sites with a low or high particle inflow host higher grazer and detritivore numbers compared to sites with medium inflow. Results for bioeroders show abundance strongly increasing with higher chlorophyll *a* variability which supports that fish species have adapted to seasonal changes of alongshore currents in the WIO. Corallivores are less impacted by connectivity due to their shorter pelagic larval duration and smaller home ranges. Given the limited inclusion of connectivity into marine protected area planning, we suggest decision making must be collaborative across country borders and connectivity metrics should be included in prioritizing areas for management and conservation.

Oral
A-1290

From immunity to community: a predictive trait space model for coral species exposed to white plague disease

Williams, S.[1], Macknight, N.[2], Beavers, K.[2], Brandt, M.[3], Mydlarz, L.[2], Muller, E.[1]
[1]Mote Marine Laboratory, Sarasota, United States
[2]University of Texas at Arlington, Arlington, United States
[3]University of the Virgin Islands, St. Thomas, U.S. Virgin Islands

swilliams[at]mote.org

Abstract

Coral disease outbreaks have played important roles in changing the structure of reef communities. Species' abilities to resist disease and their corresponding immune traits may thus provide a basis for predicting community dynamics on reefs disturbed by disease. We developed a trait space model that incorporates intraspecific variation of immune traits to predict coral community assemblages after a white plague disease outbreak. Using results from a white plague transmission experiment conducted in the United States Virgin Islands (USVI), seven species were identified as susceptible (*Orbicella favelota* and *O. annularis*), tolerant (*Colpohylia natans* and *Siderastrea siderea*), or resistant (*Montastraea cavernosa*, *Porites porites*, and *P. asteroides*). Traits considered in the model consisted of immune data (e.g. gene expression and protein activity data) gathered during the experiment. Multiple trait sets were used to compare the predictive power of different trait groups, including those related to temperature stress or other diseases, to influential traits for white plague resistance as determined by random forest analysis. An ideal trait distribution for being resistant to the disease was created using the values of the most resistant species, *M. cavernosa*, which acted as an environmental filter for the model. Mclust, an R package for normal mixture modeling, was used to compute the probability of a trait given a species using the probability density functions of the actual traits present in the seven species. Traits were randomly drawn from the ideal traits distribution to calculate probabilities of a trait given the environment where the environment was the target trait distribution. Our trait space model then used a hierarchical Bayesian model to predict the community assemblage after the environmental filter (i.e. a white plague outbreak) was applied. Trait space predicted community assemblages were validated with survey data from the USVI and tested against a suite of null models. The trait space model was able to predict an accurate post-outbreak community structure using immune traits determined to be influential for white plague resistance. Additionally, the model determined that the antioxidant, catalase, and the immune protein, Prophenyloxidase, were important immune traits for predicting community structure. Our trait space model suggests that immune traits alone are predictive drivers of reef community assemblages subjected to disease outbreaks.

Poster
A-1408

Spatial complementarity of multiple human disturbances shortens the timeline of environmental viability for the world's coral reefs

Setter, R., Franklin, E., Mora, C.
University of Hawaii at Manoa, Honolulu, Hawaii, United States

rsetter[at]hawaii.edu

Abstract

Anthropogenic disturbances are posing unprecedented challenges to the persistence of ecosystems worldwide. The speed at which these disturbances reach an ecosystem's tolerance thresholds will determine the time available for the ecosystem to adapt and for conservation to succeed. Here we introduce a new index, "expiration date", that determines the year when a given environmental stressor exceeds the bounds of an ecosystem's tolerance. Using the world's coral reefs under projected environmental and human disturbances as a case example, we show that the magnitude of the environmental crisis faced by coral reefs is being underestimated considerably by looking at disturbances independently. Given a spatial complementarity in which numerous human disturbances impact the world's coral reefs, we show that the timelines of environmental suitability are halved when disturbances are analyzed in combination as opposed to independently. Under business-as-usual scenarios, the analysis of independent human disturbances shows unsuitable environmental conditions for half the world's remaining coral reefs by 2050 (29 years left) while the combined effects of disturbances yields unsuitable conditions by 2035 (14 years left). Likewise, we find that while a mitigation of greenhouse gases and optimistic scenarios of human development lead to a considerable reduction of the impacts of individual human disturbances, the combined effects of such disturbances yields significant and pervasive consequences for a large area of the world's coral reefs (between 75% to 99% of the world's coral reefs could face expired environmental conditions under even the most optimistic scenarios when numerous human disturbances acted in complement). Under worst-case scenarios, nearly all coral reef ecosystems worldwide (~99%) would meet their environmental expiration date by 2055 by any one disturbance. Other studies have also indicated the projected dire effects of human stressors by mid-century; by analyzing a multitude of projected disturbances, our study reveals a much more severe prognosis for the world's coral reefs as they have significantly less time to adapt and for conservation to succeed.

