Book of abstracts

ECRS 2024

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Bridging knowledge gaps

between tropical, temperate, and cold-water coral reefs

The European Coral Reef Symposium (ECRS) aims to pursue within Europe, and among reef scientists based in or visiting Europe, the Missions and Aims of the International Coral Reef Society (ICRS). The ECRS is held every four years and hosted in European countries on a rotation basis by the European Chapter of the International Coral Reef Society (ICRS). ECRS 2024 will be held in Naples, Italy at the Città della Scienza and at the Anton Dohrn Zoological Station.

For this edition of ECRS, our energies were concentrating on bridging knowledge gaps between tropical, temperate, and cold-water coral reefs.

The symposium brought together coral reef scientists, researchers, conservationists, policymakers and reef managers to present the latest research findings and exchange current knowledge critical to advising international and national policies in the conservation and sustainable use of coral reefs.

Città della Scienza & Stazione Zoologica Anton Dohrn, Naples, Italy

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Contents

The European Chapter of the International Coral Reef Society (ICRS)

The European Chapter of the ICRS was inaugurated in late 2019, with three-fold main aims and objectives: 1) to pursue the Missions and Aims of the International Coral Reef Society within Europe, and among reef scientists based in or visiting Europe; 2) to promote and support the holding of European Coral Reef Symposia at (ideally) four-year intervals; 3) to promote networking and collaboration among reef scientists based in Europe, and among students studying coral reefs at European Institutions. The chair of the European Chapter represents European interests and affairs on the ICRS council.

Chapter activities included the support of competitively selected early career researchers from Europe to cover the subscription fee for the virtual 14th International Coral Reef Symposium in 2021 (three awardees) as well as the in-person 15th International Coral Reef Symposium in 2022 (three awardees).

Since then, the chapter council has advised and encouraged the organizing committee of the European Coral Reef Symposium (ECRS) in Naples (Italy) since the proposal preparation stage. It has also supported the organizing committee of the ECRS in negotiations with the ICRS council to confirm that it is an official ICRS event. Members of the chapter council have been serving on the scientific committee of ECRS 2024.

A chapter meeting was held during the ECRS 2024 on 4 July 2024, where the current members of the chapter council were re-confirmed.

More information on activities of the European Chapter of the ICRS can be also found on social media at: http://icrseurope.eu, https://www.facebook.com/ICRSeurope/, https://x.com/ICRSeurope, and https://www.instagram.com/icrseurope/

You are invited to contribute the European Chapter of the ICRS – feel free to contact us via the channels above!

Gert Wörheide

Chapter Chair

Ludwig-Maximilians-Universität (LMU) Munich, Department of Earth and Environmental Sciences & GeoBio-Center

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Plenary speeches

Marta Ribes

Senior researcher at the Spanish National Research Council (ICM-CSIC, ES)

Biography

Marta Ribes earned her Ph.D. in Biology from the University of Barcelona in 1998. Her thesis focused on benthic feeders' metabolism, utilizing in situ incubation chambers for gorgonian species, sponges, and ascidians. After her Ph.D., she conducted postdoctoral research at the Hawai'i Institute of Marine Biology, uncovering the significance of picoplankton in coral reefs and the role of hydrodynamics in nutrient acquisition. Awarded the prestigious "Ramon y Cajal" contract in 2001, she secured a tenure-track position at the Institute of Marine Science in Barcelona, becoming a permanent staff member in 2007.
Researching coastal marine benthos on rocky substrates dominated by filter feeders, she focuses on the energetic dynamics sustaining the metabolism of the dominant taxa. Her work explores strategies for resource acquisition, such as symbiosis and structural investment, and investigates ecosystem-level energy dependence through hydrodynamics. Her research lines include assessing energy inputs and nutrient acquisition through comprehensive diet studies and quantifying oxygen consumption. This energetic approach has pioneered the understanding of large-scale benthic organism mortality related to climate change. Simultaneously, she has contributed to research on energy investment in secondary production in benthic invertebrates and collaborated on understanding the geographical expansion of invasive species, such as the coral *Oculina patagonica*, emphasizing the significance of organism interactions in spatial occupation.
Her research primarily involves *in situ* studies under actual environmental conditions, emphasizing seasonal analyses across changing environmental factors. This is particularly relevant in temperate seas like the Mediterranean and crucial within the context of climate change. Her work has resulted in 66 scientific papers cited over 4,300 times, several book chapters, and outreach papers. Continuously funded as PI for 10 competitive projects and involved in over 20 projects as a research team member, she has also supervised several PhD and MSc theses.

Plenary speech: A journey from individual traits to the ecosystem functions of marine benthic communities: providing a personal perspective on where we stand and what is lacking

"Marine coastal ecosystems, including coral reefs, are globally renowned for their exceptional productivity and biodiversity, playing a crucial role in climate regulation, nutrient cycling, and primary productivity". As a benthic ecologist, this perspective has fueled my exploration of functional traits in benthic filter feeders, leading to insights into nutrient acquisition and the triggers of large-scale mortality events linked to climate change. These studies have challenged established paradigms such as the use of dissolved organic matter as food and highlighting the crucial role of picoplankton as a nutrient source on coral reefs, with benthic filter feeders acting as primary mediators. Understanding the dynamics and constraints of particulate nutrient capture has emphasized the significance of hydrodynamics in these processes.

There is growing concern about the impact of human-induced stresses, driven by climate change and global environmental shifts, on coastal ecosystems. Despite the acknowledged contributions of benthic filter feeders to the biogeochemical processes like carbon burial and nutrient recycling, which can mitigate the impacts of climate and human-induced changes, the implications of a shifting seafloor ecosystem have not received sufficient attention in academia, public discourse, or political spheres. Emerging scaling approaches in ecology, from trait-based analyses to ecosystem functioning, present challenges. The current simplistic categorization of biological traits and functional diversity overlooks the complexity of metabolic pathways and organism interactions. There is a pressing need to consider organisms as holobionts, understanding their role in mediating fluxes within the water column and their functional responses for a more accurate depiction of ecosystem functions.

Understanding the dynamic interplay between physical and biological processes is essential for grasping the ecosystem functions of benthic communities. To anticipate future biological-physical connections amidst environmental shifts, a comprehensive understanding of benthic community functioning, including particle and nutrient exchange with the water column, is imperative. Improving our knowledge of benthic exchange rates in relation to local hydrodynamics enhances our ability to predict the ecological impacts of these communities. Addressing these issues requires experimental approaches, integrated modeling, and robust observational networks that transcend biases toward specific locations and seasons. Conservation and restoration plans must be grounded in this holistic ecological understanding, emphasizing the need for proactive measures based on a deep comprehension of ecosystem dynamics.

https://youtu.be/oS-oRkQnJJA

Sergio Rossi

Associate Professor in Biodiversity and Ecosystem Functioning, Department of Biological and Environmental Sciences and Technologies, Università del Salento (IT)

Biography

As a research scientist specializing in marine natural resources and biological oceanography, Sergio Rossi’s work is dedicated to the understanding how global change affects the oceans. His primary focus extends across crucial domains, encompassing the identification of global change indicators, examination of stressors impacting coastal benthic populations, exploration of marine invertebrate distribution patterns, and the study of benthic-pelagic coupling processes. Additionally, his research contributes to the conservation and restoration of marine wildlife. Currently he holds the position of Associate Professor at the Università del Salento (DiSTeBA) and Permanent Professor at the Universidade Federal do Cearà (Labomar). Since 2016, he also held the position of Scientific Director at the ocean regeneration company Underwater Gardens International, based in Barcelona. He has also worked at the Environmental Science and Technology Institute (ICTA-Universitat Autònoma de Barcelona, Spain) and at the Institut de Ciències del Mar (ICM-Consejo Superior de Investigaciones Científicas, Spain). He has actively participated in over 50 research projects, including those under the 6th and 7th, Horizon 2020 and Horizon Europe framework EU program projects such as METRO-MED, EUROGEL, HERMES, CENSOR, MedSeA, Blue Islands, PHAROS, and more. He served as the Principal Investigator in 9 projects. These achievements were made possible through close collaboration with 6 Post Docs, 18 PhDs, and nearly 60 graduate and master's students, as well as a very extensive international network. Currently, he holds the position of coordinator for the Horizon Europe “Ocean Citizen” project and serve as the chair of the MAF-WORLD COST networking action.

Plenary speech: Marine animal forests in the Anthropocene

Combined with the compounding effects of global change, humanity's ecological footprint is increasingly imposing unsustainable pressures on marine coastal and deep ecosystems across environmental, economic, and social dimensions. The ongoing transformations and shifts are so intricate and synergistic that they may not be readily perceived as dramatic changes but rather as adaptations to current social and economic demands. The close interconnection of benthic and pelagic systems ensures that perturbations in the water column impact benthic communities most severely.

Marine Animal Forests (MAFs) stand as the foremost living three-dimensional benthic structures in the oceans, spanning from tropical to polar regions and from shallow to deep waters. Functionally similar in many ways to terrestrial forests, MAFs consist of sponges, cnidarians, bryozoans, ascidians, bivalves, and other sessile benthic organisms. Serving as ecosystem engineers, MAF builders modify local hydrodynamics, nutrient flows, and influence biodiversity distribution. We are gradually understanding the role of MAFs in fostering biodiversity and biomass, while also acting as carbon immobilizators. One often overlooked yet crucial function of MAFs lies in their contribution to the global carbon cycle, with these enduring structures, whether in shallow or deep waters, serving as significant carbon reservoirs. In fact, MAFs capture and store carbon through various mechanisms, including food ingestion and symbiotic activity, particularly in mixotrophic organisms.

Over recent centuries, mature and complex Marine Animal Forests have been in decline, transitioning into more simplified communities, thereby diminishing their role as complex biostructures. This decline is mirrored in the reduction of various ecosystem services provided by healthy Marine Animal Forests. To counteract these detrimental trends, it is imperative to halt ecosystem-destructive practices, even if they are financially lucrative. This necessitates the provision of accurate data demonstrating the tangible losses incurred by such practices on human societies, coupled with evidence that alternative approaches can deliver economic and societal benefits. Therefore, there is an urgent need for comprehensive and integrated analysis of data to inform evidence-based decision-making and foster sustainable management and regenerative practices.

This information holds critical importance not only for local communities and stakeholders but also for informing policy frameworks and shaping future scenarios by utilizing such data to assess the significance and restoration plans of these three-dimensional underwater forests. To effectively scale up restoration efforts beyond existing frameworks, new concepts must be embraced, integrating a wider range of stakeholders, and ensuring active participation. At the core of large-scale restoration endeavours lie education and citizen engagement, coupled with meticulously planned regeneration programs based on functional ecology, which can adapt restoration plans to the rapid changes occurring in our oceans.

https://youtu.be/RSl3SiMDfUo

Michael Sweet

Full Professor in Molecular Ecology, School of Built and Natural Environment, Environmental Sustainability Research Centre, University of Derby (UK)

Biography

From as early as I can remember I have loved the natural world. This wonder and deep respect for all living organisms was primarily nurtured by my mum who, when I was young, protected our local countryside as a countryside ranger. Her work allowed me many opportunities for attending bat walks, to creepy crawly shows and her patience meant our house was often full of animals ranging from ducks to foxes, tarantulas, and bearded dragons. At high school, apparently all I could talk about was becoming a marine biologist. At my reunion a few years ago, when people asked me if I reached my goal, it was a very pleasurable moment when I could say "Yes, I have!!" Our research takes on a truly collaborative approach and spans across the globe. From Australia to the Seychelles, the Maldives to the Cayman Islands and many places in-between. Aside from these sunny climes, we have also worked in the Arctic, closer to home in our freshwater rivers, and in the deep sea (2000 metres down). My team, who call the Aquatic Research Facility our home, work on sharks, turtles, crayfish, seagrass, sponges and of course, corals. We've described long forgotten species thought to be extinct, and novel diseases plaguing the organisms we love so much. This led us to pioneer two key areas of research which I will discuss more in the plenary; we were the first in the world to spawn corals ex situ, which has enabled upscaling of reef restoration efforts around the world, and we were early pioneers in the developments of harnessing the microbiome (bacteria and fungi for example) to prevent biodiversity loss. We are passionate about impact and science communication. Indeed, I've won awards on this topic from the British Science Association. You will often find me giving public lectures or workshops at schools trying to inspire the next generation to carry on this fight to save our world. We also work closely with politicians and organizations like the International Union for Conservation of Nature and the United Nations. For the UN, we used science to inform policy in the fight against plastic pollution and I am now currently leading the 'state of our coral reefs' chapter for the 2024 World Ocean Assessment. My goal is simple, save our planet and leave something amazing for future generations to come.

Plenary speech: A stitch in time saves nine: can we save coral reefs or is it too late?

Anthropogenic impacts such as climate change, pollution and land reclamation are destroying coral reefs on a global scale. This is having a devastating impact on the ecosystem services that they provide, as well as the livelihoods of close to a billion people that depend on them. With the intensity of these anthropogenic stressors predicted to increase, reducing our carbon footprint is paramount but are we doing enough? The short answer is no, so what do we do next? Many are putting their time and money into reef restoration or rehabilitation - aimed at increasing the resilience of corals, but can such practices be deployed at the scales needed? In this plenary, I will discuss the state-of-the-art approaches being undertaken around the world, with particular focus on tools aimed at enhancing coral stress resilience, and thereby supporting the regrowth of coral reefs that are robust under future environmental conditions. These include such practices such as selective sexual propagation, assisted evolution, assisted gene flow and the application of probiotics. Such techniques have now been shown to be feasible and some appear scalable, ready for deployment in the real world. We will explore of such concepts have been developed and how everyone will be able to use the technology and methods to support coral reefs across the globe. Finally, we champion the need to follow a decision-making process which accounts for different types of reefs as well as the environmental conditions. As we move into a world where implementation of adaptive interventions tailored around nature-based solutions becomes more common place, we must now attempt to standardize restoration frameworks, and deliver appropriate ecological risk–benefit assessments, for consistent and effective utilization of the methods globally. It is now time to save the world.

https://youtu.be/TnceD72nb4Q

Session 1: Lessons from the Past to Inform the Future

Coral reefs are considered one of the most vulnerable environments to future climate change. These threats include ocean acidification and coral bleaching. In recent decades, coral reefs have been repeatedly affected by these events, affecting even remote islands that have not been directly impacted by humans. It is therefore of utmost importance to assess whether and how corals can adapt to future climate change. However, this is complicated by the fact that coral reef systems are affected by environmental changes on different time scales, ranging from short-term disturbances to historical and geological periods that cannot be directly observed by humans. This session aims to bring together scientists from diverse backgrounds to investigate the interplay of past environmental and climatic changes on different time scales and their effects on corals and coral reefs. Contributions may include, but are not limited to, reconstructions of past environmental conditions, the application of geochemical proxies, coral growth and calcification, reef growth and decline, palaeontology, and paleoecology.

Keywords: geological drivers, palaeontology, paleoecology geochemical proxies, coral growth and calcification

Session chairs

Miriam Pfeiffer, Christian-Albrechts-Universität zu Kiel (Germany)

Stéphanie Reynaud, Centre Scientifique de Monaco (Monaco)

Take home message

- Different archives were presented: fossil coral, ancient reefs, coral cores, at different timescales (the session covered more than 400 million years of reef evolution). Spatial scales ranged from reef to colony, and processes inside coral polyps.
- We use these archives to track the past evolution of corals and reefs, reconstruct processes (coral calcification, reef development) and response to stress events.
- There is a clear need for more interdisciplinarity between paleobiology, geochemistry and biology to understand how corals and reefs change over time and respond to environmental disturbances.

Regular oral presentations

ID: 464 / Parallel Session 1-1: 4
Lessons from the Past to Inform the Future

Keywords: Symbiodiniaceae, Coral Skeleton, ITS2, Environmental Reconstruction

Coral skeletons as records of Symbiodiniaceae communities over time

Jose Francisco Grillo Cañizales, Maren Ziegler
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The symbiosis between reef-building corals and diverse dinoflagellate microalgae from the family Symbiodiniaceae underpins the productivity of coral reefs. Fuelled by photosynthetic energy, corals accrete calcium-carbonate skeletons that comprise the reef-framework providing a habitat to the highest biodiversity of all marine systems. Coral bleaching, the loss of the Symbiodiniaceae algae from coral tissue, poses a major threat to reef-building corals, slowing their growth and leading to mass mortalities when symbiont communities do not recover. The associated Symbiodiniaceae thus represent a dynamic community that can change in response to environmental stress over the lifespan of a coral colony. Some massive-growing coral colonies reach ages of decades to centuries and their skeletons are used as archives to reconstruct past environmental conditions. However, the dynamics of the Symbiodiniaceae community over past stress events in these long-lived colonies is unknown. Here, we present an approach to use coral skeletons for reconstructing the Symbiodiniaceae community at a decadal scale. For this, dated coral skeletons of the massive-growing species *Porites lobata* and *Diploastrea heliopora*, commonly used as climate archives, were used to optimize DNA isolation protocols from skeletal material. The Symbiodiniaceae ITS2 marker region was characterized using next-generation sequencing with the SymPortal analytical framework. Using this protocol, we demonstrate successful reconstruction of Symbiodiniaceae communities from skeletons of *P. lobata* and *D. heliopora* dating back 40 years. While questions on the mechanisms of symbiont deposition in the skeleton need to be addressed, this study demonstrates the potential of coral skeletons as reservoirs of Symbiodiniaceae genetic information. This information may aid in the interpretation of palaeobiological proxy studies and to uncover ocean-basin scale long-term trends in Symbiodiniaceae communities.

ID: 538 / Parallel Session 1-1: 6
Lessons from the Past to Inform the Future

Keywords: thermal stress, *Porites*, coral Sr/Ca, coral growth, Indian Ocean

Thermal stress signatures in *Porites* corals from the remote western Indian Ocean Island Tromelin

Saori Ito[1], Miriam Pfeiffer[1], Takaaki K. Watanabe[1], J. Henrich Bruggemann[2], Jens Zinke[3], Nicolas Duprey[4], Mireille M. M. Guillaume[5], Dieter Garbe-Schönberg[1], Daniel A. Frick[1], Îles Éparses 2017-2020 Research Consortium[1,2,3,4,5]
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Available warnings of coral bleaching risk are based on global satellite observations of sea surface temperature (SST) (e.g. NOAA Coral Reef Watch), which need to be complemented by local observations, as satellite-based SST may not accurately reflect SST variability at the reef scale nor the corals' responses to such variability. However, continuous monitoring of coral reefs in remote areas remains a challenge. Therefore, a quantitative assessment based on *in situ* archives is essential to understand the impact of thermal stress and assess their influence on the reef environment and coral growth. Massive reef-building *Porites* corals possess great potential to record the corals' response to thermal stress in their aragonite skeleton, allowing us to track past stress events. Tromelin Island, a remote island in the western Indian Ocean, is an ideal location for studying coral growth disturbances resulting from thermal stress. The impact of terrestrial runoff, pollution and anthropogenic disturbance should be negligible as the island is uninhabited, small and has a flat topography with very limited vegetation/freshwater and no coastal development. As a part of the consortium research "Iles Eparses 2017-2020," two *Porites* megacolony cores were collected in April 2019. Here, we reconstruct thermal stress events from 2008 to 2019 using coral skeletal strontium-calcium ratio (Sr/Ca) as an SST proxy, along with skeletal growth parameters. Both corals recorded two extreme thermal stress events related to El Niño (in 2010 and 2016) as a missing summer peak in the skeletal Sr/Ca, bioerosion, stress bands and lower annual growth rates. Additionally, we found that local upwelling or eddies which normally cool summer SSTs, may protect corals from severe heat stress and bleaching in certain years. Our findings provide valuable insights into the interaction of local oceanographic processes and interannual modes of tropical climate variability and the resulting impact on coral bleaching.

ID: 596 / **Parallel Session 1-1: 7**
Lessons from the Past to Inform the Future

Keywords: Coral Bleaching, *Porites*, Sclerochronology, Geochemistry

Coral bleaching signals: Sclerochronological and geochemical insights from *Porites* bleaching survivors

Laura Lehnhoff[1], Juan Pablo D'Olivo Cordero[2,1], Daniel A. Frick[3], Valby Van Schijndel[4], Thomas Brachert[5], Thomas M. DeCarlo[6], Riccardo Rodolfo-Metalpa[7], Ulrich Struck[8,1], David Handfried[1], Friedhelm von Blanckenburg[1]

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Climate change-induced coral bleaching presents an enormous threat to coral reef ecosystems globally. Understanding the impacts and responses of corals to past bleaching events is pivotal for predicting future repercussions and implementing effective conservation strategies. The geochemical and growth data preserved within the skeletons of massive corals offer a unique opportunity to retrospectively study stress events in high resolution, facilitating a deeper comprehension of long-term effects and the search for signs of potential adaptations, particularly concerning coral biomineralization. However, there remains a notable gap in understanding how the observed relationship between growth and geochemical anomalies in coral skeletons correlates with the level of stress or bleaching experienced by the coral. To address this gap, we present data from massive *Porites sp.* corals observed to have experienced varying levels of bleaching (pigmentation) during the 2016 bleaching event on the southwestern coast of New Caledonia. All coral colonies recovered from the bleaching event, and cores were extracted in November 2017. We assessed patterns in the annual growth rate and density before, during, and after the heat stress event in the coral samples using X-radiography and CT scans. Furthermore, we analysed the geochemical composition of the coral skeletons, including stable isotope and trace element ratios. By scrutinizing irregularities in the annual cyclicity of geochemical parameters, particularly those associated with stress responses in corals, our aim was to characterize the effects of transient events such as thermal stress or bleaching. The comparison of two coral groups (bleached and non-bleached) is expected to facilitate the identification of signals for retrospective bleaching assessments in the skeletal structure and geochemical parameters. This comprehensive approach, which incorporates in situ observations, will provide valuable insights into the resilience and adaptive potential of coral reefs in the face of ongoing climate change challenges.

ID: 425 / **Parallel Session 1-1: 2**
Lessons from the Past to Inform the Future

Keywords: tropical corals, symbiont bleaching, ultra-high-resolution, B/Ca, laser ablation

Reconstructing ultra-high-resolution climate variability and symbiont bleaching in tropical corals: Case study of a northwestern Pacific *Porites* colony

Luisa Chiara Meiritz[1], Jan Fietzke[1], Nadia Santodomingo[2,3], Christian Deusner[1], Thomas Felis[4], Eleni Anagnostou[1]

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Climate change poses a global challenge to many ecosystems. Tropical coral reefs, the most diverse ecosystem in the marine realm, are one of the most affected by the rapid warming of the world's oceans. As sea surface temperature increases, coral bleaching events are becoming more frequent and severe. However, many questions remain about the factors that may drive coral resilience. One outstanding hypothesis to be tested is whether bleaching events leave chemical fingerprints in the aragonitic skeletons of corals. We aim to address this question by developing and implementing a multi-proxy, ultra-high-resolution approach in corals of the present and past warmer-than-present periods by using modern and fossil colonies, respectively. Previous analyses of a modern *Porites sp.* colony from the western subtropical North Pacific (Ogasawara Islands, Japan) revealed an interesting signature of the 1995 bleaching event in the region (Felis et al. 2009). Based on µCT analyses it was found that significant growth and density anomalies correspond with a strong abnormal deviation in Sr/Ca and U/Ca proxies. In our study, we resampled the same *Porites* sp. colony using a new high-resolution laser ablation with multi-trace element ICP-MS for B/Ca, and were able to track short-term variability of the skeletal growth anomaly. The LAICP-MS proxy results in combination with daily resolved weather data from Ogasawara allowed us to trace back on the skeleton of the *Porites* colony major episodes of environmental change. In particular, the skeletal record shows abrupt short-term responses in calcification patterns with decreasing B/Ca concentrations to thermal stress in good correlation with weather events like spring cold snaps. Our results derived from a modern coral show promising prospects in the search for a suite of geochemical tracers that can be applied to better understand past bleaching events over wider geological timescales in the fossil record.

ID: 415 / **Parallel Session 1-1: 1**
Lessons from the Past to Inform the Future

Keywords: Porites, Ocean acidification, Skeletal density, Calcification, Calcifying fluid

Control of *Porites'* coral calcifying fluid carbonate chemistry in naturally acidified seawater in Palau.

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Since the beginning of the industrial era, around a quarter of the anthropogenic CO_2 emissions released into the atmosphere have been absorbed by the ocean. This has led to a drop in pH at the sea surface of about 0.1 units, a phenomenon referred to as "ocean acidification", which poses a major threat to tropical corals. However, few studies have investigated the effects of long-term natural exposure to low pH seawater on the chemical regulation and growth parameters of tropical reef-building corals. In this study, the responses of two massive corals (*Porites*) living under normal (pH_{sw} ~ 8.03) and naturally low pH conditions (pH_{sw} ~ 7.85) in the Palau reef (a long standing naturally acidified reef) were investigated using cores of skeleton sampled during the Tara-Pacific expedition.

Our results show that both colonies kept identical carbonate chemical properties in their calcifying fluid (pH, [CO_3^{2-}], DIC and Ω) since 1972. Each colony exerted a strong biological control over the calcification process, particularly under low-pH conditions. However, the skeleton deposited under the acidified conditions had a significantly lower density (15%) than the skeleton of the colony from the open sea. This later result suggests that, even if corals can control the chemistry of their calcifying fluid, their skeleton will be more fragile in the future, leading to a higher vulnerability of massive *Porites* to future global change.

ID: 483 / **Parallel Session 1-1: 5**
Lessons from the Past to Inform the Future

Keywords: Mesophotic, resilience, palaeontology, Cenozoic, biodiversity

Turbid Ecosystems in the Coral Triangle: Past, present and future

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The Coral Triangle in Southeast Asia is the epicentre of Earth's marine biodiversity. This extraordinary diversity is threatened by anthropogenic environmental changes, urging the critical identification of ecological refugia. Shallow turbid habitats may play a key role in this quest, because turbidity shades corals from damaging UV light, hence mitigating thermal stress. Palaeoecological studies revealed that pioneer coral assemblages from 30 Ma thrived in low-relief patch reefs under low light and high sediment inputs. Ancient turbid reefs hosted high coral diversity during the Oligocene (100 species) and Miocene (234 species), with minimal faunal turnover, suggesting a remarkable resilience of corals in turbid habitats over the long-term geological record. To test the hypothesis of turbid habitats acting as reef refugia, in the REEFUGIA project, we surveyed a mosaic of seven turbid and clear-water reefs in Darvel Bay (Sabah). Detailed light profiles and sediment accumulation rates were assessed between 2019 and 2021. Coral cover and diversity were quantified with video transects and coral samples. Live coral cover ranges from 33% in the most turbid locality to 55% in clear water settings. Community composition varies across turbidity levels, with acroporids dominating clear waters, massive and branching *Porites* common in low turbidity settings, and foliose forms of *Leptoseris* dominating in high turbidity settings. During the 2020 bleaching event, corals in turbid reefs showed a significantly lower impact (12.5%) compared to their counterparts in clear-water reefs, where over half of the colonies experienced bleaching. Despite their importance, these long-term resilient ecosystems face major threats from plastic pollution and coastal development. The integration of fossil and Recent data underscores the pivotal role that turbid reefs have played as resilient ecosystems over the past 30 million years in the Coral Triangle and offers a glimpse of hope for the future of reefs under the current climatic crisis.

ID: 662 / **Parallel Session 1-1: 8**
Lessons from the Past to Inform the Future

Keywords: Red Sea, modern, paleoclimate, MIS5e, Saudi Arabia

Red Sea last interglacial coral reefs differ from modern counterparts (Rabigh, Saudi Arabia)

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We compared two coral reef complexes at a same location along the Red Sea Saudi Arabian coast, a last interglacial in age (MIS5e, ca 119-124 kyrs BP) versus the current interglacial (MIS1, Holocene, 11 kyrs to present). The Rabigh site, about 150 km north of Jeddah exposes Quaternary coral reef terraces, while the coastline is fringed by modern coral reefs. These coral reefs separated by a glacial epoch are very different in their spatial organization and in some constituents. The observed differences reflect by large the accommodation space of this site, a wadi system, emblematic of many situations in the tropics. During MIS5e (ca + 6 m msl), the area was drowned by the sea extending well inland onto a flat topography, resulting in a spatially-large reefal complex, which included deep lagoons, pinnacles and microatolls. After the glacial's sealevel lowering, the sea stalled at the current 0 msl, providing no accommodation space for a structured fringing reef complex as for MIS5e, therefore leaving home only for a dimensionally modest fringing reef deprived of extensive back reef deep lagoons. The faunal comparison reveals that the two coral reef complexes differ noticeably also for their compositional aspects since MIS5e reef contains molluscs and scleractinian corals absent in the modern Red Sea. This is relevant to the debate whether the basin was or not entirely hostile to normal marine life during the glacial epoch, up to wiping out its reefal ecosystems, which re-established in the Red Sea since the postglacial. Cores were drilled on pristine MIS5e *Porites* heads to be tested for paleoclimatic-valuable geochemical signatures, including trace elements (Li, B, Mg, Sr, Ba and U) and boron isotopes. They will ultimately provide high-resolution (monthly) reconstructions of key oceanographic parameters, such as SST and seawater pH, which will help to study the seasonality during the Last Interglacial.

Speed talks

ID: 358 / **Parallel Session 1-1: 11**
Lessons from the Past to Inform the Future

Keywords: Indian Ocean Dipole, Andaman Sea, thermal history and stress response, skeletal Sr/Ca and carbon isotopes

Indian Ocean Dipole and thermal stress response recorded in Andaman Sea corals during the satellite era

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The geochemistry of coral skeletons provides information on the thermal history and likely the response to stress, in the absence of reef monitoring. Here we present monthly-resolved records of Sr/Ca-temperature proxy and stable carbon isotopes from *Porites* coral skeletons (1985-2010) collected in the southern Andaman Sea (Ko Racha Yai, Thailand). Coral Sr/Ca indicates exaggerated cooling in some winters not observable in satellite sea surface temperature (SST) coinciding with years of positive Indian Ocean Dipole (pIOD), combined pIOD and El Niño, or La Niña. This discrepancy can be best explained by temperature differences between coral depth (5-10 m) and sea surface where satellite SST are monitored. The region is characterized by large-amplitude internal waves (LAIW), carrying cold subpycnocline water into shallower reef areas that rarely extend to the sea surface. We find that the cooling effect by LAIW, recorded by the coral skeleton, may vary on interannual to decadal timescales, possibly modulated by the Asian Monsoon. Most striking are negative excursions in the monthly coral $\delta^{13}C$ record that coincide with observed thermal stress and coral bleaching in the area (1991, 1995, 2003, 2010). We speculate about potential explanations for these negative skeletal $\delta^{13}C$ excursions that may not be mutually exclusive. These include restricted or absent photosynthetic activity of the coral's endosymbiotic algae and changes in the coral's autotrophy-heterotrophy diet towards increased heterotrophy under thermal stress. Both decreased photosynthesis and coral feeding on zooplankton are assumed to contribute ^{13}C-depleted CO_2 to the coral's internal dissolved inorganic carbon "pool" from which calcification takes place. Consequently, we report for the first time a putative response to multiple thermal stress events in a coral skeletal $\delta^{13}C$ record, not available from any other source of observation. Interestingly, this response is not observed during the 1998 event, a time of inferred enhanced cooling of reefs by LAIW.

ID: 249 / **Parallel Session 1-1: 9**
Lessons from the Past to Inform the Future

Keywords: Species turnover, trait turnover, reef communities, biogeographic isolation, trait co-occurrence networks.

Identifying past and present environmental and biogeographical contributors to coral species and trait turnover with trait co-occurrence networks

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The climate crisis is causing substantial community transformation, with potential trait turnover despite functional redundancy in highly diverse coral reef ecosystems. The fossil record evidences how communities have responded to the scale of climactic change predicted over the coming decades, which is unprecedented in human history. These transformations are broadly analogous to the environmental changes, such as increases in CO_2 concentrations, temperature, and sea level reductions, that, combined with biogeographical change leading to genetic isolation, have shaped coral communities throughout the Cenozoic (66 – 0Ma). Therefore, predicting future responses to environmental change can draw insights from paleoecology that examines fossil records to understand how species assemblages have adapted.

Here, we combine Caribbean coral fossil occurrence with morphological traits to explore species and trait turnover across the Cenozoic, investigating the coral traits crucial for persistence. We analysed species turnover and extinctions with a bipartite network and explored trait turnover with trait-trait co-occurrence networks.

We found that species and subsequent trait turnover occurred during periods of environmental change, suggesting such turnover may also occur in the future with climate change. Specifically, we found trait co-occurrence modules associated with increased resilience and enhanced light scattering. The transition from the "greenhouse" (Eocene) to the "icehouse" (Pleistocene) climate over ~40 million years favoured light scattering traits such as small diameter corallites, extracalicular budding, branching growth and plocoid corallite integration. However, corals are ill-prepared for ongoing rapid warming, as past cooler climates have selected for genera with low recruitment, high disease susceptibility, and high sensitivity to thermal stress. While species loss appeared to not halt reef accretion, the decline in species diversity has simplified trait scopes, with Pleistocene reefs dominated by fast-growing *Acropora*. The study underscores the value of morphological traits in understanding biological change, offering insights applicable to both modern and fossil corals.

ID: 750 / **Parallel Session 1-2: 7**
Lessons from the Past to Inform the Future

Keywords: sea level rise, mesophotic bioconstructions, seafloor structure

The record of Holocene sea-level rise along the Apulian shelf (Adriatic Sea, Southern Italy): the migration of biogenic facies

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In the Apulian shelf, at depths ranging from 20 to 80 meters, various biogenic facies develop, giving rise to extensive and enduring structures. Specifically, three distinct facies have been identified: coralligenous assemblages in shallower waters (approximately 20-35 meters), temperate mesophotic coral bioconstructions (around 35-50 meters), and mesophotic oyster bioconstructions (below 50 meters depth).

These bioconstructions have been analysed in detail at both meso- and microscales, with a focus on morphology, inner structure, relative abundance of associated taxa, and porosity.

Significantly, intermediate facies were identified, indicating a transition in the relative abundance of taxa between different types of bioconstructions at intermediate bathymetric levels. Simultaneously, overlaps were observed, with more recent and deeper biogenic facies overlaying older and shallower bioconstructions.

These lateral-vertical relationships in facies distribution appear to document sea-level rise during the Holocene. Recognizing these spatial associations offers a model for comprehending past dynamics and forecasting future trends in the evolution of shelf communities.

Furthermore, the current distribution of these temperate biogenic facies on the shelf contributes to the complexity of the seafloor structure, fostering diverse communities that contribute to the enrichment of biodiversity.

ID: 484 / **Parallel Session 1-2: 2**
Lessons from the Past to Inform the Future

Keywords: climate reconstruction, vital effects, geochemical proxies, Sr/Ca, d18O

Wandering vital effects in tropical corals exaggerate climate variability in reconstructions from geochemical proxies.

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The high temporal resolution and excellent time control of geochemical records from massive shallow-water coral skeletons make them an excellent archive for reconstructing past tropical climate. However, while we know that biological 'vital' effects in corals influence geochemical tracers, it is unclear how much non-climatic "noise" they imprint on the recorded climate signal. Moreover, the temporal correlation structure of this noise is not well understood, which will determine how it influences climate reconstructions on decadal and longer timescales. By analysing spatial clusters of coral records from the PAGES (Past Global Changes) CoralHydro2k database, a compilation of skeletal oxygen isotope and Sr/Ca proxy records of tropical ocean hydrology and temperature for the Common Era, we can estimate, via spectral analysis, the magnitude and correlation structure of both the shared climate signal and the non-climate noise. We find that there is a large, strongly autocorrelated, noise component in geochemical records from individual coral colonies. Further, we demonstrate that this noise is largely uncorrelated between even neighbouring colonies, pointing to colony specific "wandering vital effects" as the source. The noise fraction of coral records can exaggerate the variability of reconstructed sea surface temperature variability by a factor of three at long (e.g. decadal) timescales. However, a small amount of replication, using cores from 2-3 colonies in a region, should greatly reduce this error and enable the magnitude of the remaining noise to be estimated. Our findings have the potential to improve existing and new coral-based reconstruction of tropical climate, and to strengthen proxy data – climate model comparisons.

ID: 524 / **Parallel Session 1-2: 4**
Lessons from the Past to Inform the Future

Keywords: palaeontology, Malaysia, Indo-West Pacific, scleractinian, Coral Triangle

Diversity of Oligocene Corals in the Indo-West Pacific (Eastern Sabah, Malaysia)

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The Coral Triangle biodiversity hotspot is located in the Indo-West Pacific and contains over 700 species today. Although the first-known reef corals in this hotspot appeared in the Eocene, it was not until the mid-Oligocene (~28 million years ago) that diversity suddenly increased. Preliminary studies have accounted for this peak in coral diversity, yet detailed morphological descriptions of the fauna remain to be assembled. To better understand the origins of the Coral Triangle hotspot, we present a comprehensive compilation of nearly one-hundred coral morphospecies of mid- and late-Oligocene age. In this study, we report systematically collected reef corals from 12 localities in eastern Sabah, Malaysia, a northwestern region of the Coral Triangle. We examined 1,257 Oligocene coral specimens (33.9 - 23.03 Ma) housed in the Natural History Museum, London. Most corals have been identified to morphospecies level, or at least to genera, using key morphological characters (e.g., growth forms, corallite arrangement, micromorphological and microstructural features) from the up-to-date taxonomic framework. Richness of this Oligocene coral fauna accounts for 57 genera. The most abundant species in these collections was Pachyseris speciosa, a platy coral that represented over 10% of the specimens. These findings suggest Oligocene Malaysian reefs were highly diverse with platy corals dominating the ancient fossil reef facies. The palaeoenvironments have been interpreted as small patch reefs developing under high siliciclastic inputs. Further analyses aim to contextualize the importance of this fauna in comparison with contemporary coral diversity in Sabah, Malaysia.

ID: 691 / **Parallel Session 1-2: 6**
Lessons from the Past to Inform the Future

Keywords: Coral Proxy, Climate Reconstruction, Caribbean, Uranium Isotopes

Little Ice Age freshwater variability traced in a Cuban coral using $^{234}U/^{238}U$ ratios

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The Caribbean Sea is a major source region of the global ocean overturning circulation and is subject to future enhanced sea surface warming. Moreover, the surface currents are influenced by both local and distant freshwater influxes, which play a significant role in modulating the salt budget. Little is known today about the freshwater fluxes into the Caribbean Sea and their potential impact on climate system. Here, we present a first two-century-long record of the natural 234U/238U ratio, which is generally assumed to be constant in seawater, with a value of 146.8‰, normalized to HU1 in equilibrium (Kipp, et al., 2022). The near annually resolved record of high-precision $\delta^{234}U$ values, obtained from the skeleton of a tropical coral collected in the northern part of Cuba, yields an overall mean $\delta^{234}U$ value of 146.8‰ (±0.1‰, $2\sigma_M$, n = 108) consistent with the recent seawater values. Over the past century, the $\delta^{234}U$ record shows variations exceeding the external precision, which is coherent with local precipitation data (Centella-Artola, et al., 2023) and the $\delta^{18}O_{SW}$ derived from nearby corals (Smith, et al., 2006; Harbott, et al., 2023), suggesting an influence of regional runoff on the local seawater U isotopic composition. While the overall record reveals moderate variations of less than 3.5‰, we observed the highest $\delta^{234}U$ variability, ranging from 144 to 153‰, at the end of the Little Ice Age (LIA 1778-1850). This suggests a stronger influence of variable $\delta^{234}U$ sources from local, regional or distant runoff, possibly due to weaker ocean currents resulting from a smaller Atlantic warm pool compared to present-day configuration. This case study demonstrates that comparing $\delta^{234}U$ values with regional precipitation estimates can elucidate the sensitivity of excess ^{234}U to continental freshwater discharge and can help to reconstruct the climatic conditions in the Caribbean at the end of the LIA.

ID: 455 / **Parallel Session 1-1: 13**
Lessons from the Past to Inform the Future

Keywords: Palaeoclimate, Indian Ocean, Hydrological Change

Hydrologic variability in the southwest Indian Ocean from Mauritius corals since the late 19th century and connections to the Indo-Pacific throughflow

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In the Indian Ocean, observational records of sea surface salinity are not well constrained prior to the early 2000's making any understanding of decadal to interdecadal changes in hydrological variability difficult. Existing reconstructions, associated with ocean currents and salinity in the Southwestern Indian Ocean region, do not reconstruct wider open ocean variability. Here we present a paired Sr/Ca and $\delta^{18}O$, bimonthly resolved record of a shallow water coral from the southwest Indian Ocean (Mauritius Island, 20.34°S, 57.55°E), extending from the year 1882 to 1989, providing invaluable information about hydrological changes The coral Sr/Ca-temperature proxy tracks sea surface temperature (SST) of the wider open ocean well, providing confidence to existing coral reconstructions. Our record highlights the strong increasing SST trend across the southwest Indian Ocean, with an increase of >0.5°C since 1883. Paired Sr/Ca and $\delta^{18}O$ analysis allows for seawater $\delta^{18}O$ ($\delta^{18}O_{sw}$) reconstruction, developing the first bimonthly-resolved hydroclimate record-extending past the start of the 20th century, capturing wider open ocean variability. The coral $\delta^{18}O_{sw}$ record captures Mauritius's rainy season precipitation, exhibiting a strong relationship to weather station data across the island. It is suggested that this relationship captures wider-scale precipitation variability associated with the transition of the tropical rainfall belt. It is also suggested the non-rainy season $\delta^{18}O_{sw}$ variability is controlled by oceanic processes as Mauritius lies along the South Equatorial Current, one of the major oceanic currents in the Indian Ocean and an important connection between the Pacific and Indian Ocean basins. By using a network of existing coral reconstructions from the wider southwest Indian Ocean and the newly developed Mauritius coral record, we hope to provide insights into regional variability under past, present, and future climate change. This study uses legacy data as part of the DFG Priority Programme "Tropical Climate Variability & Coral Reefs" (SPP 2299).

ID: 264 / **Parallel Session 1-1: 10**
Lessons from the Past to Inform the Future

Keywords: ENSO, Geochemistry, Sclerochronology, Thermal stress, El Niño

Common Era ENSO variability in the western tropical Pacific inferred from isotopic and trace element analysis of *Porites* microatolls

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The El Niño-Southern Oscillation (ENSO) is the most important mode of inter-annual climate variability in the Pacific, with far-reaching impacts on global climate. Currently, in 2023 and 2024, an El Niño event with distinct sea surface temperature anomalies is unfolding in the Pacific. El Niño-induced thermal stress is a major threat to coral reef ecosystems that are already coping with various climate change-related stressors.

However, it is still unclear, if the frequency and strength of El Niño events have increased in recent decades due to global warming (ENSO variability). Furthermore, El Niño events since the mid-20th century have varied in spatial structure and temporal evolution (ENSO diversity). To better understand how ENSO variability and diversity are linked to changes in climate mean states, coral archives are important as they record past environmental conditions in the chemical composition of their annually banded skeletons. Additionally, changes in calcification preserved in coral records can be used to study the physiological responses of corals to thermal stress.

Here, sub-seasonally resolved proxy records are presented from fossil *Porites* microatolls collected on Arno Atoll, Marshall Islands, in the western tropical Pacific. Coupled isotopic ($\delta^{18}O$) and trace element (Sr/Ca) analyses are used to reconstruct paleo-sea surface temperature and hydrology. Furthermore, variations in skeletal density are determined by employing a γ-densitometer. These coral records cover different intervals during the Common Era (0 – 2000 CE), such as the putative 'Little Ice Age' and 'Dark Ages Cold Period'. For proxy calibration, a modern coral has been analysed. Comparison between these and existing coral records from central equatorial Pacific sites allows inferring variations in ENSO variability and diversity during different states of mean climate in the Common Era. Ultimately, our results will contribute to improving projections of future ENSO activity and coral stress response under ongoing anthropogenic warming.

ID: 470 / Parallel Session 1-2: 1
Lessons from the Past to Inform the Future

Keywords: Devonian, Tabulate corals, palaeoecology, photosymbiosis

Distant in time but close in character? Similarities between Devonian and modern reef-building corals

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The history of reefs is not limited to modern times but encompasses 550 My, with intermingled periods of reef flourishing and extinctions. Devonian was probably the time of the most extensive development of reef ecosystems in Earth's history, with the peak of the reef growth reached during the Givetian to early Frasnian (~ 388–378 Ma) and reefs present as far as 50°S. One of the main builders of Devonian reefs were the extinct tabulate corals. Until recently, tabulate corals were considered ecologically distant from their modern counterparts, but in recent years this view has begun to change.

Based on the material from Middle Devonian reef ecosystems originating from different palaeobathymetric and biogeographical settings (modern Morocco, Belgium and Poland), we show that Devonian tabulates and modern scleractinians shared notable similarities in terms of their ecological characteristics. These similarities are manifested especially through the development of photosymbiosis and consequent morphological adaptations to both well-illuminated and low-light, mesophotic environments, as well as in the observed, apparently light-dependent phenotypic plasticity, with some vivid examples resembling e.g., the modern scleractinian *Porites silimaniana*. In addition, comparable adaptations to shallow-water, turbulent settings, including a major role of robust, branching corals in the community structure or mode of asexual reproduction and dispersion through colony fragmentation have also been observed. Because of this ecological affinity, tabulate corals may have formed reef assemblages with zonation patterns and morphological variability analogous to those typical of the contemporary, shallow-water and mesophotic reefs. Thus, tabulate corals seem to be an excellent subject for comparative analysis with modern scleractinians. Studies on the development and decline of Devonian reefs could be valuable for understanding the dynamics of modern reef ecosystems, as well as the threats posed by climate change.

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ID: 556 / Parallel Session 1-2: 5
Lessons from the Past to Inform the Future

Keywords: Tabulata, corals, functional morphology, Palaeozoic, fossil

Similar morphology of Palaeozoic and modern corals reflects similar ecology? A case study of two morphotypes of tabulate corals (Anthozoa: Tabulata)

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Both Palaeozoic and modern corals, despite deep taxonomic differences, share numerous common anatomical features, which may presumably reflect similar ecological niches occupied by morphologically similar taxa. The first coral reef ecosystems emerged during the Ordovician (485 Ma) and they were built with contribution from representatives of two coral subclasses, Tabulata and Rugosa, both extinct at the end of the Palaeozoic. In the Middle Traissic, a new group of Scleractinia started to contribute to reef building. There is no direct ancestor-descendant relationship between these groups.

The largest reef structures occurred in the Silurian and Devonian, with corals characterized by diversified anatomical traits. One of the common-representatives of the Devonian tabulate corals, *Thamnopora,* shows branching morphology with a relatively simple structure. The corallites are usually 1-3 mm in diameter and open perpendicularly to the branch surface. Branches are 5-30 mm thick. While details of the *Thamnopora* colony morphologies remain largely unknow, it is possible that these corals played similar ecological roles to representatives of modern *Acropora,* but the latter is often characterized by more complex anatomy (including axial corallite) and colony architecture. Another example of a tabulate coral are representatives of, Platyaxum that formed colonies composed of minute corallites (<1 mm im diameter) and growing as thin bifacial fronds and blades. Representatives of this genus show significant similarities to modern *Leptoseris* and *Pavona* and alike the former contributed to the oldest mesophotic coral ecosystems.

While the Palaeozoic reefs have been traditionally considered as ecologically distant from modern, scleractionian reefs, it seems that many functional traits of modern corals can be traced back to the middle Palaeozoic.

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ID: 363 / **Parallel Session 1-1: 12**
Lessons from the Past to Inform the Future

Keywords: Functional morphology, ecology, tabular corals, Devonian.

Citical coral morphology has ancient roots: convergence between tabular *Acropora* and Palaeozoic tabulate corals (Anthozoa: Tabulata).

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Coral morphology is directly related to their ecology, and it has been shown to be the strongest predictor of coral type ecological function . Tabular corals, historically widespread in tropical shallow reefs, are important ecosystem engineers. They provide structural complexity and a wide array of microhabitats, important for juvenile and small fish as a shelter, as well as place for recruitment of sessile organisms. Their presence also enhances diversity and promotes reef recovery.

Silurian and Devonian (443-459 Ma) were periods of extensive reef development. Among the most important bioconstructors of that time were extinct tabulate corals. During the peak of reef development, tabulates developed diversified morphologies, including branching. Representatives of the family Pachyporidae were especially common and diversified (currently there are over 100 described species of the genus *Thamnopora* alone). Due to the nature of the fossil record branching colonies are nearly always broken and fragmented, making reconstruction of the colony shape nearly impossible. As a result, crucial information on their ecological function remains biased.

Here we report on a very well-preserved colony of *Thamnopora?* sp. that has both the stem and central platy part, with anastomosing branches preserved. The physical characteristics in this specimen suggest that some Devonian and Silurian corals may have played a similar ecological role to modern tabular *Acropora* corals. Together with other specimens, where anastomosing, platy fragments were known it shows that the peculiar tabular morphology has evolved multiple times over geological scales in non-related coral organisms.

Recent research shows that Palaeozoic corals shared many ecological traits common with modern scleractinian corals. The presented here discovery demonstrates that Palaeozoic reef ecosystems were likely much more similar to modern reefs than previously thought. Also, tabular corals, that in modern reefs provide crucial services to the ecosystem appeared much earlier than representatives of Acroporidae.

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Lessons from the Past to Inform the Future

Keywords: corals, tropics, geochemistry, salinity, southeast Indian Ocean

West Australian coral proxy record of southeast Indian Ocean salinity variability since 1795

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The southeastern Indian Ocean off the coast of Western Australia is a key region of Indo-Pacific climate connectivity steered by ENSO. Many remote oceanic atolls and coastal coral reefs fringe the West Australian shelf which are strongly influenced by warm, poleward flowing ocean boundary currents, the Holloway Current and Leeuwin Current, fed by the Indonesian Throughflow (ITF) and the South Equatorial Current. La Nina events, like the extreme 2011 event, led to the first mass coral bleaching event unfolding across 12° of latitude off Western Australia. La Nina events are also associated with low salinity anomalies in the southeastern Indian Ocean across vast stretches of the West Australian shelf linked to intensified Australian monsoon rain and stronger ITF transport carrying low salinity water from the Indonesian Archipelago poleward. However, historical observations of salinity are extremely spare hindering our understanding the long-term surface freshwater balance in most tropical oceans.

To overcome this significant knowledge gap, we generated up to 215-year long paired coral skeletal Sr/Ca (proxy for sea surface temperature, SST) and d^{18}O (dual proxy for SST and salinity) records from massive corals growing across 12° of latitude off Western Australia. The combination of these two geochemical proxies allows us to reconstruct the surface ocean d^{18}O$_{seawater}$ variability strongly linked to salinity. Our new reconstructions reveal differing long-term trends and decadal to interannual variability at the northwest ad southwest Australian coral reefs. We find agreement with SODA and EN4 salinity products yet also diverging salinity trends in the coral reefs strongly indicating modification of salinity by site specific evaporation-precipitation and ocean current variability in shallow coral reef waters. Our new multicentennial d^{18}O$_{seawater}$ reconstructions sheds new light on the decadal to interannual thermohaline surface ocean variability across the uniquely biodiverse southeastern Indian Ocean.

Posters

ID: 853
Lessons from the Past to Inform the Future

Keywords: microeukaryotes, coral microbiome, marine microbiology, microbial biogeography

Microeukaryote diversity in coral reefs across the Pacific Ocean

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Microeukaryotes are part of diverse symbiotic interactions in coral reefs, where they are crucial for coral health and ecosystem resilience. Analysing the composition and distribution of these microeukaryotic communities in coral holobionts and the surrounding reef environment is essential for a comprehensive understanding of coral reef ecosystem functioning. The Tara Pacific expedition aimed to uncover the complex dynamics of coral holobionts in the ecosystem context across spatial scales and has established a sample set that can be used as a baseline to investigate coral reef diversity and functioning. Throughout a two-year voyage over 100,000 km across the Pacific Ocean, coral reefs at 32 islands and the open ocean connecting them, were sampled. This resulted in approximately 6,700 samples from three coral genera (*Millepora*, *Pocillopora*, *Porites*), seawater, and sediments from more than 200 sites. The variable region V9 of the 18S rRNA gene was sequenced, resulting in ~500,000 microeukaryote ASVs. We show that eukaryote microbiomes are distinct between corals, seawater, and sediments. Dinoflagellates and radiolarians were

most abundant in seawater, diatoms in sediments, and rhodophytes and apicomplexans in coral samples. Seawater had the highest ASV richness, while corals had the lowest. Microeukaryotic communities were further structured by sample-specific characteristics (coral species, plankton size fractions and proximity to the reef) and they showed strong biogeographical patterns, which match previous investigations into the better-known coral-associated prokaryote microbiome. Overall, a large fraction of sequences across all samples belonged to unknown eukaryotes or previously undescribed sequences, highlighting the large pool of microeukaryote dark matter that will require scrutiny in future studies. In summary, this unprecedented sampling effort provides insights into the complex diversity and distribution patterns of microeukaryotes within coral holobionts and their surrounding environment across the Pacific Ocean.

ID: 268
Lessons from the Past to Inform the Future

Keywords: climate variability, environmental stressors, geochemistry, Belize, Orbicella

Tropical climate variability and the influence of environmental stressors as recorded in *Orbicella* and *Siderastrea* coral skeletons, Belize, Central America

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Coral reefs are of eminent ecological importance and provide essential ecosystem services, e.g., in coastal protection, fisheries, and tourism. However, increased frequency of temperature extremes such as El Niño events, decreased calcification rates of coral skeletons due to ocean acidification, pollution, and overfishing have been pushing coral reefs to their limits. It is therefore of highest urgency to assess the impact of these factors on coral reef ecosystems by analysing coral proxy data in long time series at high temporal resolution. In this study, six coral cores of the species *Orbicella faveolata* and *Siderastrea siderea* from different environments within Belize barrier and atolls reefs, covering a period from 1815 to 2022, are being analysed. The aim is to establish a monthly resolved geochemical proxy dataset (Sr/Ca, $\delta^{18}O$, $\delta^{13}C$) for this major reef location and to assess the influence of environmental factors, e.g., sea surface temperature (SST), salinity, nutrient input, turbidity, freshwater inflow, and lowering of $CaCO_3$ saturation state. Here we present first results, including trends in the proxy records and distinct SST anomalies, and compare these with instrumental data, gridded modeled data and available sclerochronological data (density, calcification rate, extension rate) of the same cores. We also discuss visible decadal to multidecadal cyclicity as an expression of climate modes such as El Niño-Southern Oscillation, Atlantic Multidecadal Oscillation and North Atlantic Oscillation. The results will contribute to understanding the interaction between global climate change and modes of tropical climate variability and their combined impact on reef ecosystems, as well as answering the question as to how rising SSTs and ocean acidification interact with local stressors. The study is part of Priority Programme 2299 “Tropical Climate Variability and Coral Reefs – A Past to Future Perspective on Current Rates of Change at Ultra-High Resolution”, funded by the Deutsche Forschungsgemeinschaft (DFG).

ID: 642
Lessons from the Past to Inform the Future

Keywords: functional ecology, hard-soft coral community shifts, benthic composition changes

Fish communities in hard and soft coral-dominated reef plots in Bangka Island, North Sulawesi (Indonesia)

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Coral reefs are increasingly affected by a variety of anthropogenic factors like climate change, fishing, and pollution, which can lead to changes in benthic composition, often referred to as phase or community shifts. Historically research on coral community shifts has focused primarily on coral-macroalgal changes but recent research suggests that changes towards soft coral-dominated reefs may be widespread in the Indo-Pacific. Although soft coral-dominated reefs may display lower structural complexity than hard coral-dominated reefs, and thus may result in reduced habitat provisioning, this is currently not well understood. Some of the soft coral species dominating such reefs also contain potent allelochemicals, but whether these may act as a deterrent for mobile fauna, is highly unexplored.

Here, we explore the effect that different soft coral species found dominated shallow reefs in Bangka Island (North Sulawesi) have on the associated fish communities. Fish communities in 2 x 2m of reef plots are nearly monospecifically dominated by soft corals (*Xeniia viridis, Sinularia procera, Capnella imbricata,* and *Conglomeratusclera coerulea*) or hard corals (*Acropora spp., Echinopora spp.,* and *Heliopora coerulea*) were studied. The abundance and composition of the fish communities between the different types of plots were assessed. Furthermore, the fish behaviour and whether they interacted with corals were recorded to assess whether soft and hard corals provide the same functions (e.g., habitat/shelter and food).

ID: 851
Lessons from the Past to Inform the Future

Keywords: bacteria, biomineralization, climate change, marine calcifiers, skeletal structure

Long-term effects of ocean warming and ocean acidification on bryozoan species and their associated microbiome

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Global ocean warming and acidification are two of the major threats to many marine calcifying habitat-forming species, potentially affecting entire ecosystems. Consequently, the need for a better understanding and predicting the response of calcifying species has never been more pressing. Paradoxically, the combined and long-term effects of these stressors on bryozoans have remained unexplored, despite their great abundance and diversity globally. Here, we examine the long-term effects of both stressors on the populations of *Pentapora ottomuelleriana* (encrusting) and *Myriapora truncata* (erect) bryozoan species and their associated microbiome that naturally occur in CO_2 vents in the Mediterranean Sea. The proportion of cover of the encrusting species decreased from 2016 to 2020 in all the studied sites, with faster declines at the acidified ones. Our findings suggest that the combined effects of elevated seawater temperature in summer combined with low pH conditions have accelerated the mortality rates in this species, also shifting its microbiome towards the dominance of anaerobic microbial taxa. Microbial genera known to have essential functions to the host such as biosynthesis of defence compounds or thermal protection were depleted in both bryozoan species under elevated temperature and low pH, which may have reduced their resistance to acidification. Both species may thus be at risk to both warming and acidification regardless of exhibiting different skeletal mineralogical and/or morphological adjustments to counter acidification. Our results highlight the need for more multidisciplinary research on long-term impacts on a wider range of calcifying species using both stressors to study the adaptive capacity of the holobiont to a changing environment.

ID: 211
Lessons from the Past to Inform the Future

Keywords: reef island, island formation, Holocene, sea-level, Caribbean

The formation of Caribbean coral reef islands

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Assessing the physical vulnerability of low-lying reef islands has been a long-standing scientific priority due to concern that reef island nations could be uninhabitable by 2,100. Sea-level rise, coral reef degradation and increasingly frequent extreme weather events are predicted to cause widespread island instability and erosion. Island accretionary histories aid predictions of reef island futures by reconstructing the timing of and controls on past island formation and evolution. Indeed, research from the Pacific and Indian Oceans has revealed island formation occurred during both periods of higher and lower than present sea levels, suggesting that uniform assumptions of reef island futures are inappropriate. Yet, critical geographical gaps in reef island databases remain. Currently, there is no reef island formation data from the Caribbean, a region with a unique Holocene sea-level history and coral reef communities. Consequently, it's difficult and invalid to transfer reef island formation knowledge and future predictions from the Pacific and Indian Oceans to the Caribbean. We present the first Caribbean reef island chronostratigraphic study using sediment cores from two Honduran reef islands. Gravel-dominated layers and coral blocks present in cores from both islands initially suggest a contribution of high-energy events to island formation. Subsequent radiocarbon dating revealed initiation of Morgan's Cay before c.1,400 yrs. B.P. on the windward side of the reef platform, followed by island core formation at c.900 yrs. B.P. Paloma Cay, Cayos Cochinos, formed earlier, initiating before c.2,500 yrs. B.P. on the leeward side of the platform, and the island core forming at c.1,400 yrs. B.P. The formation of both islands occurred later than many Pacific and Indian Ocean reef islands, and significantly, as Caribbean Sea level continued to rise throughout the late-Holocene. Our results thus have important implications for understanding the future resilience of reef islands under future sea-level rise and environmental change scenarios.

ID: 611
Lessons from the Past to Inform the Future

Keywords: Biostratigraphy, Micropaleontology, Foraminifera, Rif Region, Morocco

Investigating advancements in biostratigraphy: analysing Cretaceous foraminifera in the Rif region for palaeogeographical analysis

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Exploring into the captivating world of biostratigraphy enables us to explore the study of fossils and their significance in determining the relative age of rock layers. The study focused on analysing Cretaceous foraminifera in the Rif region. By examining foraminiferal assemblages, we have been able to create biozones that enable us to compare different regions and identify the limits of distinct stages. By conducting meticulous analysis, geologists have gained valuable insights into historical environmental conditions by examining fluctuations in sea level and estimating water depths from the past. Planktonic foraminifera provide valuable insights into the environmental conditions, such as oxygen levels, within the water column. Microfacies analysis has provided valuable insights into the different depositional environments. Through the examination of various rock layers, geologists can acquire valuable knowledge about the age of these formations and detect any missing information in the geological record. This study highlights the importance of biostratigraphy in understanding the palaeogeography of the Rif. On the whole, studying the progress made in understanding Cretaceous foraminifera in the Rif region provides valuable insights into historical palaeogeographical conditions and environmental changes.

ID: 238
Lessons from the Past to Inform the Future

Keywords: Bermuda reefs, Reef development, Holocene

Internal structure of Holocene Bermuda reefs: a high latitude coral reef development alternative?

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Holocene coral reef development has been strongly related to Acroporid coral accretion, widely considered as a major modern reef-builder. A very well-known example, Alacran Reef, Gulf of Mexico, accreted as much as 33 m during the mid-late Holocene. Nevertheless, contemporary environmental stressors, such as sea surface temperature rise, pollution, ocean acidification, among others, have caused the decline of these tropical major reef-building corals. Therefore, future coral reef development based on this particular reef builder could be severely endangered. The reported lack of Acroporids, on the shallow (< 2 m) reef structure, together with the high-latitude location (32°N) hint that development and composition of Bermuda reefs are significantly different from Acroporid-dominated reefs, and may function as an alternative to the current decline and to traditional Holocene reef development models. To test this hypothesis, and reveal its most complete internal structure and development, we study rotary cores into Bermuda reef structures (up to ~16 m depth below sea-level). Initial core data and radiocarbon ages show that Bermuda coral reefs have indeed an absence of Acroporids throughout their entire internal structure, which began to develop ~7 ky before present. Instead, reef structure is composed of a framework sequence of small head and mound corals, mainly stress-tolerant Diploria labyrinthiformis and Pseudodiploria strigosa, followed in abundance by Orbicellids and Montastrids, with coral rubble and sand between some of them. Microbialite encrustation is common in both, framework and rubble. Based on first absolute age data, reef-accretion rate in Bermuda averages some 2 m/kyr and seems to be lower as in lower-latitude reef systems. These first results strongly suggest that despite the absence of the considered traditional reef-building components, coral reefs can successfully develop, and might persist in spite of detrimental near-future conditions for coral reef development.

ID: 534
Lessons from the Past to Inform the Future

Keywords: fossil corals, climate archives, Eocene, calcification, geochemical proxies

Calcification characteristics of Eocene reef corals (*Astreopora*)

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Scleractinian reef corals are frequently used as paleoenvironmental and paleoclimate archives. High-precision calcification records and geochemical proxy data derived from the aragonitic skeleton provide information on coral responses to global and local environmental conditions. Thus, deciphering the environmental characteristics of reef coral habitats across time may allow for estimates regarding the future distribution and adaptability of present-day reef corals under changing climates.

Here, the calcification performance under Eocene greenhouse climate conditions of massive reef corals (*Astreopora*) from a paleolatitude of ~45°N is investigated. We present calcification records, oxygen and carbon stable isotope ratios ($\delta^{18}O$, $\delta^{13}C$), and element/Ca data of corals from the Lutetian (46 Ma), Bartonian (40 Ma), and Priabonian (37 Ma) stages of France (Paris Basin) and the Ukraine (Dnipro area).

Investigated corals show low annual extension rates with mean values of 1.04 ± 0.01 mm/year (Ukraine) and 1.32 ± 0.55 mm/year (France), respectively, and low mean densities of 0.72 ± 0.25 g/cm³ (France) and 0.66 ± 0.08 g/cm³ (Ukraine). X-radiographs of the coral skeleton show frequent disruptions of the annual banding by high density stress bands and lesions indicating partial mortality events. Cyclic patterns of $\delta^{18}O$ values largely coincide with annual density bands. Maximum density is consistent with high $\delta^{18}O$ values and vice versa, allowing for a distinction between a cold (high density, high $\delta^{18}O$) and a warm season (low density, low $\delta^{18}O$). Pattens of $\delta^{13}C$ ratios indicate that the corals analysed were zooxanthellate with a maximum photosynthetic activity in the warm season. Time series of temperature-sensitive geochemical proxies (e.g., Sr/Ca) largely coincide with the cyclic pattern of $\delta^{18}O$ values.

Based on our results we suggest detrimental growth conditions, including amplified seasonal contrasts of (i) sea surface temperatures, (ii) light availability, and (iii) terrestrial runoff, which have a combined negative impact on coral calcification during the Eocene.

ID: 850
Lessons from the Past to Inform the Future

Keywords: Coral reef, Trophic networks, Ecosystem functioning, Climate changes

High vulnerability of coral reef food web and energy fluxes to global change

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Coral reefs are the most diverse marine ecosystem on Earth and are threatened by several pervasive stressors, which include coral bleaching, ocean acidification, overfishing and pollution. While the influence of these stressors on static community variables such as standing fish biomass or coral cover are well studied, trophic interactions are often overlooked. Hence, it is still largely unknow how food webs, their topology, their trophodynamics and the energy fluxes that fuel coral reefs, will respond to global changes.

Here we combine a global database of reef fish trophic interactions with fish bioenergetic modelling and a visual census dataset to provide the largest database of bipartite fish-centric coral reef trophic networks, weighted by carbon fluxes. We delineate patterns of coral reefs food webs' topology and trophodynamics at a global scale, and explore how energy fluxes are impacted by environmental and anthropogenic pressures.

We found out that the architecture of reef fish food web is not homogeneous across oceans and identified five biogeographic regions within which food webs' topology was consistent. We showed that coral reef food webs display configurations that vary between diverse, connected or modular topologies. Sea temperature, net primary production, fishing intensity, along with benthos composition, were all identified as major determinants of reef fish food web's architecture. Using Bayesian modelling, we also show that food web architecture is remarkably correlated with coral reef trophodynamics and regulates the amount of energy input from local or planktonic primary production.

Our work shed new light on how reef fish food webs and functioning will evolve under global changes.

ID: 852
Lessons from the Past to Inform the Future

Keywords: coral probiotics, microbial functioning, climate change adaptation, microbiome, cultured bacteria

Exploring cultivation methods for coral-associated bacteria: a step towards customized probiotics

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The coral-associated microbiome plays a central role in the functioning and adaptation of the coral holobiont. An increased ability of corals to tolerate stress through shifts in their microbial composition has led to the concept of "Beneficial Microorganisms for Corals" (BMC). Currently, the production and application of natural probiotics derived from stress-tolerant corals is being explored. This emerging strategy aims to supply corals in situ with microbes that provide beneficial functions to promote their health and stress resistance. However, probiotic applications are still hampered by a lack of knowledge of the active bacterial communities associated with corals and their beneficial metabolic pathways that may be involved in improving stress tolerance of the holobiont. Here we present a comparative approach to systematically isolate and culture bacterial associates from three coral species (*Galaxea fascicularis*, *Pocillopora verrucosa*, *Stylophora pistillata*) using a combination of traditional plating methods and special growth media paired with a range of cultivation conditions. Based on these results, candidate BMC will be further characterized genomically and phenotypically and related to their functions recorded in the coral holobiont under different environmental stressors. This comprehensive dataset will help to disentangle the mechanistic features of BMC and ultimately lead to a curated collection of isolates for the development of natural probiotics. In future studies, such customized probiotic cocktails may be employed in empirical trials to safeguard corals against multiple environmental stressors and across a range of species. Such multifaceted approaches have the potential to provide fundamental insights into the essential microbial functions that shape the stress response of coral holobionts and promote the active intervention of coral probiotics.

ID: 173
Lessons from the Past to Inform the Future

Keywords: reef accretion rates, Indo-Pacific, Holocene, sea-level, community structure

Spatio-temporal trends in Indo-Pacific coral reef accretion and ecological community structure

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Tropical coral reefs are threatened by the impacts of ocean warming, sea-level rise, and local stressors. Historical data on how coral reef structures respond to environmental change, and the ecological drivers of carbonate framework construction are critical in understanding future reef growth trajectories and coastal resilience as sea levels increase. Here we compile a standardized reanalysis of global coral reef accretion and community structure data for more than 500 reef cores and exposures in 97 reef sites across the Indo-Pacific region spanning the Holocene period (~11700 years ago). Reef accretion rates range from below 1 mm year^{-1} in the late Holocene to more than 20 mm year^{-1} in the early Holocene, where 68% of its variation can be explained by rates of relative sea level rise (RSLR). Majority of the core records indicate that sustained reef accretion began around ~8000 to 6000 years ago and coincide with slowing rates of RSLR. Competitive and stress-tolerant taxa represented by massive *Porites* spp. and fast-growing *Acropora* spp., respectively, were the most common reef-building corals. Transitions from competitive to stress-tolerant, competitive to generalist, and competitive to weedy taxon were observed. While limited in abundance in the Holocene record, generalist and weedy taxa were present between 8000 to 4000 years ago and reappeared in the late Holocene period, providing clues on the timing and drivers of coral community shifts and a precedent on which currently observed coral assemblage replacements in the Indo-Pacific may be evaluated.

ID: 619
Lessons from the Past to Inform the Future

Keywords: Indonesia, multiple stressors, sedimentation, coral growth, paleoclimate

Coral growth response to multiple stressors: sediment runoff and heatwaves on the Tin Island of Belitung, Indonesia.

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Coral reefs are threatened not only by bleaching as a consequence of marine heatwaves but also by other stressors like coastal development and the human-induced change in the sediment runoff regime. The combination of these stressors may further threaten coral reefs, it remains however unclear if changes in the sediment runoff enhance or reduce the impact of heat waves. To understand the impact of multiple stressors on coral reefs, we visited Belitung Island, located between the Java Sea and the South China Sea. The coral reefs in Belitung Island have been identified as potential refugia to the projected stressors because they have been less impacted by heat waves over the past 40 years. However, in the past 20 years, active tin mining and coastal development might have introduced another stressor on the coral reefs around Belitung Island. In this study, we investigated the combined impacts of recent sediment runoff and thermal stress events on coral growth over the past 40 years, using geochemical data from coral cores. We drilled coral cores near a river mouth in Belitung Island and measured the coral growth parameters from computed tomography scanning images. To determine past heatwaves and sediment runoff, we analysed the Sr/Ca ratio and trace elements in coral skeletons back to the 1980s (beyond the onset of satellite measurements). We found that the Sr/Ca reflected sea surface temperature (SST) variations while Mn/Ca ratios the excess/lack of river runoff. These proxies reflected the impact of interannual climate modes like the El Niño-Southern Oscillation and the Indian Ocean dipole, which cause anomalously high SSTs with or without large sediment runoff. This presentation will further discuss the impact of multiple stress factors from heatwaves and sediment runoff on coral growth parameters at interannual to decadal scales.

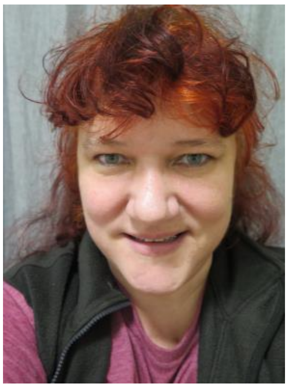
Session 2: Coral Reef Structure and Functioning

Coral reefs are amongst the most productive and diverse ecosystems on earth. The foundation of these systems is a plethora of ecosystem functions and services provided by complex interactions of micro- and/or macro-organisms. These functions and services range from the construction of a 3-dimensional reef framework as habitat and shelter to its deconstruction, increasing structural complexity and providing calcium carbonate sands, as well as from the fixation of inorganic carbon and nitrogen as the building blocks of life to the recycling and remineralization of organic matter. This complex interplay of functions and services evolved over millennia and was shaped by varying local and regional environmental conditions to form a diversity of coral reef environments across the globe.

This session encourages contributions on the latest findings on the functioning and structure of coral reef ecosystems. The aim is to bring together studies from the organism to the ecosystem level in the fields of functional and trophic ecology, evolutionary and natural history, as well as biogeography. We also invite research from mangrove, seagrass, and deep-sea environments to foster a broad interdisciplinary exchange. Understanding the role of organisms in ecosystem functioning under past and current conditions is crucial to develop effective management interventions, to counteract the ongoing degradation of these enigmatic ecosystems and to preserve them for the future.

Keywords: evolutionary and natural histories, biogeography, trophic relationships, functional ecology, bioconstruction and bioerosion processes

Session chairs



Christine Schönberg, National Sun Yat-Sen University (Taiwan)

Benjamin Mueller, Universität Bremen (Germany)

Take home message

- Reef function acts on a large range of different scales, via different factors and through an immense diversity of organisms – which was well reflected in session 2.
- We are rapidly losing very important functions that control and maintain coral reefs as they should be, and it is difficult to keep track of the developments in such a complex system, as well as to know what needs to be done to improve the situation (... we know better what to avoid)
- But we are diverse, too. As a community working on coral reef science, we have a unique opportunity and responsibility to work together, to network, share and coordinate and standardize our efforts to maximize the outcome and to inform and instruct regulators, politicians and the public. Let’s do it!

Regular oral presentations

ID: 152 / **Parallel Session 2-2: 7**
Coral Reef Structure and Functioning

Keywords: Coral host, Boring bivalves, Symbiosis, Metabolic interactions

Live coral hosts are necessary for the optimal functioning of boring bivalves

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Although the coral holobiont has been extensively studied at the microsymbiotic level, macrosymbiosis, involving macrobiota, has been much less explored. Bivalves of the genus *Leiosolenus* are found exclusively in live corals, densely inhabiting five of the most common coral species in the Gulf of Eilat/Aqaba, Red Sea. Burrowing in live corals provides mechanical protection from predation but, presumably, incurs energy costs to keep pace with the outward growth of the coral hosts. The fact that these bivalves are exclusively found in live corals suggests that they obtain compensatory metabolic benefits from this association. To better understand the nature of this relationship, we conducted a field comparison of the physiological parameters of *L. simplex* residing in live coral hosts vs corals stripped of their live tissues. One year after the experiment, the survival rates of bivalves in both treatments were similar (<5% difference), suggesting that this symbiosis is not obligatory for the bivalves. Nonetheless, the O_2 consumption was considerably lower (31%) in *L. simplex* dwelling in killed coral hosts than in live coral hosts. Surprisingly, the oxygen removal by *L. simplex* dwelling in live coral hosts was much higher than their planktonic organic carbon uptake, suggesting that even complete oxidation of all planktonic particles was insufficient to account for the respiration of *L. simplex* in live coral hosts. Direct measurements revealed a significant uptake of dissolved organic carbon. The $\delta^{13}C$ values of the bivalves compared to those of the particulate matter confirmed that the bivalves utilized additional and heavier food sources, likely of reef origin. Our data suggests that coral-boring bivalves rely to some degree on the coral hosts for nutrition. Although it is possible for *L. simplex* to survive in dead coral hosts for an extended period, live coral hosts enhance the physiological state of these boring bivalves.

ID: 293 / **Parallel Session 2-3: 6**
Coral Reef Structure and Functioning

Keywords: ultraconserved elements (UCEs), scleractinian, integrative taxonomy, biogeography

Phylogenomics and biogeography of the widespread reef coral *Dipsastraea* (Scleractinia: Merulinidae)

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Understanding corals' distribution and abundance is critical for effective management and conservation. This task can however become challenging due to undefined or artificial species boundaries, which is still the case for many reef-dwelling scleractinian corals. The Indo-Pacific genus *Dipsastraea* (Merulinidae) represents one of these cases. Of the 24 valid nominal species currently ascribed to the genus, more than half are believed to be widespread despite poor phylogenetic resolution based on single-gene analyses and the lack of a phylogenomic approach to species delimitation. In this study, we used target-capture of ultraconserved elements (UCEs) and exons to reconstruct the phylogeny of 328 specimens ascribed to genus *Dipsastraea* and to four morphologically related Merulinidae genera, from 13 localities across the Indo-Pacific. Phylogenomic reconstructions helped delimit 29 species level clades, whose representatives were morphologically re-analysed and compared with types and original descriptions. These data provided the starting point to revise current species boundaries and led us to identify several novel morpho-molecular clades, potentially representing undescribed species. Moreover, our analyses unveiled a clear separation between Indian vs. Pacific Ocean lineages. Of the 29 clades retrieved, 10 appeared restricted to the Indian Ocean, while 18 clades were exclusive of the Pacific Ocean. Within the Indian Ocean clades, seven occur exclusively in the seas around the Arabian Peninsula, further highlighting this region as a biodiversity hotspot and center of endemicity for Scleractinia. This represents the first study to address the diversity and species boundaries of *Dipsastraea* through a phylogenomic approach, unveiling potential unseen biodiversity within the genus. It also confirms the effectiveness of target-capture approaches in resolving the taxonomy of scleractinian taxa. Finally, it sheds light on the biogeographic patterns of the genus, confirming evolutionary breaks between Indian and Pacific Ocean, and enhances our knowledge about *Dipsastraea* species' diversity and distributions, facilitating potential conservation strategies.

ID: 350 / **Parallel Session 2-4: 9**
Coral Reef Structure and Functioning

Keywords: Functional indices, disturbance, remote reefs, fish assemblages, bleaching

Taxonomic and functional change of fishes on oceanic coral reefs with contrasting disturbance histories.

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Environmental disturbances can have severe impacts upon reef building corals which have flow-on effects for reef associated fishes. Changes in taxonomic and trophic structure of fish assemblages provide valuable insight into how fishes respond to habitat disturbance, yet they do not necessarily capture changes in ecological functions performed by fishes. Here we used 20 years of fish and coral monitoring at two isolated oceanic reefs with different disturbance histories to assess both taxonomic and functional response of reef fishes to fluctuations in coral cover. Severe coral bleaching in 1998 caused coral cover at Scott Reef to fall from ~60 to <5%, with recovery occurring over the ensuing 17 years. Conversely, comparatively minor disturbances on Rowley Shoals reefs meant coral cover remained >25% over the same period. Drastic coral reduction and increased cover of algae at Scott Reef was associated with reduced corallivores and an increase in herbivores/detritivores. Planktivores associated with coral habitats also declined post-bleaching whilst generalist carnivores and omnivores temporarily increased in abundance. These trends in trophic structure of fishes were not apparent at Rowley Shoals reefs. The functional space occupied by fishes did not differ greatly over the 20 years of monitoring at either Scott Reef or Rowley Shoals. However, at Scott reef functional originality was inversely correlated with *Acropora* cover whilst at the Rowley Shoals, functional originality was directly related to *Acropora* cover. This disparity relates to differences in the range of coral cover at the two locations and shifts in how fishes occupy functional space without changing functional richness. Our results suggest that the relationship between functional originality (and functional redundancy) and coral cover is non-linear and that the impact of environmental disturbance on the function of reef fish assemblages may depend on the type of coral lost, the extent of coral loss and percent coral cover after disturbance.

ID: 216 / **Parallel Session 2-2: 1**
Coral Reef Structure and Functioning

Keywords: Colombian Caribbean, Coral growth, Environmental gradient, Nutrients, pH

Growth rates of five coral species along a strong environmental gradient in the Colombian Caribbean

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Coral calcification is a critical process linked to reef growth and is highly dependent on environmental conditions. Yet, most studies focus on stereotypical coral reef conditions (e.g., clear waters, low nutrients and sedimentation, limited human disturbance), resulting in limited knowledge of suboptimal reefs. Thus, understanding coral growth's sensitivity to specific environmental conditions is crucial in understudied regions such as the Colombian Caribbean. To address this knowledge gap, this study assessed the growth (calcification and linear extension) of seven coral species at Providencia, Islas del Rosario, and Santa Marta, in the Colombian Caribbean. The measured environmental variables, collected during the rainy season (May – November 2022) and influenced by La Niña, revealed a strong environmental gradient (inshore *vs.* offshore) between the sites. Across all species, calcification rates were highest in Providencia (offshore) and at Rosario (mid-shore) but 59 and 37% lower in S. Marta (inshore), respectively. Across all sites, massive corals calcified 92% more than branching species but were more susceptible to bleaching and inshore environmental conditions (low visibility, high sedimentation, and limited water flow). Conversely, branching species grew 84% faster than massive species but had reduced survival rates due to bleaching and extreme climate events (i.e., hurricanes). A comparison of these growth rates with published rates for the wider Caribbean revealed that massive coral species in this study grow consistently more than other massive corals in the wider Caribbean region while branching species generally have similar growth. Overall, the results of this study indicate that current environmental conditions, coupled with the frequency of extreme climatic events, will favour the growth of massive rather than branching species in the Colombian Caribbean. This suggests a possible shift in future coral communities towards the faster calcifying massive species, further promoted by an ongoing dramatic regional decline in branching species over the last decades.

ID: 231 / Parallel Session 2-3: 1
Coral Reef Structure and Functioning

Keywords: coral, systematics, taxonomy, biogeography

Phylogenomics reveals extensive 'dark diversity' in *Acropora*

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Measures of species richness underpin virtually all aspects of biological research. Un-named species or 'dark taxa' can obscure patterns of diversity and biogeography, and mislead conservation efforts. Here, we use an extensive phylogenomic dataset for staghorn corals (*Acropora*) collected from across the Indo-Pacific to reconstruct a phylogeny of the group and illuminate the extensive dark diversity within the group. Our results show that the diversity of the genus *Acropora* is far greater than currently assumed, and that almost three-quarters of species on Indo-Pacific reefs are not included in recent taxonomic revisions and field guides that underpin a substantial proportion of contemporary coral reef science. While a significant proportion of these species remain undescribed, many others represent nominal species that were synonymised incorrectly. A biogeographic assessment of species ranges shows that overlap in coral assemblages between regions across the Indo-Pacific is overestimated by traditional taxonomy; many species currently considered to be widespread generally have much smaller range sizes, and peripheral locations throughout the Indo-Pacific support a high proportion of endemic species that remain undescribed. Given the increasing spatial footprint and severity of disturbances on reefs globally, this dark diversity suggests a high risk of 'silent' extinctions in reef corals that is not reflected in IUCN Red List assessments and highlights an urgent need for accurate information on the identity and distribution of these key ecosystem engineers.

ID: 156 / Parallel Session 2-1: 2
Coral Reef Structure and Functioning

Keywords: Juvenile Corals, Replenishment, Reef Recovery, Recruitment, Connectivity

Comparison of juvenile coral assemblages between Australia's Coral Sea and Great Barrier Reef Marine Parks

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Densities of juvenile corals (≤50mm diameter) are expected to vary between geographically isolated and more spatially proximate reefs, and may constrain local recovery potential. This study compared juvenile coral densities and their relationships with local abundance of adult congenerics at 17 geographically isolated reefs within Australia's Coral Sea Marine Park (CSMP), versus 17 highly connected reefs within the Great Barrier Reef Marine Park (GBRMP). Three latitudinal regions and two habitats (reef crest and slope) were examined within both marine parks to test for spatial variation. Densities of juvenile corals in the CSMP (13.99 ± 0.72 juveniles $10m^{-2}$) were significantly lower compared to those in the GBRMP (23.72 ± 1.86 juveniles $10m^{-2}$). Specifically, there were significantly less *Acropora* and *Pocillopora* juveniles on the reef crest in the central CSMP compared to the GBRMP. Relationships between juvenile abundance and percent coral cover were greatest for *Acropora* and *Pocillopora* in the GBRMP. This may be due to the low range of coral cover estimates recorded in the CSMP, especially for *Acropora* (0-15%). Low juvenile coral abundance, and in particular, the lack of fast-growing juvenile corals (e.g., *Acropora*) in the Central CSMP, in combination with low cover of brood-stock (particularly *Acropora*) on CSMP reefs, poses a significant constraint on post-disturbance recovery capacity, possibly attributable to isolation and limited connectivity among reefs in this region.

ID: 206 / **Parallel Session 2-2: 8**
Coral Reef Structure and Functioning

Keywords: Excavating sponges, coral sediment, bioerosion, Caribbean

Constraining the contributions of endolithic sponges to sediment carbonate dynamics on Caribbean coral reefs

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Biogenic sediment generated on coral reefs contributes to the formation of tropical shorelines and reef islands, and is an integral constituent of accumulating coral reef structures. Many reef taxa contribute skeletal sediment to the reef sediment pool, but some sources remain poorly quantified. Endolithic sponges are known to semi-continuously generate fine-grained carbonate sediment as a by-product of their substrate excavations. While many aspects of their bioeroding activity have been studied relatively well, the sedimentary attributes of this material and the rates at which different species generate sediment are still poorly understood. We addressed these knowledge gaps through the analysis of sedimental material produced by eight bioeroding sponge species commonly encountered on Caribbean coral reefs. Our findings demonstrate species-specific variations in sediment production rates ranging from 1.0 to 6.3 kg m^{-2} yr^{-1}, but a high degree of consistency in grain characteristics and the size fractions of sediment produced (modal sizes across species ranging from 39 to 50 µm). These species-specific data were used to explore reef-scale variations in total sponge-derived sediment generation using census data from 50 reef sites across the Mexican Caribbean. Clear between-site variability was observed with estimated annual production rates ranging from <0.01 to 0.84 kg of sediment produced per square meter of reef substrate. While these rates were predominantly driven by sponge abundance, distinct spatial variations were observed in contributions of different species. The known rapidity at which these prominent biogenic sediment producers utilize recently dead coral substrates, coupled with their documented positive response to the changing marine environment, underscores the growing importance of these sponges as many Caribbean reefs transition into states of low living coral cover.

ID: 712 / **Parallel Session 2-1: 1**
Coral Reef Structure and Functioning

Keywords: community dynamics, disturbance, recovery and restoration, reef structure, accretion and erosion

What limits recovery from extreme coral mortalities?

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A sequence of extreme disturbances drastically changed the coral reefs around Jiigurru (aka Lizard island) in the Great Barrier Reef, Australia between 2014 and 2017. A sequence of two cyclones and two mass bleaching events led to coral mortality rates of up to 98%. These devastating effects produced an opportunity to study the reassembly of coral assemblages. Using 3D maps of 21 sites around the island group, coupled with individual colony in situ annotations, we assessed the spatial and temporal variation in recovery paths over the past eight years. Collectively, we observed a five-fold increase in the number of colonies, and a doubling of the number of species since 2016. However, recovery was highly variable spatially, with some sites now having surpassed historical cover, abundance and species richness, while others have had much slower recovery paths. By individually tracking the fates of over 50,000 coral colonies, and quantifying reef structure around them, we are able to identify whether recruitment or mortality are driving these differences, and how these rates relate to reef structure. We propose approaches to identify limiting factors to natural recovery, and how to potentially alleviate them.

ID: 122 / **Parallel Session 2-3: 12**
Coral Reef Structure and Functioning

Keywords: coral composition, latitudinal diversity gradient, species turnover

Multidecadal coral assemblage shifts have transformed latitudinal gradients in reef fish diversity

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Quantification of biological diversity across large spatial scales has revealed patterns that appear to reflect general principles governing the organization of life on Earth. However, in recent decades climatic and anthropogenic pressures have driven changes in diversity patterns, creating uncertainty around whether these general patterns and principles hold in the current era of rapid environmental change. Coral reef ecosystems have experienced some of the most severe changes worldwide of any ecosystem; a product of interacting local and global drivers. We use the Long-Term Monitoring Program (LTMP) of the Australian Institute of Marine Science; one of the most comprehensive monitoring programs of coral reef ecosystems worldwide. This monitoring dataset provides the opportunity to evaluate not only how the Great Barrier Reef (GBR) has changed over long temporal scales (1995 to 2022) but also how these changes vary across a large latitudinal gradient (14°S to 24°S). We analyse how and why patterns of reef fish diversity have changed over the past three decades by examining local diversity (α) and species turnover (β). We explore possible drivers of these patterns by focusing on the latitudinal gradient, fluctuations in coral cover and changes in coral composition. We found a systematic increase in reef fish turnover and a high fluctuation in the species richness across the latitudinal gradient in the GBR and time. Particularly, we found declines in species richness of fish at lower latitudes and increases at higher latitudes, which are consistent with disturbance-driven fluctuation in coral cover and coral composition. More broadly, our work provides fundamental insight into whether classic macroecological patterns are fit for coral reef ecosystems in the Anthropocene. These analyses and insights are only possible due to this standardised large-scale and long-term monitoring effort.

ID: 135 / **Parallel Session 2-4: 5**
Coral Reef Structure and Functioning

Keywords: herbivory, macroalgae, grazing lawn, incidental grazing, macroalgae propagules

Macroalgal (Sargassum) propagules suppress grazing by herbivorous fishes on coral reefs

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Incidental grazing of seedlings of woody plants or macroalgal propagules by herbivores is often assumed to be a key process preventing shifts from assemblages of small, highly productive herbaceous plants, to larger, less productive woody vegetation. On coral reefs, the proliferation of macroalgal biomass following reductions in herbivory has led to a widely-held view that grazing fishes control macroalgal assemblages through the removal of macroalgal propagules within turf algal assemblages. However, it has never been explicitly tested whether fishes target, avoid, or incidentally graze on these early life stages of macroalgae. Here, we investigate how the presence of propagules of a common coral reef macroalga (*Sargassum swartzii*) within turf algal assemblages influenced feeding by grazing fishes. We established algal turf assemblages on small (11 × 11 cm) terracotta tiles, and seeded half of the tiles with propagules of *S. swartzii* (mean density = 10.1 propagules/cm^2). Paired tiles (with and without propagules) were then exposed to local herbivorous fish assemblages or placed within exclusion cages within two habitats (reef crest and reef flat) on Lizard Island, northern Great Barrier Reef, for six days. Although survival of *Sargassum* propagules was 39% lower on tiles exposed to local fish assemblages than on caged tiles, video observations revealed that the presence of *Sargassum* propagules reduced grazing rates on algal turfs by 36%. Indeed, 18 of the 21 fish species recorded took fewer bites on algal turfs containing propagules than those without, with small-bodied fishes (f. Blenniidae: *Ecsenius* spp) accounting for 85% of all bites recorded. These results indicate that while grazing is an important source of mortality for *Sargassum* propagules, grazing fishes reduce feeding in areas with propagules and may lead to a mosaic of grazing intensity across reef habitats, and potential lead to the gradual expansion of macroalgal biomass on coral reefs.

ID: 215 / **Parallel Session 2-1: 9**
Coral Reef Structure and Functioning

Keywords: Clownfish, SNPs, Indian Ocean, Connectivity

Population genomics confirm strong genetic differentiation between skunk clown fish from both sides of the Indian Ocean and more subtle population genetic structure among populations in the Mozambique Channel.

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Most marine fishes experience a pelagic larval phase making dispersal over long distances possible, even though empirical measurements have demonstrated that larvae of coral reef associated fishes generally do not travel far. Despite the challenging nature of measuring connectivity among populations of marine organisms, this information remains important for the conservation of genetic diversity and Marine Protected Area spacing. Here, we use RAD seq to construct a set of 2,423 SNPs to infer genetic structure in populations of the skunk clownfish (*Amphiprion akallopisos*) from across the Indian Ocean. We identified SNPs both using a de novo map approach and alignment against the reference genome of a closely related species, *A. ocellaris*. We found that the use of a reference genome greatly improved SNP identification and population genetic inference. Earlier findings of differentiation between populations in the Eastern Indian Ocean (EIO) and the Western Indian Ocean (WIO) based on both mitochondrial and nuclear (microsatellite) markers were confirmed with SNPs. Within the WIO, four genetically differentiated groups were identified: i) the East-African coast, ii) Îles Glorieuses and North Madagascar, iii) Juan de Novo and West-Madagascar, iv) the Southern islands of the Mozambique Channel. Strong coastal currents seem to promote connectivity along the East African coast. Complex biophysical patterns, including the existence of several gyres capable of trapping dispersing larvae, on the contrary, likely form barriers to dispersal in the Mozambique Channel. Additionally, the isolation of southern islands Bassas da India and Île Europe and the specific, non-optimal, environmental conditions on these reefs might promote local adaptation, although we were not able to detect such an effect with our dataset.

ID: 333 / **Parallel Session 2-2: 2**
Coral Reef Structure and Functioning

Keywords: carbonate budget, sediment budget, coral growth, geo-ecological reef functions

Coral reef growth and sediment production across habitats, atolls and a natural nutrient gradient

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Coral reef accretion and sediment generation are key to preventing shoreline erosion and control low-lying reef island development. However, quantitative data on these important geo-ecological functions are scarce, especially in the shallow habitats that are most critical for coastal protection and shoreline sediment supply. This study quantifies reef carbonate budgets and sediment budgets at deep (8-9 m) and shallow (2-3 m) fore reefs and shallow (1-2 m) lagoonal reefs around six islands in the remote Chagos Archipelago, Central Indian Ocean. The protected Archipelago experiences minimal direct anthropogenic stressors and provides the opportunity to study reef functioning across gradients in wave exposure and natural nutrient supply. Nutrient subsidies to studied reefs are provided by seabird guano run-off and vary with seabird densities on adjacent islands. Benthic surveys to estimate reef carbonate and sediment production (ReefBudget and SedBudget) were accompanied by the quantification of site-specific calcification and bioerosion rates, and the analysis of sediment composition on shallow reefs and adjacent beaches. Preliminary analyses show distinct patterns in carbonate budgets across habitats, with highest rates of carbonate production at deep fore reefs of all islands. Coral cover and carbonate budgets also show atoll-specific differences, probably caused by differences in atoll size and wave exposure. Seabird-derived nutrient subsidies increase coral calcification rates and decrease parrotfish feeding rates, but do not seem to enhance overall carbonate or sediment budgets. Sediment production and composition differ considerably across habitats and across islands and do thus not show a clear pattern associated with seabird-derived nutrient supply. Data analysis is ongoing and will produce the first spatial assessment of reef growth potential and reef-derived sediment supply around these remote reef islands, revealing the impacts of habitat- and atoll-specific environmental conditions and seabird-derived nutrient subsidies on geo-ecological reef functions.

ID: 461 / **Parallel Session 2-2: 9**
Coral Reef Structure and Functioning

Keywords: Bioerosion, Endolith, Microbioerosion, Indian Ocean, Carbonate budgets

Constraining rates and controls on microbioerosion on Indian Ocean reefs

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Bioerosion of calcium carbonate is a fundamental process that impacts net coral reef accretion, and structural complexity. Besides grazing parrotfish and urchins, organisms that bore into the reef substrate, known as endoliths, such as sponges, worms and molluscs play a large role in carbonate removal. Similarly, unicellular algae and fungi penetrate dead reef substrate and can result in bioerosion rates of comparable, and sometimes greater, magnitude. While endolithic bioerosion processes are of significant relevance on all reefs, the abundance of endolithic organisms, and therefore bioerosion rates, vary significantly over temporal and spatial scales. However, there remains a paucity of quantitative data on microbioerosion rates, and knowledge of how these rates vary with changing environmental conditions. Additionally, there is a relatively limited understanding of how endolithic community composition and the resultant microbioerosion rates vary between coral substrate types. Here we provide quantitative data regarding the impacts of depth, turbidity and coral substrate type on microendolithic community composition, and resultant microbioerosion rates, on reefs in the Indian Ocean. Turbid inshore reefs in Western Australia showed lower rates of microbioerosion compared to those found at reefs in a remote open ocean setting in the Chagos Archipelago. However, the inshore reefs of Western Australia displayed a more diverse microboring assemblage than was found in the Chagos Archipelago. The impact of substrate type and exposure period is currently being investigated in dead coral substrates of 5 different species, collected every 6 months over a two-year period following a major coral mortality event in Western Australia. We hypothesise that skeletal morphological differences will result in marked differences in erosion rates. The data collected will help to improve local carbonate budget estimates within the region and provide a context for wider regional and environmental comparisons of this important, yet often overlooked process.

ID: 840 / **Parallel Session 1-1: 3**
Coral Reef Structure and Functioning

Keywords: Skeletal extension, moonlight, dissepiments

Integrating moonlight signals in predicting coral extension along depth gradients

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Coral skeletal extension rate is the most commonly reported metric widely used to assess coral stress responses. However, the lack of physiological knowledge regarding the mechanisms controlling vertical skeletal growth has hindered our ability to predict their responses across environmental gradients. Corals extend vertically as they form structural components called dissepiments. Dissepiment formation is controlled by a moonlight cue and exhibits a binary response: they are formed in the presence of the moonlight stimulus, and in the absence of this stimulus, its formation is completely suppressed. Here, we combine empirical data and theoretical concepts to build a model capable of predicting changes in massive coral skeletal extension rates based on the number of dissepiments. To investigate the relationship between skeletal extension and the number of dissepiments, we performed skeletal analyses on coral cores collected in a depth gradient (5-40 m). Linear regression analyses showed that the number of dissepiments explained 86% of its variability, indicating that linear extension is a function of the number of dissepiments. Furthermore, based on the assumption that the formation of dissepiment has a binary response, we defined as a variable a depth threshold, which is a certain depth beyond corals cease to sense the moonlight cue, leading to the cessation of dissepiment formation, therefore decreasing the skeletal extension. We developed a light-dependent, depth-resolved model for a skeletal extension that incorporates this depth threshold and atmospheric moonlight attenuation. We explored the association between moonlight availability and skeletal extension rates, comparing patterns in sites with contrasting water clarity. The moonlight-extension model explained between 70-96% of the depth-related variation in coral linear extension rates, indicating that much of the variability in extension rates are driven by changes in the fractional contribution of moonlight availability. These results suggest a fundamental role of moonlight in explaining patterns of linear extension rates.

ID: 296 / **Parallel Session 2-4: 6**
Coral Reef Structure and Functioning

Keywords: adaptation, herbivory, functional innovations, ecomorphology, specialisation

The functional morphology of feeding in surgeonfishes

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Benthic-feeding coral reef fishes (e.g., herbivores) display an impressive degree of morphological and functional diversity. While the ecological outcomes of such feeding have been studied in detail, coral reefs are changing towards an algal turf-dominated state, suggesting new dynamics between corals, algae, and fish. This increase in a specific resource, suggest an increased consumption by herbivorous fishes. Despite this importance, the morphological adaptations and mechanisms required to carry out benthic feeding modes such as cropping, have only been sparsely studied. In our study, we used high-speed video, to film 10 species of surgeonfish feeding on filamentous algae, which we used to conduct a comparative kinematic analysis. We found a large diversity of feeding behaviours and mechanisms which are tightly linked to the nature of the turf algae (e.g., length). Surgeonfishes are able to move their jaws both laterally and dorsoventrally while they are closed around the algae, a morphological novelty allowing them to detach filamentous algae thus minimising motions required by the rest of the body. This increased kinematic diversity of the jaws in multiple planes, likely reflects the diversity and requirements of the microhabitats (e.g., flat, concave, vertical surface), the diversity of abiotic factors (e.g., water current strength), as well as the diverse nature of algal turfs (e.g., structural integrity, length, shape) found on coral reefs. Overall, our results provide evidence for the long evolutionary history and adaptation, between surgeonfishes and coral reefs, as well as their importance in influencing the future dynamics between corals and algal turfs.

ID: 726 / **Parallel Session 2-3: 15**
Coral Reef Structure and Functioning

Keywords: Darwin's paradox, coral reef productivity, oligotrophic waters, tropical waters

Challenging Darwin's coral reef paradox

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For decades, coral reefs have been touted as an ecological enigma: despite dwelling in nutrient-poor, oligotrophic tropical waters, they exhibit remarkably high internal productivity. This observation, attributed to Charles Darwin in his 1842 book ('*The structure and distribution of coral reefs*') and frequently termed the 'Darwin's paradox', has spurred ample research in ecology, oceanography, and ecophysiology. Based on historical and empirical evidence, we demonstrate that the 'Darwin's paradox' is neither Darwinian, nor truly paradoxical. An analysis of the historical literature revealed no signs of the coral reef paradox idea in Darwin's work. Instead, this paradox idea most likely emerged in the 1950s, with retroactive attribution to Darwin beginning only in the 1980s. Furthermore, contrasting the underlying assumptions of the 'paradox' with empirical data confirmed that coral reef primary production exceeds that of most other ecosystems, terrestrial or aquatic. However, coral reefs do not predominantly occur in low-production waters. Global remote sensing and in-situ data revealed that 77% of coral reefs experience waters with more than 0.1 mg chlorophyll m^{-3}, the typical threshold of oligotrophic ocean waters. Indeed, the average coral reef is embedded in waters with twice this phytoplankton concentration (0.2 mg chlorophyll m^{-3}) and every region except the Central Pacific is dominated by these relatively more productive waters. Thus, coral reefs are highly productive, but they do not thrive in waters as nutrient-poor as commonly believed. We argue that insisting on the implied dichotomy of the 'Darwin's paradox' misleads our understanding of reef functioning and constrains our capacity to consider the complex connections coral reefs maintain with neighbouring ecosystems. Echoing calls voiced some 40 years ago for an outward concept of reef ecosystems, we highlight the need to improve quantification of links between coral reefs and adjacent systems.

ID: 140 / **Parallel Session 2-1: 8**
Coral Reef Structure and Functioning

Keywords: integrative taxonomy, population connectivity, scleractinian, species delimitation, ultraconserved element (UCE)

In focus again: a population connectivity study as a first step for the revision of the family Coscinaraeidae

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Accurately estimating population genetic connectivity, the extent to which geographically separated groups of individuals are exchanging genetic material, is particularly relevant for reef building corals, which are experiencing critical declines worldwide due to several factors. This, however, first requires knowing what we are working with, i.e. accurately delimiting evolutionary units to estimate gene flow among comparable entities. This may sound trivial but becomes challenging when it comes to understudied yet widespread species such as *Coscinaraea monile* (Forskål, 1775). Here, aiming to infer connectivity among its populations around the Arabian Peninsula using genomic data (SNPs harvested from UCE-enriched reads), we found several sympatric genetic lineages suggesting the presence of previously undetected species. To re-assess species limits, we sequenced additional Coscinaraeidae from across the Indo-Pacific, including representatives of three of the four genera, and four of the eight species currently considered valid in this family. Phylogenomic and species delimitation analyses were then used to resolve the phylogeny of Coscinaraeidae and define species hypotheses, which were then evaluated with additional lines of evidence from morphology and biogeography following an integrative approach. Our results confirmed the presence of several species under the name *C. monile* and supported the recent, although controversial, description of the genus *Australaraea* Rowlett, 2020. They also allowed for the identification of *C. monile sensu stricto*, from which we inferred the connectivity among its populations, revealing their isolation in each of the major water bodies surrounding the Arabian Peninsula. All together, these results support (1) the importance of properly delimiting species, particularly within understudied taxa and areas, before proceeding with further studies, (2) the need for a taxonomic revision of the family Coscinaraeidae, and (3) the presence of multiple barriers to gene flow around the Arabian Peninsula, providing valuable insights for the implementation of effective conservation measures in this region.

ID: 659 / **Parallel Session 2-4: 10**
Coral Reef Structure and Functioning

Keywords: Seabird nutrient subsidies, parrotfish, nutritional resources, microscopic phototrophs

What's on the menu? Effects of seabird-mediated nutrients on parrotfish nutritional resources and feeding behaviour

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From the arctic tundra to mangrove islands and coral reefs, seabirds mediate nutrient availability enhancing primary productivity and shaping entire food webs. Nutrients deposited as guano at seabird rookeries leach to adjacent waters supporting coral reef health and important ecological functions. Around islands with seabird colonies, the supply of allochthonous nutrients can result in a higher overall biomass of coral reef fishes and faster growth rates of parrotfish as compared to islands without seabirds. However, the pathways by which seabird nutrient subsidies alter parrotfish demographic rates and the wider implications for key geo-ecological functions (e.g., bioerosion) performed by parrotfish are not well understood. Parrotfish target benthic microscopic phototrophs which colonise carbonate substrates, predominantly protein-rich cyanobacteria. Since epilithic and endolithic phototrophs are sensitive to nutrient inputs, we hypothesise that seabird-mediated nutrients may increase the availability and quality of nutritional resources for parrotfish. Consequently, changes to these resources are predicted to affect the feeding behaviour of parrotfish and associated functions. Using an inter-island nutrient gradient at sites in the Seychelles and Chagos archipelagos, we focus on this unexplored link by combining in situ quantification of feeding rates and foraging distances with microscopy of feeding substrate cores and nutrient content investigation. Preliminary results from analysis of cores taken from substrates targeted by *Scarus rubroviolaceus* showed higher cell densities of cyanobacteria in the orders *Nostocales, Oscillatoriales* and *Leptolyngbyales* at seabird-rich sites in Seychelles. In lagoons of the Chagos Archipelago, inter-foray distance measurements indicated that the parrotfish *Chlorurus sordidus* travelled further between foraging bouts at seabird-free sites compared to seabird-rich sites. Also, foraging intensity, recorded as bite rates, increased at seabird-free sites. Although data processing and analysis are still in progress, these early results may suggest the bottom-up regulation of parrotfish nutritional resources by seabird-mediated nutrients.

ID: 465 / **Parallel Session 2-4: 1**
Coral Reef Structure and Functioning

Keywords: benthic-pelagic coupling, microbial degradation, carbohydrates, microbialization, microbial loop

Coral Exudates shape Composition and Function of Bacterioplankton Communities from an Algae-dominated Caribbean Reef

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Corals and macroalgae exude dissolved organic matter (DOM) which differs in composition and selects for different bacterioplankton communities. Algae exudates increase microbial biomass on reefs, but concomitantly reduce microbial growth efficiency. Thus, the transfer of energy to higher trophic levels is reduced as DOM increasingly fuels microbial respiration – the microbialization of reefs. These interactions were so far only investigated for coral-dominated reefs, where algae DOM exerts a stronger effect on microbial community composition compared to coral DOM. Here we thus compared the hydrolysable monosaccharide composition of DOM released by a mixed community of four hard corals to that of two macroalgae collected from an algae-dominated reef off Curaçao, Dutch Caribbean. Subsequently, we investigated the response of ambient bacterioplankton communities to low concentrations of added exudates (~2.8 µM C) and naturally occurring water column DOM (~2.2 µM C) as controls over four-day dark incubations. Our results revealed clear differences between coral and macroalgae exudates, reflecting the composition of coral mucus (mainly arabinose) and algae tissue extracts (mainly fucose). Coral exudates selected for microbes commonly associated with coral mucus (i.e., *Rhodobacteraceae*, *Vibrionaceae*, *Phycisphaeraceae*, Flavobacteriales) and significantly increased the predicted energy-, amino acid-, and carbohydrate metabolism by 28%, 44%, and 111%, respectively. In contrast, algae exudates did not reveal any effects, which is consistent with a higher similarity of exudate compositions to ambient reef water and dominance of algae on the local reef. The strong effects of a small addition of coral exudates on the microbial community confirm the efficient transformation of coral DOM into microbial biomass, thus strengthening the transfer of energy to higher trophic levels. Overall, our results indicate that whether coral or algae DOM exerts a stronger effect on bacterioplankton composition depends on local characteristics driven by benthic community composition.

Speed talks

ID: 832 / Parallel Session 2-1: 10
Coral Reef Structure and Functioning

Keywords: coral reef ecology, demography, community dynamics, large-area imagery

Quantifying individual colony fates to better understand population dynamics of *Porites astreoides*, that would otherwise be concealed by traditional coral cover assessments

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Caribbean reefs have been experiencing major environmental and anthropogenic driven changes in coral cover, abundance, and diversity. Consequently, coral cover and overall benthic cover has become an environmental proxy for reef conditions ("health") and biodiversity. However, there are fundamental dynamics of coral reef communities (i.e., individual colony growth, growth hotspots) that need to be considered to fully understand the performance of reef communities and assess species responding differently to such anthropogenic and environmental drivers. Most coral cover assessments focus on larger coral species (i.e., *Orbicella faveolata*, *O. annularis*), one timepoint snapshots, or random point-intercept analysis, resulting in stable coral cover, but fail to acknowledge the abundant yet smaller, harder to find species throughout the reefs. Species like *Porites astreoides* undergo a series of demographic processes that include increases in abundance, high recruitment, and fission and fusion processes, but are masked by the overarching coral cover concept or larger, more structural complex species, which in turn leads to this species once coined as "winners" to now considered "losers". Here we tracked and segmented 1,488 *Porites astreoides* colonies at 6 annual large-area timeseries spanning from 2014-2021, to quantify individual colony growth, recruitment, and survivorship (fate), to better explain the population dynamics of *P. astreoides* and how enduring those processes are the reason *P. astreoides* should still be considered "winners", especially in present-day Caribbean reefs experiencing longer period bleaching events and the recent Stony Coral Tissue Loss Disease (SCTLD) outbreak.

ID: 772 / Parallel Session 2-2: 6
Coral Reef Structure and Functioning

Keywords: Biomineralisation, reef-building, skeleton, aragonite

The role of coral acid rich protein 3 in coral biomineralisation

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Coral skeletons are composite materials of the mineral aragonite and biomolecules. Biomolecules control the polymorph, morphology and structure of $CaCO_3$. We researched the role of 2 peptides, isolated from a coral skeletal acid rich protein CARP 3, in aragonite formation. We studied CARP 3 domain A and CARP 3 domain V, representing a highly acidic domain and a variable domain containing a von Willebrand segment respectively. We precipitated aragonite from modified seawater using a constant composition technique to maintain pH, dissolved inorganic carbon chemistry and Ca^{2+} within narrow limits. We used peptide concentrations of 1 to 100 µM and $\Omega_{aragonite}$ = 8-18, a range which encompasses the saturation state of the coral extracellular calcification media at the present day and in the likely future. All experiments. produced aragonite. All concentrations of CARP 3 domain A inhibited aragonite precipitation but the lowest concentration of CARP 3 domain V, accelerated precipitation. All concentrations of both peptides caused marked changes in crystal morphology and high concentrations increased the local disorder around the CO_3^{2-} in the aragonite lattice. Different sections of the CARP 3 protein play different roles in modifying the aragonite formation process.

ID: 725 / **Parallel Session 2-4: 4**
Coral Reef Structure and Functioning

Keywords: Submarine groundwater discharge, functional traits, ecosystem functioning

Submarine groundwater discharge leads to direct and indirect effects on organismal and community metabolism on coral reefs

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Environmental variability caused by natural gradients can alter biodiversity and ecosystem functioning. Coral reefs experience a multitude of natural and anthropogenic environmental gradients affecting species composition and functional trait diversity which ultimately lead to changes in community metabolism (net community production, respiration, and calcification [NCP, Rd, and NCC]). In this study, we tested the impact of a common but under-investigated natural environmental gradient on coral reef metabolism, submarine groundwater discharge (SGD). SGD is the expulsion of terrestrial fresh or recirculated seawater into a marine environment that often exhibits increased nutrients and decreased temperatures, salinity, and pH. We first assessed compositional differences of species and functional traits in areas with high and low SGD exposure along a fringing coral reef in Mo'orea, French Polynesia. We then directly tested the effect of SGD on the growth of common species in each community type, as well as the interactive effect of SGD exposure and community composition differences on community metabolism. Three dominant species (*Porites rus*, *Valonia fastigiata*, and *Halimeda opuntia*) decreased their growth in high SGD relative to low SGD exposure. Differences in community identity between naturally high and low exposure areas resulted in changes to ecosystem functioning (NCP, NCC, and Rd), while environmental exposure to SGD only increased Rd of communities found naturally in areas of low exposure. SGD influence alters growth and community metabolism through changing biogeochemistry and species identity along the reef. SGD is present across multiple ecosystems globally and provides a unique opportunity to study community responses across a variety of ecosystems. Global communities are increasingly impacted by environmental variability and new disturbance pressures. This study examines multivariable environmental shifts occurring naturally within SGD gradients to understand how future variability may alter ecosystem stability.

ID: 731 / **Parallel Session 2-1: 12**
Coral Reef Structure and Functioning

Keywords: reef benthos, microalgae, abundance, life history, microbial ecology

QPCR-based quantification of endolithic symbiodiniaceans in reef sands from Lizard Island, Australia

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Dinoflagellates from the family Symbiodiniaceae form close symbiotic relationships with a multitude of corals and other hosts, yet for many taxa symbiosis is facultative, while others preserved non-symbiotic life histories. The latter two types are commonly found as free-living cells in the environment, especially abundant in benthic habitats. Despite the importance of these environmental populations as potential symbionts for hosts, their life histories remain poorly understood. The discovery that symbiodineaceans in culture can induce microbial calcification and encapsulate themselves as viable endolithic cells, and subsequent field-based studies that suggest that this process of forming endolithic populations also occurs naturally in reef sands, led to the question of how abundant these endolithic populations are in reef sands. To address this, we employed qPCR with genus-specific primers to quantify the abundance of endolithic populations of the Symbiodiniaceae genera *Symbiodinium*, *Cladocopium*, *Effrenium* and *Fugacium* in reef sands from Lizard Island (Great Barrier Reef, Australia). Sampling was conducted in the Austral Summer and Winter along four transects surrounding Lizard Island, each comprised of three stations. Surface sands (top 1 cm) between 500–1000 mm were serially digested into an outer, epi-/endolithic and an inner, truly endolithic fraction. In addition, at two stations we profiled reef sands down to a depth of 3–6 cm. All samples, down to a water depth of 30 m, contained endolithic populations of the four genera, although abundances were consistently higher in the outer fraction. Furthermore, abundances of the different genera in both the outer and inner fraction varied markedly between stations, changed dynamically between seasons, and decreased with depth in the sediment. Our results show that reef sands around Lizard Island contain prominent, diverse, and dynamic communities of endolithic symbiodiniaceans, shedding light on an underexplored reef habitat that may be of central importance for free-living symbiodiniaceans.

ID: 765 / **Parallel Session 2-4: 3**
Coral Reef Structure and Functioning

Keywords: nocturnal ecology, hypoxia, metabolism, predator-prey interactions

In the heat of the night: may hypoxia shape the physiology and ecology of coral reefs?

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On coral reefs, oxygen supersaturation during the day and particularly hypoxic conditions during the night may be critical in explaining life history strategies for reef inhabitants. These extreme oxygen conditions have been mostly overlooked when investigating the evolutionary ecology in corals reefs. Our main hypothesis is that late-night hypoxia on tropical coral reefs is a daily bottleneck that structures physiology, life history, behaviour, and biodiversity in corals and reef-dwelling fishes. Within the lagoon in Moorea, French Polynesia, we have explored this hypothesis by measuring the daily oxygen fluctuations, filming the behaviour of damselfish at night, and measuring how oxygen affects the fishes' metabolic rates under laboratory conditions. How and when does hypoxia happen on coral reefs? What are the ensuing trade-offs and how does hypoxia affect predator-prey interactions? Here we present our field and laboratory results and discuss the insights we have gained so far.