Virtual
Oral
A-2165

Projected climate-driven shifts in the distribution of Southwestern Atlantic corals support tropicalization

Ferreira Martello, M.[1], Bleuel, J.[1], Grazia Pennino, M.[2], Ortigara Longo, G.[1]
[1]Federal University of Rio Grande do Norte, Dept. of Oceanography and Limnology, Natal, Brazil
[2]Spanish Institute of Oceanography, Vigo, Spain

melina.ferreira[at]hotmail.com

Abstract

One of the main challenges in framing the future of coral reefs has been to predict species distribution shifts. We investigated which species are most likely to shift their distribution in the Southwestern Atlantic (SWA) and how these shifts could alter the composition of coral assemblages in the future by modeling the occurrence probabilities of 12 zooxanthellate reef-building corals that occur along the Brazilian coast (1°N–27°S). We hypothesized that the distribution of most coral species is likely to expand southwards due to a potential tropicalization of this region, while tropical areas could become less suitable, and that corals with a broader distribution range would be more likely to shift their ranges due to greater tolerance to environmental variability when compared to geographically restricted populations. We used Spatial Distribution Models with a Bayesian approach to predict the species occurrence probabilities in current and future time (2050 and 2100) under an intermediate scenario of increasing greenhouse gas emissions through the 21st century (RCP6.0 – IPCC). We found that the occurrence probabilities of all modeled corals will decline within the tropics (1°N–20°S) and increase towards subtropics (20–27°S) as early as 2050, with major declines predicted to occur between 9°S and 20°S, coinciding with the region that comprises the richest reef complex in SWA, the Abrolhos bank. Great declines are expected to occur for Brazilian endemic and range-restricted reef-builders, *Mussismilia braziliensis* and *Mu. harttii*, likely causing loss of structural complexity and its associated diversity. Higher occurrence probabilities in subtropical areas support the tropicalization hypothesis in the SWA, which should benefit species that are already established in these areas, such as *Mu. hispida* and *Madracis decactis*, and potentially enrich coral assemblages through the range expansion of other broadly-distributed species, such as *Siderastrea* spp., *Millepora* spp. and *Porites* spp. These rearrangements could add complexity and functions to these marginal reefs or reverberate in unexpected ways, ultimately affecting the provision of goods and ecosystem services. Predicted losses in tropical and gains in the subtropical regions emphasize the need to support potential ecological corridors that could aid corals to move towards more suitable areas and thrive facing climate change.

Session 15D - What can photosymbiont-bearing foraminifera tell us about the past, present and future of coral reefs?

Conceptualized by: **Marleen Stuhr**[1], **Christiane Schmidt**[2], **Martina de Freitas Prazeres**[3]
[1] Leibniz Centre for Tropical Marine Research (Bremen, Germany)
[2] University of Angers (Angers, France)
[3] Naturalis Biodiversity Center (Leiden, The Netherlands)

Chaired by: **Marleen Stuhr**[1], **Christiane Schmidt**[2]

Oral
A-1113

Cold-tolerant photosymbiosis as a key to invasion success of a coral reef foraminifera in the Mediterranean Sea

S. Raposo, D.[1], Morard, R.[1], Schmidt, C.[2], Hassenrück, C.[1, 3], Titelboim, D.[4], Abramovich, S.[5], Caruso, A.[6], Kucera, M.[1]
[1]MARUM, Center for Marine Environmental Sciences, University of Bremen, Bremen, Germany
[2]ZMT, Leibniz Centre for Tropical Marine Research, Bremen, Germany
[3]IOW, Leibniz Institute for Baltic Sea Research Warnemünde, Rostock-Warnemünde, Germany
[4]School of Earth Science, University of Bristol, Bristol, United Kingdom
[5]Department of Earth and Environmental Sciences, Ben Gurion University of the Negev, Beer Sheva, Israel
[6]Dipartimento di Scienze della Terra e del Mare, Università degli studi di Palermo, Palermo, Italy