ID: 710 / **Parallel Session 2-4: 13**
Coral Reef Structure and Functioning

Keywords: Marine chemical ecology, chemosensation, sea slug, oxyoctaline formate, chemical defense

Scent of a coral reef nudibranch: exploring the natural function of a "synthetic" perfume

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Synthetic studies play a crucial role in perfumery, enabling the artificial replication of natural scents, or the discovery of "unnatural" odors appealing to humans. Among these latter cases, amber formate (oxyoctaline formate, CAS: 65405-72-3), a synthetic compound known for its distinctive and ambery character, finds extensive application in the perfume industry. This study details the isolation of amber formate and its hydroxylated derivative from the Indo-Pacific nudibranch mollusk *Jorunna rubescens* (Bergh, 1876) found in the coral reefs of the South China Sea. Intriguingly, the laboratory synthesis of amber formate preceded our identification of the compound in nature, particularly distributed in the mantle of *J. rubescens*. This region of the nudibranch body is particularly susceptible to predatory attacks and biofoulers, suggesting potential involvement in defensive strategies. Such a hypothesis gains support from our chemoecological evaluations demonstrating that amber formate prevents biofouling and acts as a feeding deterrent when proposed to a generalist crustacean. However, due to its almost insolubility in water, the compound is detected through contact in the marine environment. On land, instead, its high volatility allows for detection at a long distance by the human olfactory system. Like other previous studies [1], this research challenges the conventional distinction between smell and taste, particularly concerning the spatial range of these senses in different environments. It supports a recently proposed "unifying chemosensory theory" advocating for a more integrated understanding of the chemical senses [2]. In parallel, while elucidating the ecological role of a secondary metabolite from a coral reef nudibranch, the present study contributes a novel example to the growing list of "synthetically anticipated" natural products [3].

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ID: 636 / Parallel Session 2-2: 4
Coral Reef Structure and Functioning

Keywords: reef growth, coralline algae, calcification, climate change

Crustose coralline algae contribution to coral reef carbonate production

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The future growth of coral reefs under climate change is uncertain. Understanding the drivers of net coral reef calcium carbonate production is therefore increasingly important as ocean warming, marine heatwaves, ocean acidification, and other drivers threaten the maintenance of coral reef structures and the services these ecosystems provide. Although there is intense research on coral reef calcium carbonate production, including crustose coralline algae in reef growth budgets remains challenging, both theoretically and practically, despite their crucial role in building reefs in photic zones. While corals are typically the primary reef builders of contemporary reefs, the role of crustose coralline algae as reef builder and for reef stabilization is often overlooked. Here, we present results from several sets of data with numerical and theoretical modelling to demonstrate that crustose coralline algae carbonate production can match or even exceed the contribution of corals to reef carbonate production, particularly following major disturbances. Despite their importance, crustose coralline algae are often inaccurately recorded in benthic surveys or even entirely missing from coral reef carbonate budgets. Moreover, we will present evidence of the higher resistance of coralline algae to warming, which highlights the potentially increasing importance of coralline algae for future reefs. We will also present several recommendations to improve the inclusion of crustose coralline algae into carbonate budgets amid the ongoing climate crisis.

ID: 562 / Parallel Session 2-4: 7
Coral Reef Structure and Functioning

Keywords: Size spectrum, trophic pyramid, trophic position, fishes, stable isotopes

Trophic position remains a more accurate and powerful measure than body size to assess trophic pyramids in coral reef ecosystems

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Unravelling the dynamics of food webs is a major goal for ecology. In this context, the analysis of the distribution of biomass across body-size classes (i.e. the size spectrum) allows for the description of the shape of the trophic pyramid and for the indirect inference of energy fluxes in size-structured ecosystems. On coral reefs, an apparent inversion of the regular bottom-heavy trophic pyramid has been documented and extensively debated. Potential explanations for this phenomenon range from methodological biases in quantifying large mobile fish density, to spatial subsidies feeding higher trophic levels. Here, we show evidence that inverted size-spectra are due to a substantial lack of relationship between fish body size and trophic position. Using an extensive stable isotope dataset on fish trophic position, body mass and biomass for 262 species across 75 sites spanning five Indo-Pacific archipelagos, we explored the distribution of biomass across body-size trophic-position classes. Consistent with previous studies, our analyses revealed a positive correlation between biomass and body mass classes (i.e. which has been interpreted as evidence for inverted pyramids). However, when we used ΔN^{15} from stable isotopes as a proxy of species trophic position instead of body mass, the observed trophic pyramid exhibited a bottom-heavy shape, with higher biomass in primary consumers compared to higher trophic positions. This study challenges previous findings and suggests that coral reef fish community data cannot be described by simple size spectrum models.

ID: 764 / **Parallel Session 2-4: 8**
Coral Reef Structure and Functioning

Keywords: coral reef, fish, trophic biomass pyramid

Tipping over the inverted biomass pyramid: A reanalysis of Pacific coral reef fish communities

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The trophic structure of pristine coral reef fish communities has previously been characterized as an inverted biomass pyramid. These findings were due primarily to the high presence of large predatory fishes such as sharks and jacks observed during stationary diver surveys. Using a reanalysis of diver survey data from the coral reefs of 41 US Pacific islands and atolls, the trophic structure of fish communities very rarely exhibited an inverted biomass pyramid, even for pristine or near pristine locations. The prior characterization of these communities as inverted trophic biomass pyramids most likely resulted from an overestimation of the biomass of upper trophic level fishes that neglected to recognize the bias that occurred due to an attraction to divers from these highly mobile animals. This presentation reviews prior work on the topic of inverted biomass pyramids and shares results of the reanalysis for each island. This work gives an updated understanding of the trophic structure for pristine coral reef fish communities which is important as they provide examples of relatively undisturbed ecological structure that serve as comparative locations for disturbed reefs.

ID: 471 / **Parallel Session 2-1: 5**
Coral Reef Structure and Functioning

Keywords: coral morphology, morphological traits, niche construction

Positive and negative effects of coral structure on survival and growth of coral fragments

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Niche construction theory posits that organisms can systematically modify their environment in ways that persist in time and alter the selection pressures experienced by descendant populations. As autogenic ecosystem engineers, stony corals physically modify their environment via the complex calcium carbonate structures they build, which remain even after the coral itself dies. Using a modified common garden experiment based in Kaneohe Bay, Hawai'i, we tested the impact of coral-built structure on the survival of coral fragments to look for evidence of niche construction in corals. Coral fragments were grown near living, dead, or no adult coral colony over 14 months. Overall, coral-built structure increased fragment survival. Interestingly, fragments near their donor colony showed significantly increased mortality. Additionally, by extracting morphological metrics from laser scans of the central colonies and surrounding fragments, we explore which morphological traits of the central structures are mediating fragment survivorship and differences in fragment growth and shape change. These results provide evidence suggesting that corals, through their structure, can influence the survival and fitness of juvenile corals.

ID: 217 / **Parallel Session 2-3: 8**
Coral Reef Structure and Functioning

Keywords: octocorals, traits, database

Octocorals on board! Expanding the Coral Trait Database with global trait information on octocoral species to promote the advancement of coral reef science

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Traits—the quantifiable features of organisms—can link the performance of individuals to the functions of, and services provided by, ecosystems. Thus, trait-based approaches are improving the way we understand the ecology, structure and functioning of high-diversity systems such as coral reefs. In 2016, the Coral Trait Database was launched centralizing physiological, morphological, ecological, reproductive, biomechanical or phylogenetic trait information on stony corals (anthozoan sub-class Hexacorallia) into an open-access repository. This repository became the basis for research that has advanced coral reef science worldwide. However, these advances are limited because another group of anthozoans are common. Octocorals host more than 3500 species of mainly non-stony corals (e.g., soft corals, sea pens and sea fans) that play critical roles in coral-dominated ecosystems. Thus, octocorals are a crucial piece of the puzzle if we are to understand how these systems function, how are they being transformed by global change and how can we improve their management. Here, we present the Octocoral Trait Database, a global, open-source database of curated trait data for octocorals. This database has been integrated with hexacorals in the Coral Trait Database (www.coraltraits.org), and host species- and individual-level data alongside contextual data that provide relevant framing for analyses. The first data release contains over 93,000 trait observations, including more than 140,000 trait measurements across 99 traits and more than 3,500 valid octocoral species found across tropical, temperate, and polar regions, spanning from shallow waters to the deep sea. Moreover, the database has been developed as a community-led resource expected to grow. By expanding the Coral Trait Database with global trait information on octocoral species, our initiative will facilitate the quantification of trait variation in coral-dominated communities and promote the advancement of coral reef science.

ID: 214 / **Parallel Session 2-3: 14**
Coral Reef Structure and Functioning

Keywords: Mesophotic, Photophysiology, Stable Isotopes, Morphology, coral symbiosis

Natural variation in colony orientation facilitates adaptive physiology of the coral *Madracis pharensis* in the Eastern Mediterranean

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The distribution of symbiotic scleractinian corals is driven, in part, by light availability, as host energy demands are partially met through translocation of photosynthate. Physiological plasticity in response to environmental conditions, such as light, enables expansion of distribution and resilience to changing conditions. Here we compared the physiology, morphology, and molecular fingerprint of individual *Madracis pharensis* corals exposed to dramatically different light conditions based on colony orientation on the surface of a shipwreck at 30m depth in the Bay of Haifa, Israel. We found significant differences in symbiont species consortia, photophysiology, and stable isotopes, suggesting that these corals can adjust their metabolic physiology in response to light availability. These results highlight the potential of corals to switch to a predominantly heterotrophic diet when light availability and/or symbiont densities are too low to sustain sufficient photosynthesis, which may provide resilience for corals in the face of climate change.

ID: 760 / **Parallel Session 2-2: 13**
Coral Reef Structure and Functioning

Keywords: structural complexity, coral bleaching, small-scale fisheries, reef fish, micronutrients

Coral reef habitat complexity promotes fisheries nutrient productivity

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Tropical coral reef ecosystems produce highly nutritious catches for fisheries, which provide vital food security to people in coastal communities. The condition of coral reef habitat has a strong influence on reef fish assemblages, affecting species and nutrient compositions of fisheries catches. Currently, little is known about how differences in reef structure influence fisheries nutrient yields, providing an opportunity to investigate the production rates of nutrients in reef fish in relation to reef habitat complexity. We compared the biomass and nutrient productivity potential of reef fish assemblages at four locations across the Indo-Pacific with varying levels of fishing pressure. Reef structural complexity positively impacted nutrient productivity across locations and trophic groups of fish, except for macroalgal browsers. Biomass and nutrient productivity were highest in the unfished Chagos Archipelago, where structural complexity had a particularly strong effect on productivity, especially for piscivores. In fished locations, productivity was driven mainly by herbivore/detritivores, followed by invertebrate-feeders, although the effect of structural complexity varied between trophic groups of fish and locations. For example, in Maldives and Seychelles productivity increased with structural complexity while on the Great Barrier Reef productivity slightly decreased. The influence of structural complexity on nutrient productivity was dependent on the scale of our data, for example positive effects were more apparent at the transect-level compared to site-level means, highlighting the importance of high-resolution reef observations. The mean length of fish within each trophic assemblage was a positive predictor of productivity, however this was independent of structural complexity. Our study highlights the importance of coral reef structure for fisheries nutrient productivity and the negative implications that reef degradation could have for nutrient provisioning services from reef fisheries.

ID: 417 / **Parallel Session 2-2: 12**
Coral Reef Structure and Functioning

Keywords: Paarotfish paradigm, Managed resilience, Reef health, Disturbance

The role of fish community structure for predicting benthic composition on a remote, sheltered, and isolated, Caribbean coral reef

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Reef fish are a salient group for driving coral reef ecosystem function, often used as a management tool to mitigate coral reef decline despite a dearth of long-term evidence that reef fish predict benthic composition. Using our long-term dataset from 1999 – 2023, we examine the role of fish community structure for predicting coral reef benthic conditions on an undisturbed Caribbean coral reef. We found different aspects of the fish community structure elicited different predictions for benthic conditions. Many of our findings align with previous theories for how reef fish have both positive and negative effects for predicting different benthic components providing further evidence of the influential role of reef fish for coral reef health. However, we warn the oncoming storm of global climate change will likely alter these dynamics permanently even on this remote and isolated reef, as seen in the wider Caribbean region.

ID: 132 / Parallel Session 2-2: 5
Coral Reef Structure and Functioning

Keywords: Reef flat growth, Bioconstruction, Bio-erosion, Reef accretion, Reef erosion

Physical measurements of coral reef flat growth in the critical wave dissipation zone

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Sea-level rise is expected to outpace the capacity of coral reefs to grow and maintain their wave protection function, exacerbating coastal flooding and erosion of adjacent shorelines and threatening coastal communities. This study reports on a new method that yields highly-resolved (mm scale) direct measurements of contemporary reef accretion on a Maldivian atoll reef rim, the critical zone that induces wave breaking. Results from six years of annual measurements will be presented that show variable rates of reef flat growth, that reflect spatial transitions in ecology across the reef flat surface. The high-resolution (mm-scale) measurements provide insights into a range of reef flat accretion processes attributed to primary production, physical and biological destruction, and the import of detrital material to contribute to reef framework. Insights from this measurement approach are critical to interpret past rates of reef development, quantify contemporary rates of reef flat change and to inform future reef growth trajectories.

ID: 352 / Parallel Session 2-4: 11
Coral Reef Structure and Functioning

Keywords: horizontal surface currents, cnidarian diversity, video microscopy, computer-assisted particle tracking

Investigating the dynamics of surface-associated currents on Cnidarian polyps and colonies

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Recently, we discovered complex horizontal surface currents above the polyps of stony coral colonies (class: Anthozoa, order: Scleractinia), which seem to play a crucial role in nutrition and epithelial cleaning. After this initial discovery, however, the question arose whether other groups of cnidarians produce similar currents. During the course of a comprehensive research approach, we explored the intricate dynamics of horizontal surface currents within the phylum Cnidaria.

Employing advanced methodologies like video microscopy and computer-assisted particle tracking, we charted horizontal water flow trajectories using fluorescent microbeads. We analysed 30 cnidarian species, spanning across four classes and 11 orders. Thirteen out of 30 examined cnidarian species (7 orders), including notable representatives of the class Scyphozoa, like *Cassiopea andromeda*, exhibit these currents at speeds approaching 1 mm per second. In contrast, neither analysed octocorallia (subclass) nor hydrozoa (class) species manifest these currents. The integration of the Uniform Manifold Approximation and Projection machine learning algorithm allowed the analysis of 6014 tracks of the 13 species, utilizing eight distinct key parameters for comprehensive assessment. Our findings could play a crucial role in elucidating the significance of horizontal surface currents functioning as "conveyor belts" for nutrition transport and aiding in the cleaning of cnidarian surfaces.

The analysis unveils species-specific trajectories, illustrating a distinctive arrangement of currents in each species. The observed diversity of surface current patterns amongst the examined anthozoan orders (i.e., Zoantharia, Actiniaria, Antipatharia, Corallimorpharia, Scleractinia, Ceriantharia, Malacalcyonacea) suggests differentiated evolutionary strategies. This difference might also imply that, despite hard and soft corals often coexisting in the same habitat, both groups of species could have adapted to similar conditions but with distinct approaches. This research enhances our understanding of the ecological significance of horizontal surface currents in cnidarians, emphasizing the need for heightened attention to ensure the protection, preservation, and comprehensive understanding of Cnidaria.

ID: 347 / **Parallel Session 2-2: 14**
Coral Reef Structure and Functioning

Keywords: animal forest, gorgonian, ADCP

Caribbean octocoral communities: are they all forests?

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Over the last decade, octocorals have increased in abundance on many Caribbean coral reefs, and at some sites "octocoral forest" may be a better community descriptor than "coral reef". Implicit to the concept of a forest is that structural elements, trees, colonies, etc., alter the environment in ways that affect the structural elements themselves and the organisms that inhabit the forest. At what density do the community's structural elements create the emergent properties of a "forest?" Communities traditionally characterized as hardgrounds and coral reefs around Puerto Rico and St John, US Virgin Islands, vary in density of octocoral colonies from a few to >100 colonies/m^2. The canopy created by these colonies, defined as the summed horizontal area occupied by each colony, viewed from above, increased with colony density. In rare cases, the canopy covered > 100% of the benthic area, but average canopy cover was 21%. Canopy cover increased with colony density and appears to asymptote at ~ 60% cover. Most of the canopy was found 30 – 60 cm above the substratum, regardless of site.

Vertical profiles of flow velocities were measured up to 2.5 meters above the bed at a reef on St John with octocoral population density ranging from 0 to 20 colonies/m^2. Flow measurements identified notable wave boundary layer modification at an octocoral population density of about 12 colonies/m^2 and an estimated canopy cover of 17%, which lies in the low range of canopy cover observed at our Caribbean sites. Using this criterion, 40% of the sites on St John and both sites in Puerto Rico function as animal forests. Understanding the density at which emergent properties appear is critical to understanding the bio-physical interactions affecting the community and assessing the effects of changing abundances, as occur with storms, disease outbreaks and bleaching events.

ID: 493 / **Parallel Session 2-2: 11**
Coral Reef Structure and Functioning

Keywords: Bioerosion, grazing, urchin abundance, climate change, South China Sea

Coral bioerosion rates for different size classes of two urchin species under heat treatment in Taiwan

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Disturbed coral reefs often become erosional, but no experimental data were available about urchin grazing under elevated temperatures. To assess urchin bioerosion rates in southern Taiwan, *Echinometra mathaei* and *Stomopneustes variolaris* were counted in the intertidal at Liuqiu Island and studied for 18 days in aquaria under ambient (25°C) and elevated temperature (29°C) with "live rock" as substrate. In ambient temperature, mean bioerosion of the smaller urchin *E. mathaei* was higher (88.6±123.1 mg ind.$^{-1}$ d^{-1}) than for the larger *S. variolaris* (61.1±46.0 mg ind.$^{-1}$ d^{-1}). For *E. mathaei*, bioerosion increased with test size, regardless of temperature. In contrast, bioerosion was more intensive for smaller *S. variolaris* in 29°C, but urchin size made no difference in 25°C. Both urchins eroded more in 29°C than under ambient conditions: *E. mathaei* bioerosion increased to 180% (160.1±193.5 mg ind.$^{-1}$ d^{-1}), *S. variolaris* bioerosion nearly doubled (196%, 119.5±60.1 mg ind.$^{-1}$ d^{-1}). This was unexpected, as we thought heat would stress the urchins, leading to lower feeding activity. Instead, they were more active in higher temperature. Our field surveys found urchin densities for *E. mathaei* and *S. variolaris* to be 33.2±8.6-39.7±7.4 ind. m^{-2} and 2.3±7.4-3.2±3.1 ind. m^{-2}. This allowed us to estimate the bioerosion at Liuqiu Island for both temperatures, with 11.7 versus 25.4 t yr^{-1} for *E. mathaei*, and 0.6 versus 1.5 t yr^{-1} for *S. variolaris*. During short heat events, urchin bioerosion on coral reefs will thus increase, and possibly also with global warming. Our data addressed a research need in a little-studied location and will contribute to management and conservation. Future research should assess even higher temperatures and longer periods to better simulate global change.

ID: 285 / **Parallel Session 2-3: 9**
Coral Reef Structure and Functioning

Keywords: Octocorallia, evolution, phylogenomics, ultraconserved elements, depth gradient

Diversity and distribution of the octocoral family Ellisellidae in the Saudi Arabian Red Sea

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Marine biodiversity hotspots are widely recognized as areas hosting high species richness and contributing to distinctive evolutionary processes. Among these, in the Indo-Pacific, the Red Sea is a unique basin where peculiar environmental and geological settings shape patterns of evolution and endemism of marine taxa. However, the diversity of the anthozoan subclass Octocorallia in the region has sparsely been investigated to date, limiting our understanding of their occurrence and distribution. The family Ellisellidae is a monophyletic group of octocorals currently comprising 10 genera and around 110 nominal species. They are globally distributed from shallow to deep waters (10-900 m), with taxa forming dense aggregations and sustaining a variety of other organisms. Previous genetic studies using mitochondrial markers revealed polyphyly of six of the 10 ellisellid genera, highlighting ambiguities in the morphological characters used to identify specimens and a need for new integrated approaches to distinguish species and thoroughly understand their diversity, occurrence and distribution. Here, we used target-enrichment of ultraconserved elements (UCEs) and exons to explore phylogenomic relationships among more than 100 ellisellid specimens collected between 11 and 500 m depth, all along the latitudinal gradient of the Saudi Arabian Red Sea. Specimens were identified based on traditional taxonomic descriptions. We resolved 12 highly supported molecular clades and revealed the occurrence of a diversified Ellisellidae fauna throughout the Red Sea, with patterns of lineage-specific zonation along the depth gradient. This study represents the first attempt to characterise the Ellisellidae through a phylogenomic approach and supports the effectiveness of UCEs in disentangling evolutionary relationships within the family, providing fundamental data to unveil its diversity. Finally, our results highlight the need for genomic examinations of octocorals beyond the Red Sea, to fully unravel patterns of species occurrence and endemism in biodiversity hotspots and ultimately better preserve these ecologically important organisms.

ID: 644 / **Parallel Session 2-4: 2**
Coral Reef Structure and Functioning

Keywords: cryptobenthic communities, detritus, Caribbean, Hawai'i

More than meets the eye – Biomass, growth dynamics, and ecological functions of cryptic reef habitats

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Overhangs, cavities, and crevices constitute up to two thirds of a reef’s volume and half of its surface but are commonly neglected in coral reef ecology. Encrusting sponges residing within these cryptic habitats are increasingly recognized to play a key role in the energy and nutrient cycling of Caribbean reefs by transforming dissolved organic matter into palatable detritus particles. Nevertheless, the dynamics and functioning within cryptobenthic communities is largely unknown. We therefore (1) compared the biomass of open and cryptic reef habitats, (2) assessed cryptobenthic community compositions and growth dynamics, and (3) quantified detritus release as well as its effect on respiration rates of reef sands. Cryptobenthic biomass contributed 47±0% to the total reef biomass on Curaçaoan reefs, with encrusting sponges being the single most important group (35±18%). Cryptobenthic community assessments of cavities and a reef wall under an overhang revealed that calcifying algae (29±1% and 43±4%, respectively) and encrusting sponges (42±1% and 26±3%, respectively) jointly dominate these habitats in terms of surface cover (~70%). This composition remained unchanged over a period of 28 weeks ($p = 0.891$), suggesting a relatively stable community. However, tracking the growth dynamics of the sponge *Scopalina ruetzleri* within these communities on the individual level revealed a highly dynamic population with 38% and 41% of individuals increasing and decreasing in size during this period, respectively. Funnels placed inside cryptic habitats collected 24-times more detritus than those placed outside ($p = 0.005$), coinciding with a two-times higher dark respiration of cryptic compared with open reef sands ($p = 0.01$). Comparable community compositions (29±7% encrusting sponges) and detritus release rates (0.23±0.19 mg cm^{-2} sponge d^{-1}) from Hawai’i suggest that here presented insights may not be restricted to Caribbean reefs but indicate of a general and important role of cryptobenthic communities in resource cycling on coral reefs.

ID: 690 / **Parallel Session 2-3: 5**
Coral Reef Structure and Functioning

Keywords: Coral Triangle, Historical geographic isolation, genome-wide SNP data

Historical geographic isolation drives genetic structure in two Pocillopora spp. in the Coral Triangle

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Coral Triangle (CT) exhibits the highest diversity of reef-building corals in the world, although this region is less studied compared with other Pacific regions. Examining population structure and gene flow in the CT is critical for unraveling the evolutionary and ecological dynamics of these corals as well as for conservation in this region. In this study, we aimed to assess gene flow in the Indonesia which is situated in the center of CT for two Pocillopora species (*P. damicornis* and *P. verucosa*) using genome-wide SNPs from 166 samples across 10 sites across Indonesia. STRUCTURE analysis using 564 SNPs revealed 21 samples were assigned to the genetic cluster which is differed from their morphological identification. After splitting the two genetically different lineage dataset, *P. damicornis*-morph dominant lineage showed relatively large genetic structure between populations (global Fst: 0.088, P<0.001), while *P. verucosa*-morph dominant lineage showed smaller (global Fst: 0.035, P<0.05). Both STRUCTURE analysis and phylogenetic tree analysis, indicated gene flow of both species is broadly restricted between the western (Indian Ocean side) and eastern (West Pacific Ocean side) side with the Sunda Archipelago as a boundary. Interestingly, we found genetically different populations in the two easternmost sites in *P. damicornis*-morph dominant lineage. These patterns of genetic structure might be caused by historical geographic isolation associated with the sea level change during the glacial period as have been observed in many marine species. Our findings contributed valuable insights into the evolutionary processes underlying coral diversification within the CT.

ID: 189 / **Parallel Session 2-3: 3**
Coral Reef Structure and Functioning

Keywords: population genetics, connectivity, genomics, diversity, demographics

Population Genomics of the Brain Coral *Leptoria phrygia* in the Mariana Archipelago

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Genetic diversity is vital for coral reef ecosystems and populations to persist and adapt to changing environmental conditions. Population genetics describes biogeographic variation of genetic diversity along spatial and ecological axes. This most fundamental information remains underexplored in many common reef taxa, especially in the remote oceanic islands of the Indo-Pacific.

One such organism is the brain coral *Leptoria phrygia*. Despite its prolific abundance and occasional dominance on tropical reefs, *L. phrygia*'s population genetics have yet to be explored anywhere across its widespread range. Here, we conduct population genetic analyses on nine populations on seven islands of the Mariana Archipelago (Micronesia, West Pacific). Sample collection spans the length of the 800 km long island chain and *L. phrygia*'s depth range (0 - ~30m). We comparatively analyse a genomic reduced representation dataset to describe the intraspecific diversity in this coral as well as quantify unknown levels of population structure. Furthermore, evaluating population genetics over a depth gradient will reveal patterns of selection and dispersal that fundamentally shape *L phrygia*'s distribution. Differences in the relative abundance of photosynthetic symbiont species may correspondingly fluctuate according to depth as well. Results also clarify the importance of sexual vs asexual reproduction in this species Additionally, this study highlights the degree to which broadcast spawning corals populations are connected to one another across this remote, understudied archipelago.

Assessing the amount of genetic diversity in a common coral will add important knowledge to the context of West Pacific reefs. This study will aid in fostering better-informed stewardship of a genetically complex and rapidly changing ecosystem in this region.

ID: 652 / **Parallel Session 2-1: 7**
Coral Reef Structure and Functioning

Keywords: marine animal forest, flow intensity, sex, mortality, necrosis

Effect of flow intensity on the overall status of a black coral species (*Antipathella wollastoni*) under controlled conditions

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Black coral forests play a vital role in mesophotic and deep-water environments providing habitat, food and refuge for numerous organisms. The presence and distribution of these keystone habitats are conditioned by flow intensity, a key abiotic factor for these suspension feeders. However, little is known about its importance or how the effect of current intensity can affect the survival and overall condition of black corals. In this study, we investigated how the flow intensity affects 54 sex-selected nubbins of the black coral *Antipathella wollastoni* (Gray, 1857) throughout a 5-week experiment under controlled conditions. We evaluated three different treatments: no current (0 cm/s), low current (5 cm/s), and high current (12 cm/s) conditions, evaluating both the colony state (e.g. mortality, necrosis and propagules production) and their physiology (i.e., total antioxidant capacity) maintaining an equal sex ratio (1:1) in all treatments. We found a higher mortality rate and necrosis percentage in the "no current" treatment, and these parameters were significantly different between sexes across all treatments. Thus, all male colonies survived the course of the experiment, while females showed a high mortality rate and necrosis. In addition, the quantity of propagules varied across all treatments, with higher values found in the strong current conditions. Overall, the results obtained represent a valuable ecological knowledge for understanding the species distribution (e.g. current condition and sex ratio) in their natural environment, but also for the implementation of reproduction programs under controlled conditions for future restoration initiatives in the current context of habitat fragmentation, biodiversity loss and global change.

ID: 605 / **Parallel Session 2-3: 4**
Coral Reef Structure and Functioning

Keywords: population genomics, Whole-genome resequencing (lc-WGS), Coral, *Porites rus*, Micronesia

Coral population genetics across the Marianas Islands

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Understanding population genetic patterns is important for understanding the basic biology of a species but also for informed conservation practices. Population genetic patterns vary dramatically between species and environments, and are unknown for most coral species, even for some of the most widespread and locally abundant coral species, like *Porites rus*.

In this study, we used low-coverage whole genome resequencing to generate a genome-wide SNP dataset for *Porites rus* across the Mariana Archipelago. We found significant differences in the number and proportion of clones among and within islands that are inversely related to population density. Levels of heterozygosity were small overall and similar across islands and populations with a small but consistent heterozygote deficit, i.e. inbreeding in all populations. Consistent with these results, we observed a small but significant population structure, following a significant Isolation-by-distance pattern around Guam and across the archipelago, indicating limited effective dispersal, over ~50-100km between islands but also over 10-50km among populations within islands.

This study represents the first comprehensive population genetic study of *Porites rus*, and the first archipelago-scale genetic research across the Mariana islands. Our results highlight the limitations of pelagic larval dispersal to connect oceanic islands, even in broadcast-spawning species with significant larval duration times, i.e dispersal potentials, which has important management implications.

ID: 800 / **Parallel Session 2-3: 13**
Coral Reef Structure and Functioning

Keywords: coral, reproduction, larval performance

Pocillopora spp daytime broadcast spawning in Mo'orea, French Polynesia

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Pocillopora are abundant branching corals that create 3-dimensional reef structure. In French Polynesia, when corals were decimated by crown-of-thorns, bleaching, and a cyclone between 2007-2010, *Pocillopora* recruitment primarily drove recovery by 2016, yet spawning times are undocumented. To address this gap in documentation of *Pocillopora* spawning in Mo'orea, we surveyed *Pocillopora spp.* from September 2022-January 2023 and October 2023-March 2024 and used molecular analysis of mtORF and PocHistone markers for species identification. We documented the spawning of *P. meandrina* around the full moons in November (November 10th 06:32, full moon+3days) and reef-wide spawning December 2022 (December 9th 2022, 06:16-06:32; full moon+2days and December 10th 2022 (06:21-06:35; full moon+3days) and in October of 2023 (06:22-06:38; full moon+3days). Further, around the new moons of November and December of 2023 we documented the spawning of *P. verrucosa* (new moon ~5:45 - 6:15) and *P. tuahiniensis* (+1, +2, +3 days after new moon ~6:30 - 6:50), as well as *P. cf. effusa* (+3 days after new moon ~6:30 - 6:50). Comparison of larval physiological performance identified higher P:R in *P. tuahiniensis* associated with strong red fluorescene of the holobiont, compared to lower P:R and strong green fluorescence in *P. verrucosa*. These observations provide initial documentation of *Pocillopora* spawning in Mo'orea (to our knowledge), expanding on indigenous knowledge and increasing capacity to study Pocillopora reproduction, connectivity, and adaptation. Further, they indicate cryptic species can differ in performance across not only adult life stages, but also at the larval stage, with implications for ecological outcomes under climate change.

ID: 631 / **Parallel Session 2-3: 10**
Coral Reef Structure and Functioning

Keywords: microbiome, coral reef sediments, Biogeography, environmental drivers, Pacific

Coral reef sediments as reservoirs of microbial diversity across the Pacific

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Microbial communities in coral reef sediments play a crucial role in remineralizing organic matter and cycling nutrients, yet they remain an understudied reservoir of microbial diversity in reef ecosystems. In this study, we characterize the bacterial and archaeal (16S), eukaryotic (18S), and Symbiodiniaceae (ITS2) rDNA of the sediment-associated microbiome from 219 samples spanning the coral reefs of the Pacific Ocean at an unprecedented geographic scale. Through network analysis and co-occurrence modeling, we revealed intricate connections among microorganisms within and between taxonomic groups. Comparing microbial community patterns in sediments and stony corals from the same locations, we identified widespread and overlapping taxa, which implicate reef sediments as crucial reservoirs of microbial diversity. Moreover, we observed greater variability in microbial communities within reef sediments compared to corals, and identified environmental gradients shaping reef sediment microbial community diversity and composition. In conclusion, our research underscores the pivotal role of reef sediments as reservoirs of microbial diversity, highlighting the intricate connections among microorganisms between reef habitats. These findings offer insights into the resilience and functioning of coral reef ecosystems in the face of environmental change.

ID: 848 / Parallel Session 2-2: 15
Coral Reef Structure and Functioning

Keywords: Coral traits, functional traits, photogrammetry, spatial

Bridging the gaps: Spatial insights into coral trait space and ecosystem functionality in Culebra, Puerto Rico

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The functional trait space of corals, which encapsulates a suite of physiological, morphological, and ecological characteristics contributing to their ecological roles, is a focal point in reef management. Coral reefs face escalating threats, emphasizing the need for an in-depth understanding of factors influencing their resilience. Adopting a multi-scale approach, this study examines intricate interactions between coral traits, ecosystem function, and resilience. We leverage underwater photogrammetry techniques to track coral communities in Culebra, Puerto Rico from a plot to regional comparative framework. We apply hypervolumes to investigate complex trait interactions within coral communities, offering insights into the adaptive capacities of species in response to environmental gradients and anthropogenic pressures. Using rugosity as a proxy for the structural complexity of reef formations, and fish community metrics, indicative of biodiversity and ecological interactions, we determine how trait space impacts coral reef communities and productivity. Through comparative spatial analysis, we reveal patterns and variations in coral trait space across diverse spatial scales, ranging from the reef plot (10 m^2) to the regional level (SW Culebra, Puerto Rico). This research contributes to the advancement of scientific knowledge pertaining to coral reef dynamics, underscoring the necessity of integrating spatial scales for a comprehensive understanding of functional trait space.

ID: 439 / Parallel Session 2-2: 10
Coral Reef Structure and Functioning

Keywords: Bioerosion, biodiversity, euendoliths, faunistics, function

Bioerosion studies in the South China Sea: addressing a regional research gap by advancing local knowledge on microborers

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Southeast Asian coral reefs are biodiversity hotspots, as well as culturally and economically important areas for stakeholder nations. Nevertheless, they have experienced damaging anthropogenic impacts that commonly disturb the carbonate balance and render reefs erosional. Bioerosion contributes a large part to reef erosion, and bioeroders can benefit to some extent from coral demise and deteriorating environmental conditions. However, bioerosion research is scarce and biased in Southeast Asia. We identified a number of shortcomings in regional bioerosion research, which include a lack of faunistic species records, no knowledge from some of the stakeholder countries and a disproportional focus on macrobiotic external bioeroders compared to borers. To date, Taiwan has a minimum involvement in bioerosion research, and ubiquitous microborers remained entirely unstudied. To establish baseline knowledge, we sampled calcium carbonate substrate at Dongsha Atoll, South China Sea and submitted the material to genomic molecular analyses, assessing microborer biodiversities, as well as some of their coded functions. The samples were taken on the Atoll's eastern side from a highly disturbed reef area that was previously bleached and a similar, less disturbed reef area. Analyses on the microborers were not yet completed at the time of abstract submission, but survey data confirmed that one reef site clearly had less live coral cover than the other. Samples will generate genetically confirmed species records, a first for the South China Sea. We further expect to find different community compositions and possibly distinct regulation of functions depending on the level of habitat disturbance. The present study is part of a larger approach in the context of bioerosion, including taxonomy, field surveys and experiments on dominant bioeroders.

ID: 169 / **Parallel Session 2-1: 3**
Coral Reef Structure and Functioning

Keywords: corals, community ecology, competition, density-dependence

Bridging demographic gaps: insights into coral coexistence through early life competition studies

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The coexistence of numerous species within hyper-diverse ecosystems, such as coral reefs and rainforests, relies on the idea that conspecifics compete more intensely than heterospecifics due to a higher niche overlap. This prevents any single species from dominating locally, resulting in increased species diversity within the community. However, our understanding of coral reef systems lags significantly behind that of terrestrial counterparts, creating a critical gap in theoretical and empirical knowledge.

The early life stages of corals represent the greatest demographic bottleneck where density-dependent interactions are considered most likely to influence coexistence dynamics. We focused on the pivotal early life stages of corals, investigating competition dynamics during settlement and post-settlement survival. We explored the impacts of species identity, species diversity, and population density within local neighborhoods for two Caribbean coral species: *Colpophyllia natans* and *Pseudodiploria strigosa*. By employing a novel vital stain method, we were able to differentiate the species' larvae and thus settlers in an experimental setting.

Our results led to the calibration of a density-dependent mortality model for two coral species, incorporating data on settlement rates, post-settlement mortality, spatial settler patterns, symbiont acquisition time, and fusion status. This study bridges gaps in demographic theory and models, enhancing our understanding of coral population dynamics and recovery processes, insights that are pivotal for informed conservation efforts. Additionally, this work provides much needed insight into the role of intra- versus inter-specific competition at early life stages for corals.

ID: 234 / **Parallel Session 2-4: 12**
Coral Reef Structure and Functioning

Keywords: Transient receptor potential channels, coral adaptation, hydrothermal vent, scleractinian coral, ocean warming and acidification.

Molecular characterization and expression of Thermo-Transient Receptor Potential (TRP) Channels in a scleractinian coral, *Tubastraea aurea* (Dendrophylliidae), near the shallow-water hydrothermal vent in northern Taiwan.

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The shallow-water hydrothermal vent field of Kuieshan Island, located in Northern Taiwan are used as 'natural laboratories' to investigate environmental stressors by mimicking climate impacts on marine ecosystems. Thermo-Transient Receptor Potential (TRP) Channels are mechanoreceptors which detect and initiate responses to external stimuli to adapt environmental changes. Thermo-TRP in vertebrates plays a crucial role in providing information about thermal changes in the environment, but this pathway in Cnidarian is less understood. In order to comprehend the responses of corals to harsh environments and specifically reveal the mechanistic actions resulting from external signals, we aimed to characterize the Thermo-TRP ion channels of *Tubastraea aurea*, a scleractinian coral (Dendrophylliidae) adapted in hydrothermal vent. Currently, we have cloned and identified *T. aurea* Thermo-TRP transcripts (*taTRPs*), ran gene structure analysis and completed phylogenetic analysis. The structure and domains of *taTRPA and taTRPM* were varied greatly and divided into two main groups based on their phylogenetic relationship with other species of TRPs. Also, the expression of *taTRPs* in different tissues (tentacle, oral region, septa and aboral region) showed no significant differences by qRT-PCR, indicate *taTRPs* were widely expressed in all tissues, where they are involved in diverse physiological processes.We then compared the gene expression of *taTRPs* from *T. aurea* colonies in the vicinity of the vents (Kueishan Island, Hydrothermal vent site; HV) and populations in a non-hydrothermal vent site; NHV. The results showed no significant difference of *taTRPs* between HV and NHV. It indicates the TRP Channels in *T. aurea* have adapted to function normally in a high stress environment. A temperature challenge that imitates climate change will be carried out in the near future. In conclusion, this study gave advances knowledge on how thermal stress enables a physiological response and provided valuable insights into the molecular mechanisms underlying scleractinian coral adaptation to climate change.

ID: 817 / **Parallel Session 2-3: 11**
Coral Reef Structure and Functioning

Keywords: Caribbean, monitoring, conservation, nursery, biodiversity

Functional connectivity in fish assemblages along the mangrove-seagrass-coral reef continuum revealed by environmental DNA metabarcoding and underwater visual census

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Marine and coastal ecosystems throughout the Caribbean are highly threatened by climate change and anthropogenic stressors. In this context, understanding the functional connectivity between these ecosystems and how the degradation of one can affect the others is critical for conservation. This connectivity is traditionally studied through underwater visual censuses (UVC) that present several limitations, particularly in species-rich ecosystems or poor water visibility conditions where environmental DNA (eDNA) metabarcoding could be an adequate alternative. In this study, we used both eDNA analysis and UVC to characterize fish assemblage diversity and assess the performance of both methods on a mangrove-seagrass-coral reef continuum in Bonaire. We detected 126 and 141 taxa from eDNA and UVC, respectively, for a total of 193 taxa when cross-referencing the two methods, with the detection of rare, cryptic, or elusive species by eDNA substantially increasing the overall diversity of fish. Considering the fish traits-based functional space, similarities between reef and mangrove fish assemblages reached 59% with eDNA vs. 21% with UVC. On the other hand, seagrass beds displayed low functional similarities with coral reefs and mangroves with eDNA (2% and 4%, respectively), while it was more significant with UVC (17% and 35%, respectively). Despite potentially high functional dissimilarities, the shared volume of functional space between ecosystems still indicates substantial connectivity between fish assemblages along the mangrove-seagrass-coral reef continuum. This connectivity was further explored by analysing juvenile fish abundances of 55 species from UVC. Results confirmed that mangrove forests and seagrass beds could have a nursery function for some reef fish, from herbivores to invertivores and piscivorous species. Lastly, we argue that, currently, the use of UVC and eDNA together provides a more comprehensive overview of fish assemblages to understand the functional connectivity and ontogenic cycles of reef species along mangrove–seagrass–coral reef continuums.

ID: 581 / **Parallel Session 2-3: 7**
Coral Reef Structure and Functioning

Keywords: Madracis auretenra, reefscape genomics, photogrammetry, cryptic lineage

Clonal dispersion and cryptic diversity within a monostand-forming coral species

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Over the past decades, Caribbean coral reefs have seen major declines in coral cover. Some of the once common and dominant coral species have become threatened with extinction, leaving room for less susceptible species to become more dominant. The reef-building coral *Madracis auretenra* is one such species that is increasing in relative abundance in the Southern Caribbean, forming monospecific stands that can encompass large patches of reef. However, as molecular studies have been largely focused on threatened species, little is known about the genetic structuring of this species at the within-reef scale or the genetic diversity contained in such monospecific stands. Here, we undertake a “reefscape genomics” approach to study the molecular ecology of this species, combining photogrammetric mapping (to inform sampling a priori) and reduced representation genome sequencing. Across the genotyped samples (n = 487) we found two genetically distinct clades that appear to be largely reproductively isolated, but with no apparent gross morphological differences. The spatially explicit sampling revealed highly clonal populations (Ng/N: 137/487) across both clades, with a strong “downslope” signal, and clonal dispersal of up to 13 meters. Despite high levels of clonality, almost all studied monostands were genotypically diverse with an average of 41% of samples from each stand representing a unique genotype. Interestingly, 24% of studied monostands consisted of representatives of the two distinct *M. auretenra* lineages, indicating regular co-occurrence at the within-reef scale. Overall, these results demonstrate the importance of studying the spatial genetic structure of reef-building corals at a within-reef scale, and the potential of approaches combining photogrammetry and population genomics.

ID: 138 / **Parallel Session 2-3: 2**
Coral Reef Structure and Functioning

Keywords: Scleractinia, UCEs, phylogenetic systematics, biogeography

Unveiling the unknown diversity of the family Agariciidae along the Saudi Red Sea coast: a biogeographical and phylogenomic approach

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The stony coral family Agariciidae, comprising over 100 nominal species across the tropical belt, is an ecologically important reef ecosystem component from shallow to deep waters. However, understanding the actual species diversity of this morphologically diverse and species-rich family is hindered by overlooked diagnostic morphological characters and unresolved phylogenies, especially in the Red Sea – a biodiversity hotspot for scleractinians. There, four Agariciidae genera and 25 nominal species have been recorded based on morphology and traditional molecular markers (mitochondrial genes and nuclear rRNA), but polyphyletic and unresolved lineages highlighted the lack of resolution of previous approaches. We used target-capture of ultraconserved elements (UCEs) and exon loci to resolve the phylogenetic relationships among 159 Red Sea agariciid specimens collected between 1 and 250 m depth, covering for the first time all the currently recognized genera in the region. Additionally, 359 Indo-Pacific specimens, including some from type localities, were added for biogeographic insights and species identifications. The overall morphology of the examined materials was used to identify specimens based on traditional taxonomic descriptions and type materials. Our results revealed a highly diverse Agariciidae fauna in the Red Sea, with 26 well-supported species-level molecular clades found there, challenging traditional morphological taxonomy in Red Sea Agariciidae. Among them, 11 morphologies appear undescribed, two represent Red Sea endemic lineages, and eight are Arabian Peninsula endemics. Our study highlights that a genomic approach is supported in resolving the evolutionary history and species boundaries of Red Sea Agariciidae and, more broadly, scleractinian corals. Our findings contribute significantly to the future taxonomic revision of Agariciidae, emphasizing the importance of the Red Sea and the Arabian Peninsula as biodiversity hotspots for scleractinians. Ultimately, our work advances our understanding of coral diversity, supporting future conservation efforts and enhancing the accuracy of taxonomic classifications within stony corals.

ID: 637 / **Parallel Session 2-2: 3**
Coral Reef Structure and Functioning

Keywords: carbonate budgets, reef accretion, sea level rise, bioerosion, climate change

Projecting responses of coral reef framework in the Caribbean region to local climate change and restoration interventions

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Coral reef systems rely on the net accumulation of biologically produced calcium carbonate to maintain their ecological functions and the anthropocentric services they provide. For the three-dimensional structure of the reef framework to persist, calcium carbonate production by corals and other calcifiers needs to outpace loss due to physical, chemical, and biological erosion. Due to significant declines in coral cover over the past four decades, coupled with rising erosion rates, most Caribbean coral reefs are either in a state of accretionary stasis or are experiencing net erosion. The progression of framework altering processes, and the severity of potential habitat loss is site-specific and may be addressable with proper management. Managers, however, lack the predictive tools assessing regional responses under future climate change and evaluating the potential impact of local initiatives to mitigate effects of ocean acidification and warming. To address this, we build upon the reef persistence modelling approach developed in Webb et al. (2023) at priority sites in Puerto Rico, the Virgin Islands, the Florida Keys, and the Flower Garden Banks. Carbonate budget projections are developed using species-specific responses to site-specific climate forecasts from the latest generation of downscaled climate model projections (CMIP6). We show that reef habitat persistence will vary across the Caribbean region due to site-specific variations in climate projections and differing responses of existing reef communities to warming. Although restoration increases reef accretion (mm yr^{-1}) estimates, most sites will only be able to keep pace with future sea-level rise in a world where anthropogenic CO_2 emissions are reduced. Findings attest to the potential of appropriate restoration interventions to delay the onset of mass mortality, potentially allowing sufficient time for the implementation of a low-carbon economy.

ID: 312 / **Parallel Session 2-1: 6**
Coral Reef Structure and Functioning

Keywords: Fatty acids, SIBER, stable isotopes, population differences, trophic markers

Shift in trophic strategy is likely not the main driver for the higher bleaching resilience of coral holobionts exposed to internal waves in the Andaman Sea

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In the Andaman Sea large amplitude internal waves (LAIW) break at the continental shelf and periodically introduce cold, nutrient-rich sub-pycnocline water into shallow-water reefs while increasing organic matter flux. Locally, western island shores are exposed to LAIW-induced physico-chemical variations, while eastern shores are sheltered from LAIW influence. Exposed reefs harbor corals with increased heat resistance, yet the underlying mechanisms remain undiscovered. Heterotrophic feeding can play an important role in coral bleaching resilience, thus, a shift in trophic strategy through LAIW-enriched organic matter flux may contribute to thermal resistance. To assess this, we analysed a suite of indicators based on stable isotopes (SI) or fatty acid trophic markers (FATM) of two important reef-building species, *Porites sp.* and *Pocillopora sp.* from both shore sides of two offshore islands (Miang and Racha). The indicators reveal a highly complex picture. Differences in $\delta^{13}C$ of host and symbionts indicated higher heterotrophic nutrition in LAIW-exposed corals from Miang only. Also, FATM tended to indicate higher heterotrophy in LAIW-exposed sites, especially for *Porites sp*., while variation in $\delta_{15}N$ and SI Bayesian ellipse analysis found no such difference and by contrast, indicated even higher heterotrophy in LAIW-sheltered corals. Overall, fatty acid health markers suggest that corals exposed to LAIW were healthier. Overall, these commonly used markers do not support a strong shift towards more heterotrophic food acquisition at LAIW-exposed reefs showing that it is not the main explanation for these corals increased heat resistance. However, biochemical data support LAIW-exposed corals invest into their tissue conditions supporting a healthy phenotype.

ID: 593 / **Parallel Session 2-1: 11**
Coral Reef Structure and Functioning

Keywords: scales, fish, species richness

Scaling below the Surface: The Influence of Observation Scale on Fish Biodiversity on Coral Reefs

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The components of the observation scale, grain and extent, have considerable influence on the observed species richness within a given area. This study delves into the impact of grain and extent on the observed species richness of coral reef fish at various locations in Sri Lanka and Bermuda using a specific data collection design allowing manipulation of these scale components in an observational experiment. The analysis was done using a newly developed Python-based data analysis package.

Our findings indicate that these factors show a weak yet consistent influence on species richness across diverse locations even for such highly-mobile organisms as fish associated with coral reefs. Their significance is more pronounced over large areas when compared to sessile organisms. This study introduces a fresh perspective on the species richness of coral reef fish across distinct locations, addressing the current challenges in comparisons arising from differing sample size among data collection protocols. Furthermore, it provides a novel tool for advancing research in the realm of coral reef fish ecology.

ID: 843 / Parallel Session 2-1: 4
Coral Reef Structure and Functioning

Keywords: Topography, Geometries, Settlement Substrates, Material Sciece, Coral Reef restoration.

What geometries are more suitable for coral larvae settlement?

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Understanding the factors that influence settlement is pivotal for unravelling the complex mission of coral larvae. While chemical cues have traditionally dominated investigations into larval settlement, this study focuses on exploring the role of surface topography at the size of the body larvae (a few hundred microns). We looked at the impact of hole sizes and angles on settlement preferences. Utilizing laboratory-based experiments and 3D printing techniques, we designed tiles with specific surface topography in the form of zigzag grooves. Employing two different sizes, one that closely matches the diameter of the coral larvae, and also wider grooves where the larvae can easily explore different spots in it. A scleractinian coral, *Colpophyllia natans*, was chosen for this study. This species exhibited significantly higher settlement rates on grooves that closely matched their larval body size. Wider angles were preferred when the grooves were thinner, and smaller angles when wider. These findings underscore the significance of specific physical cues, such as surface complexity, in shaping the settlement behaviour of coral reef sessile invertebrates. And provide extra help to the widely used biochemical cues. Our investigation emphasizes the critical influence of hole size and geometry in determining larval settlement preferences, offering novel insights into the ecological processes governing habitat selection in these organisms.

Posters

ID: 716
Coral Reef Structure and Functioning

Keywords: Population Genomics, Connectivity, Phylogenomics, Scleractinia, Poritidae

Coral Connectivity and its Drivers Across the Indian Ocean – with Consideration of the Morphological Species Problem

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Coral reefs are among the most threatened habitats on the planet, yet they provide significant ecological, cultural, infrastructural, and social value for millions of people around the world and host unique and exceedingly rich biological diversity. Recent coral bleaching events (within the last five years) brought about by high sea temperatures have resulted in catastrophic losses (up to 80% in some genera) to coral reef ecosystems, which have the potential to drastically shift species compositions and reef functionality while placing strain on the livelihoods of coastal communities worldwide. Predictions of troublesome climate scenarios and the continuing threat of coral reef ecosystem loss highlights the need for ocean-wide connectivity analyses of coral taxa to ascertain future reef dynamics, recovery and resilience. Furthermore, problems in delimiting coral species governed by a range of factors that extend to both morphological and molecular incongruity represent a substantial hurdle in the applicability of conservative procedures and outcomes. Distributed widely throughout the tropical Indo-Pacific, the hermatypic coral *Porites lutea* (Scleractinia: Poritidae) is resilient to bleaching, contributes to the structural and community security of coral reef ecosystems and maintains positive carbon budgets. However, identification of *P. lutea* remains particularly challenging, and current connectivity analyses are limited nonetheless, covering only a fraction of the reported distribution. Using a multimethod genomic approach by target capture and genome skimming of ultraconserved elements, we aim to put forward the first cross-Indian Ocean connectivity report of *P. lutea,* and aim to use comparative analyses of high-resolution photography and phylogenomics to clarify the validity of 182 morphologically placed Scleractinia.

ID: 839
Coral Reef Structure and Functioning

Keywords: bioerosion, Porifera, coral rubble

The role of bioerosion in the coastal dynamics of a small Maldivian island

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The Maldives Archipelago is currently facing a precarious phase marked by significant coastal modifications resulting from the impacts of tourism and local development. The escalating climate crisis further exacerbates the negative consequences of these coastal alterations, particularly in terms of coral bleaching events and sea level rise. This research specifically delves into the evaluation of coastal dynamics, including bioerosive processes, at Vavvaru Island in the Lhaviyani Atoll, North Province, Maldives, serving as a pilot study.

The small Vavvaru Island is grappling with pronounced coastal dynamics. The northeast side, exposed to the open ocean, is undergoing rapid and continuous physical erosion, coupled with substantial sand displacement during the monsoon inversion. The northeastern reef features a substantial amount of coral rubble, hosting a well-organized community of endolithic bioeroders, extensively examined within the lagoon.

More than 80% of coral fragments longer than 20 cm exhibit the presence of boring organisms. Sponges, molluscs, and worms exhibit differing temporal scales of colonization, hinting at the potential age of the fragments. Originating from the external reef crest, a gradient in the composition of the borer community is evident from the crest to the shore. Sponges and worms consistently inhabit the fragments, while molluscs gain importance closer to the island where coral fragments are more stable due to reduced water movement and minimal rolling of rubble.

Our analysis emphasises the pivotal role of sponges, particularly evident in the examination of chips and spicules containing sediments. In the fine fraction of sediments, chips constitute approximately 2-10% of the total sediment. Both physical and biological disturbances impact the structure of the reef surrounding the island. The results highlight how sand movements are part of long-term dynamics affecting coral reef integrity and triggering an intense bioerosive activity. Understanding these pronounced erosive processes is fundamental for the conservation of Maldivian reefs.

ID: 584
Coral Reef Structure and Functioning

Keywords: CCA, CISME, physiology, ecological functioning, environmental changes

In situ calcification and physiology rates of Red Sea crustose coralline algae

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Crustose coralline algae (CCA) are calcified red algae distributed from the poles to tropics. They serve a suite of essential ecological roles in subtidal habitats, and are particularly important in coral reefs where they contribute to primary production, stabilization of the reef matrix through calcification, and facilitation of coral larval settlement. Understanding drivers of CCA physiological performance is necessary to fully understand the impacts of global environmental change and other associated stressors on their ecological functions. The aim of this study was to establish ecophysiological baselines for common species of CCA on shallow reefs on the Saudi Arabian Red Sea coast. Replicate coralline crusts were collected from 2-3 m depth and subsamples were collected for molecular identification. Rates of calcification, photosynthesis, and respiration were measured on individual crusts of two distinct species with the CISME (Community In Situ Metabolism) underwater respirometer. Monitoring over time indicates that coralline physiological rates can be species-specific and influenced by natural climate variability, including variations in temperature and light availability. Our work provides essential information on baseline calcification and photosynthetic rates of common Red Sea corallines, which sheds light on the role of different coralline species in reef ecological functioning. Furthermore, monitoring these parameters over time will provide direct insight to how environmental changes are influencing the biological performance of ecologically important taxa.

ID: 741
Coral Reef Structure and Functioning

Keywords: coralligenous assemblages, mesophotic bioconstructions, image analysis

Morphology and structure of Apulian Shelf (Southern Adriatic Sea) bioconstructions: a temperate mesophotic coral reef compared with the coralligenous assemblages

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This study investigates the physical differences between coralligenous assemblages and mesophotic temperate bioconstructions in the Monopoli area of the Southern Adriatic Sea. Utilizing large slabs and thin sections, the inner structure of these bioconstructions was examined at both meso- and microscales. Image analysis provided detailed "maps" describing relative taxonomic abundances, spatial relationships between bioconstructors and associated taxa, biodestructor presence and abundance, and porosity in terms of void number and morphology. The bioconstructions exhibited diverse structures and textures due to distinct structuring organisms. Coralline algae formed calcareous concretions at depths of 25-35 meters, characterized by smooth, thin carbonate layers with occasional cavities and holes from bioeroder action or discontinuities in layer superposition. Deeper bioconstructions (45-65 meters) were constructed by invertebrates with calcareous skeletons, including non-symbiotic scleractinian species (*Phyllangia americana mouchezii* and *Polycyathus muellerae*) and the bivalve *Neopycnodonte cochlear*. These constructions were several decimeters thick, rich in holes, cavities, and crevices, with a loose texture. Serpulids, though secondary builders, significantly contributed to structure formation, enhancing surface heterogeneity and creating microhabitats. In contrast to calcareous algae, invertebrates built thicker and more complex bioconstructions with varied cavities and crevices, resulting in a highly heterogeneous habitat. Oyster bioconstructions often formed adjacent pinnacles, further diversifying microenvironments.

The results of this research contribute to our understanding of the ecological dynamics of marine bioconstructions and provide valuable insight into the management and conservation of marine habitats.