draposo[at]marum.de

Abstract

Among the most successful Lessepsian invaders is the large benthic foraminifera *Amphistegina lobifera*, a diatom-bearing, shallow-water Indopacific species, and a prolific calcifier in coral-reef habitats. In its newly conquered Mediterranean habitat, the invasive populations are exposed to colder winters and temperature seasonality that exceeds the range of its native habitat. To predict future spread of this species, it is of critical importance to understand the mechanisms that facilitated its success in the new habitat. It is especially important to understand if the adaptation necessary to survive in the Mediterranean were already present in the source population in the Red Sea or if the invasion success was due to rapid emergence of new adaptations in the invaders. To this end, we evaluated the physiological responses of *A. lobifera* to cold temperatures for a source population (Red Sea), early invader population (Eastern Mediterranean) and invasion front population (Sicily) to temperatures of 10, 13, 16, 19°C + control (25°C). We conducted a four-week experiment in which we monitored the physiological response of the host (growth, motility) and the photosynthetic activity of the endosymbionts by Pulse Amplitude Modulation fluorometery. None of the treatments was lethal to the holobiont, but we observed a reduced growth rate for all populations below 19°C compared to the control. The motility (pseudopodia movement) of the foraminifera was also reduced at colder temperatures and dropped to zero below 13°C for all tested populations. The response of the endosymbionts was different. The Red Sea and Eastern Mediterranean populations showed reduced photosynthetic activity at colder temperatures whereas the endosymbionts of the Sicily population maintained a high photosynthetic activity even in the coldest treatments ($p < 0.05$). Since the host response did not differ across the tested range of temperatures, the invasion success of the species at the cold-end of the Mediterranean temperature range must be due to enhanced thermal tolerance of the endosymbionts in the Sicily population. Clearly, the invasion success of *A. lobifera* is related to their symbiosis and not to an adaptation of the host. This suggests that cold-tolerant photosymbiosis or the flexibility to form symbiosis with differently adapted algae, is a key to the success of past and future migrations of this species.

Virtual
Oral
A-1501

Amphistegina Foraminifera are Excellent Bioindicators of Long-Term Heat Stress on Tropical and High Latitude Reefs

Humphreys, A.[1], Purkis, S.[1, 2]
[1]University of Miami Rosenstiel School of Marine and Atmospheric Science, Marine Geosciences, Miami, United States
[2]Khaled bin Sultan Living Oceans Foundation, Annapolis, United States

afh35[at]miami.edu

Abstract

Coral reefs are in global decline and anomalously hot temperatures are primarily to blame. Foraminiferal bioindicators are important because they report on historical reef stress over periods of centuries to millennia, as compared to the few decades offered by diver surveys. Traditional reef monitoring is time consuming and lacks the longevity to make this distinction. While foraminifera-based indices exist to reconstruct histories of nutrient stress on reefs, there is a paucity of equivalent bioindicators that respond to temperature. Because ocean heat waves are the dominant driver of coral bleaching and death, there is compelling motivation to develop new foraminiferal bioindicators that inform on temperature stress over meaningful timescales and which respond to these stresses on reefs across the globe—both tropical and subtropical. Here we compare findings from two locations that span spectrums of long-term temperature stress: the tropical Solomon Islands and New Caledonia, and the Subtropical Northeast Red Sea and Gulf of Aqaba. Results from both locations indicate large benthic foraminfera from the Amphisteginidae family to respond systematically to the temperature stress that kills corals. Our results are consequential for at least three reasons. First, while the Solomon Islands and New Caledonia are in tropical latitudes, the Red Sea and Gulf of Aqaba contain the most northerly coral reefs on Earth. Establishment of a thermal bioindicator in both locations confirms the strategy can be deployed from the tropics to high latitudes, the latter which are disproportionally afflicted with heat extremes. Second, the reefs of the North Red Sea and Gulf of Aqaba—and the foraminifera they host—are famed for their thermal resilience. Foraminiferal bioindicators have not previously been trialled on reefs that have adapted in this way. Finally, as a restricted offshoot of the Indian Ocean, the level of endemism in the Red Sea is especially high. The bioindicator that we propose is apparently not compromised by endemism. Ultimately, our findings advocate for an expanded deployment of *Amphistegina*-based reef bioindicators.