ID: 610
Coral Reef Structure and Functioning

Keywords: morphology, machine learning, taxonomy

Morphological traits and machine learning for genetic lineage prediction of two reef-building coral species

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Scleractinian coral identification conventionally relied on the analysis of morphological traits. This was found to be incongruent with genetic approaches because of high levels of phenotypic plasticity and convergence. However, the disentanglement of the morphological variation across coral species should be considered for the full understanding of their distribution, evolution, life history, and ecology. Integrating molecular and morphological trait delimitation methods could be improved with more accurate, reproducible, and assisted analysis of the coral skeleton. Here, an application of machine learning models for coral species identification is presented. Random forest models were trained with macro and micro morphology manual annotations as well as SNP based genotype labelling. Corals were collected from three sites of 32 islands across the Pacific Ocean (~2000 corals) during the *Tara* Pacific Expedition. Two species were sampled based on colony morphotypes, *Porites lobata* and *Pocillopora meandrina*. *In-situ* photographs were used for measurements of the *corallum*. Scanning electron microscopy images of colony fragments were used for corallite measurements. Two models per genus were created: one using macro morphology for *in-situ* identification of corals species, and another combining macro and micro morphology as an alternative method for species delimitations. Models could classify identified genotypes based on morphology with low error rates and high accuracies for the two genera. Macro models were successfully applied for genotype prediction of coral species using *corallum* morphology. Compared with two dimensions reduction analyses (PCA, FAMD) on raw measurements, macro&micro models could identify the range of expected morphotype for each coral species. Machine learning assisted analysis with reproducible measurements can potentially be used as an alternative method for species delimitation, as to reconcile with molecular studies, and *in-situ* identification. These can also be applied to type materials that lack genotype information, and to understand the phenotypic variation across plastic species.

ID: 575
Coral Reef Structure and Functioning

Keywords: Octocorallia, biodiversity, taxonomy, phylogeny, Mozambique

Diversity and distribution of Soft Corals (OCTOCORALLIA) of Mozambique

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Coral reefs in the Western Indian Ocean (WIO) are experiencing continuous degradation and changes in their extent and functionality, and the projected rise in sea temperature indicates that they are rapidly disappearing. Mozambique has the third-largest coastline in the WIO with wide reef areas viewed as a diverse hot spot for tropical corals, however, they have been poorly studied. To assess species diversity and distribution of soft corals in this area 184 colonies were collected, using SCUBA, from 21 reefs in northern and southern Mozambique. The collected species were identified using morphological characters and molecular phylogenetic analyses with nuclear (28S rDNA) and mitochondrial (mtMutS) markers. Pairwise measures of genetic distance among sequences were computed using MEGA v.5 and a neighbor-joining tree was constructed to visualize relationships. Spatial patterns in soft coral assemblages were assessed using multivariate analyses NMDS. A total of 57 species of Octocorallia were identified along the Mozambique coast, distributed among 23 genera; 49% of the species, and 48% of the genera were not identified in the previous studies in the area. Species richness ranged from 11 to 31 taxa per site. The most species-rich site was Ponta do Ouro in the south, and nine species occurred only there, while Mozambique Island in the north had the lowest diversity. Two main assemblages were identified at a similarity level of 50%. The NMDS revealed a more similar community structure for the northern sites, with the species composition at Ponta do Ouro differing from all the other sites. β-Diversity increased significantly with increasing geographical distance between sites (Person, r = 0.8). This study updated the soft coral fauna of Mozambique with 11 genera and 28 species indicating that more studies are urgently needed to support management of the reef ecosystems in this region.

ID: 262
Coral Reef Structure and Functioning

Keywords: Canopy effect, flexible coral, functioning, in-situ flow measurements

Near-bottom tidal flow modification by black coral forests

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Arborescent corals are benthic ecosystem engineers which provide 3D complexity to the substrate.

When several individuals are present at a high enough spatial density, they form a true "forest" (animal forests). Under the canopies of those forests, some physical parameters (e.g. seawater flow, light, etc) can be different from outside, generating a microclimate suitable for several species. The local modification of physical parameters such as flow speed could also increase the resilience of the forest itself, increasing for example larvae and food retention.

To test the flow modification by flexible coral assemblages, we measured the flow velocity across the bottom boundary layer both inside and outside of black coral forests (*Anthipatella wollastoni*) composed of individuals of sizes comprised between 70 and 110 cm with various density. Measurements were made in Canary islands (Northeast Atlantic Ocean) at approximately 50 m deep in order to be out of reach of wave motion. The flow velocity was measured at 2Hz at high vertical spatial resolution (3 cm) over 3 m above the bottom with acoustic Doppler profilers. Such procedure enabled to describe the mean flow speed in the bottom boundary layer.

The flow regime was characterized by tidal currents up to 25 cm/s at 3 meters above the bed. A clear decrease of the tidal flow speed with upward vertical displacement of the logarithmic layer, was recorded inside coral assemblages compared to outside them. These measurements provide evidence that deep flexible coral assemblages alter the tidal bottom boundary layer and form actual canopy-like structure, justifying the term marine animal forest.

ID: 141
Coral Reef Structure and Functioning

Keywords: Coral complexity, trait ecology, photogrammetry, demography, morphology

Beyond macro-level views: Investigating colony size and morphology's impact on reef complexity in Southeast Asian Scleractinia

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Rugosity measures the architectural complexity of reefs. It is frequently employed to underscore shifts in living coral communities through time or following major ecological disturbance (e.g., coral bleaching). The morphological traits of individual coral colonies collectively play a crucial role in defining the total extent of habitat complexity necessary for sustaining reef fish assemblages and the coastal protection capacity at a whole reef-scale. However, current rugosity measures often neglect these individual contributions of corals. Instead, they encompass macro-level reef structures influenced by the prevailing reef topography. Therefore, it is difficult to quantify the relative contribution of specific coral taxa to reef rugosity or how reef framework complexity may vary with shifts in coral population dynamics. Here we utilize an unprecedented dataset of high-resolution three-dimensional reef models collected from reefs with varying environmental conditions across Southeast Asia. We extracted individual coral colonies from a wide range of coral genera to investigate colony-level rugosity of Scleractinia and determine how structural complexity changes with colony morphology, size, and environmental conditions. Morphology contributed the most to variance in rugosity, with an optimum size for corals and their structural complexity. This trait and demography-based approach provides accurate measures of reef complexity by focusing on the contribution of living corals to reef structure, removing macro-level (and abiotic) influences on architectural complexity. Colony-level rugosity values can be applied to identify changes in reef structure through demographic studies and can be extrapolated to past research lacking rugosity data, or for estimating coral carbonate production.

ID: 267
Coral Reef Structure and Functioning

Keywords: Contemporary baselines, trait-based ecology, climate change, ecological resilience, oceanography

Contemporary baselines: Biodiversity of coral reef fish assemblages show depth-dependent resilience to an extreme marine heatwave

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We examine the depth-dependent effects of an extreme marine heatwave on high-diversity reef fish assemblages at a remote, and historically highly productive island in the Pacific Ocean, to examine the ecological effects of climate change in the absence of confounding local human impacts. With exacerbating climate change and local human impacts, we are confronted with increasing ecological uncertainty. This uncertainty limits our capacity to make effective ecological predictions from which to base decisions of risk-control management, conservation, policy and governance. To better deal with this uncertainty, we can measure change from revised contemporary baselines as now more pragmatic points of reference, with those baselines defined from modern-day systems considered the among the most intact and near-pristine remaining, and least exposed to local human impacts. Here, we explore the ecological impacts of contemporary marine heatwave conditions at what is widely considered one of the last remaining 'pristine' coral reef systems on earth. We use multi-trait-based methods to examine ecological patterns at the community level, quantifying how thermal stress anomalies interact with reef fish ecological organisation across depth – one of the most fundamental and ubiquitous physical features of coral reefs worldwide. We link standardised coral reef monitoring data from in-water fish surveys at 231 sites conducted across 2010–2018, with satellite-derived thermal stress estimates, in the context of known large-scale ocean-climate interactions at Jarvis Island during and following the extreme 2015-16 El Niño marine heatwave. In combining cross-scale ecological, climatological, and oceanographic components, our study strives to elucidate the biophysical mechanisms underscoring variable community responses of fish assemblages to marine heatwaves in the absence of local human impacts. The results reveal depth-dependent resilience and vulnerability of coral reef fish diversity in the context of global change on a near-pristine, remote coral reef ecosystem.

ID: 649
Coral Reef Structure and Functioning

Keywords: Soft corals, Community ecology, Spatial point process analysis

Depth effects the community ecology of the Great White Wall, Fiji

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Soft corals (Alcyonacea) are widespread in the Indo-Pacific and make up a substantial component of coral reef communities, yet octocoral community dynamics are not well understood. The community ecology of sessile organisms can be investigated using spatial point processes analyses because the positions of individuals on the substrate reflects the biological and ecological processes acting on them, such as competition, mutual aggregation around areas of shared habitat preferences, or reproductive clusters. In this study, we use photogrammetry from SCUBA to create 3D models and 2D maps of the Nephthidae-dominated community on Fiji's famous Great White Wall. We mapped 5877 sessile marine invertebrates including 5291 Nephthidae soft corals across 34.5 m^2 at three mean depths (20, 26.5, and 33 m). The shallow area was the most species-rich and was dominated by soft corals, hard corals, and sponges, whereas the deeper areas had lower species richness and were dominated by filter feeding Nephthidae soft corals and hydroid colonies. We found that both mean size of Nephthidae and overall organism density increased with depth. In the shallowest area, we found that Nephthidae, hard corals, and sponges formed aggregations, likely in areas of suitable habitat, and that clusters of different species were attracted together. In the intermediate depth area, we found that Nephthidae and hydroid colonies formed aggregations, but with larger cluster radii, and that interspecific clusters showed attraction. However, in the deepest area, we found conspecific clusters with yet larger radii, but bivariate attraction was not detected, likely reflecting a homogenous suitable habitat at depth. With these data, it is possible to resolve the most likely underlying processes for observed patterns and how the balance of dispersal limitation, habitat associations, and competition change with depth.

ID: 504
Coral Reef Structure and Functioning

Keywords: Plankton dynamics, Long-term monitoring, Coral reef ecosystems, Biogeochemical cycles, Nutrient recycling

Ocean-reef connections: quantifying plankton dynamics and pelagic contributions to coral reef food webs in the central Red Sea

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Coral reefs are traditionally considered self-sustaining ecosystems in oligotrophic tropical seas. However recent evidence has challenged this paradigm, with mounting evidence suggesting that pelagic subsidies are a central component of coral reef ecosystem functioning. Despite the prevailing importance of pelagic inputs to reef food webs, surprisingly little is known about near-reef plankton dynamics and the temporal linkages between reef and ocean processes. This study aims to transform our understanding of ocean-reef connections by critically evaluating the often-overlooked role of plankton in supporting these ecosystems. On an offshore reef in the central Red Sea, we have established a suite of sensor arrays and a long-term bi-weekly sampling program to evaluate plankton dynamics and their connections to the reef with unprecedented resolution for an entire year. Our objective is to delineate the influence of plankton on the biogeochemical cycles within the coral reef ecosystem and their broader impact on coral trophic ecology. Here we present the first six months of data, evaluating changes in phytoplanktonic and zooplankton composition and productivity during the winter-to-spring transition. We reveal temporal variations in plankton communities are closely linked to the physical and chemical parameters of the reef environment. Experiments of primary production and nitrate uptake are underway to provide insights into plankton's pivotal role in nutrient recycling and energy flow, essential for the sustenance and resilience of coral reefs. Additionally, we are developing fatty acid and isotopic biomarkers to quantitatively evaluate plankton trophodynamics and the contributions of distinct planktonic sources to coral nutrition. Through this interdisciplinary approach, we are working toward a more holistic understanding of plankton dynamics and their role in sustaining coral reef ecosystems in a warming ocean.

ID: 288
Coral Reef Structure and Functioning

Keywords: Antipatharia, UCEs, Phylogenomic, Red Sea, Evolution

Genomic insights into the broad evolutionary diversity of Red Sea black corals

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Black corals (Cnidaria, Anthozoa, Antipatharia) are marine invertebrates that occur globally, acting as habitat providers and diversity aggregators from shallow to deep waters. Despite their ecological importance in several benthic ecosystems, black corals remain largely understudied, not least because >75% of known species occur below SCUBA diving depths. This, combined with a lack of diagnostic morphological traits and phylogenetically informative molecular markers, hinders the characterization of their diversity, evolutionary history, and distribution. To overcome these limitations, there is a critical need to integrate genomic-wide data. As such, we used target-capture of ultraconserved elements (UCEs) and exon loci to explore the diversity of Antipatharia in the Red Sea, representing the most extensive genomic analysis of antipatharians to date. We reconstructed the phylogenomic relationships among 320 black coral specimens collected along the latitudinal gradient of the Red Sea, spanning a 655 m range in water depth. At least 13 genera across four families were identified based on morphology, while our phylogenomic reconstruction confirmed previously identified polyphyly in traditional families, highlighting the inconsistency of classification methods based solely on morphologic traits. These results demonstrate the need for a taxonomic revision of the order, now in reach with the species-level resolution achievable through UCEs. Moreover, our findings emphasize the remarkable diversity of Red Sea Antipatharia fauna, including several novel lineages, of which some are potentially endemic to the region. From an ecological point of view, we retrieved lineages exclusively in shallow, mesophotic, or deep environments, as well as depth generalists. Our study extends beyond unravelling the Red Sea's black coral diversity, offering insights of global significance. The work underscores the critical role of UCEs in addressing knowledge gaps to the current understanding of black coral diversity, emphasizing also the necessity for continued exploration and conservation of Antipatharia.

ID: 856
Coral Reef Structure and Functioning

Keywords: Cliona, circadian rhythms, Symbiodiniaceae, photosynthesis, symbiosis

Circadian symbiont relocation in a bioeroding sponge

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Excavating sponges are important bioeroders on coral reefs, counteracting the reef-building of corals. They are thought to be more resistant to bleaching than corals and are predicted to outperform calcifiers in future conditions, potentially leading to net reef erosion in locations where they are abundant. Endosymbiotic dinoflagellates serve as an important autotrophic energy source for photosymbiotic Clionaida and stimulate their bioerosion. Observations on the Great Barrier Reef described a diel colour change of these sponges that has been explained by the relocation of the symbionts within the sponge, perhaps implying circadian rhythmicity. Synchronized behaviour and physiology with external rhythms are advantageous and promote optimal performance and survival in organisms. Here, we investigated circadian rhythmicity in a sponge-dinoflagellate holobiont (*Cliona* cf. *caribbaea* and Symbiodiniaceae) regarding the symbionts' photosynthesis and the host's diel relocation of symbionts. We quantified the retraction into the sponge tissue via surface reflectance measurements. Different light regimes were used to test the persistence of rhythms under constant conditions where oxygen production served as the measure for photosynthesis and surface reflectance as the measure for symbiont relocation. Findings suggested the existence of intrinsic circadian rhythms which regulate photosynthesis in the dinoflagellate and symbiont relocation in the host, respectively. Reflectance measurements were a reliable, non-invasive method to quantify the relocation of symbionts and supported visual evidence. Sponge and symbiont achieved maximally effective light-harvesting when rhythms were synchronized, accentuating the complex yet advantageous interplay of holobiont circadian rhythms.

ID: 810
Coral Reef Structure and Functioning

Keywords: Coral reef fish, visual detection distance, prey-predator encounter, light levels

Prey-predator encounter on tropical coral reefs: How visual detection distance determines windows of risk and opportunity.

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Most fish rely on vision to do fundamental tasks like feeding, finding mates, and avoid predation. Vision can inform an organism where an object is and what it is, meaning that a fish will be able to avoid predation if it can detect it in time to escape and shelter. Around sunrise and sunset, irradiance changes rapidly, challenging the visual detection of predators and motivating sheltering within branched corals. We believe changes in visual detection distance is a cornerstone in understanding behavioural strategies related to sheltering behaviour in coral reef fish.

Here we propose a model to explore how visual detection distance in small coral reef fishes depends on environmental light and eye design. We have adapted a visual range model developed for pelagic fish to model visual detection distance in coral reef fish. A fundamental part of this model is the module related to light. Calculating the light levels at dawn, dusk, and moonlight is challenging, and empirical measurements in tropical waters are scarce. Here, to ensure that the light patterns in the model were replicating those in the wild, we calibrated the model with relative metrics for light extracted from parameters of a high-sensitive underwater camera used during field observations. Finally, we explored how detection distance varies with changing light conditions in different light scenarios and contrasted predictions with behavioural metrics sampled from underwater videos.

By gaining better insight into the visual detection of fish, we can identify the windows of risk and opportunity for coral reef fish. This will in turn help explain the drivers behind certain fish behavioural strategies and increase our general understanding of light and visual ecology in tropical coral reefs.

ID: 451
Coral Reef Structure and Functioning

Keywords: Functioning, Marine Heatwaves, Marine Protected Areas, Coralligenous, Mediterranean

Maintaining the functioning of Mediterranean temperate reefs: a realistic goal for marine protected areas?

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Ocean warming and marine heatwaves are transforming benthic ecosystems around the world. Mass mortalities of sessile organisms, frequently affecting foundation species, are one of the main consequences of this phenomenon. The reconfiguration forced by these extreme events is often characterized by a reduction of structural complexity, followed by a loss of ecosystem functions and services. It is therefore crucial to understand the effectiveness of management strategies that are currently in place in maintaining the functioning of benthic habitats. Within this context, the efficacy of marine protected areas has been highly debated, as enhanced resilience towards extreme climate events is often assumed, but rarely detected nor quantified in natural systems. In this study, we delve into the role of marine protected areas in buffering the impacts of marine heatwaves in coralligenous assemblages, a Mediterranean mesophotic temperate reef highly susceptible to these extreme events. Specifically, we focus on octocoral-dominated coralligenous communities and aim to quantify responses across contrasting protection levels and thermal regimes. To achieve this, we propose a framework that uses trait-based approaches to study both the dominant red gorgonian (*Paramuricea clavata*) and its understory community, allowing us to track changes in the ecosystem structure and functioning. For this purpose, we benefit from long-term *P. clavata* demographic and community data gathered in 24 sites within the north-western Mediterranean, the result of more than 20 years of monitoring efforts. Our approach highlights the importance of understanding the response diversity of ecological communities to MHWs. If we are to maintain the functioning of marine ecosystems, this knowledge is essential for informing future management and conservation strategies.

Session 3: Biology and Ecology of Holobionts in Coral Reefs

Microorganisms play an important role in the life of plants and animals. They are involved in nutrient acquisition and recycling, disease resistance and in general health of their host. The term “holobiont” was therefore introduced to describe the biological entity comprising a eukaryotic host and its associated microorganisms, including bacteria, archaea, protists, microalgae, fungi and viruses, and their relationships to each other. Scleractinian corals are one of the best known holobionts in marine ecosystems. They are defined by the relationship between coral polyps and dinoflagellate Symbiodiniaceae algae and form the basis of light-dependent reef ecosystems. Other important habitat-forming holobionts are the Porifera – marine sponges that form complex partnerships with microbes, profoundly influencing their metabolic functions and facilitating niche expansion. However, macroalgae and other metazoans also represent ecologically functional holobiont systems in reef communities. The health and resilience of reef ecosystems depend on symbiotic interactions and homeostasis within reef holobionts. Anthropogenic stressors such as ocean acidification, pollution, overfishing and rising sea temperatures due to climate change can disrupt this delicate balance. Coral bleaching, for example, disrupts the symbioses of coral holobionts and can lead to reduced reef fitness and potential degradation.

Knowledge of the evolution, biology, and ecology of holobionts is critical to understanding the vulnerability of coral reef organisms to environmental stressors and their adaptability to new conditions. This session will focus on all aspects of holobiont biology, physiology, and ecology, covering processes at the molecular, cellular, and organismal levels. Contributions may include studies on symbiotic relationships, disease dynamics, holobiont genetics and adaptive traits, as well as bleaching and other stress responses associated with climate change. Our goal is to expand our knowledge of the mechanisms underlying the ability of reef holobionts to survive and thrive in our oceans, both in their current state and under the inevitable, rapidly changing environmental conditions.

Keywords: chemical ecology, photobiology, symbioses

Session chairs

Christine Ferrier-Pages, Centre Scientifique de Monaco (Monaco)

Francesca Benzoni, King Abdullah University of Science and Technology (Saudi Arabia)

Laura Núñez Pons, Stazione Zoologica Anton Dohrn Napoli (Italy)

Take home message

- Corals- including octocorals, sponges, and fish are holobionts, complex entities which include the host and microorganisms. All partners, also the host, have to be taken into account in future studies, which was well reflected in session 3. Also, not all microbes are good symbionts, even if systematically associated to the host.
- The stability of the host-microorganism associations is driven by external stressors but also by nutrient availability and exchanges between the partners. Nutrient imbalance causes dysbiosis and a decrease in network connectivity, which in turn leads to coral disease and even mortality.
- There is a clear need for more comprehensive research into the role of each microbial partner, considering that there is not a unique holobiont model, but a wide diversity of potential models.

Regular oral presentations

ID: 598 / Parallel Session 3-3: 3
Biology and Ecology of Holobionts in Coral Reefs

Keywords: Symbiodiniaceae, assisted evolution, coral restoration

Comparison of fitness traits in coral juveniles inoculated with heat evolved symbionts

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Coral fitness is strongly associated with the types of Symbiodiniaceae symbionts they associate with. Selective culturing of symbionts has yielded heat-evolved strains that have improved the heat tolerance of *Acropora* coral juveniles but their application in other coral species as well as assessment of their impact on other fitness traits is unknown. Here we investigate if survival, growth, and heat tolerance are influenced by heat-evolved symbionts in two species of juvenile corals. Corals were inoculated with a heat-evolved or a wild-type strain of either *Cladocopium or Durusdinium* symbionts and monitored for 3 months to track survival and growth. Overall, corals inoculated with *Durusdinium* had higher survival than those with *Cladocopium. Acropora kenti* corals inoculated with heat-evolved *Cladocopium* had higher survival than those with wild-type *Cladocopium.* In contrast, survival in *Platygyra daedalea* corals with heat-evolved *Durusdinium* did not differ from the wild-type treatment. Growth in both coral species was highest when hosting wild-type *Durusdinium* and the lowest growth was observed in corals hosting either *Cladocopium* symbiont. Corals were subsequently exposed to a 6-week heat stress experiment resulting in accumulation of approximately 17 Degree Heating Weeks. Bleaching was observed in both species and was significantly higher in corals hosting *Cladocopium* vs *Durusdinium* but corals hosting heat-evolved *Cladocopium* performed better than those with wild-type *Cladocopium*. Despite high levels of bleaching, both coral species had over 80% survival when hosting either strain of *Durusdinium*. In *Platygyra* corals, survival was equally high with either strain of *Cladocopium*. In contrast, survival in *A. kenti* hosting *Cladocopium* declined below 40% by the end of the experiment with no differences between heat-evolved vs wild-type strains. We will discuss these results in the context of how different symbiont strains may be used to enhance the fitness of young corals and the potential applications for restoration efforts.

ID: 688 / Parallel Session 3-3: 6
Biology and Ecology of Holobionts in Coral Reefs

Keywords: photosymbiosis, sponges, autotrophy, ecosystem productivity

The contribution of sponges to coral reef primary productivity

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Coral reefs are celebrated for their primary productivity. Autotrophy by coral holobionts and (macro)algae defines these ecosystems and supports an unexpected biodiversity in nutrient-poor, sunlit waters. Recent Caribbean research has shown that, in terms of biomass, these rich communities are dominated by sponges, a group noted for their efficient heterotrophic feeding. The genomic repertoire of sponges nevertheless predicts that many species form symbioses with autotrophic and particularly photosynthetic microorganisms. However, in the absence of empirical evidence for the resulting mixotrophic potential, sponges have traditionally been excluded from coral reef productivity assessments. Here, we combine oxygen flux measurements with chlorophyl fluorometry and electron microscopy in 24 abundant Caribbean species, and find a large array of photosynthetic sponges present, where even a small population of photosymbionts accounts for a significant proportion of the metabolic needs of the sponge host. We further use stable isotope tracer experiments to show that photosynthetically fixed carbon is indeed shared with, and used by, the sponge host, and thereby made available to higher trophic levels. Finally, and in the context of the nested ecosystems theory, we synthesize our cellular and organismal level measurements with sponge abundance and reef productivity data and argue that the contribution of sponge primary productivity at the ecosystem level should no longer be overlooked.

ID: 237 / Parallel Session 3-1: 6
Biology and Ecology of Holobionts in Coral Reefs

Keywords: Gastric cavity, ecophysiology, microbiome, microsensors, coral

Exploring microbial niches in coral holobionts

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The coral gastric cavity is the fulcrum of many fundamental physiological processes, including feeding, reproduction, nutrient exchange and symbiont acquisition. Yet, due to the technical challenges of working in a small, semi-closed cavity, we still know very little about this vital compartment. We have used microsensors to characterise the physico-chemical environment in the coral gastric cavity both in the field and during experimental manipulation, revealing a gut-like low oxygen environment suitable for supporting specialised microbial communities. Additionally, we have developed microscale methods to sample and characterise the gastric cavity microbial community of individual coral polyps. Our results suggest that a core "gut microbiome" of corals, enriched in potential anaerobic and microaerophilic taxa, may exist at least for some species. Like the gut microbiome of higher organisms, these communities may play critical roles in coral health and resilience to climate change.

ID: 738 / Parallel Session 3-3: 8
Biology and Ecology of Holobionts in Coral Reefs

Keywords: climate change, single-cell transcriptomics, symbionts, microbiome, heat-stress

Single-cell transcriptomics reveal differential responses of mixed protist symbiont communities and host cells in corals during heat-stress

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Marine heatwaves caused by climate change lead to the stress-induced breakdown of coral-algal symbiosis referred to as "bleaching", threatening the continued survival of coral reef ecosystems worldwide. Since bleaching is at its core a cellular-response to heat-stress and since corals host a vast diversity of protist symbionts including many different dinoflagellates and apicomplexans, we developed a single-cell RNA sequencing (scRNA-seq) strategy to characterize the bleaching phenomenon from the microbial ecology perspective. We exposed replicate fragments of a colony of the endangered Caribbean coral *Orbicella faveolata* containing co-dominating dinoflagellate symbionts (*Durusdinium* and *Breviolum*; Family Symbiodiniaceae) to thermal stress and generated thousands of Symbiodiniaceae and coral cellular transcriptomes at four stages of bleaching. This allowed us to study, for the first time, the contemporaneous gene expression of individual microeukaryotic symbionts and coral cells under stress. In addition to identifying coral cell-specific responses to heat-stress, we found that *Durusdinium* symbionts, unlike *Breviolum*, showed significantly increased expression of antioxidants, allowing them to survive weeks of bleaching conditions. In contrast, we found not one but two different clusters of *Breviolum*, based on their transcriptomics profile, which decreased nitrate and ammonium transporter gene expression to different degrees in response to heat-stress. The *Breviolum* cluster which showed the least amount of decrease appeared to be more resilient than the other. It also exhibited higher expression of peridinin-chlorophyll a binding proteins and chloroplast envelope transporters compared to the less thermally tolerant *Breviolum*. This experiment has been repeated with the Mediterranean red gorgonian, *Paramuricea clavata*, which does not bleach and is dominated by Corallicolids and Syndiniales to compare and contrast the microbial gene expression between different anthozoans harbouring different microeukaryotic symbionts under heat-stress conditions. These results highlight the utility of scRNA-seq in studying microbial symbioses and deepen our understanding of marine host microbial ecology at the cellular level.

ID: 218 / **Parallel Session 3-1: 3**
Biology and Ecology of Holobionts in Coral Reefs

Keywords: Beneficial Microorganisms for Corals, coral spawning, microbiome, transgenerational transmission

Vertical transmission of coral probiotics and their effect on coral larvae heat-stress performance

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Microbes living in association with corals are known to establish a plethora of interactions with their host, among which some are considered positive. Research on coral probiotics focus on identifying culturable native beneficial microorganisms (BMCs) that can be administered to corals to increase their ability to withstand environmental stressors. The experimental evidence of the effectiveness of BMC treatment in aquarium systems set the foundation to upscale this practice to broad *in-situ* applications, with the intention of providing efficient and sustainable probiotics to vulnerable corals. Nevertheless, two critical aspects of the coral microbiome harnessing practice through BMCs have not been explored yet: 1) the degree of vertical transferability of probiotics in sexual reproduction events, and 2) the potential beneficial effects of BMCs inoculation during the early stages of coral development. To fill this gap of knowledge, we collected gametes from 10-months BMC- and placebo-treated colonies of *Acropora sp.* during a mass spawning event in April 2023, in the central Saudi Arabian Red Sea. The prokaryotic 16S rRNA gene was sequenced from parent coral colonies and their respective gametes and larvae crosses to evaluate the potential vertical transmission of the administered probiotics. To understand the effect of BMCs inoculation on larvae fitness under increased seawater temperature, larvae obtained from multiple cross-fertilizations were used in a 5-days heat-stress experiment (34°C), upon treatment with either probiotics or placebo, and their mortality rate was evaluated. The results of this study shed light into the long-term applicability of BMC treatment in a coral reef system and the potential beneficial effects and the degree of vertical transferability of probiotic inoculation on coral larvae.

ID: 423 / **Parallel Session 3-2: 4**
Biology and Ecology of Holobionts in Coral Reefs

Keywords: cell-cycle arrest, apoptosis, autophagy, expulsion, population models

Population models reveal cnidarian host regulatory mechanisms of the dinoflagellate symbiont population: from symbiotic onset to maintenance

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Regulation of resident symbiont populations by the host is central for maintaining stability of the cnidarian-dinoflagellate symbiosis. The importance of host regulatory mechanisms (cell-cycle arrest, autophagy, apoptosis and expulsion) during symbiosis onset and maintenance is largely unknown. In this study, we created population models to investigate biomass regulatory mechanisms during symbiotic onset (early and late onset) and maintenance in the cnidarian-dinoflagellate symbiosis. To gather data to input into our population models, we inoculated a symbiont-free model cnidarian (*Exaiptasia diaphana*, known as 'Aiptasia') with its native symbiont *Breviolum minutum*, and three heterologous non-native symbionts: *Symbiodinium microadriaticum*, *Cladocopium goreaui* and *Durusdinium trenchii*. We then measured host apoptosis *via* caspase-3 activity, host autophagy *via* immunoblotting, symbiont expulsion *via* microscopy and symbiont cell-cycle phase *via* flow-cytometry. During the early onset of symbiosis, cell-cycle arrest of the symbionts was negligible, whilst host autophagy and apoptosis were dominant features. During the late onset, there was dampening of host apoptosis and continued high rates of symbiont cell division, allowing rapid proliferation of the symbiont population. Concurrently, symbiont expulsion increased, and host autophagy remained elevated, presumably preventing the rapidly-proliferating symbiont population from overgrowing the host. As the symbiosis reached a maintenance state, host autophagy declined whilst host apoptosis, and symbiont expulsion and cell-cycle arrest increased. Finally, arrest of the cell-cycle of the symbiont population became the dominant feature of coordinating the growth of the host and symbiont population. These findings suggest key roles for symbiont cell-cycle arrest in symbiotic maintenance. Although there were species-specific nuances, the same overall regulatory patterns were seen in all cases, with cell-cycle arrest being dominant. Our study is the first to simultaneously measure all the proposed host biomass regulatory mechanisms across time in symbiosis, and between different Symbiodiniaceae species, helping to shed light on the cellular biology underpinning a stable cnidarian-dinoflagellate symbiosis.

ID: 540 / **Parallel Session 3-3: 2**
Biology and Ecology of Holobionts in Coral Reefs

Keywords: sponge microbe symbiosis, dissolved organic matter (DOM), sponge and microbial loop, nanoSIMS, macropinocytosis

Macropinocytosis by sponge cells drives dissolved organic matter uptake in sponge holobionts

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Dissolved organic matter (DOM), the largest pool of organic carbon in the ocean, is mainly processed and cycled by planktonic microbes through the so-called microbial loop. Although considered largely inaccessible as food source to animals, sponges have recently been discovered as prolific DOM-cyclers. On coral reefs, carbon cycling though the sponge loop can be in the same order of magnitude as primary production rates for the entire ecosystem. Although DOM processing is generally assumed to be driven by the abundant and diverse microbial symbionts of sponges, the precise mechanism by which sponge holobionts incorporate dissolved compounds is not known. Here, we use electron microscopy to visualize the uptake of gold nanoparticles from seawater into host filter cells (choanocytes) over time in the low microbial abundance sponge *Halisarca caerulea* and the high microbial abundance sponge *Plakortis angulospiculatus.* Seawater is internalized by choanocytes via the endocytic process of macropinocytosis. Using specific cellular inhibitors, we also confirm that macropinocytosis by host cells is responsible for the initial uptake of isotopically-labelled DOM by these sponges. Additional subcellular analysis using nanoscale secondary ion mass spectrometry (NanoSIMS) revealed that the assimilation of DOM by both choanocytes and symbiotic microbes was substantially reduced in the presence of pinocytosis inhibitors, indicating that the sponge microbiome internally recycles nutrients and is dependent upon the feeding activity of the host. Our findings emphasize the key role of the sponge host in the uptake and concentration of DOM, and highlight how the host and microbiome together form a highly adapted and efficient unit that can derive nutrition from even the most dilute food sources, such as in the oligotrophic waters surrounding coral reefs.

ID: 686 / **Parallel Session 3-3: 5**
Biology and Ecology of Holobionts in Coral Reefs

Keywords: gorgonians, host-microbe interactions, metagenomics, nutrient cycling, Endozoicomonadaceae

The temperate octocoral microbiome: from community structure and function to novel chitinases for the circular blue bioeconomy

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Octocorals are an integral part of benthic marine ecosystems, increasing habitat complexity, and biodiversity and playing key roles in coastal food chains. They associate with diverse microorganisms, including micro-eukaryotes, prokaryotes, and viruses. Our research on temperate octocorals showed that their microbiome is distinct from the environmental surroundings, host genus-specific, and undergoes complex structural changes under dysbiosis. However, the role of microbial symbionts that populate octocorals is still poorly understood. To shed light on their metabolic capacities, we examined 66 high-quality metagenome-assembled genomes (MAGs), spanning 30 prokaryotic species, retrieved from microbial metagenomes of *Eunicella verrucosa*, *Eunicella gazella*, *Leptogorgia sarmentosa* and seawater. Symbionts of octocorals were affiliated with *Endozoicomonadaceae*, *Candidatus* Thioglobaceae, and *Metamycoplasmataceae,* among others. Phylogenomics showed that the *Endozoicomonadaceae* MAGs represent a novel genus unique to temperate octocorals, denoted *Candidatus* Gorgonimonas. All *Candidatus* Gorgonimonas MAGs showed metabolic potential to thrive in suboxic surroundings and multiple host colonization and nutrient-providing traits. These symbionts harboured chitinase and chitin-binging protein-encoding genes, indicating that they hydrolyse the most abundant polysaccharide in the ocean. Examination of >40 genomes of cultured and uncultured *Endozoicomonadaceae* strains demonstrated that chitinases and other genes involved in chitin degradation are widespread in the *Endozoicomonadaceae* family, suggesting that these symbionts play important roles in chitin turnover in invertebrate animals and benthic ecosystems. Since Candidatus *Gorgonimonas* symbionts remain unculturable, we employed synthetic biology and heterologous expression to harness their enzymes. Two novel, active chitinases from symbionts of temperate octocorals were thus successfully produced. These chitinases presented a mesophilic activity spectrum, holding promise for upcycling of sea-food waste as chitin(ase)-derived added-value products find applications in multiple sectors, from biomedicine over the food industry to agriculture.

ID: 696 / **Parallel Session 3-3: 7**
Biology and Ecology of Holobionts in Coral Reefs

Keywords: symbiosis, proteomics, microalgae

Symbiosis-induced changes in cellular proteomic architecture of *Symbiodinium microadriaticum*

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Symbiodiniaceae dinoflagellates are microalgae that can form an endosymbiotic relationship with shallow water reef-building corals. While this relationship is obligate for the coral host and represents its primary carbon source, the symbiosis is facultative for Symbiodiniaceae, reflecting only one of a wide range of marine hosts. Transitioning from the seawater environment into a controlled intracellular vacuolar environment triggers physiological changes and morphological alterations that represent a fundamental life style change for the coral symbiont. Here we undertook a comparative proteomics approach to contrast the cellular landscape between the free-living (cultured) and intracellular life stage of *Symbiodinium microadriaticum* from the coral *Stylophora pistillata* (Red Sea specimen). Combining LOPIT (Location of Organelle Proteins by Isotopic Tagging) spatial proteome mapping with quantitative proteomics, we highlight how different cell organelles and their proteomic makeups respond to symbiotic engagement, thus providing insights into activity and role of protein actors on their subcellular stage. With regard to cellular architecture, two highlights are that symbiosis induces a complete dissolution of the dinoflagellate flagellar apparatus (a cluster with ca. 150 proteins) and a profound compositional change of the plasma membrane protein complement. Essential plasma membrane ion transporters such as nitrate transporters are replaced with their high-affinity counterparts in symbiosis, reflecting the nitrogen-limited state *in hospite*. Cell-wide quantitative proteomics demonstrates a decoupling of photosynthesis from symbiont cell growth and proliferation in symbiosis. Proteins of the thylakoid photosynthetic machinery (e.g. light harvesting), fatty acid biosynthesis, triglyceride mobilization, and ATP biosynthetic processes are significantly more abundant when in symbiosis, whereas proteins related to cytoplasmic translation machinery and ribosomal biogenesis are significantly down-regulated. These spatial proteomes can be used as cellular framework for interpreting and contextualizing physiological changes on the molecular level and will provide a detailed view on the symbiosis-induced plasticity of *Symbiodinium* protein architecture.

ID: 370 / **Parallel Session 3-2: 2**
Biology and Ecology of Holobionts in Coral Reefs

Keywords: GFPs, photobiology, acclimatization, Madracis, zooxanthellae

Confocal microscopy reveals tissue-level fluorescent protein responses of reef-building corals to light gradients over depth

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Green fluorescent protein (GFP)-like proteins are highly abundant and diverse in reef-building corals and can be categorized into two groups based on emission-excitation properties: fluorescent proteins (FPs) and chromoprotein. A well-supported hypothesis is that FPs modulate light use by coral photoautotrophic endosymbionts, either by shading them from excessive irradiance (shallow water) or re-emitting light at photosynthetically-active wavelengths in low light (deep water). To test this, we investigated the light modulation role of host FPs for different species in the coral genus *Madracis* over depth, by combining confocal laser scanning microscopy (CLSM) on histological sections with symbiont photobiology analyses (cell and pigment concentrations, photochemical activity). Our optimized CLSM approach, developed by analyzing the temporal response of FPs under controlled light conditions in an aquarium setting, allows to effectively characterize the distribution and intensity of different FP groups at the cellular/tissue level. We used this optimized CLSM approach to further investigate natural *in-situ* variation of FPs and symbiont photophysiology in three *Madracis* species (*M. senaria, M. decactis, and M. pharensis*) over depth on Curaçao reefs. Our findings indicate higher fluorescence intensity in green FPs (GFP) and higher ratios of GFP to symbiont chlorophyll concentration at 5-10m depth as compared to 20-25m depth. Results suggest that the animal component regulates the (adaptive) response to depth-light gradients, while the symbiont mediates (acclimatization) light-response to tissue orientation (top/side of colonies). Further results will be presented on the acclimation patterns and time-response of FPs in two *Madracis* species (*M. mirabilis, M. decactis*) during reciprocal-depth transplantation experiments, and on FP response in (bleached vs healthy) *M. pharensis* following the mass bleaching event of late summer 2023 in Curaçao. Our work illustrates how animal and symbiont are integrated at the tissue and cellular level to maximize coral holobiont performance under natural and stress conditions on the reef.

ID: 758 / Parallel Session 3-3: 9
Biology and Ecology of Holobionts in Coral Reefs

Keywords: Microbiome, prokaryotic diversity, coral, environmental drivers

Microbial diversity of Pacific reefs and their stony corals exceeds current estimates of the global prokaryotic diversity

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Coral reefs are among the most biodiverse marine ecosystems on Earth, providing a habitat for one third of all described marine species. Yet, we are uncertain of the prokaryotic diversity underlying this macrofauna diversity. Prokaryotic diversity in coral reefs has previously been estimated to approximate the total estimated global microbial diversity. This most recent estimate of about 2.8 million distinct prokaryotic taxa (ASVs) was based on plankton, fish, and coral samples from the Tara Pacific expedition across the Pacific Ocean. However, coral-associated microbial diversity was represented by only three species, leaving a knowledge gap to what extent comprehensive coral species sampling may alter such an estimate. Here, we report on an extensive sampling effort using a novel Tara Pacific dataset comprising 2450 samples across 47 coral genera. Integrating data from these samples into prokaryotic diversity estimates, we show that the contribution of corals to reef microbiome diversity is up to three times higher than previously estimated, prompting an upwards correction of the reef microbiome diversity alone to over 4 million ASVs. This number supersedes the current total estimated bacterial diversity on Earth. Our data further show that coral species harbour highly uneven microbiomes with some super-diverse coral hosts, the significance of which we currently explore. In addition, based on a comprehensive environmental data collection, we explore the abiotic and biotic drivers that shape coral microbiome composition. Our work highlights the large currently undescribed microbial 'dark matter' of coral reefs, at risk of being lost before we can fully appreciate and understand its importance to reef function, resilience, and survival.

Tara Pacific Consortium Coordinators:

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ID: 786 / Parallel Session 3-3: 10
Biology and Ecology of Holobionts in Coral Reefs

Keywords: Microbial niches, gastrovascular cavity, compartments, Galaxea, Next Generation Sequencing

Micro-sampling and mapping of bacterial communities across compartments in *Galaxea fascicularis*

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The coral holobiont harbors a diverse community of micro-organisms, which together form a system that creates large biogenic reefs under nutrient-poor conditions. Notably, bacteria play a crucial role in coral health, alongside symbiotic Symbiodiniaceae, and impact coral holobiont resilience under changing environmental conditions.

Due to the distinct micro-environmental conditions in the various coral compartments regarding pH, nutrient concentrations etc., bacterial communities are organized differently across the coral holobiont and possibly exhibit specialized functional profiles.

However, taxonomic characterization of microbial communities via Next Generation Sequencing typically involves DNA extractions from larger parts of colonies, including several polyps, thereby masking the potential heterogeneity of microbial communities associated to the different compartments of the cnidarian host.

We employed a combination of methodologies to sample bacterial communities from the different compartments of the scleractinian coral *Galaxea fascicularis* (gastrovascular cavity, mucus, tentacles, coenosarc tissue, skeleton) alongside whole polyp samples. This approach was aimed at understanding how compartmentalized sampling strategies are superior in deciphering the real complexity of the coral microbiome. The gastric cavity fluid and the surface associated community were sampled using a non-destructive method, combined with a micro-volume DNA extraction protocol, allowing for the extraction of bacterial DNA from the gastric cavities of individual polyps.

Our results show that taxonomic profiles differ between compartments, which highlights the importance of sub-polyp scale sampling when investigating the coral microbiome. Knowledge about the location of microbes within the coral host is crucial for the investigation of specific host-microbe interactions and the development of targeted probiotic-based conservation efforts.

ID: 809 / Parallel Session 3-4: 1
Biology and Ecology of Holobionts in Coral Reefs

Keywords: Aiptasia, bleaching, symbiont, symbiosis, isotopes

Unraveling metabolic pathways in Coral-Zooxanthellae symbiosis under heat stress

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Coral reefs face an escalating threat of bleaching events globally, primarily attributed to rising sea surface temperatures. The impact of heat stress on coral health involves intricate processes, including nutrient decoupling between corals and their symbionts, which intensifies the stress and destabilizes the symbiosis. To better understand how metabolic pathways are altered under heat stress and to explore the regulatory mechanisms of this symbiosis, we used isotope-labelling in the sea anemones Aiptasia to track the flow of nutrients between partners. By tracking 15N and 13C isotopes, we differentiated the contribution of each organism to the symbiosis, the key metabolic pathways involved, and how these were affected under heat stress. We hypothesize that anemones kept under control conditions will show a higher level of isotopes in the host tissues, highlighting the capability of the animal to recycle its own ammonium waste using the carbon backbone derived from symbiont-produced carbohydrates. Under heat stress, however, symbionts should gradually decrease the transfer of photosynthates which will result in an accumulation of isotopes in the symbionts' cells. These findings highlight the pivotal role of nutrient exchange in this symbiotic relationship. By observing how heat stress disrupts the nutrient flow between partners, our study helps us understand the mechanisms underlying symbiosis regulation. We propose that the resulting dysbiosis, characterized by nutrient exchange impairment, can trigger bleaching events and, ultimately, mortality if the process is not reversed.

ID: 116 / Parallel Session 3-1: 1
Biology and Ecology of Holobionts in Coral Reefs

Keywords: Host pigments, light propagation, heat transfer, colorful bleaching, numerical simulation

Understanding colorful bleaching in corals – a computational approach

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Loss of photosymbionts from coral host, known as coral bleaching, is a major threat to reef survival. Under mild/brief periods of heat stress, sometimes, bleached corals become increasingly colourful, due to upregulation of host proteins (HPs). Here we use numerical simulations to study the effects of colourful bleaching on the internal light flux and temperature in the host tissue. We numerically solve the radiative transfer of light to understand light propagation through stratified coral tissue and skeleton. This accounts for both elastic and inelastic scattering. The model considers broadband (PAR) wavelength dependent optical properties, fluorescence yield and heterogeneity of the HPs. Subsequently, heat transfer simulations, including thermal properties on micro-scale, explore the effect of light fluxes on internal heat generation. The outcomes are supported with experimental microsensor measurements of light and temperature at different locations in the 3D coral structure. HPs can lead to local enhancement of scalar irradiance, redistribution of light and increased heat generation with in the host tissue. However, the upregulation of the HPs leads to, relative, reduction in scalar irradiance and temperature within the tissue. This can facilitate recolonization of bleached corals by symbionts.

ID: 422 / **Parallel Session 3-2: 3**
Biology and Ecology of Holobionts in Coral Reefs

Keywords: Symbiosis, Sponges, Corals, Microbiomes, Manipulative-experiment

Let's have some symbiotic conversations: Holobiont functions mediate coral and sponge competition

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Coral reefs are dynamic biogenic frameworks that provide housing, food and protection for a diversity of organisms. Corals and sponges are key players in the three-dimensional architecture of these complex ecosystems. Both taxa can interact cooperatively through trophic coupling via local nutrient recycling processes. But they can also compete for limited space, especially under circumstances of accelerated habitat loss. In either interaction type, a series of biomolecules serve as food exchanges, or as mediators of stress, acclimatization and allelochemical responses. Most of the biochemical capacity in corals and sponges, however, is thought to reside in their associated microbiomes, which themselves are particularly sensitive to climate change and anthropogenic pressures. To what extent do microbial symbiont-derived biomolecules play a role in coral/sponge holobiont physiologies and ecological responses, and which specific metabolites are involved, are largely unresolved questions. In this study we performed manipulative alterations in the microbiomes of two selected competing species in Caribbean reefs (Bocas del Toro, Panamá): the boulder coral *Siderastrea siderea* and its bioeroding sponge pest *Cliona delitrix*. We combined antibiotic treatments with light limitation in order to disrupt microbial components (Prokaryotes, Fungi and Symbiodiniaceae). We monitored how the responses to these treatments were related to coral-sponge host interactions by contrasting responses where coral and sponge were either in physical contact or apart. Measured responses of the resulting modified holobionts included metabarcoding prokaryotic community characterization based on the 16S V_4 rRNA gene marker, untargeted metabolomics, targeted metabolite quantification, fatty acids profiling and stable isotope signatures of host and symbiont cells. We found evidence for substantial microbial contributions to host primary metabolism (i.e., nourishment and energy reserves), but also in signalling mechanisms during competition for space via secondary metabolites. Our research sheds light into the functional symbioses within holobionts with the potential to mediate interactions between corals and sponges.

ID: 236 / **Parallel Session 3-1: 5**
Biology and Ecology of Holobionts in Coral Reefs

Keywords: Nutrient cycling, resource competition, coral bleaching

Nutrient cycling underpins the maintenance and breakdown of cnidarian-algal symbioses

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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 understanding the processes that maintain it in the first place. Combining physiological, (phospho)proteomics, and (Cryo)NanoSIMS imaging approaches, here we investigated the metabolic regulation of symbiotic interactions in the stable and stressed cnidarian-algal symbiosis. We show that, in a stable state, mutualistic nutrient exchange in the symbiosis is passively maintained by competition for inorganic nutrients between the host and its 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.

ID: 247 / Parallel Session 3-2: 1
Biology and Ecology of Holobionts in Coral Reefs

Keywords: allelopathy, competition, symbionts, metabolomics, microbiome

Allelopathic interactions and ecological resilience of coral reefs under climate change stressors: Insights from multi-factorial experiments

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Coral reefs, vital for providing diverse ecosystem services, are facing unprecedented challenges due to global climate change. Our study used a series of multi-factorial experiments exploring the responses of the tropical marine sponges and coral reefs to escalating environmental stressors, particularly elevated sea surface temperatures.

We investigated the influence of the sponge allelopathy on the coral *Caulastrea furcata*. Extracts from three sponge species, including *Lendenfeldia chondrodes* and a soft coral were incorporated into phytagel and tested for their effects on coral fitness as well as metabolome and microbiome composition. Extracts from these invertebrates revealed a significant decrease in photosynthetic activity of coral symbionts. Alterations in microbial community composition and bleaching responses were evident in the presence of specific sponge extracts. In addition, the pronounced allelopathic effects observed caused also significant changes in the coral's metabolome. Elevated temperatures further intensified these effects, pointing towards potential shifts in the benthic composition of coral reefs under the influence of global climate change.

When considering the combined results, a consistent theme emerged. Elevated temperatures played a central role in amplifying the deleterious effects observed in the presence of invertebrate extracts. The symbiotic relationships within coral holobionts were particularly vulnerable, with shifts in microbial community composition, decreases in photosynthetic activity, and adverse impacts on the health of the hard coral. Notably, sponge extracts, especially those from *L. chondrodes*, exhibited significant allelopathic effects, contributing to coral bleaching and altered microbial and metabolomic profiles.

These findings collectively underscore the intricate dynamics at play within coral reef ecosystems. Biotic interactions, notably allelopathy, represent crucial stressors that can exacerbate the impacts of elevated temperatures. Understanding these complexities is paramount for predicting and mitigating the effects of climate change on coral reef communities.

ID: 460 / Parallel Session 3-3: 1
Biology and Ecology of Holobionts in Coral Reefs

Keywords: Heat stress, Coral holobiont, Coral bleaching, ROS, Symbiodiniaceae

High temporal resolution of hydrogen peroxide (H2O2) dynamics during heat stress does not support a causative role in coral bleaching

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Ocean warming due to climate change triggers the breakdown of the coral–algal symbiosis. Overproduction of reactive oxygen species (ROS) by thermally-stressed algal symbionts is commonly considered the proximate cause of this phenomenon, known as coral bleaching. However, direct evidence for algal ROS production (e.g., in the form of H2O2) and coral physiological stress being the ultimate causes of bleaching remains ambiguous. Here, we investigated the temporal dynamics of H2O2 and oxygen (O2) concentrations during thermally-induced coral bleaching to disentangle cause from consequence. Microsensors measured H2O2 and O2 concentrations directly on the tissue of *Pocillopora damicornis* nubbins exposed to baseline temperatures (30°C) and to minor (33°C), moderate (36°C), and high (39°C) levels of acute heat stress using the Coral Bleaching Automated Stress System (CBASS). We show that a temporary decline in O2 concentration, accompanied by a declining photosynthetic efficiency and loss of Symbiodiniaceae and pigmentation, is the initial response to moderate thermal stress. This response was neither provoked nor followed by an increased H2O2 concentration at the coral tissue. A steady light-independent increase of H2O2 was only detected during high heat stress, resulting in the complete and permanent loss of photosynthetic activity. Our findings do not support a direct connection between algal photodamage and an increase in H2O2 concentration during thermally-induced bleaching and call for further research on the function of H2O2. This notion is further substantiated by the observation of an additional source of H2O2, likely oxidative bursts, that were common at the baseline temperature and under minor heat stress, while infrequent under moderate and high heat stress. Resolving the multifaceted and dynamic roles of H2O2 in coral bleaching is critical to better understand the response of the coral holobiont to thermal stress and identifying the processes underlying the breakdown of the coral–algal symbiosis.

ID: 616 / **Parallel Session 3-3: 4**
Biology and Ecology of Holobionts in Coral Reefs

Keywords: coral larvae, coral meta-organism associations, algal-prokaryotic associations, coral reef microbiome, nitrogen pollution

Algal–prokaryotic associations maintain coral larval development under nitrate enrichments

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Coral meta-organisms consist of the coral, and its associated Symbiodiniaceae, bacteria, and other microbes. Corals can acquire photosynthates from Symbiodiniaceae, whilst Symbiodiniaceae uses metabolites from corals. Prokaryotic microbes provide Symbiodiniaceae with nutrients and support the resilience of corals as meta-organisms. Eutrophication is a major cause of coral reef degradation; however, its effects on the transcriptomic response of coral meta-organisms remain unclear, particularly for prokaryotic microbes associated with corals in the larval stage. To understand acclimation of the coral meta-organism to elevated nitrate conditions, we analysed the physiological and transcriptomic responses of *Pocillopora damicornis* larvae, an ecologically important scleractinian coral, after 5 days of exposure to elevated nitrate levels (5, 10, 20, and 40 µM). The major differentially expressed transcripts in coral, Symbiodiniaceae, and prokaryotic microbes included those related to development, stress response, and transport. The development of Symbiodiniaceae was not affected in the 5 and 20 µM groups but was downregulated in the 10 and 40 µM groups. In contrast, prokaryotic microbe development was upregulated in the 10 and 40 µM groups and downregulated in the 5 and 20 µM groups. Meanwhile, coral larval development was less downregulated in the 10 and 40 µM groups than in the 5 and 20 µM groups. In addition, a generalized linear mixed model, using least absolute shrinkage and selection operator, demonstrated that the Symbiodiniaceae could both benefit and cost coral larval development. Furthermore, the most significantly correlated prokaryotic transcripts maintained negative correlations with the physiological functions of Symbiodiniaceae. Results suggested that Symbiodiniaceae tended to retain more nutrients under elevated nitrate concentrations, thereby shifting the coral-algal association from mutualism towards parasitism. Prokaryotic microbes provided Symbiodiniaceae with essential nutrients and may control Symbiodiniaceae growth through competition, whereby prokaryotes can also restore coral larval development inhibited by Symbiodiniaceae overgrowth.

ID: 210 / **Parallel Session 3-1: 2**
Biology and Ecology of Holobionts in Coral Reefs

Keywords: Symbiosis, nutrients, Symbiodiniaceae, Darwin Paradox, symbiont farming

Digesting their photosynthetic symbionts helps reef corals thrive in nutrient poor environments

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Coral reefs are highly diverse ecosystems that thrive in nutrient-poor seas, a phenomenon frequently referred to as the "Darwin paradox". Nonetheless, even in nutrient-poor ocean basins, reefs can be replenished regularly with dissolved inorganic nitrogen (N) and phosphorus (P) from deeper, nutrient-rich water through upwelling, internal waves and vertical mixing. Substantial amounts of nutrients in their inorganic form are also released by filter feeders in the intimate vicinity of the corals or enter the reef from land-based sources. These inorganic forms of N and P constitute a key nutrient pool, which is, however, primarily accessible to the photosynthetic symbionts and not to the coral host. Accordingly, it is unclear to which extent dissolved inorganic nutrients contribute directly to the success of symbiotic corals.

We demonstrate that symbiotic coral animals can satisfy a substantial amount of their N and P demand through 'farming' and digestion of excess symbiont cells. Thus, we show that both the symbionts and the host gain growth-related benefits through the efficient, reciprocal exchange of the essential cellular nutrients. Since both organic and inorganic sources of N and P are overall scarce in oligotrophic tropical waters, the symbiotic lifestyle offers corals a truly competitive edge over exclusively heterotrophic animals that rely solely on N and P in organic forms, or exclusively autotrophic plants such as macroalgae that are restricted to N and P in dissolved inorganic form.

The fully closed cycle of reciprocal N and P exchange between the symbiotic partners can explain the evolutionary and ecological success of symbiotic corals in well-lit, nutrient-limited warm water habitats. It also underpins the vulnerability of symbiotic corals to disturbances of their nutrient environment.

ID: 824 / **Parallel Session 3-4: 2**
Biology and Ecology of Holobionts in Coral Reefs

Keywords: microbes, holobionts, Autonomous Reef Monitoring Structures (ARMS), reef cryptobiome, ocean acidification

Understanding the holobionts of the cryptic reef

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Microbes play vital roles across coral reefs both in the environment and inside and upon macrobes (holobionts), where they support critical functions such as nutrition and immune system modulation. These roles highlight the potential ecosystem-scale importance of microbes, yet most knowledge of microbial functions on reefs is derived from a small set of holobionts such as corals and sponges. The synthesis of knowledge across scales, from individual microbes and holobionts to ecosystem-wide communities and processes, has recently been called for by multiple authors. However, studies mostly neglect microbial roles, and microbe-macrobe interactions, in the vastly understudied coral reef cryptobiome, or the ~90% of reef diversity that lives hidden within the reef matrix. Here we showcase the use of Autonomous Reef Monitoring Structures (ARMS) and multi-omic data to investigate relationships between microbes and diverse coral reef holobionts. First, we highlight the impact of ocean acidification (OA) on whole communities of benthic organisms (e.g. sponges, tunicates, algae and bryozoans) and their microbial communities. Genetic and chemical data from ARMS sampled across CO_2 seeps in Papua New Guinea show that under OA the microbiome and metabolome of cryptobenthic communities become less compositionally distinct from those observed in sediments, suggesting environmental microbes colonise benthic communities to a higher degree under acidified conditions. Second, using ARMS from 43 sites across the Pacific Ocean we highlight the role of macrobial diversity in driving bacterial diversity on the cryptic reef, rather than biogeography or anthropogenic stress. Organism-scale studies provide information about the response of key species to environmental change. However, the holistic approach we demonstrate here is now needed to accurately evaluate and predict impacts on coral reefs. Our findings show that ARMS provide a novel tool for taking this "nested ecosystem approach" and elucidating the roles of microbes at ecosystem-scales.