Session 15E - Will coral reef islands survive 21st century sea-level rise?

Conceptualized by: **Thomas Mann**[1], **Paul Kench**[2]
[1] Leibniz Centre for Tropical Marine Research (Bremen, Germany)
[2] Simon Fraser University (Burnaby, Canada)

Chaired by: Yannis Kappelmann[1], Kathrine Maxwell[1]
[1] Leibniz Centre for Tropical Marine Research (Bremen, Germany)

Oral
A-1586

Reef island formation in the Indonesian Archipelago

Kappelmann, Y.[1, 2], Westphal, H.[1, 2, 3], Kneer, D.[1], Mann, T.[4]
[1]Leibniz Centre for Tropical Marine Research (ZMT), Bremen, Germany
[2]University of Bremen, Bremen, Germany
[3]King Abdullah University of Science and Technology (KAUST), Thuwal, Saudi Arabia
[4]Federal Institute for Geosciences and Natural Resources (BGR), Hannover, Germany

yannis.kappelmann[at]leibniz-zmt.de

Abstract

In the tropics, valuable settlement area is provided by reef islands, whose stability in the context of changing environment and sea-level rise is a subject of uncertainty. To understand mechanisms of formation and development, and to predict possible future scenarios, site-specific understanding of these landforms is of strong interest. Here we discuss sedimentological data of two inhabited reef islands located in the Spermonde Archipelago, Indonesia. One of these islands, located on the mid shelf, has accumulated in prograding sequences of reef-derived material over some 5,000 years from the early Holocene onwards, with a significant gap in sedimentation during a sea-level highstand with simultaneous reversal in the dominating monsoon wind system. The second island, located on the outer shelf, has gained most of its recent surface area in the past century, as shown by satellite data. Furthermore, the sedimentary facies of the second island are relatively heterogenous, suggesting that the landform is receiving material from different sources. Overall, both islands investigated show a strong morphodynamic dependence on the monsoon winds, making it one of the key factors also for future scenarios. Our results also imply that even on a small regional scale, generation of island forming sediment and patterns of accumulation can be highly variable, whereby responses of individual reef islands to a changing environment may also be not uniform. For coastal protection management, individual assessments are needed.

Poster
A-1231

Future sea-level rise and tidal dynamics at the reef-scale

Hill, J.[1], Lee, K.[1], Mawson, E.[2], Webster, J.[3], Vila-Concejo, A.[3], Duce, S.[4], Figueira, W.[5], Hacker, J.[6, 7]
[1]University of York, Department of Environment and Geography, York, United Kingdom
[2]Heriot-Watt University, School of Engineering and Physical Sciences, Edinburgh, United Kingdom
[3]University of Sydney, School of Geosciences, Sydney, Australia
[4]James Cook University, College of Science and Engineering, Townsville, Australia
[5]University of Sydney, School of Life and Environmental Sciences, Sydney, Australia
[6]Airborne Research Australia, Parafield, Australia
[7]Flinders University, College of Science and Engineering, Adelaide, Australia

jon.hill[at]york.ac.uk

Abstract

Tides are a crucial mechanism for distributing nutrients, larvae and spores over the Great Barrier Reef (GBR). However, tidal flow is complex. Bathymetry plays a critical role in governing the tidal flow in and around coral reefs and bathymetry is itself complex on a reef system. As sea-level rises, tidal dynamics will change also. Large scale simulations have shown that a future rise in sea-level will alter both the timing, range and velocities of the tides on the GBR, but these studies lack the detail of changes that will occur on an individual reef scale. On a reef-scale, how will future sea-level rise impact tidal dynamics? Here, we model tidal flow over and around One Tree Island, in the Capricorn Group section of the GBR, at very high resolution (metre-scale) using an extreme multi-scale tidal model of the whole southern section of the GBR. We use high resolution (25 cm) LIDAR data collected in 2018 of One Tree Island which is used within a 5 metre resolution finite element model, with model resolution then increasing to 25 km (four orders of magnitude change in resolution) over the whole domain. The high resolution model captures small-scale reef features including grooves and spurs, tidal channels, sand aprons and patch reefs within the lagoon. We show that under various sea-level rise scenarios that fundamental changes in the tidal regime occur at the metre-scale, affecting the flushing rate of the lagoon. Moreover, the tidal velocities show a marked change in flow over the reef when sea-level is higher, particularly over the windward side and the groove and spur structures. The work here has implications for reef management and conservation as well as informing about detailed mechanisms of tidal flow at a single reef island-scale.