ID: 226 / **Parallel Session 3-1: 4**
Biology and Ecology of Holobionts in Coral Reefs

Keywords: Trace elements, Cnidarian Holobiont, Radio isotope, Holobiont Stability, Resource Sharing

Unveiling critical resource sharing in the holobiont under different temperatures using radio isotopes.

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Cnidarians including Scleractinian corals inhabiting both temperate and tropical systems often form crucial symbiotic relationships with dinoflagellates from the family Symbiodiniaceae. Symbiodiniaceae can supply up to 95% of a coral host's nutritional needs, but under stress this relationship can breakdown. Thus, the future survival and distribution of corals largely hinges on how well they can sustain symbiosis to maintain their nutritional needs. Assessing nutrient dynamics of the coral-Symbiodiniaceae symbiosis typically involves destructive sampling that limits assessment of bioaccumulation. Here, we present an adapted gamma-emitting radioisotope tracer protocol developed specifically for use in studies pertaining to the resource sharing in cnidarian-Symbiodiniaceae symbiosis. Model cnidarian *Exaiptasia Diaphana* was tested in the initial experiment. Selenium (radioisotope ^{75}Se) was selected as the test element due to its essential roles in all plants and animals. Se is well known for its redox regulation properties and ability to increase photosynthetic efficiencies, making it an important element in cnidarian-Symbiodiniaceae symbiosis. Test taxa were exposed to selenium enriched artificial sea water, and rates of bioaccumulation were assessed, in conjunction with a suite of physiological assessments (e.g., fluorometry, respiration, symbiont cell density and chlorophyll a concentrations). Given the influence of external temperatures on cnidarian metabolic processes and metal speciation, the study was conducted at two temperatures (26 °C and 32 °C). The work provides new insights into the trace metal requirements of cnidarian under different thermal regimes and details a new method that can be optimised for other radiotracers and Cnidarian taxa.

Speed talks

ID: 239 / **Parallel Session 3-2: 7**
Biology and Ecology of Holobionts in Coral Reefs

Keywords: symbiosome, pH, regulation, cell cycle, photosynthesis

Symbiotic dinoflagellates on acid: low pH as a key regulator of symbiotic lifestyle

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The intracellular endosymbiosis between cnidarians and dinoflagellates from the Symbiodiniaceae's family is essential to sustain the structural and trophic foundation of coral-reef ecosystems. Such a tight relationship results of hundreds million years of co-evolution and adaptation of both partners to symbiotic lifestyle constraints. Regulation of the endosymbionts by the host is a key element to ensure symbiosis balance. The pH of the symbiosomal vacuole of the cnidarian gastrodermal cells has been shown to be particularly low (<6). Inside of this very acidic microenvironment, Symbiodiniaceae go through life cycle modifications: division rate reduction and flagella loss. We hypothesized that low pH is a fundamental parameter for the host to regulate its endosymbiont's life cycle and promote symbiotic interactions. We compared two cultivated strains of temperate Symbiodiniaceae originating from the sea anemone *Anemonia viridis*: the specialist *Philozoon actiniarum* and generalist *Breviolum psygmophilum* and we mimicked the symbiosome's acidic microenvironment *in vitro* by cultivating the cells at low pH (from 4 to 6). For both strains, we showed that cultivation at pH 4 and 5 induced motility and growth inhibition and we were able to link these effects to a cell cycle arrest in G2/M. Interestingly, while *B. psygmophilum*'s photosynthetic activity was not impacted by low pH, *P. actiniarum*'s photosynthesis was significantly enhanced at pH 5 and 6. To further investigate those results, we combined transmission electron microscopy with global carbohydrates and lipids measurements to analyse the morphologic and metabolic state of both strains. Overall, our results strongly support the hypothesis that symbiosome's acidic pH is involved in endosymbiont's regulation by the host and represents, especially for the specialist *P. actiniarum,* a key element for adaptation to symbiotic lifestyle.

ID: 506 / **Parallel Session 3-2: 20**
Biology and Ecology of Holobionts in Coral Reefs

Keywords: bacterial microbiome, Cnidaria holobiont, metabolism, genetic transformation, correlative imaging

Elucidating bacterial metabolic contributions to the cnidarian holobiont using a genetic transformation approach

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Research into the bacterial component of Cnidarian holobionts has increased considerably over the last decade. To date, the focus has primarily been to characterise the structure and stability of Cnidarian bacterial communities across phylogenies, ontogenies, gradients of abiotic stressors, health states, and within broad microhabitats of individual animals. The metabolic roles of specific bacterial taxa and the fine scale localisation of these endosymbionts and epibionts is still poorly understood. In this project, we use the photosymbiotic cnidarian model organisms, anemones *Aiptasia mutabilis* and *Anemonia viridis,* to further our understanding of the mechanistic interactions of cnidarian-associated bacteria with both the host and the symbiotic algae in order to elucidate their role in holobiont fitness. To do this, we combine experimental microbiome manipulation, genetic transformation, correlative imaging, and omics in a multipronged approach. Specifically, we isolated and characterised dozens of bacterial strains from wild Mediterranean *Aiptasia mutabilis* and *Anemonia viridis*. Candidate isolates with putative roles in metabolite assimilation and translocation to the anemone host or algal symbiont were selected through 16S rDNA gene sequencing and functional genomics. Moving forward, selected isolates will be tagged with fluorescent proteins via genetic transformation and used in host inoculation experiments. Stable isotope labelling coupled with a correlative fluorescence and NanoSIMS imaging will be used to both localise the bacteria and assess their metabolic interactions with other holobiont members *in hospite*. This workflow will be applied to experimental assays whereby environmentally relevant biotic and abiotic factors will be manipulated to investigate how these interactions are impacted by a changing environment. By studying metabolic interactions in light of their spatial dynamics, this approach promises to develop a mechanistic understanding of the bacterial contribution to cnidarian holobiont functioning.

ID: 366 / Parallel Session 3-2: 13
Biology and Ecology of Holobionts in Coral Reefs

Keywords: Holobiont, Resilience, Climate, Multi-omics

Coral holobiont complexity underlying climate resilience

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Reef ecosystems are in global decline, and predictions of catastrophic global loss of coral reefs due to anthropogenic activity made over 20 years ago are becoming a reality. Thus, it is important to devise new strategies that can mitigate coral bleaching, i.e., the loss of endosymbiotic microalgal symbionts driven by ocean warming. Corals show regional variation and species-specific responses to thermal stress. Hence, other factors besides latitude must play a role in determining thermal resilience, such as frequencies and severity of Sea Surface Temperature Anomalies (SSTAs) and Thermal Stress Anomalies (TSAs). Consequently, response norms vary over space and time with evidence that recent and prior exposure to (frequent) temperature anomalies increases thermal resilience, giving rise to the notion of “bright spots”. Here we comprehensively analysed coral holobionts from regional reefs in the strait of Lombok (Indonesia) that differ in their long-term climate variability but not their average maximum summer temperatures to assess how holobiont complexity maps onto thermal tolerance differences. We assessed host gene expression, algal association, and microbiome diversity and functional potential using a suite of next-generation sequencing approaches. Firstly, extending the catalog of microbial genes associated with coral metaorganisms is critical to further our (conceptual) understanding of how microorganisms contribute to coral holobiont function and stress tolerance. Secondly, multi-omics approaches allow to clarify if resilient holobionts carry unique molecular signatures that can serve as biomarkers and assist in the search and identification of ‘climate-proof’ sites.

ID: 669 / Parallel Session 3-4: 14
Biology and Ecology of Holobionts in Coral Reefs

Keywords: Benthic microalgae, biodiversity, phenotyping, photosynthesis

Photophysiological characterisation of three strains of *Halluxium pauxillum* alongside reference strains from six other Symbiodiniaceae genera

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Dinoflagellates belonging to the family Symbiodiniaceae play a crucial ecological role in coral reef ecosystems, as they form trophic, photosymbiotic relationships with a diverse range of coral species and other host organisms. However, in many cases the photosymbionts also retained the ability to live independent of their hosts, in the environment. In both cases, as trophic symbionts and as free-living microalgae, their photosynthetic activity appears to serve as their primary mode of nutrition. Recently, we isolated three novel Symbiodiniaceae strains from reef sands near Heron Island in the Great Barrier Reef, which we described as *Halluxium pauxillum* Calado, Craveiro & Frommlet 2020, and which are unlike any other available Symbiodiniaceae strains in that they display noticeably low levels of pigmentation, and they grow exceedingly slow in f/2 medium, a standard culturing medium for photolithoautotrophs. Here, we report on the characterisation of these three *H. pauxillum* strains in terms of their growth rates, pigment content, and photophysiology, as measured by Multicolour PAM fluorometry. The examined *H. pauxillum* strains exhibited growth rates and pigment contents an order of magnitude lower than six Symbiodiniaceae reference strains, each belonging to a distinct genus within the family. Furthermore, light curves indicate that one of the *H. pauxillum* strains has a lower tolerance to high light intensities compared to the other two strains and it showed similarities, both in terms of the wavelength-dependant functional absorption cross-section of PS II ($Sigma(II)_l$) and the QA reduction time constant (Tau), with a strain of the free-living species *Effrenium voratum*. Our study represents the first photophysiological characterization of *H. pauxillum*, highlighting their distinctiveness and potentially unique survival strategy compared to other strains within their family, and adding to the considerable range of physiological phenotypes inherent to this group of dinoflagellates.

ID: 745 / **Parallel Session 3-4: 18**
Biology and Ecology of Holobionts in Coral Reefs

Keywords: Amino acids, Metatranscriptomics, Metabolomics

Tissue-specific microbiome in cnidarian-dinoflagellate symbiosis

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Coral reefs are one of the most biodiverse ecosystems on Earth and owe their productivity to scleractinian corals and their symbiotic relationships. Corals are so-called holobionts that encompass the coral host, dinoflagellate symbionts, and a myriad of microorganisms, including bacteria, archaea, viruses, fungi, and protists. Research has primarily concentrated on understanding the metabolic interactions between the coral host and their dinoflagellate symbionts in the family Symbiodiniaceae. However, the contribution of bacteria to nutrient utilization in this context remains relatively underexplored. Here, we focused on the host-prokaryotic partnerships within the coral symbiosis model Aiptasia and examined its microbial assemblages across different tissue landscapes and symbiosis states. Tissue-specific metatranscriptomics highlighted that symbiosis reshapes the microbiomes. Symbiotic Aiptasia exhibited a significantly higher bacterial load, especially in their gastrodermal tissue layer. Functional analysis of differentially expressed genes suggested a critical role for these bacteria in nitrite assimilation. Isotope labelling with ^{15}N-nitrite and ultrahigh-resolution metabolomics confirmed that these bacteria process environmental nitrite and algae-derived photosynthates into essential amino acids. We propose that this microbiome restructuring constitutes a metabolic complementation that allows the host to tap into an important nitrogen source that is otherwise inaccessible to it, and that it potentially also provides a means to control nitrite as a source of nitrogen available to their dinoflagellate symbionts. Our study illuminates the often-overlooked roles of bacteria in coral metabolic productivity, providing new insights into the complex interdependencies that enable coral to thrive in typical nutrient-limited marine environments.

ID: 579 / **Parallel Session 3-4: 7**
Biology and Ecology of Holobionts in Coral Reefs

Keywords: stony coral tissue loss disease, Symbiodiniaceae, algal symbionts

The role of algal symbionts (Family Symbiodiniaceae) in the relative susceptibility of Indo-Pacific corals to stony coral tissue loss disease (SCTLD): implication for disease spread

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Stony coral tissue loss disease (SCTLD), perhaps the most virulent and pervasive coral disease recorded to date, has spread throughout Florida and the wider Caribbean and has left already vulnerable scleractinian coral populations dwindling and, in some cases, ecologically extinct. Field observations and laboratory studies have shown SCTLD disproportionally affects corals associating with algal symbionts in the genus *Breviolum*, with coral colonies exclusively associating with *Breviolum* showing a 2-fold increase in SCTLD susceptibility. However, members of other Symbiodiniaceae genera, such as *Cladocopium* and *Durusdinium* are not immune. Here, we tested the relative susceptibility of four Indo-Pacific coral species to SCTLD using a standardized-exposure laboratory assay. Using susceptible and non-susceptible Caribbean coral species as internal controls, we compared the response of the Indo-Pacific coral species associating with members of *Cladocopium* and *Durusdinium* in a 30-day exposure period. We found these Indo-Pacific species showed no signs of SCTLD despite the fact that Caribbean coral species showed the same Symbiodiniaceae susceptibility hierarchy we previously documented (*Breviolum*>>*Cladocopium* and *Durusdinium*>>*Symbiodinium*). Moreover, we found that *Acropora cervicornis*, a non-susceptible Caribbean coral, showed some signs of disease in these closed-system trials suggesting the disease dose administered in our experiments likely exceeds that on reefs. Together, these findings indicate that Indo-Pacific species hosting Indo-Pacific *Cladocopium* and *Durusdinium* are not susceptible to SCTLD and indeed may be less susceptible than putatively non-susceptible Caribbean species. These results further support *Breviolum*, which is much more common in Caribbean corals, as the principal risk factor underpinning SCTLD susceptibility, point to further research investigating intrageneric variation in susceptibility among some Symbiodiniaceae, and suggest that Indo-Pacific reefs may be at lower risk of SCTLD due to the hosted algal symbiont communities. Indeed, the tendency of Mediterranean corals to host *Breviolum* may lead to a higher risk of SCTLD than their Indo-Pacific counterparts.

ID: 355 / **Parallel Session 3-4: 22**
Biology and Ecology of Holobionts in Coral Reefs

Keywords: Probiotics, Holobiont, Aiptasia

Functional testing of microbiome bacterial isolates to increase thermal tolerance of the coral model Aiptasia

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Host-microbe symbioses form a central part of coral biology, given their reliance on associated prokaryotic and microalgal symbionts. Thus, microbiome-targeted active interventions in the form of probiotics or microbiome transplants are emerging as potential solutions to counter environmental stress. Although probiotic provisioning is shown to improve coral bleaching recovery, the mechanistic underpinnings are unknown. Research progress is hindered by coral holobiont complexity and a lack of standardized diagnostics to assess the impact of microbiome manipulations. Here, we present our efforts to address existing shortcomings by employing short-term acute thermal stress assays to obtain standardized phenotype diagnostics, generating bacterial isolate libraries, and pre-testing approaches to achieve high throughput probiotic screening using the coral model Aiptasia. We further present the development of a broadly applicable protocol to transform probiotic bacterial isolates with fluorescent reporter-carrying plasmids to elucidate colonization success, residency, and spatial assemblage. These efforts provide an avenue to identify and molecularly examine the mechanisms underlying microbiome-conveyed thermal tolerance.

ID: 406 / **Parallel Session 3-2: 15**
Biology and Ecology of Holobionts in Coral Reefs

Keywords: holobiont, nanopore, shading

Long-term shading does not lower *Montipora capitata* thermal tolerance

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Light intensity plays a central role in the biology of coral holobionts. Reduced light intensity is known to mitigate coral bleaching, the breakdown of the coral-Symbiodiniaceae mutualistic relationship. It is thus hypothesized that deeper reefs could act as potential refugia for shallow reefs if sea surface temperatures and solar irradiance rise beyond coral tolerance thresholds. However, the extent to which such habitats with decreased light intensity profiles may induce changes in the taxonomic composition and the function of coral holobionts remains unknown. We herein aim to address this question through a controlled, in-situ experiment conducted at the Hawai'i Institute of Marine Biology coral nursery. We fragmented nine *Montipora capitata* coral colonies in six identical pieces, placed half of the resulting fragments at ambient light and the second half at reduced light. We performed shading using a cotton line fabric of 73% shading efficiency, and monitored the coral colonies for two years. We used a dual, full-length 16S and ITS2 DNA metabarcoding approach trough Nanopore sequencing to describe microbial and microalgal diversities. Our findings show distinct bacterial community structure among light treatments accompanied by significant changes in photosynthesis rates and symbiont densities. Additionally, genotype was the strongest predictor of photosymbiont clade prevalence, with no evidence of light-associated shift. This genotypic signal is congruent with patterns of observed mortality, with clade-D-dominated coral genotypes showing the highest mortality rates at ambient light. Our results suggest that acclimatization mechanisms include microbiome restructuring and photosynthesis regulation, and highlight how genotype-specific associations may alter such responses. We provide valuable insights into how corals respond to decreased levels of light intensity, which is critical in the context of the deep reef refuge hypothesis.

ID: 413 / **Parallel Session 3-2: 16**
Biology and Ecology of Holobionts in Coral Reefs

Keywords: Zooxanthellae, Dyes, Post-thaw cells, Cryopreservation, Cnidarian-Dinoflagellate Symbiosis

Evaluating existing methods to assess the viability of *Breviolum* sp. in culture and development of new methodology.

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Coral reefs are the most spectacular and diverse ecosystems of tropical oceans. Corals rely on the mutualistic relationship between scleractinian corals and photosynthetic dinoflagellates of the family Symbiodiniaceae (zooxanthellae) which are crucial to the health of the host cnidarian. To better understand zooxanthellae, laboratory culture model systems are one valuable tool allowing for experimental manipulation. However, the maintenance of algal cultures is expensive and labor-intensive. Cryopreservation offers a solution for long-term storage of cultures, but a system is needed to reliably assess cell viability after thawing. Multiple methods to assess the viability of zooxanthellae exist, but many of these are tested on dead zooxanthellae killed with heat which is of little use when trying to assess the viability of cells killed by freezing. Therefore, we evaluated the utility of existing viability methods to assess live vs frozen-killed *Breviolum* sp. (formerly Clade B) isolated from the sea anemone *Aiptasia* spp. Of 38 dyes tested on zooxanthellae maintained in culture, none could distinguish live from frozen-dead cells despite replicating exactly published methods or varying concentrations and staining times. For cultured cells, live vs frozen-dead cells could easily be differentiated by a shift in autofluorescence from red to bright green for the latter. In contrast, freshly isolated live vs frozen-dead zooxanthellae could be differentiated using Acridine Orange and DAPI. These could be a promising method for evaluating the viability of cryopreserved zooxanthellae.

ID: 769 / **Parallel Session 3-4: 20**
Biology and Ecology of Holobionts in Coral Reefs

Keywords: dinoflagellates, free-living life history, autoendolithic niche, horizontal transmission

Recruitment of endolithic Symbiodiniaceae by *Exaiptasia diaphana* sea anemones from symbiolites

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Most coral species acquire their microalgal symbionts from the environment as young recruits. Environmental populations of potential symbionts reside predominantly in benthic habitats such as reef sands, and previous studies could show that reef sands promote symbiont recruitment. The discovery that free-living symbionts in culture can form microbialites, so-called symbiolites, that encase the microalgae as viable endolithic cells, and field-based evidence that indicates that the formation of endolithic symbiont communities also occurs naturally in reef sands, led us to the hypothesis that symbiont recruitment could involve the acquisition of endolithic Symbiodiniaceae populations. To test if cnidarians can access endolithic symbionts, we presented symbiolites to *Exaiptasia diaphana*. Both symbiotic and bleached anemones actively ingested symbiolites for up to several hours before egesting them again. The latter behaviour enabled us to document symbiolites before and after ingestion. Using light microscopy and microscopy imaging-PAM fluorometry, we assessed the effects of ingestion on symbiolites and on the photophysiology of the endolithic cells. Symbiolites frequently showed signs of moderate mineral dissolution and the number of endolithic cells was often reduced following ingestion. Meanwhile, F_v/F_m of remaining endolithic cells showed no negative effects of having been ingested. In another experiment, we assessed whether endolithic cells could be recruited as symbionts. For this, chemically bleached anemones were inoculated with symbiolites containing a compatible symbiotic strain, alongside several controls involving planktonic cells and a non-symbiotic strain. To assess symbiont acquisition, chlorophyll autofluorescence of anemones was recorded non-invasively for two weeks. Thereafter, symbiont densities were quantified and normalized to host protein. Both methods provided clear evidence for the ability of anemones to acquire endolithic symbionts. Our study provides first evidence for the ability of cnidarians to release and recruit endolithic symbiont populations, processes that could potentially play a major role in symbiont recruitment on the reef.

ID: 601 / **Parallel Session 3-4: 11**
Biology and Ecology of Holobionts in Coral Reefs

Keywords: green fluorescent pigments, coral optical properties, light environment, photobiology

Characterization of green fluorescent pigments (GFP) in coral tissues under light-limited conditions

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Corals have adapted to optimize light capture under different environmental conditions, and it has been suggested to be one of the most efficient organisms at collecting light and utilizing light energy in nature. In this sense, the internal light environment in corals can be modified due to variations in the coral tissue and skeletal optical properties. Additionally, green fluorescent pigments (GFP) granulates produced by corals have been proposed to play an important role in the modulation of the internal light environment of corals. Depending on the location of GFP granules, they are suggested to be photoprotective or photosynthesis enhancing. Here, we experimentally acclimated *Favia* sp. fragments to shallow and deep light conditions in flowthrough aquarium systems to understand how GFP granulates optical properties change as a function of light availability in corals and to test the photoprotection and photosynthesis enhancement hypotheses proposed for GFPs. Coral tissue optical properties, light capture, steady state electron transport rate and photosynthesis were characterized. Moreover, to study the role of GFPs in light capture, the location and structure of GFP aggregates were characterized using Optical Coherence Tomography and airyscan confocal laser-scanning microscopy. We found differences in coral photobiology and optical properties under such contrasting light environments but no differences in the photobiology between specific coral areas with GFP aggregations compared with areas with no GFP aggregates.

ID: 200 / **Parallel Session 3-1: 14**
Biology and Ecology of Holobionts in Coral Reefs

Keywords: coevolution, boring bivalves, reproductive cycle, coral host

Life history traits of the holobiont: Corals and their macro symbionts boring bivalves

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Coral reefs, the most biodiverse and productive marine ecosystems, are built upon numerous coevolutionary interactions. Many studies have highlighted the importance of micro-symbiosis relationships, such as those involving corals and dinoflagellate algae, while the potential roles of macro-symbiotic relationships in certain key processes in coral-reef ecosystems have been comparatively overlooked. This study is part of a wide, long-term project aiming to better understand the long-debated coral-bivalve symbiotic relationship, uncovering potential co-evolved processes affecting the health of coral reefs.

The boring bivalve *Leiosolenus lessepsianus* is an obligatory species-specific symbiont of the coral host *Stylophora pistillata in the northern Gulf of Eilat/Aqaba.* The annual reproductive cycles of corals with and without boring bivalves were studied using histological examination to examine potential effects of boring bivalves on the life-history traits of the coral host. In addition, the annual reproductive cycle of the boring bivalves was studied to elucidate possible co-evolved processes between the symbiotic partners.

These observations were subsequently compared with a large-scale, unpublished, similar dataset, acquired five decades ago. Our findings suggest the presence of co-evolved reproductive traits between the associated partners. The bivalves initiated their reproductive cycle several weeks prior to the coral hosts. Upon the onset of coral reproduction, a reduction in its calcification rate is expected, owing to energetic constraints, consequently leading to a decrease in its growth rate. This specific timeframe might be advantageous for the juvenile bivalves to undergo metamorphosis and growth. This process appears to alleviate the competitive pressure arising from the need to keep pace with the coral's growth through decalcification. Despite notable shifts in the timing of reproductive peaks for both bivalves and corals, their synchrony endured over time, supporting the hypothesis of specific co-evolved traits in their life history.

ID: 294 / **Parallel Session 3-2: 9**
Biology and Ecology of Holobionts in Coral Reefs

Keywords: Symbiosis, microbiome, Mediterranean, Maldives

New insights into the microbiome composition of Mediterranean and Maldivian coral species

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In the last 15 years, coral associated microbiome emerged as an extremely important research field for its key role in the health-status of corals and their potential response to diseases and environmental changes. Despite these evidences, nowadays our knowledge of microbial communities associated with corals remains remarkably scarce, especially in the Mediterranean and Maldivian area, due to the novelty of this topic and the difficulties related to the analysis protocols.

In this context, this study aimed to describe and compare for the first time the microbiomes associated with three species of scleractinian corals: two from the Mediterranean Sea (*Cladocora caespitosa* and *Madracis pharensis*) and one from the Maldives (*Herpolitha limax*). Taxonomic analyses were conducted by Illumina sequencing of the V5-V6 16S rRNA hypervariable regions.

From the analysis of beta diversity, calculated on the relative abundance of the 19 most abundant families, it was possible to infer the existence of two distinct microbiomes, one on the Mediterranean coral specimens (mainly Comamonadaceae) and the other one on *Herpolitha limax* individuals (mainly Burkholderiaceae and Nocardiaceae).

Moreover, the microbiome of healthy and diseased (Brown Band Disease) individuals of *Acropora tenuis* collected in the Maldives was analysed, revealing the presence of genera as *Acinetobacter* sp., *Bacillus* sp., *Oceanobacillus* sp., *Streptococcus* sp., *Marinobacter* sp., *Brevundimonas* sp., *Achromobacter* sp. and *Stenotrophomonas* sp., but also some important differences in terms of values of biodiversity indexes with other already published studies.

Further studies are needed to better understand how the different biotic and abiotic factors shape microbiome composition; this information could be crucial to define the microbiome role in coral survival, especially in the modern context of global climate change. Furthermore, these findings could also be used to improve the main mitigation tools currently used to cope with the problem, such as coral restoration.

ID: 477 / **Parallel Session 3-2: 18**
Biology and Ecology of Holobionts in Coral Reefs

Keywords: Light acclimation, Photodamage, Photorepair, Excess energy, Energy budget

Energetic cost of coral photoacclimation: Scaling up physiological performance into ecological models

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Photoacclimation of reef-building corals across depth gradients involves modulating a suite of physiological traits, eliciting specific physiological states. Regulation of protein turnover facilitates these changes and is considered the largest contributor to the maintenance costs of all living cells. Insufficient physiological and molecular knowledge regarding coral acclimatory mechanisms and costs has hampered our ability to predict their responses to stressors. In this study, we aim to test the hypothesis that high-light acclimation proportionally raises the energetic costs for zooxanthellae metabolic maintenance (i.e., increased protein turnover), affecting the amount of energy that could be translocated to the coral host. To investigate this hypothesis, we exposed corals to four light conditions ranging from a diurnal exposure of 4 to 32 mol quanta m^{-2} day^{-1}, simulating a depth gradient equivalent to 34 - 4 m depth (K_d = 0.07 m^{-1}). After a period of 4+weeks, biometrics revealed distinct coral photoacclimatory phenotypes. Respiration rates increased proportionally with light exposure, indicating an elevated demand for ATP, while maximum gross photosynthesis remained unaffected by differential light treatments. Furthermore, increased light exposure resulted in significant reduction in tissue pigmentation, exponentially enhancing coral efficiency in light absorption. We quantified diurnal Photosystem-II (PSII) damage-repair activity from zooxanthellae *in hospite* by Pulse-Amplitude-Modulation (PAM) fluorometry in the presence and absence of the protein inhibitor chloramphenicol, and by measuring (*psbA*) D1 protein abundance through western blots and PSII-complex transcript abundance through RNA-sequencing. An exponential decay of PSII lifetimes ($t_{1/2}$,h) with increased light exposure is documented, resulting in corals increasing PSII turnover rates (day^{-1}) to maintain optimal photosynthetic activity in such conditions. Our findings support the increased metabolic demands for photorepair at increasing light levels. Finally, a primary productivity model was developed to integrate the varying light-dependent cost of photoacclimation, resolving adjustments in the symbiosis energy balance across the vertical distribution of zooxanthellate corals.

ID: 667 / **Parallel Session 3-2: 11**
Biology and Ecology of Holobionts in Coral Reefs

Keywords: Microbial community, nutrients, coral holobiont, seawater stoichiometry

Effect of seawater N:P stoichiometry on coral-associated prokaryotic communities

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Reef-building corals form associations with both symbiotic algae and diverse bacterial communities. These coral-associated bacteria are thought to play a role in nutrient cycling and defending against pathogenic bacterial taxa, thereby providing nutrients to both host coral and algal symbiont and protection against disease. However, coral-associated bacterial communities are highly diverse and responsive - varying with environmental conditions, host coral species, and holobiont health status. Because of this, the exact function of these bacterial communities is poorly understood, and their relative importance in different coral species remains elusive. Furthermore, the influence of altered seawater N:P stoichiometry on coral-associated microbial community structure is not well defined. Here, we show the differing physiological and bacterial community responses of two phylogenetically and morphologically divergent reef-building corals to altered seawater nutrient availability. We find that the reef-building corals *Turbinaria reniformis* and *Pocillopora damicornis* associate with markedly different bacterial communities under optimal conditions, whilst altered seawater nutrient availability results in a species-specific response of the microbial community. Interestingly, we show that whilst microbial communities are host species specific across nutrient landscapes, bacterial community network structure is lost in both *Turbinaria reniformis* and *Pocillopora damicornis* under nutrient imbalanced conditions. Our results demonstrate how coral-species specific changes in microbial community structure could contribute to the physiological response and tolerance of the host coral to environmental stress. Investigating how environmental stressors shape species-specific coral-associated microbial communities will help determine the effects of nutrient stress on coral reef ecosystems under a changing climate.

ID: 498 / **Parallel Session 3-1: 7**
Biology and Ecology of Holobionts in Coral Reefs

Keywords: metabolomics, DOM, microbial ecology, bleaching

Coral bleaching alters coral organic matter exudation and reef microbial communities

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Coral bleaching events are degrading reef habitats worldwide. While the process of bleaching is heavily studied not much is known on the implications of bleaching events for water column microbes and its biogeochemistry. During a bleaching event on the reefs of Mo'orea in 2019 we measured how unbleached and bleached corals alter dissolved organic matter (DOM) exudation in response to thermal stress. Further we investigated the effects of the respective exudates on reef water microbiomes, in terms of growth and community structure. When experiencing thermal stress the unbleached corals tripled their DOM release compared to ambient temperatures, whereas the previously bleached corals exhibited similar DOM release rates at elevated and ambient water temperatures. The exometabolome released by all stressed corals (heated and/or previously bleached) was compositionally distinct from the healthy controls. Further all stress-exometabolomes significantly enhanced microbial growth, enriching for copiotrophs and bacterial taxa related to known pathogens. We predict that positive feedbacks perpetuated by the stress exometabolites released by bleached corals will cause shifts in the water column microbiome, ultimately impacting the health of the reef community. At the onset of a bleaching, the dramatic pulse of DOM released by stressed corals induces microbial growth that negatively impacts the whole community (even corals that did not bleach originally). Translated to a reef-wide scale these feedback mechanisms could severely affect susceptibility of systems to thermal anomalies and the trajectory of mass bleaching events. Reefs that have recently experienced bleaching events may be less affected by these feedback loops due to the decreased exometabolites release of previously bleached corals. Also reefs with already lower coral cover or higher abundance of DOM consumers like sponges may evade this feedback loop and so increase their resilience towards thermal variations.

ID: 164 / Parallel Session 3-1: 12
Biology and Ecology of Holobionts in Coral Reefs

Keywords: Managed breeding, hybrid, genetic diversity, *Acropora*, thermal tolerance

Algal symbiont (Family: Symbiodiniaceae) partner is driver of thermotolerance among Floridian Caribbean Acroporids

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Reef-building staghorn and elkhorn corals, *Acropora cervicornis* and *Acropora palmata*, have experienced severe declines over the past several decades. Although restoration efforts through asexual propagation and outplanting have been successful throughout the Caribbean region, managed breeding efforts are needed to rebuild genetic diversity and guard against further declines. *A. palmata* and *A. cervicornis* can breed to make the *Acropora* hybrid, a coral that has grown faster than both parent species and has been speculated to withstand higher thermal thresholds. In August 2022, we created 9 unique *A. palmata* and 9 unique hybrid crosses through assisted breeding of *A.palmata* and *A.cervicornis* from Florida's Coral Reef. A year later, we ran a 30-day heat stress experiment to compare the thermal thresholds of *A. palmata* versus hybrid *Acropora* juveniles. Chlorophyll fluorometry was used to measure photochemical efficiency (Fv/Fm) and tissue samples were taken from all juveniles throughout the experiment to measure changes in symbiont-to-host (S:H) cell ratios. All juveniles hosted *Durusdinium trenchii*, an algal symbiont that has been shown to increase thermal tolerance in corals. Despite a significant difference in quantified bleaching (relative symbiont-to-host (SH) cell ratio) ($p=0.047$), there was no significant difference in thermotolerance between A.palmata and the hybrid ($p=0.337$), indicating that dominance by *Durusdinium trenchii* might negate difference in thermotolerance between Acroporid species. These data may enable ranking of heat tolerance among juveniles that can inform future selective breeding of *A. palmata* and the hybrid and the potential for *Durusdinium trenchii* to further enhance thermal tolerance. Future work will include breeding novel combinations of *A. cervicornis* and *A. palmata* parents with high thermal thresholds to populate our dwindling reefs.

ID: 491 / Parallel Session 3-2: 19
Biology and Ecology of Holobionts in Coral Reefs

Keywords: Coral Reefs, Thermotolerance, Cryptic species

Physiological state and thermal performance of *Pocillopora grandis* and *Pocillopora verrucosa* varies by season.

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Pocillopora species are diverse and contain multiple morphologically similar cryptic lineages that can co-occur. To test the hypothesis that thermal tolerance varies between dominant *Pocillopora* species in Mo'orea French Polynesia, first, in May 2022 we surveyed the relative abundance *Pocillopora spp* using mtORF and PocHistone markers. Second, both in May and December 2022 we examined the physiology of *Pocillopora grandis* and *Pocillopora verrucosa*. Third, both in May and December 2022 we quantified thermal performance of *P. grandis* (mtORF Haplotype 1a), and *P. verrucosa* (mtORF Haplotype 3b) at 6 temperatures from 22-36°C using a thermal performance curve approach. We found significant differences in physiological parameters and in thermal performance curves of photosynthesis between *P. verrucosa* and *P. grandis* in May, but not in December. Physiologically, *P. grandis* displayed higher values compared to *P. verrucosa* for chlorophyll-a, symbiont soluble protein, and symbiont ash free dry weight in the cooler, higher light season of May of 2022, but these metrics were statistically indistinguishable in the warmer, lower light season of December 2022. These results are likely driven by differential seasonal acclimatization of *Cladocopium pacificum* in *P. verrucosa* versus *Cladocopium latusorum* in *P. grandis*. Curve fitting of metabolic rates supported the physiological results, where Ctmax and Rmax for photosynthesis were greater in *P. verrucosa* in May, but there was no difference in December and Rmax was significantly lower in both species. While dark respiration rates increased with temperature, there were no differences in curve parameters between species at either sampling points. This work suggests thermal tolerance will depend on species of symbiont hosted and the baseline state of the symbiosis at the point of thermal stress. Collectively, it provides us an enhanced understanding of thermal tolerance differences between cryptic species, with implications for their populations on future reefs under climate change.

ID: 663 / **Parallel Session 3-4: 13**
Biology and Ecology of Holobionts in Coral Reefs

Keywords: symbiosis, thermal resilience, metagenomes, coral microbiome

Microbial insights into the high thermal resilience of Arabian Gulf corals

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Escalating degradation of global coral reefs due to climate change has instigated a worldwide pursuit to identify resilient coral species and comprehend underlying future survival mechanisms. The Arabian Gulf, with its naturally extreme environment where corals thrive in temperatures exceeding 35°C for prolonged periods, serves as a unique setting for unraveling the adaptive processes necessary for thermal stress survival. While the coral microbiome has long been hypothesized as a critical mechanism, the specific functional roles of coral-associated prokaryotes remain poorly understood despite extensive research in this field. Here, we investigate bacterial functional dynamics within the coral *Platygyra daedalea* over a five-month period, spanning the extended summer season, across two environmentally distinct locations—one characterized as thermally benign (Snoopy rock, Fujairah) and the other as thermal extreme (Saadiyat reef, Abu Dhabi). Our analysis reveals consistent stability in the composition of coral-associated bacterial communities over time at both sites. However, metagenome-assembled genomes (MAGs) extracted from *P. daedalea* unveil notable differences in microbial functional potential. Functional gene analysis indicated that elevated temperatures (> 34°C) heighten the virulence potential of coral-associated bacterial communities. Additionally, genes associated with viral defence, antimicrobial activity, sulphur and nitrogen metabolism, and evidence of stress resistance exhibit increased abundance of these genes in response to higher temperatures. Intriguingly, despite the stability in bacterial community composition, the functional gene profiles of the overall microbiota underwent significant alterations. Our findings shed light on the nuanced responses of microbial communities during environmental temperature shifts, emphasizing the pivotal role played by specific microbial members and the intricate mechanisms enabling them to potentially contribute to coral resilience.

ID: 590 / **Parallel Session 3-4: 8**
Biology and Ecology of Holobionts in Coral Reefs

Keywords: microbial ecology, biogeochemistry, symbiosis, metabolism

Exploring the Influence of Trophic Strategies and Natural Environmental Change on Coral-Associated Denitrification

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Nitrogen (N) is fundamental for biomass production in coral reef environments. Despite the importance of N for corals, an N-limited state is required for corals to maintain the symbiotic relationship with their algal symbionts, i.e., Symbiodiniaceae. Recent research discovered specific microbes -namely denitrifiers- that may aid in alleviating the coral from excess N. Yet, detailed knowledge about drivers of coral-associated denitrification is lacking. Thus, we investigated how coral-associated denitrification is affected by the trophic strategy of the coral and by natural seasonal change. We expected that highly autotrophic corals would exhibit higher denitrification than those more heterotrophic, as denitrifiers likely rely on photosynthates released by the Symbiodiniaceae. Additionally, we hypothesised that environmental parameters like nutrient availability and water temperature would be drivers of denitrification. We selected four Red Sea corals that vary in their trophic strategy: *Stylophora pistillata, Acropora* sp., *Millepora dichotoma, Tubastrea coccinea*. We measured their denitrification activity over a year via COBRA-assays, whilst concurrently measuring environmental parameters. We found 4-fold higher denitrification activity in the fully heterotrophic *T. coccinea* compared to the mostly autotrophic *S. pistillata*. It is thus apparent that denitrifying microbes do not solely rely on photosynthates for their energy supply. We also found a strong positive correlation between denitrification and temperature for *Acropora* sp. and *T. coccinea* with relative denitrification activity 3-fold higher in summer compared to winter. Surprisingly, we found no correlation between denitrification and environmental inorganic N concentrations across the year. Based on our findings, we anticipate seeing species-specific increases in denitrification activity with rising temperatures. With increased internal N availability under elevated temperatures (due to higher amino-acid catabolism), we speculate that increased denitrification may help to maintain an N-limited state, thereby preserving the health of the coral holobiont. Our findings deepen our understanding of the complex cycling of nutrients within coral holobionts.

ID: 431 / **Parallel Session 3-2: 17**
Biology and Ecology of Holobionts in Coral Reefs

Keywords: coral reef fishes, host-microbe interactions, environmental change, marine biodiversity, Panama

Sister Species an Ocean Apart: Investigating the drivers of coral reef fish microbiome composition across the Isthmus of Panama

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Three million years ago, the rise of the Isthmus of Panama caused dramatic environmental shifts that set populations of coral reef organisms on separate evolutionary trajectories. Organisms separated by the Isthmus adapted to different environments, forming pairs of sister species. The microbes that interact with these sister species adapted in tandem with their hosts, creating an unparalleled natural experiment to understand the evolution of host-microbe interactions within coral reefs. We investigate the ecological and evolutionary factors driving microbiome composition using seven pairs of sister fish species from Pacific and Atlantic reefs in Panama. Given the importance of the external environment in shaping marine species' surface microbiomes, we expected the fishes skin microbiome to cluster by ocean, whereas the gut microbiome – which has been shown to be influenced by host factors such as diet and phylogeny – would be more strongly driven by host species, such that sister fish gut microbiomes would be more similar than those of distant relatives inhabiting the same ocean. We find evidence for the importance of the host in structuring both skin and gut microbial communities, suggesting long-lasting and important symbioses. However, as predicted, gut microbiomes were more strongly linked to host species than skin microbiomes, likely due to greater host control coupled with the selectivity of the internal gut environment. Gut microbial profiles were more similar across species within dietary strategies (e.g., corallivorous butterflyfishes) and between sister species pairs which indicates that shared host traits play a role in structuring microbiomes. These sister fish species and their unique evolutionary histories are an ideal system to expand our understanding of the drivers underlying coral reef holobionts and, consequently, our ability to protect the diversity of coral reef organisms faced with rapid environmental change.

ID: 221 / **Parallel Session 3-2: 6**
Biology and Ecology of Holobionts in Coral Reefs

Keywords: holobiont, genome, chromosome, linkage map, recombination rate

Title: Adaptive capacity of endangered Caribbean holobionts is not limited by the recombination rates of the hosts

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Coral holobionts face unprecedented rates of environmental change. Adaptation to this change is in part driven by genomic structure and diversity of host and symbionts. Here, we present chromosome-scale genome assemblies and genetic linkage maps of two critically endangered coral species, *Acropora palmata* and *A. cervicornis*. These Caribbean acroporids have 14 chromosomes and comparable genome sizes. Chromosome structure was also similar between species but smaller translocations and inversions were observed that may help explain the low fertility of their F1 hybrid (*A. prolifera*). By comparing offspring to parents, genetic linkage maps for *A. palmata* and *A. cervicornis* were constructed. *A. palmata* and *A. cervicornis* have high sex-averaged genome-wide recombination rates (3.53 cM/Mb and 3.04 cM/Mb, respectively) relative to other animals. Both host species associate predominantly with one species of photosynthetic symbiont: Symbiodinium “fitti”. Nevertheless, genomic population structure analysis of *S. fitti* shows that algal populations are differentiated by host species. The genomic resources now available for Caribbean Acroporids and their symbionts enable unprecedent insights into the adaptation dynamics of coral holobionts. These data sets revealed that adaptive capacity of *A. palmata* and *A. cervicornis* is not likely to be limited by their recombination rates. Together, the assemblies and genetic maps presented here enable genome-wide association studies and discovery of quantitative trait loci; tools that can aid in the conservation of these endangered corals.

ID: 208 / **Parallel Session 3-2: 5**
Biology and Ecology of Holobionts in Coral Reefs

Keywords: Probiotics, Microbiome Stewardship, Mesocosm, Endozoicomonas, Beneficial Microorganisms for Corals (BMCs)

Insights into the culturable community and symbiosis-related traits of bacteria from long-term aquarium and Red Sea tropical octocorals

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Corals are under unparalleled pressure due to climate change, with octocorals (Subclass *Octocorallia*) being affected by rising temperatures, pathogens, and anthropogenic disturbances too. Host-microbe interactions play key roles in octocoral health, but our ability to benefit from such interactions to preserve octocorals remains underexplored. This project examines the role of aquarium facilities in octocoral microbiome conservation and aims to develop a 'probiotic cocktail' to mitigate climate change-induced stress in octocorals. Three tropical octocoral species, *Litophyton* sp., *Lobophytum* sp. and *Sclerophytum* sp., from a long-term aquarium mesocosm (Oceanário de Lisboa), and two octocoral species, *Litophyton* sp. and *Sclerophytum* sp., from the Red Sea, were sampled. The taxonomic composition of octocoral-associated microorganisms was assessed through cultivation-dependent and -independent analyses. While metagenomics analyses are ongoing, a total of 152 bacterial strains were isolated in our culture-dependent approach with strains grouping into six bacterial classes, 14 orders and 27 genera. Additionally, six unclassified isolates were obtained, likely representing new bacterial families in the *Alteromonadales* and *Cellvibrionales* orders. The collection comprised multiple, 'hard-to-cultivate' genera such as *Endozoicomonas*, *Fictibacillus*, and *Flammeovirga*. The *Endozoicomonas* genus has been frequently suggested as a core symbiont of healthy corals. Based on genus-level diversity, phenotypic screenings for host-beneficial properties of 25 bacterial isolates were performed. Twenty-two isolates presented antioxidant properties, eighteen showed cellulose- and nine chitin-degradation capabilities, with *Actinobacteria* frequently degrading both polysaccharides. Antimicrobial activity was tested against coral bacterial and fungal pathogens under control (26ºC) and stress (34ºC) temperatures and 19 isolates displayed antagonism towards pathogens under heat stress conditions. The preservation of core symbionts of corals in captivity highlights the possibility of using sustainable, man-made ecosystems as repositories of stable and healthy coral microbiomes. The observed antimicrobial and enzymatic activities indicate potential beneficial traits among our isolates. Mesocosm experiments are now underway to determine their probiotic effects in octocorals.

ID: 383 / **Parallel Session 3-2: 14**
Biology and Ecology of Holobionts in Coral Reefs

Keywords: Corals, CSIA-AA, isotopes, feeding, stress

To whom benefits heterotrophy in corals? An investigation done by Compound-Specific Isotope Analysis in Amino Acids

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The intricate symbiotic relationship between corals and photosynthetic dinoflagellates underpins the formation of coral reefs. This association is based on the capacity of each partner to exploit different nutrient sources and on the continuous exchange of nutrients between the partners. While it has long been established that dinoflagellates transfer photosynthates to the coral host for nutrition and calcification, the reciprocal transfers from the host to the symbiont have remained relatively unexplored.

To shed light on this mutual exchange, a first experiment was carried out by maintaining the scleractinian coral *S. pistillata* under three different conditions: pure autotrophy (light with no food), pure heterotrophy (no light, only food), as well as under mixotrophy, for several weeks at 26°C. At the end of the treatments, ^{13}C and ^{15}N - CSIA-AAs (Compound Specific Isotope Analysis in Amino Acids) was applied. Surprisingly, the results showed that heterotrophy mainly increased the ^{15}N-AAs of the symbionts, giving them a trophic status equal to 2.3, generally attributed to carnivores. This result suggests that heterotrophy mainly benefitted the symbionts under normal growing conditions. A second experiment applied a thermal stress to corals maintained under mixotrophy, where we showed that prey capture decreased under thermal stress. However, the trophic index of both the host and the symbionts significantly increased, suggesting nevertheless increased heterotrophy. These two experiments were combined with experiments where corals were fed with ^{15}N enriched preys, showing that N allocation between host and symbiont is species specific. All together, these results show a diversity of behaviours, which could be one of the keys to the adaptation of corals in stressful situations.

ID: 532 / **Parallel Session 3-4: 4**
Biology and Ecology of Holobionts in Coral Reefs

Keywords: microbiome, metabolomics, porifera

Microbial communities, metabolomics profiling, and secondary metabolites of a mediterranean sponge (*Petrosia ficiformis*) from CO_2 vents

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Ocean acidification (OA) is recognized to be a major threat for calcifying species. Porifera has been forecasted to be as "winners" under OA due to the lack of a calcareous skeleton. In particular, Demospongiae shows great plasticity to adapt to varying environmental conditions due to their calcification independence for growth. *Petrosia ficiformis* is a high microbial abundance demosponge, widespread in the Mediterranean Sea. Its distribution ranges from dim light to dark habitats, including caves. Microbial communities associated with *P. ficiformis* have been previously studied, revealing anatomical peculiarity (bacteriocytes), exclusive horizontal transmission and associations with specific cyanobacteria. Its microbiome is furthermore considered to produce a variety of chemical compounds, including secondary metabolites with still unknown ecological functions. These compounds comprise several polyacetylene species, of which the petroformynes are the main family. CO_2 vent systems are used as "natural laboratories" for future OA conditions. This allows the possibility to study organisms over long-term exposition to low pH conditions. Here we aimed at disentangling phenotypic acclimatization traits in the microbiomes, metabolomics patterns, and secondary metabolite profiling using a multidisciplinary approach. We compared *P. ficiformis* populations living in low pH conditions at a CO_2 vent system and ambient pH conditions, outside the influence of the emissions (control sites), off Ischia Island (Naples, Italy). Our results showed microbiome and metabolomics dissimilarities across sampling sites with different pH conditions, and correlations between defining taxa and metabolites. Specimens from ambient pH sites had overlapping microbiomes, diverse from those from the vent sites. Metabolomics and secondary metabolites profiling, instead, showed differences only in specimens sampled from one of the vent sites. In essence, *P. ficiformis* revealed general tolerance to OA. Microbiome flexibility, together with a marked growth plasticity, are likely to contribute to the adaptation capabilities to low and variable pH environmental conditions.

ID: 728 / **Parallel Session 3-4: 17**
Biology and Ecology of Holobionts in Coral Reefs

Keywords: coral bleaching, oxylipin, nitric oxide, preconditioning

Are oxylipins the next step in the bleaching cascade after Reactive Oxygen Species increase?

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Coral bleaching has been studied for decades to unravel the physiological mechanisms behind this phenomenon. It is mainly hypothesized to begin with a burst in Reactive Oxygen Species (ROS), but the following steps have not been completely resolved. As ROS are mostly produced in chloroplastic and mitochondrial membranes-associated electron transport chains, the role of oxidized fatty acids/oxylipins is worth exploring. Such compounds have already been identified as the signalling molecules following ROS after exposure to some abiotic stresses in plants. Here, we did not observe ROS increase after the addition of 2,4-Decadienal/2,4-DD (an oxidation product of w-6 polyunsaturated fatty acids) neither in *Breviolum minutum* nor in *Exaiptasia pallida* H_2, which tends to confirm the appearance of oxylipins downstream and not upstream of ROS. During the bleaching cascade, after a heat stress for example, an increase in NO has been measured in anemones. Here, we observed that 60 µM 2,4-DD doubled NO content in both symbiotic and bleached *E. pallida*. A similar NO increase was observed in cultured *B. minutum* although requiring a higher concentration of 500 µM. Thus, the animal is more sensitive to oxylipins than its microalgae. Oxylipins are known to play a role in the immune system and this is why genes encoding for their enzymatic production are downregulated in healthy symbiotic anemones. Given our preliminary results, and the ability of oxidized fatty acids to cross membranes, we will explore the following hypothesis for the bleaching cascade: oxylipins production by ROS with spontaneous/non-enzymatic reactions in Symbiodiniaceae, mainly with photosynthesis, membranes crossing, and immune response triggering in the animal. Alongside this potential role in bleaching, preconditioning experiments are ongoing to determine if small doses of oxylipins can enhance the defences of anemones against heat stress, as already shown in plants.

ID: 759 / **Parallel Session 3-4: 19**
Biology and Ecology of Holobionts in Coral Reefs

Keywords: photosymbiosis, invertebrate, algae, single-cell transcriptomics, waminoa

Know the enemy to not fear: understanding the photosymbiotic coral-dwelling flatworm *Waminoa* at cellular resolution

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The flatworm *Waminoa* (phylum Xenacoelomorpha) is a basal bilaterian symbiotic with dinoflagellate algae and lives on tropical marine sediments and as an ectosymbiont on coral surfaces. *Waminoa* can represent a threat to corals by competing for light and prey capture and consuming coral mucus, in some cases stripping the coral of its protective cover. Despite being a relevant component in coral reef ecosystem function, little is known about the coral-worm relationship, worm ecology, and the molecular basis of the worm-algae photosymbiosis. Therefore, a better understanding of *Waminoa* holobiont function at the cellular level can offer crucial insights into their role in coral reef health. Further, there is a need to develop non-cnidarian photosymbiotic systems to study the convergent evolution of dinoflagellate symbiosis across animals and how those symbioses function at molecular levels. Our lab has established *Waminoa* as such a model, with asexual and sexual reproduction in laboratory cultures, isolation of algal symbionts, and the production of aposymbiotic animals that can be repopulated with symbiotic algae.

To investigate the holobiont function at the cellular level, we used single-cell transcriptomics of live dissociated symbiotic worms captured on the 10X Genomics platform. From 5734 cells mapped to a *de novo* transcriptome we generated, we identified 12 clusters covering host cell types. In cells containing symbiotic algae, we found diverse marker genes upregulated, including those related to carbohydrate metabolism, likely connected to algal photosynthate production. We are using FISH to localize key marker genes in these cell types in the holobiont. Finally, we are also using LC-MS metabolomic platforms to further investigate the photosymbiosis by measuring polyketide toxin production in symbiotic and aposymbiotic *Waminoa* and free-living algae. Thus, we aim to establish this small tropical flatworm as an emerging molecular model to study photosymbiosis in coral reef organisms

ID: 159 / **Parallel Session 3-1: 11**
Biology and Ecology of Holobionts in Coral Reefs

Keywords: Octocorals, Tropical Eastern Pacific, microbiome, extended phenotype, acclimation.

Microbial shifts associated to ENSO-derived thermal anomalies reveal coral acclimation at holobiont level

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The coral microbiome conforms a proxy to study effects of changing environmental conditions. However, scarce information exists regarding microbiome dynamics and host acclimation in response to environmental changes associated to global-scale disturbances. We assessed El Niño Southern Oscillation (ENSO)-derived thermal anomalies shifts in the bacterial microbiome of *Pacifigorgia cairnsi* (Gorgoniidae: Octocorallia) from the remote island of Malpelo in the Tropical Eastern Pacific. Malpelo is a hot spot of biodiversity and lacks direct coastal anthropogenic impacts. We evaluated the community composition and predicted functional profiles of the microbiome during 2015, 2017 and 2018, including different phases of ENSO cycle. The bacterial community diversity and composition between the warming and cooling phase were similar, but differed from the neutral phase. Relative abundances of different microbiome core members such as *Endozoicomonas* and *Mycoplasma* mainly drove these differences. An acclimated coral holobiont is suggested not just to warm but also to cold stress by embracing similar microbiome shifts and functional redundancy that allow maintaining coral's viability under thermal stress. Responses of the microbiome of unperturbed sea fans such as *P. cairnsi* in Malpelo could be acting as an extended phenotype facilitating the acclimation at the holobiont level.

ID: 168 / **Parallel Session 3-1: 13**
Biology and Ecology of Holobionts in Coral Reefs

Keywords: Coral disease, gene expression, machine learning

Leveraging coral disease transcriptomic datasets for the development of predictive and classification machine learning models

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Coral disease is a significant and increasing threat to coral reef systems, especially to Caribbean ecosystems where white plague (WP) and stony coral tissue loss disease (SCTLD) have decimated reefs. One of the more destructive characteristics of these diseases is their ability to affect multiple coral species and spread quickly on a reef. Elucidating species susceptibility and forecasting impacts to coral community structure during and after disease outbreaks are key goals of disease research. We have numerous disease datasets containing gene expression from multiple coral species, including two parallel transmission experiments to study the susceptibility of WP and SCTLD. Large scale transcriptomic datasets from these experiments can be leveraged to understand various aspects of the diseases, including the description of shared coral and algal symbiont response, unique species-specific responses to diseases, and disease resistance or risk in corals pre and post epidemic. We are also applying novel machine learning algorithms to these datasets to predict disease in healthy coral and provide tools to classify and diagnose different diseases. Using several approaches such as support vector machine recursive feature elimination (SVM-RFE), logistic regression, Partial Least Squares Discriminant Analysis (PLS-DA) paired with differential expression analysis, we find that a subset of genes can predict if a coral will likely get disease and a set of several hundred genes that classify WP and SCTLD infected corals. Some notable pathways that delineate differences between corals infected with WP and SCTLD involve protein trafficking, apoptosis and autophagy/symbiophagy. The application of machine learning tools for transcriptomics research plays a crucial role in unravelling the molecular mechanisms underlying coral disease susceptibility and in developing useful models for predicting disease outcomes and classification algorithms that may inform conservation and restoration activities.

ID: 148 / **Parallel Session 3-1: 10**
Biology and Ecology of Holobionts in Coral Reefs

Keywords: Marine microbial ecology, holobionts, host-microbe interactions, cross-talk

Frenemies on the reef? Resolving the coral-*Endozoicomonas* association

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Stony corals are poster child holobionts due to their intimate association with diverse microorganisms from all domains of life. We are only beginning to understand the diverse functions of most of these microbial associates, including potential main contributors to holobiont health and resilience. Among these, bacteria of the elusive genus *Endozoicomonas* are widely perceived as beneficial symbionts based on their genomic potential and their high prevalence and ubiquitous association in coral tissues. Simultaneously, evidence of pathogenic and parasitic *Endozoicomonas*-lineages in other marine animals is emerging. Synthesizing the current knowledge on the association of *Endozoicomonas* with marine holobionts, we challenge the perception of a purely mutualistic coral-*Endozoicomonas* relationship and propose directions to elucidate its role along the symbiotic spectrum.

ID: 137 / Parallel Session 3-1: 9
Biology and Ecology of Holobionts in Coral Reefs

Keywords: Mitochondrial DNA copy number, Coral Aging, digital droplet PCR, Coral reproduction

Mitochondrial DNA content decreases from larvae to adulthood

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Most molecular biomarkers and methods used to evaluate aging, (e.g., telomere length) are laborious, have low throughput, and yielded conflicting results regarding coral aging. Recent studies have revealed declining mitochondrial DNA copy numbers (mtDNA-CN) with chronological age in mice, fish and humans. The specific mechanism controlling this decline remain largely unknown, although age-related decline in mitochondrial function has long been considered a hallmark of aging considering mitochondria vital role in energy production. We explored the potential of mtDNA-CN as a biomarker for aging and health in a fast growing, presumably 'short-lived' scleractinian coral—*Stylophora pistillata*. Mitochondrial DNA was quantified across *S. pistillata* age groups and from colony centre and periphery. We designed a TaqMan assay specific for *S. pistillata* mitochondrial and nuclear genes, which allowed absolute quantification of mtDNA-CN per cell using droplet digital PCR (Bio-Rad). We found the highest mtDNA content in *S. pistillata* larvae, followed by week-old settled individuals (spats), and adult colonies. The colony periphery (growing branch tips) and spats were not significantly different, while the oldest area of the colony, near the center, had the lowest number of mtDNA-CN per cell. We did not find a significant effect of colony size on mtDNA content at the colony periphery or centre. These findings assert expected differences in energy demands within the colony and across age groups: actively swimming larvae have high energy demand, and spats and colony edges experience high cell proliferation accompanied by mitochondrial proliferation, compared to the centre of the colony.