Session 15F - How has mass coral bleaching changed through time and how is it expected to progress into the future: Tools, products, and analyses. / Can evolution rescue corals from the effects of climate change?

Conceptualized by: **William Skirving** [1], **Mark Eakin**[2], **Ove Hoegh-Guldberg**[3], **Simon Donner**[4], **Neal Cantin**[5]
[1] NOAA (Cranbrook, Australia)
[2] NOAA (College Park, MD, USA)
[3] University of Qeensland (Brisbane, Australia)
[4] University of British Columbia (Vancouver, Canada)
[5] Australian Institute of Marine Science (Cape Cleveland, Australia)

Chaired by: **Mark Eakin**[2], **Neal Cantin**[5]

15F - How has mass coral bleaching changed through time and how is it expected to progress into the future: Tools, products, and analyses. / Can evolution rescue corals from the effects of climate change?

Oral
A-1839

A changing climate for coral reef management and adaptive restoration

Bay, L.[1, 2], Cresswell, A.[1], Haller-Bull, V.[1], NIelsen, J.[1, 2, 3], Morris, L.[1, 2], Quigley, K.[1], Ortiz, J.[1]
[1]Australian Institute of Marine Science, Townsville, Australia
[2]AIMS[at]JCU, Townsville, Australia
[3]James Cook University, College of Public Health, Medicine, and Veterinary Sciences, Townsville, Australia

l.bay[at]aims.gov.au

Abstract

Despite significant protection and management, the Great Barrier Reef (GBR) is in long term decline. The World Heritage listed ecosystem is under threat from a range of often cumulative disturbances. For example, the scale and severity of coral bleaching is causing mass coral mortality and increasingly eroding the Reef's resilience. Even if carbon emissions are reduced, the legacy effects of historic emissions will result in significant warming over the coming decades. It is now clear that very rapid adaptation will be required for corals to continue to provide critical ecosystem services into the near future. Consequently, understanding the natural rates of coral adaptation, and the potential enhancement by accelerated evolution is at the heart of many proposed conventional and active management strategies. In this talk we will outline the challenges faced when attempting to incorporate the current knowledge of observed thermal tolerance and potential enhancement from the literature into ecological models and upscaled macroecological theory. We will examine how adaptation is typically studied, identify common limitations in the information provided in most experimental studies and describe alternative pathways to overcome these challenges. We will then discuss the consequences of the current uncertainty in enhancement potential for predicting the future of reefs and the outcome of restoration scenarios. We conclude that well-parametrized ecological models developed across spatial scales will need to be based on a multidisciplinary perspective to understand how coral populations may respond naturally and under enhancement. Such adaptive (conventional and novel) management actions must not detract from the need to curb CO_2 emissions and stabilise ocean temperatures. However, when based on the data discussed here, they can be used to evaluate benefits and risks to the health and value of the Great Barrier Reef in the future.

Oral
A-1914

Genomic basis of bleaching tolerance across the genus Acropora

Bay, R., Guerrero, L.
UC Davis, Davis, United States

rbay[at]ucdavis.edu

Abstract

In recent decades, as ocean warming linked to anthropogenic climate change places increasing stress on coral reefs, researchers have been searching for means of predicting differences in bleaching susceptibility across individuals, populations, and species. On one end of the divergence spectrum, previous studies have defined broad-scale, macro-evolutionary patterns associating trait variation and life history strategies with bleaching outcomes among species. On the other hand, population-level studies have identified genetic variants and symbiotic associations that predict differences in bleaching outcomes among individuals. The connection between these two levels of understanding is largely unexplored. Are the same genetic mechanisms that predict within-species variation also involved in tolerance differences among species? Do we see patterns of parallel/convergent evolution in multiple ‘tolerant’ lineages or are there multiple pathways to tolerance?