ID: 594 / Parallel Session 3-4: 9
Biology and Ecology of Holobionts in Coral Reefs

Keywords: bleaching susceptibility, metabolomics, symbiosis

Metabolomic signatures predict heat stress performance of a *Montipora capitata* population hosting *Durusdinium sp.*

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Anthropogenic increases in ocean temperatures cause widespread bleaching and pose a severe threat to the global persistence of coral reefs. Resilience-based conservation practices aim to harness the natural occurrence of thermal tolerance found in certain species and genotypes with the aim to enrich this trait within the population, but the cellular and molecular mechanisms underpinning the phenomenon of variable heat sensitivity remain poorly understood. Heat tolerance has primarily been attributed to the algal symbiont community hosted by the coral, with symbionts of the genera *Durusdinium* being particularly resilient. Both the symbiont, the host, and their interaction, however, contribute to the resilience of the holobiont. By heat stress testing a population of 54 colonies of *Montipora capitata* from a single reef in Kāne'ohe Bay, Hawaii, we observed that coral genotypes principally hosting symbionts of the genera *Durusdinium* exhibited a wide range in bleaching thresholds. We collected samples of these colonies prior to heat stress and used high resolution mass spectrometry to analyse the metabolome to determine if there were inherent signatures of bleaching resilience in the holobiont. A machine learning model predicted the heat stress performance with high accuracy. *M. capitata* colonies hosting any *Cladocopium* sp. symbionts were distinctly different from those with *Durusdinium* sp., but the metabolome of the *Durusdinium* colonies were still strongly predictive of heat stress outcomes. Top metabolite predictors of thermal tolerance were from a range of metabolite classes such as small polar metabolites, peptides, steroids and triacylglycerols. Our findings provide new insight into metabolic pathways underpinning thermal tolerance in these corals, which is valuable for selecting coral with better thermal tolerance traits for restoration practices aimed at boosting the resilience of native populations.

ID: 545 / **Parallel Session 3-4: 5**
Biology and Ecology of Holobionts in Coral Reefs

Keywords: Cassiopea, heat stress, proteomics, photosynthesis, Symbiodiniaceae

Tolerance of *Cassiopea andromeda* and its symbionts *Symbiodinium microadriaticum* to mild and long-lasting heat stress through proteomic adaptations in both partners

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The symbiotic partnership between cnidarians and Symbiodiniaceae displays a complex energetic metabolism, involving respiration from both partners and photosynthesis from the dinoflagellates. Despite the major importance of these two processes, their interplay and regulations remain poorly studied. Abiotic factors can unsettle the symbiotic balance, leading to the collapse of the association and threatening the survival of entire ecosystems. Among them, the rise in sea water temperature is getting more and more concerning as global warming takes place. We explored this topic by examining the emerging model organism Cassiopea, which was found to be easily culturable and offers an alternative to stony corals for studying symbiosis.

Our approach involved examining the impact of a sustained rise in water temperature (four weeks at 32°C, with growth temperature at 26 °C) on the energetic physiology and total proteome of *Cassiopea andromeda* medusae and their symbionts, *Symbiodinium microadriaticum*.

The jellyfish from both control and heat-stressed groups exhibit similar growth patterns, alongside analogous symbiont and pigment density, as well as comparable photosynthetic yields and respiration rates. To understand the factors that ensure this stability at the cellular scale, bottom-up proteomics was conducted on total protein extracts. Out of the approximately 4000 proteins identified in separated animal tissues or isolated symbionts, *ca.* 100 Cassiopea proteins and *ca.* 300 *Symbiodinium* proteins exhibit differential expression patterns between heat-stressed and control jellyfish. A deeper analysis of the role of these proteins will allow us to unveil processes involved in the tolerance of this symbiosis. Despite this stability at 32°C, the heat-stressed jellyfish showed an increased sensitivity to a subsequent increase in water temperature up to 34°C.

Overall, these results suggest that *Cassiopea andromeda* and its symbionts cope with a long-lasting mild heat stress and that this tolerance is mediated by a significant change in proteome expression.

ID: 572 / **Parallel Session 3-4: 6**
Biology and Ecology of Holobionts in Coral Reefs

Keywords: Trophic plasticity, Mesophotic, Symbiodiniaceae, Experimental and field approach

Symbiosis along a depth gradient in a temperate gorgonian

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Global warming and human pressures are impacting shallow coral populations around the world. However, mesophotic coral ecosystems, subjected to more stable environmental conditions, are generally thought to be less vulnerable and more protected from disturbances than shallower ones. *Eunicella singularis* is one of the most common gorgonians in the Mediterranean Sea and the only one presenting a symbiosis with dinoflagellate algae, which enables for a mixotrophic feeding strategy. This species inhabits in a wide bathymetrical gradient with contrasting environmental conditions, especially for light availability. Understanding of the trophic plasticity of *E. singularis* along a depth gradient could be crucial to develop effective and efficient conservation action. Our results (from microscopy and genetic analysis) confirm that deep populations of *E. singularis*, previously considered as asymbiotic, present photosymbiont cells in their tissues. Moreover, chlorophyll a concentration per symbiotic cell is significatively higher in colonies from deep populations (>40 m depth) than in shallow ones (<20 m depth), suggesting a photoacclimatization of symbiont cells along the light gradient. The trophic plasticity experiment showed that colonies from 30 m depth can faster acclimate to light environmental changes. In contrast, the high mortality rates observed in colonies from 60 m depth after 6 months exposed to shallow conditions suggest that an excessive light intensity can cause a symbiont photodamage that generates reactive oxidative species (ROS). Therefore, deep populations could present a reduced flexibility in photoacclimatization of their symbiotic cells, whereas upper mesophotic populations could present a high phenotypic plasticity. This phenotypic plasticity offers a particularly powerful mechanism to cope with short-time environmental change fluctuations, which can be of crucial importance for species to respond to current and future climate change. Therefore, the protection of upper mesophotic populations should be prioritized, since could be essential in the future for the conservation and persistence of the species.

ID: 323 / **Parallel Session 3-2: 10**
Biology and Ecology of Holobionts in Coral Reefs

Keywords: Trophic strategy, reef-building coral, autotrophic and heterotrophic lifestyles, nutrient pollution

Trophic strategy exerts profound control on the response of reef-building coral to nutrient pollution

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Coral reefs are the most biodiverse and productive marine ecosystems on the planet, providing invaluable ecological goods and services. Unfortunately, many coral reefs are undergoing rapid global degradation due to human-induced nutrient pollution. Reef-building corals have the unique ability to live a mixotrophic lifestyle: depending on the food source, corals can obtain energy and nutrients from either their endosymbionts (autotrophic lifestyle), or fromallochthonous organic sources (heterotrophic lifestyle). This ability to use or switch between multiple trophic strategies is essential to coral stress resilience, thus playing a crucial role in maintaining the health and productivity of coral reef ecosystems. However, it remains largely unclear how corals use these different trophic strategies to respond to nutrient pollution. To address this question, our study pre-incubated *Galaxea fascicularis* samples under various nutrient conditions: in-situ conditions, enhanced heterotrophic conditions, and enhanced autotrophic conditions by feeding the coral with Artemia or supplying ammonia as the nutrient source. After 28 days of incubation, corals with different trophic strategies demonstrated distinct differences in symbiont densities, C:N ratios, and growth rates. Additionally, our coral samples were then spiked with $^{15}N\text{-}NH_4^+$ and $^{13}C\text{-}HCO_3^-$ to trace the uptake rate and fate of fixed carbon and nitrogen. We found that corals with different trophic strategies have distinct responses to nutrient amendment. The heterotrophic lifestyle corals showed higher DIC and NH_4^+ assimilation rates, and retained a higher fraction of the fixed carbon and nitrogen. By contrast, the autotrophic lifestyle corals displayed lower DIC and NH_4^+ assimilation rates and higher carbon and nitrogen release rates. These results suggest that trophic strategy has a profound impact on the response of coral to nutrient input, providing new insights into understanding the interaction between coral metabolism and nutrient pollution.

ID: 244 / **Parallel Session 3-2: 8**
Biology and Ecology of Holobionts in Coral Reefs

Keywords: nitrogen, elevated temperature, physiology, microbiome

The Great Barrier Reef coral *Acropora kenti* responds to heat stress and nitrate enrichment with shifts in its metabolism and in its associated microbial community.

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Coral holobionts are sensitive to multiple environmental stressors, rendering the understanding of drivers of coral resilience and demise intricate. Although the impact of heat stress on coral bleaching has been extensively studied, much remains to be learned about the complexity of the coral responses, particularly when elevated temperatures occur in concert with other environmental factors. Nitrogen plays a fundamental role in coral holobiont functioning, but the effect of its most abundant environmental form, nitrate, on the coral response to stress is equivocal. While nitrate sustains symbiont communities, it has also been reported to adversely affect responses to oxidative stress and exacerbate bleaching. Using a crossed treatment experimental design in a mesocosm setup, we aimed to identify the individual and combined effects of heat stress and nitrate enrichment on the physiological performance and the microbiome of the Great Barrier Reef coral *Acropora kenti*. Over four weeks, coral nubbins were exposed to a 4 DHW temperature stress, with or without a 5 µM nitrate enrichment. Monitoring coral health revealed moderate to severe bleaching induced by elevated temperatures, which was unaffected by increased nitrate supply. This occurred concurrently with a reduction in the photosynthetic capacity of the endosymbionts and a clear disruption of the holobiont's metabolism impacting respiration and growth rates. Interestingly, nitrate enrichment did not mitigate the overall impact of heat stress. High-throughput sequencing of the 16S rRNA gene showed the microbiome associated with *A. kenti* was affected by all treatments, suggesting that both heat stress and nitrate drive shifts in microbial communities, potentially impacting the health status and stress response of the holobiont. This holistic approach revealed effects both on the coral physiology and associated microbiome in response to stress, emphasizing the importance of exploring the complex effects of the interplay between environmental stressors on corals at the holobiont level.

ID: 511 / **Parallel Session 3-2: 21**
Biology and Ecology of Holobionts in Coral Reefs

Keywords: Adaptation, Conservation, Photo-physiology, Transcriptomic, Low-light

Investigating the Photo-Physiological and Transcriptomic Responses of the coral *Pachyseris speciosa* Subjected to Acute Low-Light Conditions

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Coral reefs worldwide confront escalating threats, characterized by heightened sedimentation and diminished light penetration due to extensive land reclamation and coastal development. This critical issue is exemplified by the drastic reduction in underwater visibility, notably in Singapore, where levels have dwindled from over 10 meters in the 1960s to approximately 2 meters today. This study endeavours to explore the repercussions of acute low-light stress on the photo-physiology and transcriptomics of the common tropical coral *Pachyseris speciosa*.

The research implemented a 4-week experiment involving three distinct light treatments: control, representing normal light conditions; intermittent light, with 5 days of normal light conditions and 2 days of total darkness; dark, maintaining constant total darkness. Comprehensive photo-physiological data, encompassing parameters like zooxanthellae density, chlorophyll a concentration, colour score, and chlorophyll fluorescence (EQY and MQY), were recorded at the experiment's onset and conclusion using a DPAM-II. Additionally, coral samples collected at the beginning and conclusion of the experiment underwent RNA sequencing via Illumina for transcriptomic analysis, enhancing the depth of understanding regarding molecular responses.

Post-experiment analysis revealed the resilience of all *P. speciosa* colonies, albeit with notable disparities in photo-physiological status. The dark treatment induced substantial reductions in chlorophyll a concentration, zooxanthellae density, and MQY. Interestingly, colonies subjected to intermittent light treatment exhibited signs of photo-acclimation, evident in a significant increase in EQY. Transcriptomic analysis unveiled unique gene expression patterns, particularly in intermittent light-treated colonies, showcasing differential expression of genes associated with low-light adaptations. Pathway analysis emphasized enrichment in photosynthesis-related genes, indicating enhanced light capture and utilization in corals exposed to intermittent light.

Overall, our findings suggest that *P. speciosa* may possess the photo-physiological and molecular capacity to adapt to low-light stress, positioning it as a promising candidate for use in restoration projects in low light environments affected by reduced light penetration.

ID: 721 / **Parallel Session 3-4: 16**
Biology and Ecology of Holobionts in Coral Reefs

Keywords: Octocorals, Pulsating coral, Ontogeny, Coral-algal symbiosis, Red Sea

Symbiotic dance: ontogenetic aspects of soft coral pulsation

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Octocorals are an abundant benthic group on most coral reefs and contribute to the reef's structure, function and biodiversity. Several species of the family Xeniidae are characterized by the unique pulsation of their tentacles. Furthermore, the function of pulsation is of biological and ecological importance and has been studied throughout the past 200 years. Yet, the ontogenetic aspects of this phenomenon have been overlooked and remain uninvestigated. Moreover, coral reefs are in decline due to anthropogenic disturbances. Ocean warming negatively affects the mutual symbiotic state between the coral host and its photosynthetic endosymbionts. In this study, we examined the commencement of pulsation in early life stages of the common Red Sea soft coral *Heteroxenia fuscescens*. Planulae of *H. fuscescens* are azooxanthellate and symbiont acquisition in the newly settled and metamorphosed primary polyps coincides with the opening of the mouth. We compared the development of pulsation and physiological parameters of primary polyps over time, also in relation to algal symbiont acquisition by them. For this purpose, some of the laboratory-reared polyps were challenged by parental algal isolates, others were kept azooxanthellate. The latter were manipulated to remain without their symbionts based on the hypothetical scenario of failing to acquire them from the environment as a response to heat stress. Hitherto findings indicated that at the initiation of metamorphosis, both zooxanthellate and azooxanthellate polyps exhibited asymmetrical growth as well as independent and sluggish motion of tentacle buds. At later stages, most azooxanthellate polyps ceased movement and exhibited a higher mortality rate, whereas zooxanthellate polyps expanded and contracted fully. In conclusion, the sole dependence of xeniid octocorals 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.

ID: 775 / **Parallel Session 3-4: 21**
Biology and Ecology of Holobionts in Coral Reefs

Keywords: machine learning, transcriptomics, disease resistance

Classifying and Characterizing of Coral Diseases Resistance – an application of machine learning with 'omics

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Reef building corals are susceptible to various diseases with high mortality rates, significantly reducing coral coverage in reef ecosystems. However, not all corals are equally susceptible to diseases or have the same rate of tissue loss. Two diseases, stony coral tissue loss disease, and white plague, have different mortalities but can have similar visual phenotypes of disease. In this study, we use transcriptomic data from the previously published disease exposure experiments, using coral genotypes to identify disease resistance. Fragments of the same genotype were present in both control and disease exposure groups, and disease spread was tracked. For this study, the time to lesion appearance in each exposure study was used as the variable for disease resistance. We applied machine learning approaches, including principal component analysis, logistic regression, and support vector machine learning (SVM), to identify gene expression biomarkers associated with resistance to disease. A partial least squared discriminant analysis (PLS-DA) was developed using the biomarkers identified to develop an algorithm that classifies disease resistance. The initial machine-learning applications identified over 400 biomarkers that classify whether a coral fragment got diseased or not. After testing and validation, the PLS-DA algorithm could successfully delineate disease resistance through these gene expression biomarkers. These biomarkers provide key information about the biology of the disease resistance, and the biological and molecular functions that play a role in conferring resistance. This is the first resistance algorithm for tissue loss diseases in the Caribbean and can be used to identify corals resistance or susceptibility to disease outbreaks and help us understand the drivers and consequences of these events.

ID: 600 / **Parallel Session 3-4: 10**
Biology and Ecology of Holobionts in Coral Reefs

Keywords: Ryukyus, Zoantharia, Symbiodiniaceae, symbioses

On the evolution and ecology of azooxanthellate cave-living *Palythoa* spp.

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Among the diverse marine symbioses of coral reefs, the association between host invertebrate species and photosynthetic dinoflagellates of family Symbiodiniaceae is of primary importance, as the energy provided from symbionts to the hosts allows for the creation of complex reef structures. The host-Symbiodiniaceae association dates back to the formation of modern coral reefs in the Jurassic, and since this time, the association has spread to numerous host phyla and resulted in a highly diversified family of Symbiodiniaceae. Despite ubiquity and importance, how these symbioses shape host species' evolution and function remain little studied. There are three major reasons for the comparative lack of research on these symbioses: 1) most Symbiodiniaceae are unculturable in the laboratory, rendering studies on their physiological requirements and needs near impossible, 2) species diversity studies are far from complete, and 3) comparative studies between symbiotic (=zooxanthellate) and asymbiotic (=azooxanthellate) host species are difficult, with very few model systems in place. In this research, we investigate the third point, and examine Symbiodiniaceae and host species of *Palythoa*, a common group of coral reef zoantharian hexacorals. Within genus *Palythoa*, there exists a unique situation with two species of azooxanthellate species in the genus, *P. mizigama* from Okinawa Island and *P. umbrosa* found on Iriomote Island. Both species were recently described, and both are closely related to sibling zooxanthellate *Palythoa*species. This presentation introduces initial findings of this research, elucidating the preferred environments of the two species and comparisons with nearby sympatric zooxanthellate species. Our results demonstrate that the two species prefer differing low-light coral reef cave environments, particularly in caverns of specific shapes and form, suggesting that adaptation to available niches and habitats in the complex structure of coral reef edges has driven these species' moves into such environments, including the loss of symbioses.

ID: 653 / Parallel Session 3-4: 12
Biology and Ecology of Holobionts in Coral Reefs

Keywords: Sponges, Microbiome, Red Sea, Coevolution

Microbiome diversity and composition among Red Sea haplosclerid sponges is driven by phylogenetic relatedness

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Sponges, pervasive constituents of coral reef ecosystems globally, thrive in Red Sea coral reefs. This study delves into the microbiomes of 158 sponges within the order Haplosclerida (Class Demospongiae), gathered along the Saudi Arabian Red Sea coast. Employing clade-specific elements, we construct a robust phylogeny of the sampled sponges, aiming to assess if sponge microbiome diversity and composition correlate with cladogenesis in haplosclerids. A total of 1,490,491 high-quality reads were acquired, clustered into 488 major operational taxonomic units (OTUs). The 16S rRNA OTUs span 27 bacterial phyla and 2 archaeal phyla, with a notable proportion of unclassified OTUs retrieved from the analysed microbiomes. Predominant bacterial phyla in the sponge microbiomes include Proteobacteria, Cyanobacteria, and Bacteroidota. Interestingly, microbiome beta diversity appears unaffected by the host's geographical location; conversely, phylogenetic distances emerge as superior predictors of microbiome similarity among Red Sea sponges. This investigation sheds light on the intricate relationships within haplosclerid sponges, providing valuable insights into the factors influencing microbiome dynamics in the Red Sea coral reef ecosystem.

ID: 518 / Parallel Session 3-4: 3
Biology and Ecology of Holobionts in Coral Reefs

Keywords: biodiversity-productivity effects, contact-free interactions, biocommunication, stony & soft corals, macroalgae

Contact-free interactions shape productivity of stony corals

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Coral reef organisms engage in intricate interactions with each other, which are shaped by both contact-based and contact-free mechanisms. Field-based observations suggest that contact-free interactions affect the health and growth of stony corals, but a systematic assessment of the underlying mediators and resulting productivity patterns is missing. We investigated the immediate and long-term changes in stony coral productivity in response to contact-free interactions with other stony corals, soft corals, macroalgae, and sponges. Combining the results of four experiments, we show that corals sense the presence of other organisms without physical contact and subsequently modulate their photosynthesis and growth rates. Depending on the species, exposure to contact-free stimuli of reef neighbours either boosted or reduced productivity, resulting in productivity levels that were up to 50 % higher or lower compared to single-species cultures. Close proximity of sessile reef neighbours, and especially an increase in biomass among these neighbours, frequently resulted in severely decreased productivity of some stony coral species (e.g., *Porites rus; Montipora digitata*), suggesting a dose-response relationship. Conversely, the productivity of other coral species predominantly increased (e.g., *Pocillopora verrucosa*) or remained stable (e.g., *Stylophora pistillata*) in response to diverse neighbours, which may be the result of distinct ecological strategies of the species. By systematically excluding other biotic and abiotic factors, we provide evidence that changes in coral productivity are mediated by contact-free stimuli via the seawater. We hypothesize that coral-associated microorganisms and secondary metabolites mediate these contact-free interactions, which might trigger a self- and non-self-response of the historecognition system in corals. Our results reveal contact-free species interactions as an overlooked element that shapes productivity in coral reefs. These interactions are prone to be impacted by the ongoing biodiversity crises, with potential downstream effects that are not yet fully understood.

ID: 127 / **Parallel Session 3-1: 8**
Biology and Ecology of Holobionts in Coral Reefs

Keywords: Allelopathy, Anabaena, chemical ecology, coral reef, cyclic lipopeptides.

Benthic cyanobacterial metabolites interact to reduce coral larval survival and settlement.

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Benthic cyanobacterial mats (BCMs) are becoming increasingly abundant on coral reefs worldwide. High growth rates and prolific toxin production give them the potential to cause widespread coral recruitment failure through allelopathic effects, but few studies have made the link between their toxicity for coral larvae and *in situ* toxin concentrations. Here we investigated the allelopathic effects of the benthic cyanobacterium *Anabaena* sp.1 on larvae of the coral *Pocillopora acuta*. This cyanobacterium produces several non-ribosomal cyclic lipopeptides of the laxaphycin family with cytotoxic properties. Therefore, we measured the concentration of laxaphycins A and B in *Anabaena* mats and in the water column and tested their effects on coral larvae. We found that *Anabaena* crude extract reduces both larval survivorship and settlement and that laxaphycin B reduces settlement. When larvae were exposed to both laxaphycins, there was a reduction in both larval survival and settlement. In the natural reef environment, laxaphycin A and B concentrations increased with increasing proximity to *Anabaena* mats, with concentrations being consistently above LC_{50} and EC_{50} thresholds within a 1 cm distance of the mats. This study demonstrates that laxaphycins reduce the survival and inhibit the settlement of coral larvae at concentrations found near *Anabaena* mats *in situ*. It further shows a combined effect between two cyanobacterial metabolites. As BCMs become more common, more of their secondary metabolites might be released in the water column. Their occurrence will lead to a reduction in coral recruitment rates, contributing to the continuing decline of coral reefs and shift in community structure.

ID: 356 / **Parallel Session 3-2: 12**
Biology and Ecology of Holobionts in Coral Reefs

Keywords: Coral disease, microbiome, symbiodiniaceae, metabarcoding, transcriptomics

Coral pathobiome community structure, network dynamics, and expression signatures provide critical context into molecular-based definitions of infectious coral diseases

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Corals are host to a mixture of microbes containing prokaryotes, microeukaryotes, and viruses that have evolved to play critical functional roles with their host. During unfavourable environmental conditions the coral immunity degrades, fostering proliferation of alien pathogens, or previously residential microbes that become malicious. Corals are susceptible to a wide variety of maladies that have critical impacts on host physiology, fecundity, and survivorship. In severe cases, epizootics such as the Stony Coral Tissue Loss Disease (SCTLD) outbreak can spread through entire reefscapes turning vibrant complex communities from reefs to rubble. Many other coral diseases have persisted on reefs through time, having chronic effects on coral reef succession. Here we explore several coral diseases, teasing apart pathobiome structure, dynamics, and expression during pathogenesis across multiple hosts. Corals were collected on shallow reefs from Curaçao showing signs of dark spot disease, red band disease, black band disease, Caribbean ciliate infection, and SCTLD. Triplicate samples were taken from the following areas of interest: healthy tissues (healthy hosts), apparently healthy (healthy tissue from diseased host), disease transition line, and dead skeleton (post-infection). Coral holobiont RNA and 16S/18S rRNA genes were sequenced from ~250 samples, allowing exploration of the coral host gene expression and both prokaryotic and microeukaryotic community dynamics across diseases. The prokaryotic community compositions show clear trends where specific tissue types cluster together across the pathogenesis spatial landscape. In contrast, the microeukaryotic communities have less predictable composition structure, display decreasing symbiodiniaceae abundance and increasing diversity across the host landscape, and become increasingly dominated by opportunistic microbes such as ciliates through pathogenesis. Expression patterns in the host and zooxanthellate counterparts display stress-related COGs providing further context to various coral disease descriptions. Unravelling the pathobiome structure and holobiont functional response during pathogenesis provides a better understanding of the molecular characterizations between different infectious coral diseases.

ID: 674 / **Parallel Session 3-4: 15**
Biology and Ecology of Holobionts in Coral Reefs

Keywords: interspecies interactions, primary productivity, chemical ecology, coral reef microbiome, holistic perspective

Interconnection of coral holobionts in the reef environment: A holobiome perspective

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Reef-building corals are model holobionts owing to their close association with diverse microorganisms from all domains of life. Notably, these associated microbes and their metabolites extend beyond the coral colony and are also found in the surrounding seawater, creating a unique signature for each coral holobiont. These signatures may act as information carriers between organisms, yet it is unknown if corals are capable of detecting such stimuli. Here we synthesize a series of experiments that provide evidence that corals can sense the presence of other organisms via the surrounding seawater. We demonstrate that corals modify their rates of photosynthesis and growth in response to the presence of other organisms without physical contact and to the traces they leave behind. The effects of extrinsic stimuli vary from negative to positive or neutral, depending on the coral species. The strength of this response is determined by the identity and biomass of the stimulating organisms. We further show that the metabolic signatures of distinct functional groups in the reef vary and are altered by changes in the diversity of surrounding organisms. These results suggest that corals have the ability to sense and respond to the presence of nearby organisms, providing insights into the significance of chemical signals in marine ecosystems and their effects on the productivity of the organisms. Our research thus provides a new perspective on the interconnectedness of organisms within coral reefs, extending beyond individual coral colonies to the community of holobionts that, together with the surrounding environment, compose the coral reef holobiome. The existence of this complex and interdependent web also has implications for how we approach the preservation and restoration of these endangered ecosystems.

Posters

ID: 395
Biology and Ecology of Holobionts in Coral Reefs

Keywords: Symbiosis, Microbiome, Transcriptomics, Coral Holobiont, Gorgonians.

Investigating the intracolonial coral holobiont variability through a multiomic approach.

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The Mediterranean Sea is a significant hub for marine life and has been profoundly impacted by the climate crisis. Marine Heat-Waves (MHW) have caused a significant decline in gorgonian populations, which represent one of the most important organisms in sustaining biodiversity. The coral holobiont is a complex system of interactions between the animal host and all the microbes living in association with it, such as bacteria, protists, archaea, and viruses. These microbial communities contribute to the physiological traits of their host, including resistance to environmental stressors. In challenging conditions, shifts in microbial communities have been observed, with differential responses between corals of the same species. The modular nature of these animals suggests that variations in the holobiont functional response and the microbiome may be observed across the different areas of the colony. In this study, we used a multiomics approach to investigate this intracolonial variability in the gorgonian *Eunicella singularis*. We used bulk RNA sequencing along with 16S and 18S rRNA genes metabarcoding to investigate the transcriptome, prokaryome, and eukaryome of three distinct regions (top, centre, and bottom) of the colony of *E. singularis*. Identifying the regions that harbour the most attractive traits for transplantation is crucial. Among those, high reproductive potential is of particular interest. This information will allow us to pinpoint what would be the most appropriate region to be used for restoration projects.

ID: 186
Biology and Ecology of Holobionts in Coral Reefs

Keywords: Scleractinia, dust, metals, thermal stress, photosynthesis

Effects of desert dust on the ecophysiology of two thermal stressed Scleractinia corals

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Desert dust is considered an important nutrient source for marine primary productivity. Dust storms can be remarkably important in highly oligotrophic systems surrounded by deserts, such as the Red Sea. As the dust is enriched with trace metals, it is thought to enhance the photosynthetic functions of autotrophic organisms, such as reef building corals. It has been suggested to contribute to the resilience of corals to bleaching, since reefs located in the Red Sea are particularly resilient. To investigate the effects of desert dust supply on the photosynthesis of Red Sea corals, we have continuously provided dust to two heat-stressed (26°C; 32°C) species (*Stylophora pistillata* and *Turbinaria reniformis*) during 1.5-month period under laboratory-controlled conditions. We measured different proxies of coral photosynthetic performance, including gross photosynthesis, chlorophyll and symbionts density. We also conducted analysis of several metal content (Mg, Zn, Cd, Mn, Fe, Ni, Cr, Cu, Mo and Co) and bulk stable isotopes (Cu, Zn, Fe) in the tissues of the host and symbionts separately. Our results indicate that desert dust significantly improves the photosynthetic performance of heat-stressed *Stylophora pistillata* and *Turbinaria reniformis*, and also non- stressed *Turbinaria reniformis*. Stable isotope analysis and metal content in the host tissues of and symbionts were affected by desert dust supply. As a result, several lines of evidence indicate that desert dust promotes photosynthesis in corals in parallel with enhanced uptake of metals, and maybe a involved in the particularly high bleaching resilience of Red Sea corals.

ID: 521
Biology and Ecology of Holobionts in Coral Reefs

Keywords: holobiont, eutrophication, microbiome, Ostreobium, Symbiodiniaceae

Functional diversity of complex symbiotic networks: effects of eutrophication on Guam's key scleractinian corals

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As climate change and anthropogenic disturbances escalate, coral bleaching and disease events have become more intense and frequent, creating a crisis for reciprocal resilience of coral reef ecosystems. While it is now well recognized that corals are complicated meta-organisms, consisting of the host and endosymbiotic microorganisms, we still do not have a holistic understanding of the highly complex symbiotic networks. To help fill this gap, we aimed to understand capacities for holobiont resilience through the functional diversity of these symbiotic networks. Specifically, we focused on endosymbiotic Symbiodiniaceae, *Ostreobium* algae, and bacteria, operating within two distinct microcompartments: coral tissue and skeleton. In Guam, an island highly threatened by poor water quality, we are using multidisciplinary approaches to better understand the impact of environmental stressors on coral health through a combination of *in situ* reciprocal transplant coral gardens and *ex situ* controlled experiments. Preliminary results indicate that coral host, phenotype, and environment can lead to distinct physiological responses, despite similar symbiotic diversity. For example, the typically overlooked microbial green layer within the coral skeleton presents distinct skeletal ring patterns and photosynthetic properties depending on their original habitats. Upon completion of this research, we aim to present a larger integrative view of the coral's symbiotic network dynamics and discuss the importance for coral reef resilience.

ID: 553
Biology and Ecology of Holobionts in Coral Reefs

Keywords: Maldives, microbiota, Symbiodinium, metabarcoding

First screening of microbial assemblages in corals from Maldives atolls

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The Maldivian Archipelago is hosting large coral reefs and is being under study for its ecological diversities, however to date microbiome diversity in different coral morphotypes remained unexplored in this area.

In this study, for the first time, the microbiota composition (both symbiont and bacteria) was investigated in various coral morphotypes sampled during spring 2022 across Maldivian atolls (Ari, Malé Nord, Malé Sud e Rasdhoo). A total of 26 samples (*Acropora*, *Pocillopora*, *Porites*, *Fungia* and gorgonians) were collected by scuba diving at reef sites located either on the ocean-exposed reefs or in lagoon sites. Samples of the surface seawater were also collected using an innovative eDNA pump (citizen scientist from Smith-Root).

On the extracted DNA metabarcoding analyses were conducted targeting the 16S rRNA gene and the Internal Transcribed Spacer 2 (ITS2) rRNA region to assess bacterial composition and microalgal endosymbiont clade diversity, respectively.

The results obtained showed a strong diversity, shaped by coral morphotype, rather than profundity or atoll geography. In *Acropora* the most abundant bacterial genera encountered were *Pseudomonas*, *Bradyrhizobium*, *Synechococcus_CC9902*. Their microbiota was more similar to *Pocillopora* morphotypes, where *Epulopiscium* and *Romboutsia* were also abundant. *Porites, Fungia* and Gorgonia showed more specific compositions as compared to the other morphotypes.

The distribution of *Symbiodinium* showed similar patterns, most belonging to the clade C, however, the *Acropora* corals also showed a significant presence of clade D. At the subclade level, clear patterns between morphotypes were distinguished.

Seawater samples showed higher diversity as compared to corals, without showing differences between sites, and bacterial SAR groups were observed among the most dominant bacteria genera in surface water.

Overall, this study provides background information useful for monitoring local corals and predicting potential impacts of changing environmental conditions.

ID: 401
Biology and Ecology of Holobionts in Coral Reefs

Keywords: Stable isotopes, heterotrophy, turbidity, Singapore

Trophic ecology of corals under high turbidity regimes in Singapore

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Scleractinian corals are the dominant reef-building taxa on coral reefs and typically thrive in shallow and nutrient-poor tropical oceans. Yet, recent studies have highlighted that corals are not solely confined to clear-water regions, with extensive coral growth occurring in marginal coastal areas characterised by high terrestrial sedimentation and nutrient inputs (i.e., turbid coral reefs). Corals are sustained by a combination of autotrophy (via symbiosis with photosynthetic dinoflagellates) and heterotrophy (via particle capture and assimilation of dissolved compounds). As light availability is significantly reduced within turbid environments, it is hypothesised that turbid corals may exhibit a greater degree of heterotrophy in order to meet their nutrient requirements. This suggests a difference in the relative importance of the algal endosymbionts in coral nutrient acquisition under turbid versus clear water settings, which may underpin bleaching resilience and reef development. However, trophic strategies of turbid corals, and the relative importance of their algal endosymbionts, is poorly understood. This is due to the lack of studies quantifying nutrient acquisition strategies for turbid coral genera. Here, we gain a comprehensive understanding of the trophic dynamics for thirteen coral genera covering five different growth morphologies from highly turbid reef sites in southern Singapore. Trophic dynamics were quantified using bulk stable isotope measurements ($\delta 13C$ and $\delta 15N$) and isotopic niche analysis of coral tissue and symbionts, further supplemented by local water quality data. Our results define the extent of heterotrophy in largely unstudied coral species, revealing a range of mixotrophic strategies employed by the different coral genera in Singapore, and suggests that turbid corals might not be as heterotrophic as previously assumed.

ID: 666
Biology and Ecology of Holobionts in Coral Reefs

Keywords: far red, Symbiodiniaceae, Anemonia, Cladocora, temperate reefs

Effects of spectral quality and temperature in reared coral species models

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The soft and hard corals *Anemonia viridis* and *Cladocora caespitosa* are excellent models for studying cnidarian-dinoflagellate symbiosis in shallow temperate waters. In the Mediterranean Sea, symbiont corals experience seasonal variations in solar radiation and temperature, and face more and more frequent heatwave events.

The aim of this work is to observe the response of two temperate corals raised in different light and temperature conditions. The experimental aquariums were set up to test the hypothesis that corals' size, Symbiodiniaceae concentration, photosynthetic efficiency of the symbionts and Chl-a contents do not change as a function of factors "temperature" (two levels: 20° C, 23 °C) and 'light spectrum' (two levels: white light, white light + 20% far red).

A submersible pulse amplitude modulated fluorometer (Diving-PAM) was used to evaluate the photosynthetic efficiency *in hospite* of the symbiont as a function of light and temperature conditions, thanks to the analyses of fluorescence-derived parameters.

The concentration of Symbiodiniaceae was greater in colonies held at 23°C under white light, while the increase in colony height was greater in samples held under far-red light at both temperature levels. Photosynthetic efficiency was higher in colonies raised at 23°C regardless of the spectral composition of the light.

The results of this experiment on the photobiology of temperate cnidarians could help understand or predict the effects of climate change on cnidarian living in shallow waters and could also be useful in setting optimal rearing conditions for coral cuttings to be transplanted during restoration activities.

ID: 111
Biology and Ecology of Holobionts in Coral Reefs

Keywords: Photobiology, symbiosis, fluorometry

Photobiology of algal symbionts associated with the reef coral *Galaxea fascicularis* in the Red Sea

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Shallow-water zooxanthellate corals rely on photosynthesis for the majority of their energy need. As a result, photosynthesis governs metabolic functions and can be indicative of coral health. Through this, species-level physiology drives community-scale responses to seasonal and extreme environmental changes. Further, as extreme climate events are predicted to increase in frequency and severity, a baseline of inherent variability is needed to evaluate extreme change in time. Yet, underlying seasonal variability is largely unknown in central Red Sea corals. To investigate seasonal fluctuation of photochemical efficiency, 18 permanent transects, 5 – 10 m deep, were installed on six reefs in the central Red Sea in June 2022, spanning a cross-shelf gradient to capture spatial variability of communities. Three colonies of the model organism *Galaxea fascicularis* were tagged along each transect. The effective photochemical efficiency of tagged colonies was measured *in situ* every month from June 2022 with the Diving-PAM II, and averaged by reef at each time point to determine seasonal patterns. In addition, the capacity for the Diving-PAM II to non-invasively detect decreased photosynthetic activity prior to visible signs of bleaching was evaluated following a bleaching event in August 2023. While not significant, average effective photochemical efficiency was highest during Winter 2022 and lowest during Summer 2023. This was likely related to temperature, which was negatively correlated to effective photochemical efficiency. This presentation will discuss seasonal variability in the ecophysiology of some of the most thermally-tolerant corals, and elucidate colony-scale mechanisms that underpin community-scale responses in the context of climate change. This research comes at an important time, as climate change issues have been prioritized by both Saudi national and global initiatives.

ID: 647
Biology and Ecology of Holobionts in Coral Reefs

Keywords: symbiosis, immunity, Aiptasia, phagocytosis

Immune control of cnidarian endosymbiosis establishment

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Many cnidarians form an endosymbiotic relationship with photosynthetic *Symbiodiniaceae* algae, and this relationship dictates the health of coral reefs. Typically, every new generation of cnidarian larvae acquire their symbionts from the environment via phagocytosis. To be able to live inside a eukaryotic cell, the symbiont must circumvent the innate immune defences of the host, which is intrinsically linked to the success of cnidarian-algal symbioses. For instance, symbiosis establishment inhibits immune signalling, while during bleaching, immunity becomes activated. These data suggest that immunity must be tightly controlled to establish and maintain a healthy symbiotic relationship. However, we still lack mechanistic insight into if and how immunity alters stages of symbiosis, including symbiont uptake. To understand this, I use the sea anemone *Exaiptasia diaphana* (Aiptasia) as a model organism. Similar to corals, Aiptasia forms a symbiotic relationship with *Symbiodiniaceae* but with the advantage of being easier to grow and manipulate in the lab. I compared symbiont uptake in Aiptasia larvae when exposed to immune agonists during the first 24 hours of infection. Lipopolysaccharide exposure throughout the first 24 hours of infection promotes expulsion of phagocytosed symbionts leading to decreased proportion of infected larvae. However, exposure to peptidoglycan during the first hour of infection increases symbiont uptake and the proportion of infected larvae. This suggests early immune stimulation is beneficial to establish symbiosis but once the relationship is formed, immunity must be inhibited to limit symbiont expulsion. To determine the downstream immune signalling involved in symbiont uptake and successive expulsion I have generated immune mutants via CRISPR/Cas9, which await further testing. Together, these data highlight the importance of immunity in establishing and maintaining an endosymbiotic relationship and the application of CRISPR/Cas9 opens the door to a multitude of possibilities to explore the role of immunity on the different stages of symbiosis.

ID: 450
Biology and Ecology of Holobionts in Coral Reefs

Keywords: Symbiodiniaceae, Persian Arabian Gulf, coral holobiont, symbiosis, climate change

Symbiont restructuring on the hottest coral reefs on Earth

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Corals in the Persian Arabian Gulf (PAG) and Gulf of Oman (GO) exhibit resilience to a range of disturbances (e.g., high water temperature, high salinity), exceeding those observed in the majority of reefs globally. These local coral communities offer valuable insights into potential adaptive mechanisms for global coral reefs in the face of climate change. The stress tolerance of the coral holobiont has been shown to be influenced by its associated microbes, particularly the endosymbiotic microalgae in the family Symbiodiniaceae. Previous studies have identified the thermotolerant species *Cladocopium thermophilum* that broadly associates with corals in the southern PAG. However, the level of partner fidelity is unclear, and it is unknown if distinct lineages of *C. thermophilum* are found associated with different coral hosts and whether those associations are temporally stable. Here, we sampled two dominant corals (*Porites harrisoni* and *Platygyra daedalea*; n = 198) at three sites along the coast of the United Arab Emirates, two in the southern PAG and one in the GO. Using high throughput ITS2 marker gene sequencing and the SymPortal analytical framework, we identified several ITS2 type profiles of *C. thermophilum* as the dominant symbiotic partners in both corals in the southern PAG. In the marginally cooler waters of the GO, the two coral species were predominantly associated with symbionts of the genus *Durusdinium*, typically found in warmer regions outside the PAG as a thermotolerant alga. Comparative analyses revealed a shift in ITS2 type profiles in *Platygyra daedalea* (in the PAG and GO) over the recent decade. If correct, this suggests loss of high partner fidelity due to even more extreme environmental conditions or population demise of formerly associated algae that prompted algal symbiont switching, both of which hold important clues for our understanding of the consequences of changing thermal regimes in coral reefs globally.

ID: 277
Biology and Ecology of Holobionts in Coral Reefs

Keywords: Volcanic eruption, Micronutrients, Photophysiology, Coral Health, Biomineralization

Corals and Volcanoes: moderate volcanic ash exposure enhances symbiont photophysiology in the hermatypic coral *Stylophora pistillata*

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Explosive volcanic eruptions are capable of generating large volumes of tephra (fragmented magma in the form of rocks and fine particles), disrupting all ecosystems in their vicinity and influencing biogeochemical cycles globally. Studies reporting on the effects of tephra deposition on coral reefs are scarce and commonly report mass mortality of large portions of the coral reef close to the volcano. Information about the physiological response of corals to volcanic ash has not been gathered yet. Here, we report the first known effects of volcanic ash on the physiology and elemental cycling of a symbiotic scleractinian coral under laboratory conditions. Nubbins of the branching coral *Stylophora pistillata* were reared in aquaria under controlled conditions (insolation, temperature, and pH), while environmental parameters, effective quantum yield, and skeletal growth rate were monitored. Half the aquaria were exposed to volcanic ash every other day for 6 weeks (250 mg L^{-1} $week^{-1}$), which induced significant changes in the fluorescence-derived photochemical parameters (Φ_{PSII}, F_v/F_m, NPQ, rETR), directly enhanced the efficiency of symbiont photosynthesis (P_g, P_n), and lead to increased growth rates. The enhancement of symbiont photosynthesis was induced by the supply of essential metals (Fe and Mn), derived from volcanic ash leaching in ambient seawater or within the organism following ingestion. The present study introduces a new experimental approach to connect coral biogeochemistry with volcanology and explores for the first time the beneficial role of volcanic ash as an important micronutrient source for living symbiotic corals. The implication of this advantageous interaction needs to be tested for the more complex coral reef ecosystem, but yields the potential to counterbalance external stresses such as those induced by climate change.

ID: 432
Biology and Ecology of Holobionts in Coral Reefs

Keywords: High Phosphate, High temperature, Stress Physiology, Coral Photophysiology, Coral Ecophysiology

A multi-stressor perspective in the Arabian Gulf: High temperature and high phosphate effects on coral photo-metabolism

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The Arabian/Persian Gulf is recognized as a unique marine ecosystem, characterized by its naturally extreme environment, including elevated temperatures, hypersalinity, high evaporation, and limited freshwater input. These inherent challenges have been intensified in recent decades due to global climate change and local anthropogenic pressures. Eutrophication has become a particularly important concern linked to the burgeoning human population in the Gulf. In contrast to its conventional association with coastal agriculture, eutrophication in the Arabian Gulf is linked with treated-wastewater discharge, resulting in excess nutrients load in coastal waters, especially of phosphorous and nitrogen.

This work focuses on the metabolic effects of high phosphate levels on corals surviving in this extreme environment. Fragments from two coral species (*Cyphastrea microphthalma, n=80* and *Platygyra daedalea, n=80*) were collected during December from Abu Dhabi (UAE) reefs and aquaria acclimated over three months to average summer temperature (33.5°C).

Four experimental treatments were established to assess species response to the isolated and combined effects of maximum summer temperature (35.5°C) and phosphate high concentration (4µm), against control (33.5°C and 0.2µm) representing summer ambient conditions, using an orthogonal design.

Photosynthetic performance (Fv/Fm) was monitored *in vivo* every two days for 14 days under each condition via PAM fluorometry. Additionally, subsets of coral fragments were sampled on both the 7^{th} and the 14^{th} days of the experiment to assess stress responses across treatments, including monitoring of antioxidant enzyme activity (CAT and SOD), symbiont density, and chlorophyll concentration.

Preliminary results showed that photosynthetic performance, symbiont density, and chlorophyll concentration decreased at higher temperatures relative to controls. The effect of high phosphate was minimal. Results suggest that at these concentrations, phosphorus enrichment doesn’t interact with or exacerbate thermal stress response in corals, and that thermal stress itself is the primary driver of impaired performance in corals on Abu Dhabi reefs in recent years.

ID: 306
Biology and Ecology of Holobionts in Coral Reefs

Keywords: Coral calcification, Bivalve, Bioerosion, coevolution

Construction vs. destruction: The effects of boring bivalves on the calcification rates and skeleton properties of their coral host

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In the Gulf of Eilat/Aqaba (GOE/A), *Stylophora pistillata* is thought to maintain a continuous equilibrium between growth (calcification) and bioerosion, as it serves as a specific host species for the boring bivalve *Leiosolenus lessepsianus*. Although the boring activity of *L. lessepsianus* is often considered parasitic, *S. pistillata,* one of the most common coral species in the GOE/A, appears to thrive and survive with numerous colonies found with hundreds of bivalves. Nevertheless, the effects of *L. lessepsianus* on host fitness are not yet fully understood.

Unpublished data collected by Y. Loya suggest that the reproductive output of *L. lessepsianus* peaks approximately two months before the calcification rate of *S. pistillata* decreased to a minimum, which corresponds to the period when *L. lessepsianus* larvae spend in the water before settlement. This suggests that the competitive pressure on the larvae to settle and keep pace with coral growth by decalcifying it is reduced. These findings form the basis of our hypothesis that certain life-history traits may have been acquired as host-bivalve symbiosis co-evolved.

Here, we present our results comparing calcification rates between *S. pistillata* colonies with and without their symbiotic bivalves. For a year-long experiment, corals were incubated in metabolic chambers once a month to assess their calcification rate using the total alkalinity (TA) technique. Additionally, the skeleton morphology, density, and porosity were determined by high-resolution micro-computed tomography (µCT) scanning. The results of this study are expected to provide a better understanding of the nature of the *S. pistillata* and *L. lessepsianus* relationships and provide a better assessment, enabling us to support or refute our hypothesis.

Given that ocean acidification poses a threat to coral reef growth and survival worldwide, there is an urgent need to investigate the coral-boring bivalve association and its impact on coral reef stability and resilience.

ID: 577
Biology and Ecology of Holobionts in Coral Reefs

Keywords: Coral, Symbiosis, Cell Atlas, Proteomics, Symbiosome

A spatial proteome of the *Exaiptasia diaphana* endodermal cell

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Endosymbiosis between cnidarians (i.e. corals, sea anemones) and dinoflagellates (i.e. algae) are the foundation of coral reefs. Breakdown of endosymbiosis is the basis of ecologically-devastating coral bleaching events. These endosymbiotic interactions are crucial for aquatic ecosystems, yet the cellular processes that maintain them are poorly understood. Importantly, coral systems are difficult to study in the lab. The cnidarian-dinoflagellate endosymbiotic system, *Exaiptasia diaphana*, is a tractable model for understanding the molecular mechanisms that underpin these ecologically-significant cell-cell interactions. A successful symbiont must establish a cellular niche (the symbiosome) in the host endodermal cell. But what are the host proteins and pathways that sense and regulate this process? To identify these host proteins, I am using hyperLOPIT (hyperplexed Localisation of Organelle Proteins by Isotope Tagging) to create a spatial proteome of the *Exaiptasia* endodermal cell. This approach involves breaking open host endodermal cells, separating the individual organelle and cellular compartments into discrete fractions, and using proteomics and machine learning to ascertain the precise sub-cellular distribution of thousands of unknown proteins. To generate the material required for hyperLOPIT, I have developed an approach of enzyme treatment coupled with density gradient based centrifugation to dissociate and enrich millions of symbiont-bearing endodermal cells from lab-cultivated adult *Exaiptasia*. Performing hyperLOPIT on these isolated cells has generated a preliminary spatial proteome that reveals the host structural features that allow an intracellular microbial symbiont to be accommodated. This includes a list of candidate host proteins that localize to the symbiosome during symbiosis. Successive hyperLOPIT runs, and concatenation of these additional data, will be necessary to improve the resolution of these predicted localizations. Once complete this data will constitute a reference-level spatial proteome of the symbiotic cell-type in a cnidarian-dinoflagellate endosymbiosis. This is important for understanding the core cellular machinery that governs symbiosis in *Exaiptasia* and corals.

ID: 161
Biology and Ecology of Holobionts in Coral Reefs

Keywords: Coral reproduction, Peninsular Malaysia, Coral Spawning, Phylogenetics, Monsoonal influence

Coral reproductive phenology in Malaysia -Spawning patterns on opposite coasts

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Broadcast-spawning corals reproduce by releasing their gametes into the ocean for external fertilisation. This phenomenon generally follows annual reproduction cycles which often culminate in synchronous mass spawning events. These cycles are linked to specific seasons and times of the year and vary between and within species and geographical location. Spawning synchrony and timing is regulated by a range of environmental cues, however the precise role that each cue plays is still poorly understood.

Conclusive findings about reproduction patterns are hampered by the difficulty of reliably identifying individual species based on skeletal, morphological, or geospatial characteristics, particularly within the complex *Acropora* group. We therefore aim to carry out phylogenetic analyses of the target species before we compare their reproduction patterns.

Peninsular Malaysia offers a remarkable opportunity to examine whether different spawning seasonalities are linked to genetic traits or environmental factors. The region holds an extraordinary species diversity and is exposed to two contrasting monsoonal influences on the west coast and east coast of the peninsula. In Malaysia, bi-annual multi-specific spawning events have been observed in March/April and September/October.

The objective of my PhD is to investigate differences in coral spawning timing and synchrony of *Acropora hyacinthus*, *Acropora nobilis* and *Diploastrea heliopora* between east and west coasts of Peninsular Malaysia. Data will be collected over two years with two sampling periods per annum in the inter-monsoonal seasons starting in February 2024. Analytical methods include DNA analyses, rapid maturity assessments, dissection, and histology. Synchronous spawning events are critical to the persistence of coral reefs as sexual reproduction is central to both recovery and adaptation of tropical reef corals.

ID: 595
Biology and Ecology of Holobionts in Coral Reefs

Keywords: Corallicolids, Apicomplexans, Coral, Holobiont, Mediterranean

Targeted genomics of apicomplexan symbionts in Mediterranean corals

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The severe heat waves that are occurring in the Mediterranean due to the climate crisis are causing mass mortality events which have been especially devastating for habitat-forming species such as corals. Corals are known to host a complex symbiotic microbial community, the eukaryotic part of which is widely unexplored. Corallicolida are a family of abundant and widespread coral microeukaryotic symbionts that have been discovered recently and that belong to the Apicomplexans, a well-known group of parasitic protists. Corallicolids have been found in high abundance in thermal-sensitive coral colonies, suggesting that they can play a role in reducing the fitness of their host during heat stress. Obtaining the genome of the corallicolid symbionts would help us understand the functions that they have in corals and how they contribute to coral health. In this project, we attempt two different approaches to build the base of a methodology that will allow us to obtain the genome of Corallicolida in the future. One of the approaches consisted on implementing Probe-Seq, a targeted genomics methodology used to isolate and sequence-specific cell populations from heterogeneous tissue. To do so, several Fluorescence In Situ Hybridization (FISH) and flow cytometry tests have been performed but were found to be challenging on coral samples due to their autofluorescence. The other approach, based on an enrichment method using Percoll gradients, has been more promising so far. We were able to successfully enrich *Paramuricea clavata* samples with corallicolids using Percoll gradients, and their presence was confirmed through polymerase chain reaction (PCR) using 18S rDNA and primer sets that were designed by ourselves and tested in silico. The methodologies optimized and the results obtained in this work provide key tools and information that bring us closer to the final goal of obtaining the genome of Corallicolida.

ID: 253
Biology and Ecology of Holobionts in Coral Reefs

Keywords: symbiosis, host/symbiont separation, nitrogen

Optimizing the host/symbiont separation protocol in *Diploria labyrinthiformis* for nitrogen transfer experiments

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The relationship between scleractinian corals and their single-celled symbiotic algae (Symbiodiniaceae) is complex and remains an intense field of study as corals face numerous local and global threats. To study this relationship, which is dependent on a delicate nutrient balance, Symbiodiniaceae cells are often separated from their coral host cells based on physical force and density differences. The protocols for symbiont-host separation, however, vary substantially between publications with potentially differential effects on downstream analyses. Here, we optimized the density separation protocol and quantified the contamination between fractions using *Diploria labyrinthiformis* bulk tissue samples. To break open coral host cells for zooxanthellae release, the electric homogenizer achieved near total host cell breakage and was more reproducible than the manual glass tissue grinder. For zooxanthellae/host separation, the homogenate was centrifuged at several different spin speeds for 10 minutes, and zooxanthellae cells remaining in the host supernatant fraction were manually counted using a haemocytometer. The contamination found within each host fraction was <0.4% with the best results obtained at spin speeds at or above 1200 rcf. Washing the pellet fraction to remove coral tissue did not result in significant loss of zooxanthellae cells. Repeated centrifugation of the coral tissue fractions to remove remaining zooxanthellae cells resulted in the loss of biomass (determined by mass spectrometry) of up to ~10% of the total mass of the host fraction. These results demonstrate a high purity of separation with minimal loss of material from both fractions. The optimized protocol includes use of an electric homogenizer, a single centrifugation of the homogenate at ~1200 rcf for 10 minutes at a temperature of 4°C, followed by three washes of the zooxanthellae pellet fraction. This optimized protocol will be applied to downstream analyses to quantify the *Diploria labyrinthiformis* holobiont nitrogen budget.

ID: 199
Biology and Ecology of Holobionts in Coral Reefs

Keywords: xenia, regeneration, octocoral

A molecular investigation of coral behavior: using regeneration as a tool to understand the mechanism of xeniid pulsation

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The unique, hypnotic pulsation of xeniid corals has fascinated scientists since Lamarck. However, the neural mechanism of repetitive pulsation in these animals, likely to be controlled by a pacemaker, has never been investigated. As such, *Xenia umbellata*, a fast-growing Red Sea octocoral, was developed as a laboratory model to explore the mechanism of pulsation in xeniid octocorals. Our recent study has revealed that this organism possesses rapid regenerative abilities. During oral disc regeneration, the pulsation behaviour develops in stages, indicating stepwise regeneration of the pacemaker. By utilizing this feature of behaviour development throughout regeneration, we set out to reveal aspects of how *X. umbellata* performs this unique behaviour. Using transcriptomic and immunohistochemical analysis, we have explored the molecular mechanism of pulsation, as well as the structural development of the neuromuscular system. Using differential expression analyses, candidate ion channels, neurotransmitters, and transcription factors were identified that correlate with the development of pulsation behaviour, and the likely location of the pacemaking unit was identified. Our research should open the door to a deeper understanding of pacemaker functioning in these intriguing corals.

ID: 752
Biology and Ecology of Holobionts in Coral Reefs

Keywords: zooxanthallae, Symbiodiniacea, biodiversity, Tropical Eastern Atlantic

Symbiotic and free-living Symbiodiniaceae communities from the Cape Verde Archipelago

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The symbiotic relationship between corals and dinoflagellates from the Symbiodiniaceae family is vital for coral survival. This family is notably diverse, with each lineage exhibiting distinct physiological characteristics. The distribution of Symbiodiniaceae is influenced by various factors including host specificity, the reproductive strategies of the host, the availability of symbionts in water and sediment, and environmental conditions across different spatial and temporal scales. Free-living communities of Symbiodiniaceae act as reservoirs of symbionts for corals, particularly those recovering from bleaching events. These communities are crucial in forming and sustaining new symbiotic relationships with corals and other symbiotic invertebrates. Therefore, understanding the factors driving the associations between coral species and their specific symbiont communities requires prior knowledge of the available Symbiodiniaceae species in a given location. The Cape Verde archipelago, comprising ten main islands and eight islets, all of volcanic origin and never connected to the mainland, is a biodiversity hotspot. It is recognized as one of the eighteen most important centres for multi-taxon endemism in tropical reef biodiversity and is among the top ten global priorities for reef conservation. The objective of this study is to investigate the diversity of Symbiodiniaceae associated with both coral species and free-living (seawater and sediment) in the Cape Verde Archipelago. Symbiodiniaceae assemblages were assessed using next-generation sequencing (NGS) on the ITS2 molecular marker. This analysis included samples from five coral species, as well as sediment and water samples collected from five islands (São Vicente, Santa Luzia, Sal, Maio and Fogo) in the study area. A comprehensive understanding of the threats posed by climate change to coral reefs necessitates an equal focus on both the host corals and their symbiontic counterparts. Thus, gathering data on host-symbiont associations from various habitats and regions is critical for conservation efforts and ecological understanding.

ID: 719
Biology and Ecology of Holobionts in Coral Reefs

Keywords: sponges, microbiome, transplants, ocean acidification

Tasting acidity: Investigating sponge-microbiome acclimatization towards ocean acidification through reciprocal transplantation

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Marine sponges are ecologically important components of the benthic communities that provide habitat for a plethora of species, and mediate nutrient recycling and benthopelagic coupling. Despite their simple anatomy, Porifera represents one of the most successful and functionally relevant taxa colonizing the sea bottoms. Such capacity has been partially attributed to the intimate partnerships with microorganisms that enlarge their metabolic arsenal, supplementing host heterotrophic diet with photosynthates or DOM re-cycling products, and supplying UV-protectants and chemical defences. The plasticity in symbiotic microbial communities, metabolic functionalities, and nutrient utilization may allow sponges to rapidly adapt. It has been hypothesized that sponges may be “winners” in future global change scenarios compared with other benthic invertebrates with calcareous shells or skeletons. We investigated the sponge-microbiome responses toward ocean acidification through reciprocal transplantation experiments. These experiments were conducted at the Grotta del Mago site, at Ischia Island (Naples, Italy), a semi-submerged rocky cave with an average pH_T ~7.6 where abundant and diversified sponge assemblages thrive in illuminated and shaded zones. The respective control site was a second rocky cave with ambient pH ~8.0 conditions. Three sponge species, commonly inhabiting Mediterranean hard bottom substrates, were selected based on the feasibility of transplants and their trophic strategy: *Petrosia ficiformis* (mixotrophic to heterotrophic), *Chondrosia reniformis* (heterotrophic), and *Chondrilla nucula* (mostly photosynthetic). Cross and self-transplants of the three sponge species at the two sites were carried out in June 2023. Transplants and origin individuals were collected after 2.5 months for high throughput sequencing of the prokaryotic 16S rRNA gene. Here we present the preliminary results of the diversity of sponges’ microbiomes and their changes induced by ocean acidification to shed light on the potential role of microbial symbionts in holobionts' acclimatization.

ID: 452
Biology and Ecology of Holobionts in Coral Reefs

Keywords: photoadaptation, GFP, zooxanthellae, laser scanning confocal microscopy, light gradients

Beyond colors: Mapping the diversity and abundance of coral green fluorescent proteins and symbiont photobiology in the genus *Madracis* across a Caribbean reef slope.

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Unraveling eco-physiological contributions of fluorescent proteins (FPs) within reef-building corals is important to understand how coral reefs might respond to future climate threats. We investigated the role of green fluorescent protein (GFP) and associated symbiont photobiology in the response of coral holobionts to light gradients (depth and colony orientation) amongst three *Madracis* species (*M. pharensis, M. senaria,* and *M. decactis*). We used histological techniques and laser scanning confocal microscopy to differentiate and quantify GFP across tissue sections at cellular resolution. In tandem, symbiont cell densities, chlorophyll concentrations and photosynthetic performance were measured. On a species level our research revealed no significant differences in symbiont photobiology. However, *M. senaria* showed significantly higher GFP than *M. pharensis*. (areal mean intensity: 834±171 vs. 735±386 relative fluorescence units, for *M. senaria* and *M. pharensis*, respectively). We found significantly higher intensity in GFP at 5-10m as compared to 20-25m depth, suggesting a role of GFP in the adaptation to high light (areal mean intensity: 772±208 vs. 764±209 relative fluorescence units, for shallow and deep, respectively). There were no differences in symbiont densities or photopigment quantities between depth groups. Within a colony, acclimatization mechanisms involved adjusting symbiont density and cellular chlorophyll content. The top-oriented surfaces of the colony hosted significantly more symbionts than the side-oriented surfaces ($2.24±1.54x10^6$ vs. $3.46±2.63x10^6$ cells/cm^2, for top and side, respectively), however the sides showed significantly higher chlorophyll content per symbiont cell (2.94±1.56 vs. 2.91±1.01 pg/cell, for top and side, respectively). Our findings imply that the host component plays a role in regulating the adaptive response of the *Madracis* holobiont to depth-light gradients, whereas the symbiont component is more involved in mediating the light acclimatization (based on tissue orientation) within colonies. This is an important finding for better understanding the complex photobiological responses of corals and their symbionts to the reef environment.

ID: 367
Biology and Ecology of Holobionts in Coral Reefs

Keywords: coral holobiont, symbiosis, resource partitioning, nutrient enrichment

Response of coral host and symbiont to natural nutrient enrichment

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The coral holobiont exhibits discernible responses to different nutrient regimes, altering host growth, symbiosis, and resource partitioning. We examine these responses of the holobiont to nutrient enrichment on a well characterized natural environmental gradient induced by submarine groundwater discharge (SGD) through a field experiment in Moorea, French Polynesia. In coastal waters, SGD establishes a connection between land and sea through the marginal seabed, reshaping the nutrient regime adjacent to seep sites. Particularly along high tropical islands, this dynamic process forms a natural environmental gradient that initiates biogeochemical cascades with documented impacts to coral growth and metabolism. This study exposed two coral species, *Pocillopora acuta* and *Porites rus*, both prevalent in the fringing reef of this region, at 20 stations across different relative influences of SGD over a 7-week soak period. We examined coral growth, endosymbiont counts, and stable isotopic ratios against parameters indicative of nutrient enrichment. From prior research, we expect to see a monotonically increasing response of coral growth and endosymbiont density, with an accompanying increase in autotrophy in corals subjected to increasing levels of SGD.

ID: 543
Biology and Ecology of Holobionts in Coral Reefs

Keywords: coral lipids, biomineralization, hermatypic corals, climate change

The roles of lipids within reef-building coral and their response to environmental change.

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Understanding the effects of climate change on coral biomineralization is critical for projecting the future of coral reefs. Essential to this understanding are lipid biomolecules which occur both within the tissues and skeletons of corals and fulfil a variety of biological functions. Here we report fieldwork and culturing experiments to identify how the environment influences the lipid compositions of coral tissues and skeletons. Lipid composition varies in response to temperature, depth, and genotype/species. Unsaturated fatty acids contribute more to the total fatty acid pool at 5m water depth compared to 25 m in the tissues of *Acropora retusa* and *Pocillopora meandrina* collected from a reef site in Moorea. This collection of work highlights a role of lipids in the adaptation of hermatypic corals to their surrounding environment. Skeletal fatty acids in these species are dominated by saturated fatty acids C16:O (palmitic acid) and C18:O (stearic acid), the main building blocks of a variety of different lipid molecules. We observe no significant difference in skeletal lipids between reef depths. To explore the role of lipids in biomineralization we precipitated aragonite *in-vitro* under the pH and dissolved inorganic carbon conditions inferred to occur at the coral calcification site and in the presence and absence of lipids identified within coral skeletons in this and previous studies. Lecithin (a mixture of phospholipids, the primary constituents of biological membranes) significantly inhibited aragonite precipitation and altered the morphology of the aragonite crystals produced. Stearic acid and cholesterol had no significant effects on precipitation rate or on aragonite morphology. This research demonstrates that coral tissue lipids are influenced by the environment and that skeletal lipids may be involved in controlling the formation of the coral skeleton.

ID: 393
Biology and Ecology of Holobionts in Coral Reefs

Keywords: high variability, coral thermal stress tolerance, internal wave, stress hardening

Natural thermal stress-hardening in corals: Cold-water pulses likely boost heat resistance

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Stress-hardening by environmental priming could increase the odds for corals to resist ocean warming. Natural environmental fluctuations, such as those observed on offshore reefs in the Andaman Sea, provide an ideal natural environment to study these effects of stress-hardening. Here, internal waves (IW) generate short deep-water pulses that peak from January to June and are absent from August to November. Additionally, western shores of islands are fully exposed to this stress-hardening stimulus of IWs, while eastern shores are more sheltered. This study therefore examined (1) whether exposed corals are more heat stress resistant than their sheltered conspecifics and (2) whether this trait persists during the season of priming stimulus absence. We exemplify those thermal regimes featuring cold- and deep-water pulses successfully induced heat stress-hardening in corals. Corals from the IW-sheltered shore responded strongly to heat stress irrespective of the season, while stress responses of IW-exposed corals were either undetectable (during stimulus presence) or very weak (during stimulus absence). We demonstrate that priming stimuli do not need to exceed certain upper thermal thresholds to be effective, but stimulus re-occurrence may be necessary to maintain heat resistance. Nonetheless, we argue that cooling pulses represent a safer stress-hardening regimen potentially implemented in conservation strategies since it avoids warming-stress accumulation.

ID: 424
Biology and Ecology of Holobionts in Coral Reefs

Keywords: microbial communities, microbial exchange, coral reef diversity

Maintenance and exchange of the coral reef microbiome

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Coral-reef microbial communities are compositionally and functionally diverse and are as critical in sustaining the ecosystem as they are to individual hosts. While these microbial communities have been well-characterised for many individual coral-reef hosts, we lack a clear understanding of how the host microbiomes are regulated across and between host organisms and their environment. Here, we explored how the local (i.e. host-associated) microbial communities of seven sessile coral-reef hosts (belonging to stony corals, soft corals, macroalgae, or sponges) influence and are influenced by the broader reef microbial metacommunity within a controlled experimental aquarium. Given the alarming decline in reef biodiversity, we examined shifts in host-associated and exuded microbiomes under reduced (i.e. coral-reef hosts in isolation) and complex (i.e. coral-reef hosts in a semi-natural environment) reef-community conditions. We found the microbial exchange to be species-specific and to cluster the hosts by functional group, with stony corals contributing the least to the microbial pool available in the surrounding water. The microbial exchange of most hosts was influenced by the complexity of the ambient reef community. In a complex reef community, the microbiomes of the two soft corals *Sinularia* sp. and *Xenia* sp. and the two macroalgae *Caulerpa* sp. and *Peyssonnelia* sp. were more host-specific, whereas the microbiome of the stony coral *Montipora digitata* and the sponge *Haliclona cnidata* were less host-specific, and the soft coral *Sinularia* sp. was more selective in the microbial community it exuded. Our study reveals species-specific responses in coral-reef host microbiomes to varied biological complexity, suggesting that a decline in coral-reef cover and diversity impacts the microbial interactions of the persisting hosts with the environment. These results highlight the important role biodiversity plays in the assembly and maintenance of microbiomes, linking it to the functioning and health of individual hosts and the entire coral-reef ecosystem.

Session 4: Global Climate Change and Environmental Stressors

Coral reef ecosystems, spanning from tropical to temperate latitudes, are confronting significant environmental stressors, including warming, ocean acidification, and deoxygenation. These challenges not only directly impact the metabolism and survival of reef organisms but also indirectly contribute to the emergence of diseases and alter the natural trophic structure of coral reefs. As we grapple with alarming predictions for the future, gaining a better understanding of how organisms and communities respond to environmental changes becomes increasingly crucial. Specifically, we need to explore evidence of their ability to acclimatize and potentially adapt.

Multiple approaches can aid us in this endeavour. Lab experiments under controlled conditions can discern subtle changes in organism metabolism and fitness, helping us to disentangle the combined environmental impacts on organisms and/or communities. Examining real-world examples of habitat simplification and the tropicalization of reef ecosystems provides valuable insights into the ongoing shifts that some coral reefs are experiencing. Leveraging natural laboratories, such as CO_2 seeps, semi-enclosed lagoons, and mangroves, becomes pivotal for integrating responses within a more ecologically relevant context.

For this reason, in this session, we invite contributions from scientists engaged in lab-based experiments, in situ observations, and studies at natural analogues. By fostering collaboration across these diverse approaches, we aim to advance our understanding of coral reefs resilience in the face of environmental challenges.

Keywords: climate crisis effects, dynamics of coral reefs through climate change, relationships between environmental changes and coral disease, tropicalization, what we can learn from marginal and extreme reefs

Session chairs

Riccardo Rodolfo-Metalpa, Institut de Recherche pour le Développement (New Caledonia)

Ulisse Cardini, Stazione Zoologica Anton Dohrn (Italy)

Take home message

- It is still essential to continue studying the mechanisms governing coral reef responses to stressors, from molecular processes to population and community dynamics.

- There is overwhelming evidence that coral reefs are suffering worldwide due to both climate change and local stressors. At the same time, many studies show evidence of rapid acclimation and adaptation, from individual genotypes to the community level.
- The potential for rapid adaptation is already present in nature, as demonstrated by studies in natural laboratories, hot seas, and long-term lab experiments. This highlights the need for the protection and conservation of both the high genetic diversity and the variety of habitats and populations that reefs encompass, to safeguard their adaptation potential.

Regular oral presentations

ID: 480 / **Parallel Session 4-2: 12**
Global Climate Change and Environmental Stressors

Keywords: Gorgonian, ocean acidification, warming, epigenetic, transcriptome

Effects of ocean acidification and warming on Mediterranean gorgonians: physiological, transcriptomic, and epigenetic responses

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The current rate of climate change may outweigh marine metazoans' ability to adapt to future conditions. Acidification and marine heat waves threaten the Mediterranean gorgonian corals. Phenotypic plasticity is critical for slow-growing gorgonians as adaptation through natural selection might not be fast enough to cope with rapid environmental changes. Epigenetic mechanisms such as DNAm (DNA methylation) could offer gorgonians greater ability to buffer the impacts of environmental changes by fine-tuning gene expression in response to warming and acidification. This study aims to assess the physiological responses of the gorgonians to warming, acidification and their combination over two weeks to understand the underlying transcriptome and epigenetic mechanisms of phenotypic plasticity.

In controlled lab conditions, gorgonian corals (*Eunicella singularis* and *Paramuricea clavata*) were exposed to low pH (-0.35 units) and high temperature (+ 4℃), either alone or in combination. Low pH, high temperature and their combination did not lead to necrosis or mortality. The interaction between pH and temperature significantly affected oxygen consumption rate and polyp activity in *E. singularis*. High temperature induced up/down regulation in transcripts (De novo transcriptome assembly) involves intracellular protein transport, protein cargo traffic, protein export, protease and isomerase activity. There was no significant effect of low pH, warming and their interactions on global DNA methylation in *E. singularis*. The oxygen consumption rate in *P. clavata* was not significantly affected by pH, temp and their interaction. We suggest that acidification and warming alter gorgonians' physiological and transcriptome responses.

ID: 563 / **Parallel Session 4-5: 2**
Global Climate Change and Environmental Stressors

Keywords: climate change, local stressors, sublethal impacts, sclerochronology, Siderastrea siderea

Century-scale coral growth declines in Martinique associated with local and climate anthropogenic stressors

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The contribution of corals to reef carbonate production is key for the functioning of coral reefs. Anthropogenic local and global stressors, particularly coastal development and rising temperatures, can negatively impact coral growth and reef accretion rates. Here, annual growth rates (skeletal extension, density, and calcification) were measured in twelve massive *Siderastrea siderea* coral cores from Martinique (Caribbean Sea), spanning the years 1912 to 2020, and analysed in relation to human population, sea surface temperature (SST), precipitation, and river discharge. Linear extension and calcification rates showed a significant decrease over the whole record (1912 to 2020) and displayed a significant negative relationship with human population rise between 1950 and 2020. All coral growth parameters exhibited a strong negative response to human population rise between 1950 and 1985, despite a mild positive influence of SST maxima (SSTmax), indicating the predominant influence of local stressors on coral growth decline. The positive relationship between SSTmax and extension/calcification was lost from 1986 to 2020, and density switched to a negative response, forming a parabolic response over 1950 to 2020. Moreover, a rapid decline in density observed in the most recent decade (2010 to 2020) suggests a potential surpassing of the thermal optimum of *S. siderea* corals in Martinique. These findings underscore the importance of local stressors driving long-term coral growth changes and highlight the urgency of implementing strategies to both mitigate climate change and manage local stressors.

ID: 351 / Parallel Session 4-4: 1
Global Climate Change and Environmental Stressors

Keywords: Mass Mortality Events, Ecological traits, Trait erosion

Species trait impairment in the Mediterranean Sea following mortality events

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Unravelling the functional pathways of marine ecosystems in the face of global change poses a pressing challenge. This is particularly critical in the Mediterranean Sea, a biodiversity hotspot that is also one of the most impacted marine ecosystems by human pressures. In this study, we investigate the traits of benthic species that suffer from mass mortality events due to nine different stressors, utilizing species traits and extensive mass mortality event datasets spanning from 1986 to 2020. Analysing ten ecological traits of 410 benthic species, including 32 habitat-forming corals, we identified 236 functional entities (FEs, defined as groups of species sharing the same trait values) where 56 were impacted. Our results unveiled a risk of trait erosion supported by limited trait redundancy and a significantly higher vulnerability in specific trait categories. Notably, 54% of mortality records showed severe impacts which affect similar FEs such as tree-like and massive forms, slow growth rates, calcifying and large individuals. Specifically, 29 FEs suffered extreme mortality (higher than 90%), impacting 18.4% of the species trait volume (the volume covered by the FEs). Contrasting impacts were observed across regions, with the western region being the most affected in terms of trait diversity (FEs = 44) followed by the central region (FEs = 33), and the eastern region (FEs = 25). Overall, our results demonstrate a significant 10.9% increase in the impacted trait volume over the last five years across the Mediterranean, highlighting the risk of a rapid ecological transformation of the Mediterranean Sea.

ID: 500 / Parallel Session 4-1: 9
Global Climate Change and Environmental Stressors

Keywords: ocean acidification, coral reef, ecosystem metabolism

Ocean acidification disproportionately impacts recovering coral reef communities

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Recent mass bleaching events on coral reefs caused by thermal stress highlight the continuing need for accurate predictions of climate change impacts on marine ecosystems. Concurrent impacts of increased atmospheric CO_2 causing ocean acidification (OA) have remained subtle (e.g., decreased skeletal density of calcifiers), but the predicted long-term degradation of the physical structure of coral reefs by OA presents a serious concern. A key feature of reefs recovering from major disturbance is the overall decrease of size structure in foundation species such as reef-building corals. To understand the interaction between size structure and projected effects of OA, we initiated the present study to understand how coral reefs that are in the active phase of recovering from disturbances (i.e., they were dominated by communities of small corals) would be impacted by OA relative to the effects on established communities composed of larger corals. We manipulated coral size structure to test for colony size-dependency in the response to OA. Our results indicate that metabolic function (net community calcification) of coral communities composed of small colonies (i.e., ≤ 5 cm diameter) under OA conditions (i.e., at a *p*CO2 of ~1000 µatm), was decreased by 44% relative to coral communities composed of large colonies, transitioning from net accretion to net dissolution at ~6 hrs post-dawn. The community metabolism of large corals (i.e., ≥ 10 cm diameter) was depressed in response to OA, but was maintained net accretion, suggesting more established coral communities have an increased capacity to buffer against OA effects. These results highlight the complexities of scaling results of OA experiments from individual corals to whole communities, but they also highlight the crucial need to limit CO_2 emissions to prevent community transitions to net dissolving reefs.

ID: 474 / **Parallel Session 4-3: 6**
Global Climate Change and Environmental Stressors

Keywords: thermal stress, thermal history, stress response, stress response history, skeletal geochemistry

Tropical Climate Variability and Coral Reefs - a Past to Future Perspective on Current Rates of Change at ultra-high Resolution

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The history of heat exposure and response of corals to thermal stress prior to the start of satellite observations and reef monitoring are not well known. Identifying whether corals have exhibited stress responses during extreme temperatures in the recent past may be beneficial to extending observations of these events. The DFG Priority Programme “Tropical Climate Variability & Coral Reefs” aims to improve our understanding of tropical climate variability and its impacts on coral reef ecosystems in a warming world. This improved understanding comes from geochemical and isotopic tools applied to coral skeletons. We present results from a central equatorial Pacific *Porites* colony, which survived the 2015/16 El Niño warming that resulted in substantial coral bleaching and death at the site. Sub-monthly to near-weekly resolved records of Sr/Ca, $\delta^{18}O$, Mg/Ca, $\delta^{13}C$, and density were generated from the coral skeleton. A distinct high-density stress band coincides with peak warming during the El Niño. The coral Sr/Ca temperature proxy closely follows local SST, with no indication for anomalous behaviour even during peak warming. In contrast, coral Mg/Ca, $\delta^{18}O$ and $\delta^{13}C$ reveal pronounced anomalies coinciding with peak-warming and stress band, likely caused by disturbances in the physiological controls of coral calcification as response to thermally-induced stress. Further, coral Mg/Ca and $\delta^{18}O$ indicate anomalous behaviour a few months prior to peak warming, coinciding with anomalously high SST. The latter may suggest skeletal geochemistry can reveal subtle coral responses to thermal stress that are not manifested by skeletal stress bands. We will present boron isotope and multi-element/Ca records to improve the detection of past stress events in skeletons of massive, long-lived corals, and highlight knowledge gaps and future directions in this emerging field. This study contributes to a better understanding of the response of corals and coral reefs to ongoing and future climate change.

ID: 789 / **Parallel Session 4-4: 14**
Global Climate Change and Environmental Stressors

Keywords: multi-stressor, disease, bleaching, transcriptomics, immunity

Leveraging historic data and long-term monitoring to identify markers of coral multi-stressor resilience

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The escalating effects of global climate change and other anthropogenic stressors have subjected reef-building corals to an increasing onslaught of challenges. Coral reef environments are now characterized by frequent disturbance events, many of which are temporally linked. Still, efforts to investigate mechanisms of coral resilience have largely focused on singular stressors: heat, disease, ocean acidification, etc., leaving many questions regarding mechanisms of coral persistence in the fact of multiple stressors. Here, we leverage a long term, multi-omic dataset to identify holobiont markers of resilience to multiple disturbance events: disease and bleaching. We have sampled 3 species of stony coral in Carrie Bow Cay, Belize consistently over the past 5 years, tracking host fate and physiology (gene expression and immune metrics), Symbiodiniaceae communities, and microbiome community structure. Here we leverage historic host data from 2019, coupled with fate tracking data from recent SCTLD and bleaching events to identify genetic predictors of stressor response. Gene expression analyses reveal several candidate genes which are reliable markers of host fate in individual species. Integrative multi-species analyses will be used to identify reliable, species-independent markers of resilience. Our study is among the first to leverage long term holobioint physiological data to assess hypotheses related to multiple stressor resilience in several coral species simultaneously. The results of this study will be an important first step towards identifying potential predictive markers of general coral resilience.

ID: 202 / **Parallel Session 4-3: 2**
Global Climate Change and Environmental Stressors

Keywords: Marine heatwave, resistance, recovery, reef fish, herbivory

Increased resilience and a regime-shift reversal through repeat mass coral bleaching

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Coral reef ecosystems are expected to decline in coral dominance, and more reefs undergo regime-shifts to non-coral states, due to increasingly frequent and severe marine heatwaves. However, long-term detailed ecological datasets spanning multiple heat stress events are rare, making ecosystem predictions less certain. We assessed coral reefs across the inner islands of the Seychelles using a 28-year dataset, spanning severe marine heatwave events in both 1998 and 2016, which both caused severe coral bleaching and mortality. Following the 1998 bleaching event half the reefs underwent regime shifts to macroalgae, while half recovered their coral cover. We anticipated subsequent severe bleaching events would mean more reefs undergo regime shifts, and overall condition declines. However, we document faster coral recovery from the more recent 2016 mass bleaching event, than the earlier 1998 event, with recovery trajectories about 4 years ahead. Further, compositions of benthic and fish communities were more resistant to change following the more recent heat stress, having stabilized in a persistent altered state following the initial climate disturbance. Surprisingly, one reef that had regime-shifted to macroalgal dominance following the 1998 bleaching event, is recovering to a coral-dominated regime following the second bleaching event. This is a rare example of a regime-shift reversal in a natural system. Collectively, these patterns indicate that the system may be more resilient to repeat heatwave events than anticipated, perhaps due to adaptation of coral populations and increased herbivory. This is not to say severe and frequent coral bleaching events will not keep reefs in a degraded low coral cover state if climate change increases unabated, but it does give some reason to be optimistic that meeting ambitious climate targets could result in coral reefs persisting.

ID: 191 / **Parallel Session 4-2: 1**
Global Climate Change and Environmental Stressors

Keywords: ocean acidification, coral-algae interaction, turf algae, dissolution, bioerosion

Turf algae dominates and dissolves coral-turf algae communities under OA

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Decades of investigations have provided a better understanding of the physiological effects of OA, but the ecological and biogeochemical effects remain unclear. Together with the decrease in calcifying organisms, OA is driving an increase in the chemical dissolution of inert coral skeletons and coral reefs sediments. It has been suggested the biological activity of turf associated microbes could result in increased CO_2 release, potentially leading to localized acidification in coral reefs. Despite turf algae's global ubiquity and common interaction with hermatypic corals, the outcome of this competition has yet to be described under future elevated pCO_2 conditions. In this study, coral-turf algae competitive outcomes and turf algae's contribution to $CaCO_3$ dissolution were investigated by creating a microcosm of coral-algae interactions, where coral microcolonies had half of their tissue stripped, providing bare skeleton for turf settlement akin to naturally occurring turf settlement following lesioning. Aquaria and field transplantation (shallow volcanic CO_2 seep) experiments were conducted across two temperature regimes using two species of corals for each experiment from two main reef building genera: *Acropora solitaryensis* and *Porites heronensis* (warm-temperate), *Acropora hyacinthus* and *Porites cylindrica* (subtropical). Turf algal coverage on both genera of coral-algae communities increased under OA, leading to net daily dissolution rates has high as 25.7 (*Acropora*) and 21.5 µmol $CaCO_3$ cm^{-2} d^{-1} (*Porites*). This turf-occupied exposed coral skeleton showed high diel oxic and pH fluctuations leading to $\Omega_{aragonite}$ decreases from 4.13 ± 1.79 (present-day) to 0.75 ± 0.28 (OA). This study shows turf algae are competitively favoured over corals under OA and this together with local acidification driven by turf-associated biological activity increases bioerosion. As turf algal growth and prevalence is expected to increase under OA, its role as a bioeroder should be integrated into current end-of-the-century global accretion models.

ID: 701 / **Parallel Session 4-5: 9**
Global Climate Change and Environmental Stressors

Keywords: Coral demographics, Life history, Environmental gradient, Demographic modelling

Population dynamics and climate change vulnerability of scleractinian corals in the Indo-Pacific region

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The impact of climate change on the long-term response of coral communities remains uncertain given the varied life histories of corals and their interactions with the environment spectrum. Continuous exposure to environmental fluctuations in marginal subtropical populations might bolster their capacity to withstand stressors induced by climate change. This, in turn, could enhance their demographic resilience, enabling them to resist and recover from significant changes in their population structure. Here, we evaluate the life history strategies of tropical and subtropical coral populations throughout the Indo-Pacific region in Mozambique, Japan, Taiwan, and Australia to assess how population dynamics differ across regions and environmental conditions as well as how populations respond to projected future thermal scenarios. Utilizing Integral Projection Models (IPMs) with continuous coral planar area measurements, we integrate individual-level information from coral colonies to create a comparison in coral population across tropical and subtropical environments and different ecoregions

We found higher coral species richness in the Pacific region compared to the Indian Ocean, presenting more promising forecasts for Pacific reef status in the future. Models on the most numerous taxa showed that *Porites* populations remain most stable and hold great capacity to endure thermal stress, whereas *Acropora* populations are forecasted to fluctuate but eventually go through substantial population decrease under future thermal conditions. Subtropical populations generally possess greater demographic resilience compared to their tropical counterparts but we did observe variations among different morpho-taxa populations within the same environmental condition. Our results suggest a shift towards homogenous reefs with the potential loss of structural complexity across all environments, highlighting the threats to biodiversity and loss of functionality in coral ecosystems under climate change.

ID: 609 / **Parallel Session 4-2: 9**
Global Climate Change and Environmental Stressors

Keywords: Ocean acidification, Light availability, Natural analogues, Hermatypic corals, Heterotrophy

Energetic pathways of hermatypic corals exposed to ocean acidification under different light environments

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Under normal conditions, corals mainly utilize the energy acquired from their photosynthetic symbiont (autotrophy) and heterotrophy to support their metabolism, biosynthesis, and skeleton production. Ocean acidification (OA) could cause corals to expend greater energy to maintain their calcification, at the cost of other processes. The combined effects of OA and reduced light levels such as those observed in the deeper reef zone could cause corals to face unbalanced energetic requirements and inputs, yet some coral species can compensate by increasing their heterotrophic feeding. Here, we investigated the shifts in energetic pathways of corals exposed to OA under differing light regimes for three coral species: *Acropora solitaryensis* (Japan), *Pocillopora acuta* and *Porites rus* (Palau). This was accomplished through an aquaria experiment (Japan) and *in situ* experiment by transplanting corals at two natural analogues for OA in Japan (CO_2 seep), and Palau (semi-enclosed bay). Corals host and symbiont physiology were assessed together with their isotopic niche to identify the shifts towards heterotrophy. In both aquaria and *in situ* experiments, symbionts' maximum photosynthetic efficiency of PSII (*Fv/Fm*) showed significant increases under OA, yet no positive effects of OA on *Fv/Fm* were reflected on corals skeletal growth. In aquaria, only corals under OA and high light treatment showed a greater propensity for heterotrophy. *In situ*, innate physiological adaptation was observed in *Porites rus* originating from the Palau natural analogue as they showed higher skeletal growth than their present-day counterparts regardless of CO_2 and light conditions. Our study suggests that some corals such as *Porites rus* could resist future OA levels through diverse physiological mechanisms, however, corals such as *Acropora solitaryensis* may be susceptible to OA under low light conditions due to their inability to shift towards heterotrophy.

ID: 117 / **Parallel Session 4-1: 6**
Global Climate Change and Environmental Stressors

Keywords: ocean acidification, transcriptomics, population genetics

Utilizing natural analogs of future oceans to study the adaptive potential of fish communities to climate change

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Understanding if and how fishes will adapt to climate change is essential in understanding the future of fish populations. Unique sites such as CO_2 seeps provide a natural analog to predicted future ocean conditions under climate change and offer the opportunity to understand how fishes may be able to adapt to these extreme environments. Our study examined the brain and gill transcriptome of *Pomacentrus coelestis* at a CO_2 seep in Shikine Island, Japan, to examine the genetic mechanism for adaptation to climate change and found differentially expressed genes associated with acid-base regulation, O_2 transportation, and immune response similar to previous studies in natural analogs, as well as genes related to vision and otolith which differ from previous work on ocean acidification (OA). We also examined the population structure of *P. coelestis* and found loci that may be under selection, suggesting both short and long-term adaptation to climate change. However, there may also be adverse effects of OA, which warrant further investigation and highlight the importance of natural analogs of future oceans to study how fishes will respond to climate change.

ID: 420 / **Parallel Session 4-3: 13**
Global Climate Change and Environmental Stressors

Keywords: hypoxia, ecophysiology, scleractinian, Panama, heat stress

Can environmental history modulate coral resistance to heat and hypoxia stress?

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Corals are ecologically important and increasingly affected by local as well as global stressors, including rising seawater temperatures and diminishing seawater oxygenation. Despite their individual impacts on organismal functioning, the combined effects of these stressors and their modulation by a history of environmental variability remain poorly understood. In Almirante Bay, Bocas del Toro, Panama, strong environmental gradients of dissolved oxygen (DO), temperature, and pH exist both spatially and across depths. Shallow reefs closest to the mainland (i.e., inner bay) experience the highest variability in these seawater conditions compared to both deeper and ocean adjacent reefs (i.e., outer bay). However, less variable deeper depths do not always provide more favourable conditions, as temperatures can be chronically higher, and DO concentrations and light levels lower. In a mesocosm experiment, we investigated the influence of environmental history on the stress tolerance of *Porites astreoides* originating from 3 and 10 meters in both the inner and outer bay. We hypothesized that shallow inner bay colonies would exhibit greater resistance to heat (32.5°C), hypoxia (20% DO) and their combination compared to conspecifics from either outer bay or deeper reefs. We found all colonies survived across treatments, but key physiological indicators of coral health revealed enhanced stress tolerance to increased warming in inner bay corals from both depths. Despite varied histories of DO concentration and variability, across all corals there were only slight significant effects of hypoxia on metabolic rates. Enhanced responses to heat stress by inner bay corals, such as retention of photochemical efficiency and delayed bleaching, suggests that environments with high and variable temperatures, and not dissolved oxygen, may serve as resilience hotspots. These reefs may harbor corals with heightened resistance to climate change stressors and thus, emphasizing the importance of considering environmental history in predicting coral responses to changing ocean conditions.

ID: 640 / **Parallel Session 4-4: 13**
Global Climate Change and Environmental Stressors

Keywords: adaptation, natural selection, extreme environment, environmental filtering, Symbiodiniaceae communities

Genomic evidence for rapid holobiont adaptation to an extreme environment in a reef-building coral

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Reef-building corals are critically threatened by anthropogenic climate change, which puts in jeopardy the diverse ecosystem services they provide and and the high biodiversity that they support. Ocean warming and freshwater stress from terrestrial runoff and altered precipitation patterns are already causing frequent mass coral bleaching and subsequent widespread mortality, which, together with ocean acidification and deoxygenation acutely test the adaptive capacity of reef-building corals. To help resolve the dichotomy between global ecological catastrophe and evolutionary optimism, we studied corals living in the semi-enclosed lagoon of Bourake in New Caledonia, where they thrive in a multi-stressor extreme environment encompassing future ocean conditions. We sequenced the coral genomes of 90 *Acropora tenuis* colonies to an average of 67x coverage and characterized their Symbiodiniaceae communities along a steep environmental gradient from Bouraké lagoon to a nearby reef. We found that despite the high genetic similarity among sites, a few relevant genes appeared highly associated with the extreme environment, a signal of rapid adaptation through environmental filtering and natural selection. Demographic history reconstructions supported this finding, showing the demographic expenses of natural selection and suggesting that adaptation is a rewarding yet pricey evolutionary mechanism. Additionally, we found highly divergent symbiont communities among study sites, pointing to symbiont shuffling as an acclimatization response to the stressful semi-enclosed lagoon. Together, our results show that the coral holobiont can employ a suite of rapid adaptive responses simultaneously to overcome environmental stress, potentially within a single generation, via environmental filtering. This provides some hope that at least some reef-building corals can persist in the Anthropocene, but also warns that severe bottlenecks and compositional changes in coral assemblages can be expected, reflecting the demographic expenses of natural selection.

ID: 783 / **Parallel Session 4-6: 3**
Global Climate Change and Environmental Stressors

Keywords: Resilience, Global Change, Tropical Eastern Pacific, El Niño-Southern Oscillation, Pocillopora

Disentangling the determinants of Tropical Eastern Pacific corals' responses to thermal anomalies

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The Tropical Eastern Pacific (TEP) is considered to host some of the most resilient coral reefs in the world but the mechanisms by which these systems resist and recover from perturbations remain poorly known. Reefs thrive in the TEP despite seasonal upwelling and interannual El Niño-Southern Oscillation (ENSO) events that create extreme environmental conditions for corals and other reef organisms. We are using multi-year data from a network of permanent sites across the TEP of Panama combined with laboratory experiments to compare the extent to which colonies of the two dominant species of cauliflower corals, *Pocillopora cf. verrucosa* and *P. grandis*, can maintain critical physiological functions in the face of thermal anomalies, and whether physiological responses vary depending on coral genotype, dominant algal symbiont type, microbiome or exposure to seasonal upwelling. Monitoring of tagged corals over the 2023/24 ENSO thermal stress event suggests that *Pocillopora cf. verrucosa* is more susceptible to high thermal anomalies than *P. grandis* regardless of exposure to seasonal upwelling and regardless of the dominant algal symbiont type. Contrary to expectations, exposure to seasonal upwelling did not produce significant shifts in bleaching thresholds of either coral species in short-term heat-shock experiments. We did find that the coral microbiome was significantly more diverse and more variable among bleached corals in both species. Our results suggest that susceptibility or resistance to thermal anomalies in TEP corals may be primarily determined by coral host species traits and adaptations rather than previous exposure to environmental fluctuations or the presence of specific symbionts. These findings underscore the importance of factoring in species-specific traits when assessing resilience for the conservation and management efforts of TEP coral reefs in the face of climate change.

ID: 585 / **Parallel Session 4-5: 8**
Global Climate Change and Environmental Stressors

Keywords: Thermal preconditioning, Coral bleaching tolerance, transcriptomics, Pocillopora damicornis

Transcriptomics response of thermally preconditioned *Pocillopora damicornis* to heat stress

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Thermal preconditioning has been demonstrated to enhance bleaching tolerance in tropical reef-building corals, offering potential applications for coral farming and restoration, and assisted evolution strategies. Although experimental evidence supports the efficacy of thermal preconditioning in increasing tolerance in corals, the molecular mechanisms underpinning this process remains poorly understood. Limited investigations have been conducted on the molecular basis, with only few coral species being the focus of such studies. Therefore, in this study, colonies of *Pocillopora damicornis* were subjected to thermal preconditioning through controlled exposure to sub-lethal temperature (28 ºC, for 2 weeks), simulating conditions that induce increase tolerance in previous studies. Non-preconditioned colonies were maintained under lower stable conditions (25 ºC). All experimental groups were then subjected to a heat stress of 33 ºC. RNA was extracted from coral samples, and high-throughput RNA sequencing was employed to determine the transcriptome-wide changes in gene expression. Bioinformatics analyses were conducted to identify differentially expressed genes, pathways, and functional categories. The transcriptomic analysis revealed significant differences in gene expression profiles between preconditioned and non-preconditioned *P. damicornis* colonies. Key stress-response genes were upregulated in preconditioned corals, indicating the activation of adaptive heat-stress mechanisms. Additionally, genes associated with symbiotic relationships and antioxidant defense mechanisms exhibited distinct expression patterns. The non-preconditioned colonies displayed a less pronounced stress-responsive transcriptomic signature, suggesting reduced preparedness for future thermal-stress events. These findings provide a comprehensive understanding of the molecular dynamics governing thermal preconditioning in coral. Overall, this investigation will contribute to bridge the knowledge gap surrounding the molecular mechanism of thermal preconditioning, providing essential insights for the practical implementation of this technique in conservation strategies.

ID: 569 / **Parallel Session 4-5: 3**
Global Climate Change and Environmental Stressors

Keywords: hypoxia, metabolism, coastal oxygen, coral ecosystems

Metabolic storms drive coral bleaching and mortality

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The global decline in coral reef health is primarily attributed to rising ocean temperatures, but the role of aerobic stress from metabolic oxygen imbalance is poorly understood. While the combined effect of temperature and oxygen can induce aerobic stress in most marine animals, a causal link to coral health has not been established. We diagnosed drivers of coral health over two years at six Caribbean reefs by combining experimental temperature-dependent hypoxia tolerances for multiple coral species with hourly field measurements of temperature and oxygen. Observed coral bleaching and mortality was tightly linked to sharp reductions in the environment's capacity to meet corals' metabolic oxygen demand. While high temperatures exacerbate corals' aerobic stress, short episodes of low O_2 were the primary driver of both mild and severe reef bleaching. Acute aerobic stress caused by such metabolic storms is a major emerging threat to the health of reef ecosystems but can be ameliorated by coastal hypoxia management and climate stabilization.

ID: 139 / **Parallel Session 4-3: 1**
Global Climate Change and Environmental Stressors

Keywords: Coral Bleaching, Climate Change, Marine Heatwaves, Sea Surface Temperature, El Niño

Record-setting marine heatwaves lead to large-scale coral bleaching and mortality across the eastern tropical Pacific and wider Caribbean: Is the 4th global mass coral bleaching event imminent?

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Coincident with the arrival of El Niño in June 2023, mass coral bleaching due to anomalously warm sea surface temperatures (SSTs) began throughout the eastern tropical Pacific (ETP) and Caribbean side of central America. Unprecedentedly high SSTs and mass bleaching spread to Florida and the Bahamas by mid-to-late July. By October, a marine heatwave, record-setting in magnitude and spatial scale, spanned the entire Caribbean biogeographic region; every reef area (except Bermuda) exceeded heat stress levels known to elicit coral mortality (> 8ºC-weeks). In many reef areas, this historically high heat stress started 1-2 months earlier and was sustained for longer than the typical seasonal changes. For example, in Florida, the previous record-high SST was exceeded for 29 days; many reefs were exposed to more than double the amount of heat stress that is expected to elicit mortality and some sites experienced nearly three times their highest level of heat stress on record. The full ecological impacts of this event will not be fully realized for months-to-years, but preliminary reports have been alarming. The acroporid corals, which were the dominant, shallow-water, reef-building corals throughout the Caribbean for thousands of years, were the most severely impacted, with reports of 90-100% mortality on reefs in Florida, Mexico, and Puerto Rico. Unexpectedly, rapid tissue loss occurred in gorgonian soft corals in Florida; prior to this event, these taxa had been winners in the Caribbean, as their abundances had been stable or increasing across the region. As of December 2023, mass coral bleaching has been reported from at least 35 countries and territories spanning 5 different oceans/seas in 2023. Historical data indicate that the ETP and Caribbean marine heatwave events likely represent the beginning of a global mass coral bleaching event over the next 12-24 months as the El Niño phase of ENSO continues.

ID: 697 / **Parallel Session 4-2: 16**
Global Climate Change and Environmental Stressors

Keywords: reef-building corals, ocean acidification, boundary layer, calcification, metabolism

Integrating coral responses to ocean acidification from the microscale to the colony-scale

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Ocean acidification (OA) constitutes a long-term threat to reef-building corals, typically reducing calcification rates. Coral species vary in their susceptibility to OA, which could be related to effects acting at different spatial scales, from whole-colony scale to microscale. At the microscale, the concentration boundary layer (CBL) at the coral surface can buffer colonies from surrounding acidified seawater and reduce coral susceptibility to OA. However, the integrated effects of OA across scales from the coral CBL to the colony level remain poorly understood. Here, we examined these effects on small-polyped reef-building corals (*Acropora*, *Pocillopora*, and *Porites* spp.) in a series of long-term experiments. Specifically, we assessed the effects of prolonged OA exposure (> three months) at the colony-scale on seven physiological parameters (calcification, growth, photosynthesis, energy) and at the microscale on CBL traits (O_2 and H^+ thickness, surface concentrations, and flux). We found that while species varied in their OA response at the colony-scale, at the microscale CBL traits remained largely stable, except surface pH values. Overall, the H^+ CBL was thin (103–107 µm) and led to species-specific reductions in surface pH. In general, micro- and macro-scale responses did not strongly coincide, especially in *Pocillopora* with the lowest surface pH but high calcification rate as well as low reduction in calcification in response to OA, which were similar to those in *Porites*. *Porites* and *Acropora* had similar reductions in surface pH, although the latter had the largest decrease in calcification. However, reduced energy reserves were observed only in *Pocillopora*, potentially indicating an energetically costly higher regulation of internal pH. Thus, while OA susceptibility is not clearly associated with changes at the CBL scale, complex links between OA effects on corals across spatial scales may occur. These findings provide novel mechanistic insights into species-specific coral susceptibility to OA.

ID: 608 / **Parallel Session 4-6: 5**
Global Climate Change and Environmental Stressors

Keywords: Climate change, Coral bleaching, Adaptation

Variation in heat tolerance of *Platygyra daedalea* on the Great Barrier Reef

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Coral reef ecosystems are severely threatened by climate change and need to adapt rapidly to keep pace with global warming. While the physiological and ecological impacts of coral bleaching have been studied extensively, less is known about evolutionary responses to increasing temperatures and the extent of standing genetic variation for heat tolerance in coral populations. Here we evaluated the susceptibility to bleaching in the common Indo-Pacific brain coral, *Platygyra daedalea*, across the Great Barrier Reef (GBR). During a heatwave in 2020, the bleaching state of 450 colonies from the Northern, Central and Southern GBR was assessed using a Coral Health Chart and every shade of the scale (1-6) was represented with more than 40% of colonies bleached (<4 on the scale). The strongest impacts were observed in the Southern GBR with an average score of 2.5 among all surveyed colonies. Despite experiencing the highest number of Degree Heating Week colonies from the Central GBR showed the least amount of bleaching. To determine whether patterns in the bleaching susceptibility were consistent over time, a subset of 55 colonies from the Northern and Central GBR were re-sampled for an acute heat stress assay to evaluate their bleaching phenotype 3 years after the natural bleaching event. Colonies from the Northern GBR showed higher resilience to experimental heat stress, measured by their retention of photochemical efficiency. To understand the genetic basis of the observed variation in heat tolerance during natural and experimental heat stress, we performed whole genome sequencing on all colonies. The anticipated results will give a deeper insight into the potential of corals to adapt to climate change and lay a foundation for reef restoration efforts by identifying individuals with an increased heat resilience.

ID: 114 / **Parallel Session 4-1: 5**
Global Climate Change and Environmental Stressors

Keywords: Warming, heatwave, fish, transcriptomics, Metabolic Rate

Multi-Tissue Transcriptomics Reveals Novel Insights into the Response of a Coral Reef Fish to Ocean Warming

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Long-term ocean warming and marine heatwaves are predicted to have a range of effects on coral reef fish, with many adverse physiological and molecular responses reported. However, the differing effects of long-term and acute exposure to elevated temperature are less clear, whilst our understanding of the acclimatory/legacy effects of early life-stage exposure to temperature stress are limited. Furthermore, transcriptomic studies of fish often focus on a single tissue type, thus capturing a fragment of the overall molecular response. To address these knowledge gaps, we conducted an aquaria-based experiment comprising of 3 treatments and 2 sampling temperatures to investigate the long-term, acute, legacy and acclimatory effects of elevated temperature on clownfish. Physiological response was investigated via measurements of weight and metabolic rate, whilst the molecular response was investigated by tissue-specific transcriptomic sequencing of the brain, liver, gill, heart, muscle, intestine, and pancreas. Results indicate that acute temperature stress increases resting metabolic rate regardless of thermal history, however its effects are reduced with increasing developmental exposure to +3°C. We observe a tissue-specific molecular response to long-term, acute, and legacy temperature stress with 50-100 DEGs in the brain/gills, and >600 DEGs in the liver/pancreas. A range of functions were disrupted at +3°C including those related to neural development in the brain, solute transport in gills, metabolism in the liver, cholesterol homeostasis in the heart and barrier integrity in the intestine. Additionally, we observe significant disruption to insulin signalling and glucose uptake pathways in fish at elevated temperatures, as 186 genes associated with insulin signalling and secretion were downregulated in the pancreas. As insulin signalling and glucose homeostasis are major controllers of energetics and metabolic functioning it’s likely that these changes underpin many phenotypes previously observed in fish at temperatures associated with ocean warming.

ID: 489 / **Parallel Session 4-5: 1**
Global Climate Change and Environmental Stressors

Keywords: cryptic species, heat tolerance, *Acropora hyacinthus*, Great Barrier Reef, intraspecific variation

Environmental, host, and symbiont drivers of heat tolerance in a species complex of reef-building corals

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Reef-building coral populations are under unprecedented threat from climate warming. Yet, variation in coral heat tolerance exists whereby some colonies can cope with higher sea temperatures than others and thus may hold unique value for conservation and restoration. Here, we quantify variation in heat tolerance of an ecologically important tabular coral species complex across the Great Barrier Reef (GBR) while also measuring genomic variation in the coral host and symbiont partners. Coral bleaching and photochemical traits were measured in 569 colonies within the *Acropora hyacinthus* species complex from 17 reefs following exposure to standardized acute heat stress assays. We detected substantial variation in heat tolerance, where individual colony thermal thresholds differed by up to 7.3°C and 5.7°C among and within reefs, respectively. Sea surface temperature climatology was the strongest predictor of heat tolerance, where colonies from warmer northern and inshore reefs typically exhibited the highest thermal thresholds, while colonies from cooler southern reefs were able to tolerate greater temperature increases relative to their local summer temperatures. Heat tolerance was also positively associated with exposure to thermal stress in the weeks preceding measurements. Assignment of colonies to host genomic clusters revealed four putative species within the *A. hyacinthus* complex that did not vary in their responses to experimental heat stress. Symbiodiniaceae communities within colonies were comprised primarily of Cladocopium ITS2 variants that differed spatially but had minimal effect on heat tolerance. Between 36 - 80% of heat tolerance variation was explained by environmental, host, and symbiont genomic predictors, leaving 20 - 64% to be explained by additional underlying drivers such as functional genomic variation not measured here. These results may be used to inform conservation and restoration actions, including targeting heat tolerant individuals for selective breeding, and will provide a foundation for evaluating the genomic basis of heat tolerance.

ID: 587 / **Parallel Session 4-5: 14**
Global Climate Change and Environmental Stressors

Keywords: Climate change, Coral adaptation, the Red Sea

Resolving the potential for high thermal stress resistance amongst corals of the northern Red Sea

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Corals in the northern Red Sea demonstrate remarkable thermal tolerance despite exposure to high heat stress. This native resistance has been attributed to a similar bleaching threshold throughout the Red Sea (32°C) due to a selection process at Bab ElMandab strait during the initial development of Red Sea reefs. Thus, corals in the north are rarely pushed beyond this threshold due to the lower annual temperature range of the far northern Red Sea (25–28°C). Validation of this hypothesis using remote sensing SST data and historical bleaching records supports the likelihood of a common thermal threshold assumption. In addition, projected warming rates across the Red Sea under various greenhouse scenarios also indicate that temperature in the northern Red Sea is anticipated to persist below the assumed thermal threshold by the end of the century. Despite this, the exceptional thermal resistance for corals in the northern Red Sea has not, in fact, yet been experimentally resolved. Further, the landscape of thermal stress in the northern region is not homogenous. There are likely hydrodynamic regimes that promote localized thermal resistance of corals, leading to 'pockets of resistance'. This study seeks to examine the fine-scale temperature patterns in the Northern Red Sea and empirically link these with patterns of thermal stress in coral populations. We used extensively validated, high-resolution (1 km) hydrodynamic model simulations to evaluate the thermal characteristics of five locations. In addition, we will employ standardized acute thermal stress assays (CBASS) to link thermal thresholds to diverse thermal histories. This work will provide a unique data set that enables a more regionally tuned understanding of bleaching severity, and empirically identifies areas (and coral populations) that support spatial planning for coral conservation goals to preserve and identify the stress-resistant "brood stocks" of the northern Red Sea.

ID: 349 / **Parallel Session 4-3: 12**
Global Climate Change and Environmental Stressors

Keywords: coral bleaching, reproduction, recovery, egg

Recovery of corals post thermal stress: significance of life history strategies

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Discovering the mechanisms involved in tolerance and recovery of corals after thermal stress is crucial 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 corals' ability to continue sexual reproduction and produce viable offspring. In this study, we examined the reproductive capacity, symbiont and microbial transmission to eggs, and long-term (nine-month) physiological recovery in corals that were bleached naturally and experimentally. We found that bleached corals of *Montipora capitata* (a hermaphroditic spawner) were able to reproduce but that gamete development was delayed, and spawning occurred later in the summer. In *Porites compressa*, a gonochoric species, different sexes showed distinct physiological signatures after thermal stress, with male colonies exhibiting higher bleaching susceptibility. *M. capitata* allocated 10% more carbon to gametes despite bleaching by limiting the allocation of carbon to adult tissues, with 50–80% less carbon allocated to bleached compared to nonbleached colonies. Over the same period, *P. compressa* maintained carbon allocation to adult tissues, only allocating surplus carbon to gametes. Our study highlights the importance of autotrophy for carbon allocation from adult corals to gametes, and species specific differences in carbon allocation depending on bleaching susceptibility.

ID: 807 / **Parallel Session 4-6: 4**
Global Climate Change and Environmental Stressors

Keywords: oxygen, coral reefs, thermal thresholds, deoxygenation, climate change

The role of oxygen in determining the acute thermal thresholds of reef-building corals is species-specific

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Rising ocean temperatures pose a significant threat to the persistance of coral reef ecosystems throughout the Anthropocene. In recent years, deoxygenation has emerged as a stressor in coral reefs, excarcebated by ocean warming which decreases oxygen availability through reduced solubility and increased organismal oxygen demand. Additionally, warming is predicted to increase the hypoxic thresholds of marine organisms, reducing their ability to withstand low oxygen concentrations.

Despite a growing awareness of the effects of coastal deoxygenation on coral reef ecosystems, experiments assessing the interacting effects of temperature increases and oxygen concentrations remain scarce. Here we aim to investigate how oxygen availability affects thermal thresholds of three reef-building coral species from the Red Sea (*Acropora cf. hemprechii, Galaxea fascicularis* and *Stylophora pistillata)*, specifically if corals can survive higher temperatures when provided with excess oxygen.

To assess this we exposed coral fragments to three different oxygen treatments during an acute thermal stress experiment: 10 mg O_2 L^{-1} (supersaturated), 6.5 mg O_2 L^{-1} (control), and deoxygenated (<2 mg O_2 L^{-1}). We observed oxygen mediated thermal tolerance in two of the three species (*G. fasicularis* and *A. cf. hemprichii*), with a 0.4°C increase in median lethal temperature (LT_{50}) threshold between the control and deoxyenated treatments however *S. pistillata* showed no difference between treatments.

We also observed that oxygen supersaturation significantly enhanced respiration and deoxygenated conditions reduced the aerobic scope of the coral species studied. Oxygen did not significanty effect rates of net photosynthesis, and the optimum temperature reported for each species was between 30-32°C with net photosynthesis ceasing in all species at 38°C - aligning with the onset of mortality.

Our results indicate that like hypoxic thresholds in corals, the ability of corals to make use of available oxygen in the water column to modulate thermal tolerance is likely species-specific.

ID: 266 / **Parallel Session 4-2: 5**
Global Climate Change and Environmental Stressors

Keywords: ocean acidification, acclimatization, corals, oxidative stress, energy reserves

Coping with ocean acidification: Coral plasticity in the Palau archipelago

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The impact of rising atmospheric CO_2 levels on ocean acidification is well-known. Previous studies on coral species have highlighted the detrimental effects of ocean acidification on physiological aspects such as calcification. Studying corals living in naturally acidified sites provides a unique opportunity to understand potential acclimatization or adaptation strategies. Here, we compared biochemical parameters related to animal biomass, calcification, symbiotic state, nutrient uptake, energy storage, cell protection, and cellular damage between *Porites* sp. colonies from control and acidified sites in the Palau Archipelago. Our results revealed that colonies living in acidified sites exhibited reduced levels of antioxidant defences and cellular stress damage, suggesting some level of acclimatization or adaptation to low pH conditions. In addition, decreased carbonic anhydrase activity and isotopic signatures of host tissues and symbiotic dinoflagellates in acidified environments indicate a shift in the corals' carbon utilization strategy. Photosynthesis shifts from a reliance on bicarbonate (HCO_3^-) to the more easily available carbon dioxide (CO_2). The diffusion of CO_2 through the tissues may create an energy economy and/or reallocation that could help explain the preservation of other physiological parameters under ocean acidification. However, the additional energy might not be enough to fully maintain calcification under acidified conditions. Indeed, calcification is modified as skeleton extension increases at the expense of its density; additional energy might be needed, causing the decrease in coral lipid reserves. In conclusion, *Porites* sp. can acclimatize to acidified conditions, but this may lead to an increased vulnerability to additional stressors.

ID: 180 / **Parallel Session 4-2: 11**
Global Climate Change and Environmental Stressors

Keywords: Marine heatwaves, habitat-forming octocorals, transcriptomics, Mediterranean Sea

Exploring red coral resilience pathways in a warming Mediterranean

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The effects of extreme climatic events (ECEs) such as marine heatwaves (MHW) are increasingly affecting populations of Mediterranean habitat-forming organisms such as the red coral *Corallium rubrum*. Here, we aim to understand the transcriptomic responses to thermal stress in this species. We submitted 6 individuals from two populations from contrasted thermal environments (18m vs. 48m) to a control (18°C) and a marine heatwave treatment (25°C), following a common garden experimental set-up. We sampled the 6 individuals at three time-points in each treatment during the course of the experiment resulting in 18 replicated samples for each population from which the transcriptome was sequenced (N=36). First, we evaluate the general gene expression patterns comparing control and treatment conditions to obtain an overview of the response to thermal stress. Then, we compared the transcriptomic responses for each population to detect the specific molecular mechanisms transcribed by shallow and deep populations during thermal stress. Finally, we compared the gene expression in the control among the two populations to test for the occurrence of transcriptional frontloading. Considering the two populations, a total of 1,094 differential expressed genes (DEGs) potentially linked to hypoxia, immune responses, and anaerobic metabolism were affected by thermal stress. The shallow population showed less DEGs in comparison with the deep population (236 vs 587 DEGs) during the treatment, and stress responses were driven by heat-shock proteins, DNA damage and apoptosis, but with different underlying genes in both populations. Finally, less transcriptional activity was observed during control (77 DEGs) between shallow and deep populations suggesting absence of stress and reduced expression changes between the two populations (i.e. transcriptional frontloading). In conclusion, our study reveals differential insights into the thermal stress tolerances of two contrasting populations of *C. rubrum*, suggesting differential plasticity mechanisms to respond to MHWs in the Mediterranean Sea.