To investigate the connection between within- and among-species variation in thermal tolerance, we focus on the genus Acropora, which is the most speciose of coral genera and has been a workhorse of coral population genetics. We combine signatures of transcriptomic response to heat stress with whole genome differentiation across species and environmental gradients to develop an understanding of the molecular mechanisms of tolerance across closely related Acropora species. First, we use transcriptomic data from standardized experiments across seven species collected from the same area to identify whether gene expression responses to heat stress are conserved across the genus (i.e. potential ‘biomarkers’) and find expression divergence related to species-level thermal tolerance. Additionally, we use previously published whole genome data gathered from across environmental gradients to examine the evolution of tolerance and susceptibility across the phylogeny of Acropora, including identifying genomic regions associated with species-level tolerance and comparing those regions to within-species signals of selection. Together, this data should aid in our understanding of the evolution of thermal tolerance, the distribution of adaptive genetic variation, and the limits to genomic predictions of evolutionary rescue. Such insights are necessary for integrating evolution and adaptive capacity into models that predict future coral population and community dynamics.

15F - How has mass coral bleaching changed through time and how is it expected to progress into the future: Tools, products, and analyses. / Can evolution rescue corals from the effects of climate change?

Oral
A-1777

How the Climate-Driven 2014-17 Global-Scale Coral Bleaching Event Became the Most Damaging Ever Recorded

Eakin, C. M.[1, 2], Devotta, D. A.[1, 3], Connolly, S. R.[4], Liu, G.[1, 5], Geiger, E. F.[1, 5], Heron, S. F.[1, 6], De La Cour, J. L.[1, 5], Skirving, W. J.[1, 7], Spady, B.[1, 7], Manzello, D. P.[1]
[1]NOAA/NESDIS/STAR/SOCD, Coral Reef Watch, College Park, MD, United States
[2]Corals and Climate, Silver Spring, MD, United States
[3]Global Science & Technology, Inc., Greenbelt, MD, United States
[4]Smithsonian Tropical Research Institute, Balboa, Ancón, Panama
[5]University of Maryland, Earth System Science Interdisciplinary Center/ Cooperative Institute for Satellite Earth System Studies, College Park, MD, United States
[6]James Cook University, College of Science and Engineering, Townsville, QLD, Australia
[7]ReefSense, Aitkenvale, QLD, Australia

corals.and.climate[at]gmail.com

Abstract

Accelerating anthropogenic climate disruption has made severe coral bleaching more extensive, frequent, and damaging. In 1998 and 2010, a global pattern of warm-season marine heatwaves with resultant bleaching and mortality propagated from the central Pacific to the Indian Ocean, Southeast Asia, the Coral Triangle, North Pacific, and the Caribbean. While the 1998 and 2010 events lasted less than 12 months, the Third Global-scale Coral Bleaching Event (GCBE3) lasted three full years (June 2014-May 2017).

During GCBE3, the global pattern of marine heatwave propagation repeated in 2015 and 2016, and more than half of affected reefs were struck twice. The unprecedented duration, extent and magnitude of this three-year event caused widespread damage throughout the tropics, including loss of many corals and associated fauna and the extinction of at least one coral species.

Extensive collection of bleaching and mortality observations from coral reefs worldwide during GCBE3 resulted in a database of 15,066 surveys, approximately twice the size of the existing bleaching observations database spanning the 1960s-2010. Onsite observations were compared with satellite-derived heat stress (NOAA Coral Reef Watch v3.1, *CoralTemp*). Our analysis revealed that 80% of surveyed reefs experienced significant heat stress-driven coral bleaching and 35% experienced significant heat-stress driven coral mortality.

Using statistical relationships between satellite-derived heat stress and resultant non-linear probabilities of bleaching and mortality on surveyed reefs we estimated the total likely damage to reefs around the world during GCBE3. Based on the fitted model and the global distribution of heat stress, we predict that at least 51% of the world's coral reefs suffered significant bleaching and 15% significant mortality, surpassing damage from any prior global bleaching event.

GCBE3 occurred at a time when the global surface temperature was around 1.0°C above the pre-industrial average – already halfway to the Paris Agreement's 2.0°C target and two-thirds of the aspirational goal of 1.5°C, beyond which the potential for coral reef ecosystem survival is greatly diminished. It also occurred during four of the eight warmest years in human history – all of which have been since 2014. This presentation will provide the latest analysis of the damage to tropical reef ecosystems caused by the 2014-17 GCBE3, demonstrating the urgent need to limit global warming to protect coral reefs.

Oral
A-1297

Are thermal refugia safe-havens for coral reefs under mass bleaching

Lachs, L.[1, 2], Donner, S.[2], Mumby, P.[3, 4], Gouezo, M.[4, 5], Bythell, J.[1], East, H.[6], Edwards, A.[1], Golbuu, Y.[4], Humanes, A.[1], Guest, J.[1]
[1]Newcastle University, Newcastle Upon Tyne, United Kingdom
[2]University of British Columbia, Department of Geography, Vancouver, Canada
[3]The University of Queensland, School of Biological Sciences, St Lucia, Australia
[4]Palau International Coral Reef Center, Koror, Palau
[5]Southern Cross University, Marine Ecology Research Centre, East Lismore, Australia
[6]Northumbria Univeristy, Department of Geography and Environmental Sciences, Newcastle upon Tyne, United Kingdom

l.lachs2[at]newcastle.ac.uk

Abstract

Climate change and ENSO are triggering mass coral bleaching events with increasing frequency and severity. However, historic thermal conditioning of corals in more or less extreme environments may influence their bleaching susceptibility. Here, we explore contrasting historic thermal regimes in Palau, and their influence on reef connectivity, coral adaptation and future bleaching trajectories under climate change. To do this, we combined 36-years of sea surface temperature data with modelled larval connectivity, historic bleaching observations, and future climate projections under 4 emissions scenarios. We find that 18% of Palau's reefs occur in a persistent southwestern hotspot, and 13% in thermal refugia in the north. These consistently ranked as the most and least heat-stressed reefs, respectively. Compared to thermal refugia, we found that hotspot reefs had approximately twice the diversity of larval sources (*i.e.*, catchment area) and twice the supply strength, but have a lower potential to replenish larvae to other reefs. These characteristics are key factors for spatial prioritisation of conservation and restoration actions, for example, thermal refugia reefs lacking adequate larval supply may be candidates for restoration. We found that coral reefs in Palau are already adapting to warming at a rate of +0.1 ºC/decade, based on 13 Bayesian bleaching prediction models forced by heat stress under different adaptation rates (increasing stress threshold through time). The spatial uncertainty from these models shows that for a given heatwave stress, there is a higher probability of coral bleaching in the northern region where corals are more naïve, based on their thermal history. To assess how future bleaching trajectories are affected by coral adaptation and differential thermal regimes (hotspot vs. thermal refugia), we downscaled future bleaching conditions from 17 global climate models. Despite differences in projected heat stress among thermal regimes, the risk of high frequency bleaching was only mitigated under the most-ambitious and the middle-of-the-road climate scenarios (SSP1 and SSP2) under coral adaptation. Together, these results suggest that thermal refugia in Palau may not provide long-term protection for corals against warming. To ensure the continued persistence of coral reefs, global emissions reductions need to be realised alongside management actions that can promote coral adaptation.

15F - How has mass coral bleaching changed through time and how is it expected to progress into the future: Tools, products, and analyses. / Can evolution rescue corals from the effects of climate change?

Oral
A-1276

Global projections of risk of future coral bleaching from next-generation climate models

Mellin, C.[1], Brown, S.[1], Heron, S.[2], Fordham, D.[1]
[1]University of Adelaide, Adelaide, Australia
[2]James Cook University, Townsville, Australia

camille.mellin[at]adelaide.edu.au

Abstract

The world's coral reefs are exposed to increasingly severe and frequent marine heatwaves, causing mass bleaching events and threatening the continued provision of ecosystem services. However, the rate at which bleaching events will increase in frequency is likely to differ not only between climate models and scenarios, but also between bioregions and reef systems. Therefore, spatially explicit projections of future coral bleaching risk from a wide variety of models are required to identify thermal refugia where reef corals are more likely to withstand future heat stress and continue to support important ecosystem functions. Here, we used the latest generation of global climate models (developed under the sixth phase of the Coupled Model Intercomparison Project) and a novel downscaling approach to project future bleaching risk for the world's coral reefs from 1985 to 2100 at biologically relevant scales. Our projections reveal a mean annual increase in Degree Heating Weeks of 0.32°C-week year^{-1} under a business-as-usual scenario (SSP5-8.5), moderated to 0.17°C-week year^{-1} under a lower-emission scenario as pledged in the Paris agreement (SSP2-4.5). However, these average rates of increase in thermal stress are highly variable among bioregions and reef systems, with marine heatwave intensity in some locations increasing up to twice as fast as in others. Our projections are embedded in an online data portal featuring a user-friendly interface to help guide future research and conservation in warming oceans.

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Oral
A-1254

A global review of coral bleaching field surveys methods

Rivera-Sosa, A.[1], Fox, H.[1], Bonelli, A. G.[2], Muñiz-Castillo, A. I.[3], Darling, E.[4], Donner, S. D.[5], Asner, G.[2]
[1]Coral Reef Alliance, Oakland, United States
[2]Arizona State University, Center for Global Discovery and Conservation Science, Tempe, Arizona, United States
[3]Independent Researcher, Conceptos Arkipelago, Merida, Mexico
[4]Wildlife Conservation Society, New York, United States
[5]University of British Columbia, Department of Geography, Vancouver, Canada

arivera-sosa[at]coral.org

Abstract

Massive coral bleaching events are becoming more severe and frequent due to extreme marine heat waves caused by climate change. A united global response from marine scientists, practitioners, and policymakers is urgently needed. Numerous studies have highlighted the lack of comparability and the need for global integration of coral monitoring strategies. In this study, we helped address this gap by comprehensively reviewing coral bleaching field survey methods as a first step for global ground-truthing of the Allen Coral Atlas (the Atlas) satellite-based bleaching monitoring tool. To do this, we implemented both qualitative and quantitative approaches to assess the most commonly applied survey methods in published literature as well as those used by key monitoring programs and organizations at the global scale. First, we qualitatively surveyed (300+) coral reef scientists and managers across the world to capture practical experience and field survey methods used. We then performed a quantitative analysis using a recently published global coral-bleaching database(van Woesik and Kratochwill, 2022) to identify the spatial and temporal distribution of survey methods used. Our analysis identifies strengths, limitations, intended audiences, and scale of application, among other indicators. Special attention was paid to survey methods that are most useful for coral bleaching sensitivity analysis and those most appropriate for validating satellite-based products. Initial results show photo quadrats as one of the common methods, in addition to belt and line transects. Our work provides a thorough synthesis, typology, and classification scheme for coral bleaching field methods used at the global scale that could be used for the validation of the Atlas coral bleaching detection tools.

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Virtual
Oral
A-1796

Quantifying thermal stress and potential adaptive capacities to predict bleaching response of Pacific Island reefs

Chancellor, K.[1], Pederson, N.[1], Edwards, C.[1], Petrovic, V.[2], Fox, M.[3], Kuester, F.[2], Smith, J.[1], Sandin, S.[1]
[1]UC San Diego, Scripps Institution of Oceanography, La Jolla, California, United States
[2]UC San Diego, Calit2, La Jolla, California, United States
[3]Woods Hole Oceanographic Institution, Falmouth, Massachusetts, United States

kchancel[at]ucsd.edu

Abstract

Coral bleaching, a result of anthropogenic climate change, is impacting coral reefs at a global scale. Although climate change is increasing the intensity and frequency of bleaching events, we find evidence that some corals show resistance to the negative effects of warm-water events. Characteristics known to be linked with high thermal tolerance include community composition dominated by thermally tolerant taxa and environments with a recent history of exposure to thermal stress events. Here we explore the bleaching response observed at 32 coral reef sites across 16 uninhabited to low-population Pacific islands experiencing levels of thermal stress between 0 and ~11°C-weeks. We assessed the bleaching response of ~50,000 coral colonies distributed across the 32 photographically archived 100 m^2 plots and compared the bleaching response to the relative thermal stress at the time of sampling quantified by Thermal Hotspot (a metric that analyzes the maximum temperatures during El Niño-Southern Oscillation neutral years to best determine temperature thresholds of Central Equatorial Pacific Reefs (Mollica et al. 2019)). We observed a positive relationship between relative thermal stress and percent benthos represented by bleached corals. However, the positive trend between relative thermal stress and bleaching response captured appreciable variability. Some sites had anomalously low bleaching relative to statistical expectation, with reefs in the Phoenix Islands, exposed to ~6-11°C-weeks, having a similar bleaching response to that observed on reefs exposed to only ~1-2°C-weeks. We explored candidate hypotheses of thermal tolerance to better describe statistically anomalous sites. The data suggest that enduring past thermal stress can influence future thermal thresholds of coral reefs across these 16 Pacific islands. In an era when thermal stress events are becoming increasingly prevalent, it is essential to account for potential adaptive capacities of species to changing conditions if we are to understand ecological changes ahead.

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