ID: 372 / **Parallel Session 4-4: 8**
Global Climate Change and Environmental Stressors

Keywords: acclimation, warming, plasticity, host-symbiont interaction, metabolic switching

Trade-offs in a reef-building coral after six years of thermal acclimation

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There is growing evidence that reef-building corals can acclimate to novel and challenging thermal conditions. However, potential trade-offs that accompany acclimation remain largely unexplored. We investigated physiological trade-offs in colonies of a globally abundant coral species (*Pocillopora acuta*) that were *ex situ* acclimated to an elevated temperature of 31°C (i.e., 1°C above their bleaching threshold) for six years. By comparing them to conspecifics maintained at a cooler temperature, we found that the energy storage of corals was prioritized over skeletal growth at the elevated temperature. In addition, their skeletal growth rates decreased. This was associated with the formation of higher density skeletons and consequently lower skeletal extension rates, which entails ramifications for future reef-building processes and reef community composition. Furthermore, symbionts were physiologically compromised at 31°C and had overall lower energy reserves, likely due to greater exploitation by their host, resulting in an overall lower stress resilience of the holobiont. Our study shows how biological trade-offs of thermal acclimation unfold, helping to refine our picture of future coral reef trajectories. Importantly, our observations in this six-year study do not align with observations of short-term studies, where elevated temperatures were typically associated with the depletion of energy reserves, highlighting the importance of studying acclimation of organisms at relevant biological scales.

ID: 671 / **Parallel Session 4-1: 1**
Global Climate Change and Environmental Stressors

Keywords: coral calcification, calcifying fluid chemistry, environmental mosaic, ocean acidification, ocean warming

Coral calcification mechanisms across a natural environmental mosaic in Hawai'i

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Coral calcification is key to coral reef growth and function but may be compromised under global and local anthropogenic stressors. Corals modify the chemistry of their calcifying fluid, however, little is known about how these mechanisms vary across a natural environmental mosaic. Here, we used boron-based geochemical proxies ($\delta^{11}B$, B/Ca) to investigate how three common Hawaiian coral species (*Montipora capitata*, *Porites compressa*, *Porites lobata*) regulate the carbonate chemistry of the calcifying fluid along a natural gradient of seawater temperature, pH, significant wave height and chlorophyll *a*. We also analysed coral skeletal trace element composition (Sr/Ca, Mg/Ca, Li/Mg, B/Mg, U/Ca, Ba/Ca, Pb/Ca). Temperature was an important driver of differences in Mg/Ca, Li/Mg, B/Mg and U/Ca composition in all species, whereas the carbonate ion concentration of the calcifying fluid influenced Sr/Ca in *M. capitata* and potentially baseline levels of several trace element/Ca ratios in *P. lobata*. Calcification strategies were governed by complex species and site interactions: while all species had a significantly different calcifying fluid chemistry at each of the four sites, the same species often displayed similar calcification mechanisms across sites. These calcification strategies highlight varying degrees of plasticity and potential resistance to climate change stressors but were not consistently linked to the known resistance of these species to future ocean acidification and warming scenarios. Our findings provide important insights into how corals calcify across a natural environmental mosaic and highlight differential potential for adaptive capacity in calcification mechanisms.

ID: 530 / **Parallel Session 4-2: 15**
Global Climate Change and Environmental Stressors

Keywords: multi-stressor, natural laboratory, coral bleaching, heat tolerance, extreme

Caribbean corals increase their heat tolerance following transplantation into a thermally variable, multi-stressor habitat

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Corals from naturally highly variable or extreme environments tend to have increased stress tolerance, allowing them to persist in suboptimal conditions, such as warmer temperatures and lower pH compared to surrounding reefs. Such environments are potential hotspots of naturally stress-resistant coral populations and can be used as natural laboratories to address significant knowledge gaps on 1) which species can acquire heat tolerance and 2) the time scales required to gain tolerance. To address this, we conducted a reciprocal transplant experiment (RTE) using two species of Caribbean corals (*Siderastrea siderea* and branching *Porites* sp.) between a thermally variable, warmer, multi-stressor inland bay and a nearby more thermally stable and environmentally optimal reef. Following one year of transplantation, we conducted a 10-day heat stress experiment on all four transplant groups. Control corals were maintained at ambient seawater temperatures (28°C), while treatment corals were exposed to 32°C (~24 degree heating days). We measured maximum quantum yield (F_v/F_m) every other day, performed rapid light curves at the end of the experiment to assess coral photosynthetic performance, and measured bleaching (symbiont density and chlorophyll a). Overall, bay natives of both species maintained the highest F_v/F_m (higher tolerance), followed by reef-to-bay transplants. Reef natives had the lowest F_v/F_m and highest sensitivity to heat stress. *Siderastrea siderea* bay-to-reef transplants maintained tolerance, even after one year of transplantation. Branching *Porites* sp. were more sensitive to heat stress than *S. siderea*, with significant declines in photosynthetic performance across all four treatment groups. We provide evidence of increased heat tolerance following one year of exposure to a thermally variable, warmer, multi-stressor habitat, which confirms that some species can rapidly acclimatize to such conditions. We highlight that naturally stress-resistant corals can maintain their thermal tolerance in a less variable, cooler environment, which has implications for selecting coral populations for reef restoration.

ID: 330 / **Parallel Session 4-1: 3**
Global Climate Change and Environmental Stressors

Keywords: Seeps, habitat use, Climate changes, adaptation, corals

Behavioural and molecular responses of a specialist coral-associated fish under multiple environmental stressors in a natural analogue

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Natural analogues such as CO_2 seeps and enclosed bays are mimicking future ocean conditions that can provide insights on how coral reef communities will change or how species will adapt/acclimatize in response to projected climate change. Semi-enclosed Nikko Bay in Palau offers a variety of changing environmental conditions including spatially varying dissolved CO_2, temperature, oxygen, turbidity and chlorophyll-a levels. In selected sites we evaluated coral and fish communities' patterns to assess biogenic habitat shifts and habitat selection of fish. This led us to design and perform a reciprocal transplant experiment focussing on behavioural and brain transcriptomic responses of the coral-associated cardinalfish *Sphaeramia nematoptera* exposed to different CO_2, temperature and habitat conditions. We hypothesized that fish may show differing habitat selection and use via behavioural changes, thus revealing behavioural adaptation to future ocean conditions. Spatial comparisons between control (pCO_2=470µatm; pH=8; T=30.8 °C on average) and future ocean conditions (pCO_2=1218µatm; pH=7.6; T=31.5 °C) revealed changes in the composition of coral communities and a shifting association of the cardinalfish from the dominant coral species *Porites cylindrica* in control conditions to the opportunistic coral *Montipora stellata*, which was more common under future ocean conditions. Results of experimental trials showed changes in transplanted fish activity levels and habitat use (i.e., of the two coral species) as well as in expression changes of specific molecular pathways in the brain. Differences in genes' expression are presented and linked to the observed behavioural changes. Overall, such responses can contribute to highlight the potential adaptation/acclimatization mechanisms of marine species under future ocean conditions.

ID: 392 / **Parallel Session 4-4: 9**
Global Climate Change and Environmental Stressors

Keywords: Upwelling, stable isotope analysis, temperature profile, boosted regression tree modelling, oceanography

Climatic and oceanographic drivers of localised upwelling on remote coral reefs

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Upwelling delivers key nutritional and energetic subsidies to coral reef benthic communities and provides localised cooling to near surface waters. But exactly how upwelling impacts reef community structure, competitive dynamics and coral physiology remains unclear. In this study, we quantify the upwelling regime across three atolls in a remote archipelago in the Indian Ocean using high resolution in situ temperature records. By converting these raw data into a Degree Cooling Hour (DCH) metric, accounting for both the magnitude and duration of cold pulses, we characterise spatiotemporal variation in upwelling across this region. These data are supplemented with 40+ years of oceanographic and atmospheric data which characterise ocean-climate interactions during our data collection window and beyond. We use boosted regression tree modelling to build a statistical framework of upwelling which explains variation within our DCH dataset and predicts variation in upwelling outside of our temperature recording window. Signals of oceanographic nutrient delivery are also explored within the biological reef community itself; using stable isotope analysis of δ15N of a calcifying alga (Halimeda opuntia) we demonstrate a shift in the dominant nitrogen source to the benthic reef community during periods of upwelling. We show how broad-scale ocean-atmospheric interactions change local environmental conditions on coral reefs, laying the foundations for further research into the individual physiological and community responses of corals and coral communities to oceanographic forcings. This research provides a framework for predicting environmental drivers of coral reef outcomes under changing climatic and oceanographic conditions.

ID: 591 / **Parallel Session 4-6: 1**
Global Climate Change and Environmental Stressors

Keywords: Thermal stress, Ocean warming, Red Sea, Transcriptomics, Resilience

Coral bleaching resistance and recovery in the Gulf of Aqaba: Physiological and transcriptome insights from heat wave experiments

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The accelerating frequency and intensity of marine heat waves pose an imminent threat to coral reefs, leading to widespread loss and degradation of these essential ecosystems and their vital functions. The resilience capacity of corals, which is critical for their ability to withstand and recover from stress, plays a pivotal role in determining the overall impact on reefs. In the Gulf of Aqaba (GoA) in the northern Red Sea, various marine taxa exhibit exceptionally high thermal thresholds, positioning the region as a potential refuge for coral reefs facing the challenges of climate change. To gain deeper insights into the physiological mechanisms governing resilience, we conducted comprehensive experiments exposing two common pocilloporid coral species from the GoA to simulated marine heat wave scenarios. Temperatures were increased by +3-4°C and +7-8°C above ambient seawater temperature, followed by a recovery period. We explored the physiological responses on the organismal and transcriptomic levels, comparing the resilience capacities of *Stylophora pistillata* and *Pocillopora verrucosa* during the heat wave as well as during recovery. *S. pistillata* exhibited heightened sensitivity, responding distinctly to the different temperature scenarios. At +3-4°C, enhanced photosynthetic parameters were observed, while at +7-8°C, severe bleaching occurred, followed by partial recovery. In contrast, *P. verrucosa* demonstrated minimal bleaching, indicating exceptional thermal resistance. Transcriptome analysis revealed greater gene expression regulation in *P. verrucosa* during the +7-8°C heat wave, showcasing cellular-level resistance mechanisms. This involved stress responses related to immunity, hypoxia, and mitochondrial activity during heat stress, shifting towards processes involved in cell generation afterwards. Both species exhibited genotype-dependent variability in bleaching resistance, and particularly RNA expression profiles were influenced by coral genotypes. Our findings illuminate species-specific stress and recovery responses, how these may shape future coral reef communities, and underscore the importance of supporting genetic diversity in management and restoration efforts to promote reef resilience.

ID: 371 / **Parallel Session 4-1: 2**
Global Climate Change and Environmental Stressors

Keywords: Ocean Acidification, Natural Analogue, Sponge, Algae, Coral

Examining benthic dominance in Palau's natural analogue environments

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Anthropogenic stressors alter the chemistry of the ocean resulting in increased progression of processes such as ocean acidification (OA). Previous coral reef research has focused on OA effects on organisms such as scleractinian corals, however, competitive benthic organisms with tolerance against OA pressures such as sponges, zoantharians, and soft corals are still comparatively understudied. Conducting surveys including these understudied groups can help inform how reef ecosystems could change under OA. Recently, some studies have examined the effects of OA using natural analogue sites, areas that have pH levels emulating or exceeding future ocean projections. Here, we examined the natural analogue site of Nikko Bay, Palau (pH =~7.8), focusing on the coverage of five benthic groups: hard corals, soft corals, macroalgae, sponges, and zoantharians. Six 10 m transects per site were analysed at 4-5 m depths, with an additional six 10 m transects at <1 m depth at sites with an overhanging "notch". Additionally, environmental DNA (eDNA) water samples were collected from each site to include benthic organisms that were difficult to see on the transects. Surveys were also conducted outside Nikko Bay where the pH is higher than inside the bay (pH =~8.0). Preliminary results showed that the dominant group in low pH sites and the control sites was hard corals. However, the second-most dominant group in low pH sites alternated between algae and sponges, indicating a potentially negative correlation between these groups. Additionally, sponges were the differentiating component between low pH sites and control sites. In control sites where sponges were absent on the transects, algae were the dominant group after scleractinian corals. Results such as these from natural analogue sites will help inform what benthic taxa could persist or become dominant on the reef as the global ocean pH levels continue to decrease into the future.

ID: 692 / **Parallel Session 4-1: 10**
Global Climate Change and Environmental Stressors

Keywords: physiology, acclimatization, trade-offs, stress tolerance

The potential for corals to acquire multi-stress tolerance from exposure to highly variable environments: mechanisms, trade-offs, and lessons learned from manipulative experiments

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Tropical coral reefs thrive under stable environmental regimes, and as a result, symbiotic corals typically have evolved limited environmental tolerance ranges. As such, current rapid climate change increasingly pushes corals outside their tolerance limits with regards to major stressors such as ocean warming, acidification, and low dissolved oxygen, and towards coral reef decline globally. However, stress-resistant coral populations have occasionally been found in reef environments with strong environmental variability. This raises the question whether, and how, exposure history to environmental conditions near the tolerance limits of corals, can widen their tolerance envelope and increase survival under acute stress. Here, we will synthesize data from two years of multi-stressor experimental approaches, linking warming, acidification, and/or hypoxia, to changes in a broad range of physiological parameters indicative of short- and long-term coral health such as detailed metrics of skeleton and tissue growth, photobiology, and metabolism in several Caribbean coral species. We show that corals from variable environments in Curacao differed physiologically from their conspecifics from stable environments in their stress tolerance. Specifically, corals from variable environments were found to be more effective in implementing physiological trade-offs between stressful and non-stressful conditions, to realize increased survival under severe and acute stress. Similarly, adjustments in environmental exposure regime were met over time by corresponding changes in skeletogenesis, photobiology, metabolism and tissue properties, depending on both the nature of the manipulation as well as the environmental parameters involved. Crucially, we found that stress tolerance could be both acquired as well as lost. Altogether, these dynamics underline the complex interaction between environment and organism, emphasizing both the need for further research as well as the potential for some coral species to acclimate to changing environments.

ID: 131 / **Parallel Session 4-2: 10**
Global Climate Change and Environmental Stressors

Keywords: adult fitness, heatwaves, reproduction success, resilience

Parents matter: reproductive success in front of heatwaves is related to parental fitness

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The frequency and severity of marine heatwaves causing mass mortality events in tropical and temperate coral species increases every year, with serious consequences on the resilience and persistence of coral populations. Although viability of coral populations is closely related to adult fitness, as well as larval survival and settlement, much is still unknown about how adult fitness can determine the reproductive success in front of heatwaves. In the present study, increased water temperature effects (+4°C and +6°C above ambient,20°C) on reproductive output, larval survival and settlement rate was evaluated according to adult fitness in two of the most representative Mediterranean octocoral species (*Eunicella singularis* and *Paramuricea clavata*). In *E. singularis,* the thermal stress impacts were experimentally assessed depending on trophic strategy (autotrophic or mixotrophic) of adult colonies. In *P. clavata*, we evaluated the reproductive success of two populations with a differential response to heatwaves (i.e., high and low mortality rates). Our results show that in *E. singularis*, the reproductive output is not determined by trophic strategy, but the absence of heterotrophic food could have adverse consequences on their reproductive phenology, shortening the breeding event. In *P. clavata*, the level of affectation did not show consequences on timing of spawning, however preliminary results suggest that the injured populations could display lower reproductive output than healthy ones. Additionally, thermal stress drastically reduced the survival of *P. clavata* larvae and their settlement rates in both affected and unaffected populations, whereas in *E. singularis,* larval survival and settlement rates was strongly related to parental fitness independently of thermal conditions. The present results highlight the importance to have into account not only early life history stages, but also adult fitness over all the period of development of sexual products to fully understand the long-term persistence, resilience capacity and connectivity of populations under continued ocean warming.

Speed talks

ID: 589 / **Parallel Session 4-5: 4**
Global Climate Change and Environmental Stressors

Keywords: transcriptome, thermal limit, Persian Arabian Gulf

The paradoxical vulnerability of the world's most thermally tolerant corals

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Whether coral reefs will exist into the future remains uncertain as intensifying ocean warming continues to drive coral decline and demise worldwide. Corals found in extreme environments such as the Persian/Arabian Gulf (PAG), the world's warmest sea, represent a promising resource for assisted gene flow efforts and to study genetic signatures of thermal tolerance. However, precise knowledge of their thermal limits in relation to their surrounding environment remains to be resolved. As part of 'Global Search', we applied a standardised approach to empirically assess thermal thresholds for coral populations in the PAG and other ocean basins. The Coral Bleaching Automated Stress System (CBASS), an acute short-term heat stress assay, was used to determine the upper thermal threshold of corals via modelling the dose-response relationship of photosynthetic efficiency (Fv/Fm) in correspondence to thermal exposure. Within the southern PAG, the most common species – *Porites harrisoni, Platygyra daedalea*, and *Cyphastrea microphthalma* – across three different sites that experience between 31 and 34°C as their long-term maximum summer temperatures, were stress tested prior to summer heat-loading. Using CBASS and ED50s, we measured the highest absolute thermal thresholds ever recorded thus far, in particular for *Porites* - a consistently resilient species in bleaching events. However, unlike other reef regions, there was a negative correlation between their thermal thresholds and a site's long-term maximum temperature suggesting that these corals are close to or even beyond their thermal limit. We are currently conducting RNA-Seq analyses to assess their heat stress and recovery transcriptional response to better understand how these corals can handle such high temperatures, and also whether there are indicators of a limited thermal recovery.

ID: 522 / **Parallel Session 4-2: 3**
Global Climate Change and Environmental Stressors

Keywords: nutrient, enrichment, experiment, bleaching, Maldives

Impact of nutrient enrichment on susceptibility to temperature-induced bleaching in an oligotrophic reef setting, Maldives.

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Introduction: Anthropogenic nutrient enrichment and rising seawater temperatures pose significant threats to coral reefs globally. Their combined effect causes complex interactions between the coral host and their symbiotic dinoflagellates, disrupting the relationship through impacts on nutrient stoichiometry and ultimately lowering bleaching thresholds. This study from the Maldives is the first to document the response of scleractinian corals to such interactive stressors on an oligotrophic reef.

Methods: Here, we exposed 30 *Pocillopora* spp. corals to N-based slow-release fertilisers in a 6-month *in-situ* enrichment experiment (between 3-10m). This period included a moderate-severity temperature-induced bleaching event. One of three treatments were randomly allocated as control (no nutrient addition); high N (150g of 18-9-10 NPK); or high P (150g of 13-13-13 NPK), with fertiliser replenished every 6-8 weeks. Temperature was recorded throughout, with bleaching surveys conducted every 2-3 weeks. Insights into physiological responses to N and C acquisition were determined through subsequent N, $\delta^{15}N$, C and $\delta^{13}C$ analysis of coral tissue and algal symbiont samples.

Results: Bleaching severity was significantly reduced for corals enriched under both treatments ($p < 0.01$) treatments relative to the control plots. $\delta^{15}N$ signatures of the coral tissue and symbionts became significantly depleted under both treatments ($p < 0.01$) (trending towards that of the fertiliser). Relative to controls and high P treatment, C:N ratios of the symbionts were significantly lower in the high N treatment ($p < 0.01$) but not the tissue.

Conclusions: Initial findings indicate that under elevated nutrient and temperature, uptake, and incorporation of N increases. This may help buffer this species of coral to thermal stress events. These findings suggest that longer term experiments are warranted to fully understand the longer-term impacts. As an atoll-island nation dependent on resilient reefs, understanding factors that mitigate and exacerbate the prevalence and intensity of bleaching events is critical.

ID: 550 / **Parallel Session 4-4: 6**
Global Climate Change and Environmental Stressors

Keywords: Tropicalisation, coral adundance, fish communities, climate change

Changes in coral abundance and fishes across tropical to temperate reefs in Japan

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The increases in ocean temperatures as a result of climate change lead to the degradation and transformation of marine ecosystems. Range expansions, whereby species migrate poleward, drive shifts in community structure and composition of temperate reefs as tropical species invade. Such topicalization has led to widespread losses of temperate macroalgal communities, such as kelp forests, that are replaced by either turf or coral communities. However, exactly which species are benefiting from topicalization, and which species are being lost, is not well explored.

Here, we quantify the reassembly of subtropical and temperate benthic and fish communities over an 8-year period at 35 sites across tropical to temperate environments in Japan. We apply multi-variate and Bayesian models to species prevalence and abundance data from visual and environmental DNA sampling to quantify community and functional shifts in space and time. We report substantial reductions in macroalgal cover at several sites and both losses and gains of corals at temperate sites. Additionally, we find losses of obligate temperate fish species that associate with kelps, whereas tropical fish biomass fluctuated with coral cover at temperate sites. For example, tropical fishes were significantly reduced in both richness and biomass in a previously high-coral cover area that experienced a significant decline in coral abundance possibly as a result of cold-water bleaching. Our findings provide baseline data for long-term observation of community-wide shifts, and highlight how stochasticity in both environmental and biological drivers render topicalization processes difficult to predict.

ID: 222 / **Parallel Session 4-4: 15**
Global Climate Change and Environmental Stressors

Keywords: coral bleaching, cross-ecosystem nutrients, invasive species, island restoration, recovery dynamics

Seabirds boost coral reef resilience

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Global climate change threatens tropical coral reefs, yet local management can influence resilience. While increasing anthropogenic nutrients reduce coral resistance and recovery, it is unknown how the loss, or restoration, of natural nutrient flows affects reef recovery. Here, we test how natural seabird-derived nutrient subsidies, which are threatened by invasive rats, influence the mechanisms and patterns of reef recovery following an extreme marine heatwave using multiyear field experiments, repeated surveys, and Bayesian modeling. Corals transplanted from rat to seabird islands quickly assimilated seabird-derived nutrients, fully acclimating to new nutrient conditions within 3 years. Increased seabird-derived nutrients, in turn, caused a doubling of coral growth rates both within individuals and across entire reefs. Seabirds were also associated with faster recovery time of *Acropora* coral cover (<4 years) and more dynamic recovery trajectories of entire benthic communities. We conclude that restoring seabird populations and associated nutrient pathways may foster greater coral reef resilience through enhanced growth and recovery rates of corals.

ID: 670 / **Parallel Session 4-6: 12**
Global Climate Change and Environmental Stressors

Keywords: corals, algae, competition

The changing nature of coral-algal interactions: a review of four decades of research

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Recent declines in coral cover are accompanied by increases in other benthic taxa, namely algae, that rapidly colonise the dead coral skeletons. Any recovery of coral assemblages, therefore, must occur against a backdrop of elevated algal cover. Understanding the mechanisms and outcomes of coral-algal interactions, and how they vary among coral and algal taxa and among coral life stages is crucial for forecasting future reef configurations. We conducted a systematic review of the evidence on coral-algal interactions to investigate taxonomic, functional and life stage biases for both corals and algae, and how these influence the outcomes of coral-algal interactions. Across 169 studies and >1,300 coral-algal interactions, most available data was based on adult corals, with relatively few studies investigating the potential effects of algae on early life stages of corals. There were also regional differences in the taxonomic and functional identity of the coral and algal taxa investigated, with interactions across the tropical Atlantic focusing on *Porites* and other massive corals, while those in the Indo-Pacific focused on *Acropora* and other branching corals. While algal communities are typically diverse, and spatially and temporally variable, most studies investigated the effect of a single algal-coral pair over a relatively short temporal scale, few studies considered the potential effects of multiple algal taxa or broader habitat-scale effects of algal assemblages on corals.

ID: 660 / **Parallel Session 4-6: 13**
Global Climate Change and Environmental Stressors

Keywords: Coral bleaching, Great Barrier Reef, Ecosystem Impact, Thermal tolerance

A new approach to effectively categorise and communicate impacts from mass bleaching events on the Great Barrier Reef

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Mass bleaching events are characterised by bleaching of a high proportion of corals across an expanse of reef communities in response to intense periods of thermal stress. Coral colony-level bleaching severity is directly related to survivorship and is a function of both the intensity and duration of summer maximum temperatures, which continue to intensify and accelerate throughout the world's coral reefs due to climate change. Linking colony-scale and reef community bleaching severity with ecosystem impacts caused by mortality from bleaching is inherently challenging, but critical to understanding the adaptive capacity of coral reefs and to support communities to better prepare for and adapt to escalating climate change. Given both the large spatial scale and iconic nature of the Great Barrier Reef (GBR) ecosystem, capturing and communicating the spatial variability and prevalence of bleaching-related impacts to the ecosystem has broad-reaching implications. In this study, we have combined a range of techniques developed during three decades of bleaching on the GBR, including in-water community surveys (to categorize colony and taxa-level bleaching response), together with broadscale aerial surveys (to guide and define the overall impact and severity of each mass bleaching event on local, regional and whole of ecosystem scales). We combine our ecological understanding of community bleaching with long-term trends in temperature (1980's – present) to develop a novel framework that compares six mass bleaching events (1998, 2002, 2016-17, 2020 and 2022) and categorises the impact to reef communities as a function of: (i) heat stress exposure; (ii) colony level bleaching response; (iii) prevalence of severe bleaching and mortality; and (iv) spatial extent of partial bleaching, fully bleached and recently dead coral colonies within each reef community across local, regional and whole ecosystem scales. This approach aims to streamline the communication of critical information regarding the impacts of thermal stress on the Great Barrier Reef.

ID: 844 / **Parallel Session 4-2: 6**
Global Climate Change and Environmental Stressors

Keywords: Coral, micro-computed tomography, mangrove, biomineralisation

Skeletal structure and adaptive mechanisms of corals inhabiting a mangrove environment

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Coral skeletons form the foundational framework of coral reef ecosystems but can become increasingly porous and fragile under climate change stress. There are however some extreme and marginal environments, such as mangrove habitats, where corals are found to survive and grow. These environments provide a natural setting to examine the long-term effects of climate change on the skeletons of resident corals and identify adaptive mechanisms that corals may adopt to survive under future ocean conditions. Using micro-computed tomography, we investigated the effects of environmental conditions on the skeletal microstructure of three species of corals: *Pocillopora acuta*, *Acropora millepora* and *Montipora digitata*, from the Low Isles mangrove system in the Great Barrier Reef. Corals were collected from sites with increasing distance from the mangroves. Assessment of the benthic foraminifera assemblages and surficial sediments indicated that the mangrove sites were marginally suitable for coral growth. Sediment analysis indicated the presence of organic matter throughout the Low Isles system that corals may utilise for heterotrophic feeding. Species-specific microstructural changes were recorded in coral skeletons in response to distance from mangroves where skeletons were generally more porous and thinner closer to the mangroves, where conditions were the most marginal. *Montipora digitata* was able to maintain the most robust skeleton in the mangrove environment and formed significantly larger calyxes at these sites, potentially indicating the use of increased heterotrophy as a mechanism to support skeleton growth. This study suggests the integrity of coral skeletons may be compromised by climate change stress but that some corals can utilise organic matter originating from the mangrove habitat that may help some coral species tolerate these conditions.

ID: 718 / **Parallel Session 4-4: 17**
Global Climate Change and Environmental Stressors

Keywords: range expansion, Pocillopora, Symbiodiniaceae, high-latitude, environmental gradient

Subtropical specialists dominate the Japanese coral range expansion front

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The coral host-symbiont relationship is critical to coral survival. Understanding how both scleractinian host and symbiont Symbiodiniaceae diversity changes along environmental gradients can help predict responses to environmental stressors, such as potential range shifts from ocean warming. We ask if the fast-growing, stress-tolerant *Pocillopora* corals and associated symbiont communities are expanding their range northwards in the western Pacific Ocean. Along the Kuroshio Current, which carries warm water from the equatorial regions to Japan, we collected coral tissues from 23 tropical to temperate reefs, from Iriomote in the Ryukyu Islands (24° N) to Kushimoto on mainland Japan (33° N) in 2023. In total, we sampled from 330 *Pocillopora* corals along this ~1500 km latitudinal gradient. We examined host identities through sequencing of the mitochondrial open reading frame (mtORF) region, and built symbiont type profiles with next-generation sequencing of the internal transcribed spacer 2 (ITS2) region of the ribosomal DNA, following the SymPortal framework. We show a dramatic reduction of *Pocillopora* haplotypes and a marked change in dominant symbiont types northwards from Cape Sata (30° N), Kagoshima. This suggests a biogeographic break north of the well-known Watase Line/Tokara Gap where tropical *Pocillopora* haplotypes are notably absent on mainland Japan. We also demonstrate high host specificity between the subtropical *Pocillopora* hosts and one still undescribed *Cladocopium* symbiont genotype (SymPortal unique identifier: 6597_C). Our findings show that *Pocillopora* host and symbiont diversity remain low in the mainland Japan range expansion front, raising important questions regarding future range expansions and persistence of zooxanthellate corals in novel environments.

ID: 299 / **Parallel Session 4-6: 15**
Global Climate Change and Environmental Stressors

Keywords: stony corals, SCTLD, biomineralization, tissue loss lesions, calcium carbonate

Multiscale chemistry and structure of stony coral tissue loss disease lesions

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Scleractinian corals protect their soft polyps by building an exoskeleton from aragonite, a polymorph of calcium carbonate. In hierarchically organized corallites, aligned single-crystalline aragonite fibers extend radially about centers of calcification (COC), containing clusters of amorphous calcium carbonate (ACC) precursor. While many aspects of nucleation and growth of coral skeletons are not yet fully understood, even less is known about the effect of diseases on the skeleton. Stony Coral Tissue Loss Disease (SCTLD) is a coral disease that first emerged in South Florida in 2014 and has since been reported in coral colonies in the Carribbean. This disease has decimated coral communities, and it is currently believed that SCTLD is caused by microbial pathogens and exacerbated by rising ocean temperatures and acidification.

In this study, samples of healthy and diseased *Montastraea cavernosa* stony coral species were compared to investigate how SCTLD affects the degree of mineralization, the elemental composition, the mesoscale hierarchical organization, and orientation of aragonite crystallites. Raman and FT-IR chemical mappings were performed, revealing a decreased amount of aragonite mineral and greater presence of precursor ACC in diseased samples, indicative of a possible hinderance in the aragonite mineralization process. Energy Dispersive X-ray Spectroscopy (EDS) carbon maps revealed a homogenous distribution of carbon around the COC, while the SCTLD samples exhibited carbon clusters at the sub-micrometer level. Electron Backscatter Diffraction (EBSD) was used to obtain nanoscale mappings of the crystalline phase and orientation of aragonite grains, which showed a decrease in aragonite grain size and crystal orientation in the diseased corals. Further studies investigate the crystal defects in biogenic and abiotic aragonite crystals using atomic-resolution Transmission Electron Microscopy (TEM). These results contribute to the understanding of coral skeleton biomineralization and the transformation processes undergoing in diseased stony corals, which can help us draw parallels to other pathogenic demineralization processes.

ID: 599 / **Parallel Session 4-5: 5**
Global Climate Change and Environmental Stressors

Keywords: bleaching, disease, symbiosis, immunity, multiple stressors

Leveraging a natural bleaching event to investigate the mechanistic link between bleaching and disease in tropical corals

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Heat-induced bleaching and disease outbreaks are two of the largest drivers of global scleractinian coral decline. Associations between these two stressors have been frequently observed, with disease often occurring in the weeks to months following bleaching; however, the mechanisms of these associations remain understudied. Recent developments in understanding cnidarian symbiosis-immune dynamics suggest that fluctuations in symbiont densities during bleaching and recovery may affect host immunity and ultimately disease susceptibility. Nonetheless, there is a paucity of existing fine-scale data from natural coral systems which might support this hypothesis. We leveraged the 2023 bleaching event in Carrie Bow Cay, Belize to generate one of the first such datasets. Specifically, we tracked metrics of holobiont physiology, as well as general bleaching and disease outcomes, for five species of coral from peak bleaching through recovery (sampling ongoing). This comprehensive dataset will provide unprecedented insight regarding the effect of bleaching-associated dynamic changes in symbiosis and energetic reserves on innate immunity, and, consequently, disease susceptibility in scleractinian corals. Here specifically we will discuss preliminary findings regarding changes in symbiont density and host immune metrics from peak bleaching through acute recovery. Specifically, we will detail relationships between these physiological changes and both bleaching and disease outcomes. The results of this study will not only provide a better understanding of mechanisms linking bleaching and disease, but will also shed light on potential predictors of coral health outcomes during multiple stress events.

ID: 144 / **Parallel Session 4-2: 13**
Global Climate Change and Environmental Stressors

Keywords: Turbidity, Physiology, Sediments, Indian Ocean, Environmental stressors

Extreme tolerance of shallow-water black corals (Antipatharia) to increased particles loads during short-term exposure

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Like scleractinian corals, antipatharians can be key species in coral reef ecosystems, possibly dominating the mesophotic or even the shallow-water zone and forming marine animal forests. They are usually inhabiting areas with strong currents, low luminosity, or high turbidity. Turbidity can be influenced by anthropogenic activities such as local deforestation and mining, as well as natural events such as cyclones. Such anthropogenic activities are releasing an increasing amount of inorganic material into coastal waters, affecting coral ecosystems. Therefore, the aim of this work was to determine the impact of suspended sediment loads on several antipatharian species of the northern Great Reef of Toliara, in front of the Fiherenana river in SW Madagascar. Surface sediments were collected in the northern pass of the reef and the granulometry was characterized by sediment traps. Nubbins of 4 species belonging to two morphotypes (branched versus whip) and two different families were collected from the same site. In the laboratory, they were exposed to 5 concentrations of suspended particles during 3-hour cycles on two consecutive days. For each concentration tested, the respiratory rate of each nubbin was recorded as an indicator of metabolic impact. The response of the antipatharians to the treatment differed from one species to another, without being related to morphology or family affiliation. The 4 species tested showed the ability to recover from short-term stress. However, they did not show any short-term acclimation to increased sediment load in the water column. Comparison with data previously recorded in 2022 suggests a possible acclimatization to the frequent cyclones that occur in the region.

ID: 457 / **Parallel Session 4-3: 3**
Global Climate Change and Environmental Stressors

Keywords: Thermal Thresholds, Temperature Range, Coral Adaptation, Climate Change, Temperature Stress

Resolving heat but also cold bleaching thresholds predicts coral temperature vulnerability

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Warming ocean temperature has led to multiple mass coral bleaching events in tropical seas. In this context, thermal tolerance thresholds for multiple coral species and locations are beginning to be determined worldwide in a standardized manner. However, only upper-temperature bleaching thresholds have been explored, despite a growing number of reports on (mass) coral bleaching events due to low ocean temperatures ('cold bleaching'). Here we determined the lower and upper-temperature thresholds and recovery potential of three scleractinian corals of the Red Sea (*Acropora* sp., *Pocillopora verrucosa*, *Stylophora pistillata*) at peak summer and peak winter temperatures by using the short-term and standardized 'Coral Bleaching Automated Stress System' ('CBASS'). First results indicate species-specific responses to cold and thermal stress: during summer, *Acropora* sp. exhibits the highest thermal threshold (38.68 ± 1.23°C), whereas *P. verrucosa* is least tolerant to heat stress but displays a cold temperature threshold ~2 °C below that of *Acropora* sp. and *S. pistillata* (22.59 ± 1.48°C vs. 24.18°C ± 1.56 and 24.88 ± 1.74°C, respectively). Notably, bleaching susceptibility and recovery capabilities also seem to vary between species. We observed bleaching and reduced photosynthetic efficiency of *Acropora* sp. after a recovery phase subsequent to heat stress, whereas our results indicate that *P. verrucosa* and *S. pistillata* seem to obtain recovery potentials after being exposed to extreme cold temperatures. Determining heat and cold bleaching thresholds resolves the viable temperature range of corals, and thus, provides better prediction regarding their temperature vulnerability and recovery potential in a changing world.

ID: 386 / **Parallel Session 4-6: 10**
Global Climate Change and Environmental Stressors

Keywords: reef fishes, nutrient pollution, 16S, pathogens, human nutrition

Gut microbiome and nutrient assimilation in parrotfish across a gradient of wastewater pollution in Mayotte

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Wastewater pollution resulting from sewage outfalls and coastal runoff is often associated with dysbiotic patterns and the emergence of pathobiomes in reef organisms, ultimately impacting their health. However, the mechanisms leading to microbial dysbiosis in reef fishes are still poorly understood. In addition, less is known about the relationships between gut microbial metrics and the assimilation of macro- and micronutrients in fishes. This knowledge gap is particularly apparent for important herbivores such as parrotfishes which are keystone species for ecosystem function and human nutrition. Here, we used a multidisciplinary approach, coupling field collections of turf, sediment, water and individuals of *Chlorurus sordidus* from six reef sites in Mayotte that vary in their levels of exposure to wastewater, with 16S metabarcoding and biochemical analyses. We found significant differences in bacterial diversity, community composition of turf, sediment and water samples across reef sites. We link pathways between anthropogenic impacts and microbial dysbiosis in parrotfish and the presence of potentially harmful taxa for fishes and humans. Additionally, we unravel potential links between the microbiomes of parrotfish guts and the assimilation of macro and micronutrients. These results have important implications for the roles of parrotfish in nutrient cycles as well as for human nutrition.

ID: 703 / **Parallel Session 4-5: 7**
Global Climate Change and Environmental Stressors

Keywords: preconditioning, photosynthetic efficiency, bleaching, thermal tolerance, recovery

Shifts in baseline physiology accompany thermal stress hardening in corals

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Global warming threatens reef-building corals by challenging their natural adaptive capacity. Therefore, developing effective strategies, such as stress hardening by thermal preconditioning, that may help corals survive is crucial. Stress-hardening approaches are based on the recognition that individuals found in thermally variable environments cope better with marine heat waves. However, stress-hardening approaches in corals lack a systematic assessment of their effects on baseline physiology and immediate and long-term resilience to stress across species. Here, we compared the thermal tolerance of six stony coral species after exposure to three preconditioning temperature regimes: stable-high at 29 °C, variable-high at 29 °C (daily oscillation ± 1.5 °C), and ambient stable control at 26 °C. We quantified the increase of thermal tolerance by assessing the changes in photosynthetic efficiency and bleaching intensity directly after heat stress (3 h at 36 °C) and up to 30 days later. Both preconditioning treatments significantly increased photosynthetic efficiency after heat stress compared to the control in five of six coral species. Preconditioning also reduced bleaching intensity in four species, indicating higher thermal tolerance. While preconditioning had negligible effects on heat stress tolerance of *Stylophora pistillata*, the largest increases in tolerances were recorded in *Galaxea fascicularis* and *Acropora muricata,* with reductions of their stress response by over 80 % compared to the control. These results highlight differences in the receptivity of species to preconditioning, which also affected their long-term resilience. After 30 days, most preconditioning-receptive corals had increased survival and recovery rates compared to the control, which lacked any physiological recovery. Notably, our study detected changes in the baseline physiology of corals right after the preconditioning treatments, such as slight paling and lower photosynthetic efficiency. These physiological shifts might entail trade-offs. Therefore, effective protocols for thermal stress-hardening will require careful consideration of coral species traits and physiological baseline shifts.

ID: 468 / **Parallel Session 4-3: 4**
Global Climate Change and Environmental Stressors

Keywords: Galápagos, Pocillopora, marginal reef, mtORF haplotype, symbiont community makeup

Molecular mechanisms underlying heat and cold tolerance in Galápagos *Pocillopora spp.* communities

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Mass coral bleaching and mortality events jeopardize the persistence of coral reefs worldwide. Galápagos corals experience a wide range of temperatures and inhabit marginal conditions compared to other tropical reefs. The stress tolerance of corals remaining after recent warm- and cold-water bleaching events in the archipelago may be the product of adaptation and acclimatization. In the spring of 2019, we investigated thermal tolerance differences in *Pocillopora* sp., a widespread reef-building coral in the Indo-Pacific found throughout the Galápagos. We unexpectedly found that corals from northern sites–which experience warmer and less variable annual average temperatures–were more resilient than those from central and southern sites, having both greater heat and cold tolerances. In this study, we sequenced the mitochondrial open reading frame (ORF) to determine Pocillopora haplotype, amplified actin using quantitative PCR to determine symbiont type, and used Tag-Seq to explore gene expression patterns in our samples. We aim to understand how these variables correlate with heat and cold tolerance. Preliminary results suggest that the thermally tolerant symbiont *Durisdinium* is absent from most central and southern sites, and a thermally tolerant *Pocillopora* ORF haplotype (type 1) exists in far northern and most central southeastern communities, possibly explaining differences in thermal tolerance across regions. Our results can provide insight into the adaptive potential of reefs worldwide as they endure warm and cold stress events.

ID: 495 / **Parallel Session 4-4: 4**
Global Climate Change and Environmental Stressors

Keywords: corals, bleaching, diversity, health condition

Benthos condition in coral reefs around Cuban island during extreme sea surface temperature

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As in the entire Caribbean region, Cuban reefs are degrading due to local (e.g. overfishing) and global (e.g. rising sea temperatures) anthropogenic impacts. In Cuba, coral reefs make up 98% of our shelf edge, however, never before has a survey been carried out around the entire island to assess its current condition. Due to this, the objective was to evaluate the condition and health of the coral reefs around the entire Cuban shelf. The research was carried out between July 18 and September 9, 2023. Fore reef and spur and grooves biotopes were selected at 64 sites in 23 reef zones. The evaluation of hermatypic corals (species composition, diversity, density) and *Diadema antillarum* (density, size, albinism) was carried out through the 10m long by 1m wide band transect. Substrate coverage was evaluated with the 10m long linear transect. For both methods the replication was ten sampling units per site. 57,839 colonies were evaluated, 53 species of corals were identified and the density was 42 col/10m^2. The southwestern area of Cuba was the one that presented higher abundance values (16,855 col). The predominant species are *Siderastrea siderea*, *Porites astreoides* and *Agaricia agaricites*. All areas and reefs presented more than 60% of the colonies with bleaching, with the entire southwestern and central region being the most affected. The incidence of diseases was less than 5%. White syndrome was reported for the first time in Cuba. Due to the current situation of some reefs, it is recommended to deepen our knowledge while also suggesting to evaluate the spatio-temporal variability of bleaching and its effects.

ID: 130 / **Parallel Session 4-1: 8**
Global Climate Change and Environmental Stressors

Keywords: Corals, Mortality, Bleaching, Marginal coral communities, Cabo verde

Bleaching and mortality of *Millepora alcicornis* and *Tubastraea coccinea* in marginal coral communities (Cabo Verde, East Atlantic Ocean)

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The hydrocoral *Millepora alcicornis* and the azooxanthellate scleractinian *Tubastraea coccinea* dominate the marginal coral communities of shallow rocky bottoms of Santo Antão (Cabo Verde, East Atlantic Ocean). Both species have been affected by the unprecedent marine heat waves that have occurred in spring and summer 2023 in the Atlantic Ocean, with 1ºC to 2ºC positive sea surface temperature anomalies. In this study, we report quantitative results about the resulted bleaching (*Millepora alcicornis*) and mortality (*Tubastraea coccinea*) in the southern coast of the island. Most colonies of *Millepora alcicornis* were partially or completely bleached, with no differences in affectation among colonies located at 5, 10 and 20 m depth. Similarly, *Tubastraea coccinea* showed high mortality at 5 m depth. The reported bleaching and mortality of two dominant coral species may result in an oversimplification of the community with severe functional impacts at shallow depth. Monitoring in the coming years will provide information on the long-term response (degradation or recovery) of the two species in the poorly known marginal coral communities of Cabo Verde.

ID: 615 / **Parallel Session 4-2: 8**
Global Climate Change and Environmental Stressors

Keywords: eDNA metabarcoding, coral reef, biodiversity, natural anlaogue sites

Inside versus outside: eDNA metabarcoding unveils high eukaryotic community variation within the waters of Palau´s Nikko Bay

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Coral reefs, vital for global biodiversity and ecosystem services, face escalating threats from climate change and ocean acidification, already significantly impacting coral reef communities worldwide. Accumulating bleaching events, exacerbated by increasing temperatures, coupled with elevated seawater partial pressure of CO_2 (pCO_2), raises uncertainties about the future of these vital ecosystems. Fortunately, Palau's coral reefs have so far proved resilient. Particularly intriguing is Nikko Bay, a semi-enclosed bay in Palau's inner reef, where high coral cover persists despite elevated temperatures and pCO_2.

This study explores these unique marine environments of Palau, using environmental DNA (eDNA) metabarcoding targeting the COI gene. Water samples from diverse coral reef habitats across Palau, including two outer reef sites (n=2), four inner lagoon sites (n=4), and six sites within Nikko Bay (n=6), were analysed to unravel eukaryotic community compositions. Nikko Bay, a natural analogue site, was chosen to understand the influence of low pH conditions on coral reef communities. Outer reef sites showed a higher MOTU richness than the inner lagoon and Nikko Bay. However, a remarkable homogeneity in eukaryotic species composition was observed within the outer reef sites and inner lagoon sites, respectively. In stark contrast, Nikko Bay harboured a strikingly diverse composition of eukaryotic species communities. The extent to which the unique conditions of the bay, including the comparatively low pH, contribute to these distinct and diverse marine communities, and the contribution of prevailing water circulation, requires further investigation.

This study contributes to the broader understanding of marine biodiversity in Palauan ecosystems and underscores the importance of incorporating natural analogue sites like Nikko Bay into biodiversity assessments. These sites are crucial outdoor laboratories for studying ecological implications of environmental stressors, setting the stage for future investigations into the resilience and adaptability of marine organisms, especially coral reefs, in Palau's dynamic reef environments.

ID: 782 / **Parallel Session 4-6: 2**
Global Climate Change and Environmental Stressors

Keywords: Acropora, Growth Anomaly, Hsp60, I-PAM, Thermal stress

Physiological and cellular responses of three morphotypes of skeletal growth anomalies on *Acropora muricata* under short-term thermal stress

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Scleractinian corals have been reported to be affected by skeletal growth anomalies (SGAs). Limited studies have investigated both the physiological and cellular changes associated with SGA morphotypes on corals and their thermal responses. This study assessed the photo-physiological and the cellular responses associated with three morphotypes of SGAs (Exophytic-Ex, Crateriform-Cr and Bosselated-Bo) on *Acropora muricata*. The photo-physiology and the heat shock protein 60 (Hsp60) expression patterns under 3-hr exposure at 28, 30 and 32°C were analyzed in both healthy and diseased colonies. With the exception of the Bo-SGA, the photo-physiological assessment, using Imaging Pulse-Amplitude-Modulated (I-PAM) fluorometer, revealed no significant changes in effective quantum yield at photosystem II (Φ_{PSII}), maximum relative electron transport rates ($rETR_{max}$) and non-photochemical quenching (NPQ_{max}) between the SGA and the healthy-looking coral parts at 28ºC. A significant reduction was observed in Φ_{PSII} and $rETR_{max}$ of Bo-type SGA compared to the healthy-looking part. Using Western blot technique, Hsp60 levels were found to be significantly lower in the healthy-looking coral parts than the SGAs. Relative to 28ºC, about 1% and 19% reductions in Φ_{PSII} were recorded in the healthy-looking coral parts at 30ºC and 32ºC, respectively. Compared to 28ºC, a 4%, 29% and 53% significant reduction in Φ_{PSII} at 30°C, and a 17%, 70% and 62% significant reduction at 32ºC were observed in the Ex-, Cr- and Bo-type SGAs, respectively. In contrast to 28ºC, Hsp60 levels were found to be up-regulated in the healthy-looking tissues by 11% and 30% at 30ºC and 32ºC, respectively. Compared to 28ºC, Hsp60 levels increased at both 30°C and 32°C by about 51%, 45-50% and 10% in Ex-, Cr- and Bo-type SGAs, respectively. These findings imply that climate change-driven high seawater temperature events may compromise the physiology of SGA-affected corals and possibly increase the thermal susceptibility of heat-vulnerable Acroporid species.

ID: 198 / **Parallel Session 4-4: 11**
Global Climate Change and Environmental Stressors

Keywords: Desalination plants, brine discharges effects, Red Sea, coral's health, management decisions

Responses of *Acropora* spp. and *Stylophora pitillata* to a combined effect of salinity and temperature

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While 71% of the Earth is covered by water, it is reported that only about 1% of total water worldwide is potable. Given the current water demand, desalination plants are increasingly becoming a competitive solution for water security worldwide. Among the main stressors associated with these, the increase of salinity and temperature, and other substances such as chemicals, anti-fouling, and heavy metals can be present in the brine and may be found in the vicinity of the outfall. The effect of these on marine biodiversity is however poorly studied. Therefore, to better understand the responses of marine species to brine discharges, we investigated the salinity tolerance thresholds of two common Red Sea corals. Five colonies of *Acropora spp.* and *Stylophora pistillata* were randomly collected in the central Red Sea (22°N, 39°E). The fragments were allocated to six salinity treatments corresponding to 100% simulated effluent and four dilutions (dilution factor 0.5; at control temperature of 27 °C), a combined treatment of simulated effluent and increased temperature (30 °C), and a control (salinity 41, temperature 27 °C) for a 7-days exposure period. Biochemical markers related to corals' oxidative status (cellular damage, antioxidant defences) redox balance and metabolism, along with molecular markers (16S and ITS2) were assessed to investigate the potential impacts of elevated salinity and temperature on the fitness of coral species and associate changes of the coral microbiome. Our results indicated that substantial mortality, tissue loss, and changes in physiological parameters (total protein and symbiont density) occurred above salinity 44. We anticipate that these changes will also match shifts in the composition of the coral-associated microbiome and biochemical performance. The results observed support that both coral species are sensitive to increased salinity and temperature and can guide mitigated actions toward the sustainable growth of the desalination industry.

ID: 444 / **Parallel Session 4-5: 10**
Global Climate Change and Environmental Stressors

Keywords: Marine heatwaves, Gulf of Aqaba, Stylophora pistillata, Pocillopora damicornis, climate change

Physiological responses of common reef-building corals to recurring marine heatwaves in the potential coral refuge, Gulf of Aqaba

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The consistent rise in sea surface temperature is the most detrimental factor to coral reefs, coupled with more frequent and intensifying marine heatwaves. Among the coral colonies that survive marine heatwaves, some demonstrate "sensitization" while others present "acclimatization" to the succeeding events. Corals from the Gulf of Aqaba (GoA) in the Northern Red Sea, recognized for their thermal resilience, survived without evident bleaching the hottest marine heatwave on record in the summer of 2021. However, the projected intensifying heatwaves raised concern regarding the Northern Red Sea to serve as a coral refuge from warming oceans. Here, we assessed the physiology of *Stylophora pistillata* and *Pocillopora damicornis* from the northern GoA for 3.5 years (four winters and three summers; 14 time points), encompassing the hottest (2021; Max temp of 30.9˚ C at 2-m depth; 8 DHWs) and one of the most thermally stressful summers on-record (2023; Max temp of 30.4˚ C; 14 DHWs). We monitored eight tagged *S. pistillata* and *P. damicornis* and assessed their algal densities, chlorophyll-a content, and energy reserves (carbohydrates, proteins, lipids) for the host and symbionts as a proxy for metabolic stress. We aim to explore if there is an energetic cost, or evidence for acclimatization, to the frequent marine heatwaves in this globally significant coral refuge.

ID: 301 / **Parallel Session 4-3: 8**
Global Climate Change and Environmental Stressors

Keywords: Coral reef, Coralline algae, marine heatwave, Halimeda, environmental variability

Role of diurnal temperature variability in modulating responses of reef associated macroalgae to marine heatwaves

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Calcifying macroalgae are an essential component of healthily functioning coral reefs. Algal carbonate production can equal and even surpass that of reef-building corals, particularly after coral mass mortality events. Ocean warming and marine heatwaves (MHWs) are principal drivers of the global decline in coral cover. Despite their importance in maintaining reefs, however, the responses of reef algae to these drivers, and the role of temperature variability in modulating responses, are poorly known. To this end, we conducted an experiment evaluating the role of diurnal temperature variability in influencing responses of different calcifying reef algae to normal and anomalous summer temperature regimes. For two and a half months, our four study species (*Lithophyllum* sp., *Neogoniolithon* sp., *Halimeda tuna* and *H. discoidea*) were exposed to six temperature regimes: “A” = 31°C constant, “B” = 31°C + 1.5°C diurnal variability with the peak during the day, “C” = 31°C + 1.5°C diurnal variability with the peak during the night; “D” = 31°C + a symmetric six-week heatwave with a intensity of 34°C and no variability, “E” = 31°C + the simulated MHW and a diurnal variability of 1.5°C peaking during the day and “F” = 31°C + the simulated MHW and a diurnal variability of 1.5°C peaking during the night. During the experiment several photophysiology and calcification metrics were monitored to assess species-specific responses to diurnal temperature changes in isolation and in interaction with a MHW. Heatwave exposure generally depressed calcification rates while diurnal variability elevated them. However, positive impacts from temperature variability were reduced when high temperatures occurred at night or due to the interaction with the MHW (e.g., *Neogoniolithon* sp.). Impacts on photo physiology were typically limited. Our results suggests that if thermal maxima are confined to daylight hours local temperature variability can enhance tolerance to MHWs in certain species.

ID: 634 / Parallel Session 4-5: 6
Global Climate Change and Environmental Stressors

Keywords: Coral Bleaching, Bleaching Mitigation, Thermal preconditioning

Thermal preconditioning postpones coral bleaching by inducing anantioxidant response and cellular defense mechanisms in two coralspecies, Pocillopora damicornis and Stylophora pistillata.

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Coral reefs worldwide are declining due to high sea surface temperatures, causing coral bleaching and the endosymbiosis rupture between the coral polyps and the unicellular algae Symbiodinaceae. Bleached corals will likely die because Symbiodinaceae algae provide most of the energy coral colonies need. Among the newly developed strategies to prevent coral bleaching is thermal preconditioning, i.e. applying sub-lethal temperature on corals before heat stress which has shown promising results in slowing coral bleaching. However, the cellular mechanisms that increase heat tolerance by thermal preconditioning are still unknown. This study showed that thermal preconditioning on the two coral species, namely *Pocillopora damicornis* and *Stylophora pistillata*, postponed the adverse effects of heat stress-inducing bleaching. Thermal preconditioning was performed by exposing the coral colonies to the sub-lethal temperature of 28°C for one week, after which thermal stress was applied at 31°C for another seven days. We assessed coral bleaching by analysing the Symbiodinaceae density, taxonomical identification, and chlorophyll concentration (Chl). Moreover, we compared the expression of Heat shock protein 70 (Hsp70), a molecular chaperone involved in cell protein protection, the activity of three antioxidant enzymes such as superoxide dismutase, catalase, and glutathione peroxidase and the lipid peroxidation in preconditioned, non-preconditioned and control colonies. Our results showed that Chl concentration and symbiont density were higher in preconditioned corals than non-preconditioned corals in both coral species. In addition, no difference in Symbiodinaceae identity was observed. Then, preconditioned *S. pistillata* and *P. damicornis* had higher antioxidant enzymes activity and higher expression of Hsp70 compared to non-preconditioned colonies. Therefore, our results suggest that thermal preconditioning delayed coral bleaching in both *S. pistillata* and *P. damicornis* by mitigating oxidative stress and maintaining cellular homeostasis, indicating the possible role of thermal precondition as a valuable technique for enhancing thermal resistance of coral colonies used worldwide in coral restoration projects.

ID: 748 / Parallel Session 4-5: 13
Global Climate Change and Environmental Stressors

Keywords: climate variability, dynamics of coral thermal tolerance, coral resilience, coral calcification, coral bleaching susceptibility

Contribution of past and recent Climate Variability on contemporary Patterns of Coral Bleaching Susceptibility

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Rising sea surface temperatures (SSTs) around the globe are leading to a higher frequency and severity of bleaching events where corals experience the loss of their associated endosymbiotic algae. A common notion postulates that bleaching occurs at about 1-2°C above the long-term maximum summer temperatures. Besides such large-scale patterns, more recent studies have shown that coral thermal stress responses vary strongly between reefs within any given region, with studies indicating that not only the summer maxima but also climate variability contribute to shaping patterns of resilience. To assess how such fine-scale climatic differences affect coral resilience, we are investigating two coral species in each of two geographically close-by sites around Gili Asahan, Indonesia, that exhibit similar summer maximum temperatures, but different climate variability patterns. Using standardized acute thermal stress assays (CBASS) and potentiometric titrations of CaCo3, we are determining dynamics of thermal tolerances and calcification rates across reef sites, seasons, and years in relation to climate variability patterns. First results indicate the ability of coral species to adjust thermal tolerances between seasons, while calcification rates seem to be disconnected from thermal tolerances. Thus, this project aims to resolve the contribution of long-term and recent climate variability on contemporary patterns of coral resilience to better understand the impact of a warming world on coral reef ecosystems.

ID: 539 / Parallel Session 4-1: 7
Global Climate Change and Environmental Stressors

Keywords: Coral Reef, Reciprocal Transplant Experiment, Coral Phenotypic Plasticity, Multiple Stress Environment, Climate Change

Coral phenotypic plasticity and acclimatization to an extreme and marginal reef environment

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Coral reefs are threatened by global and local stressors, however, some corals have increased stress tolerance compared to others. Significant knowledge gaps remain on the full extent of coral adaptive strategies and their phenotypic plasticity response, in the context of multiple co-varying stressors. Extreme and marginal habitats can be used as natural laboratories to gain insight into the ability of coral species to cope with multiple stressful physiochemical conditions, including increased seawater temperatures, lower pH, and elevated nutrients. Here, we utilized a semi-enclosed inland bay in Curaçao as a natural laboratory to evaluate coral adaptive strategies under extreme conditions, such as high average and highly variable seawater temperatures, acidity, and nutrient concentrations compared to a nearby fringing reef site.

We conducted a reciprocal transplant experiment (RTE) between the inland bay and the nearby reef using two species (branching *Porites* sp. and massive *Siderastrea siderea*) and monitored key physiological parameters after 0, 4, and 12 months of transplantation. To evaluate the corals' acclimatization capacity, we measured calcification, respiration (R), and photosynthesis (P) rates, and calculated P:R ratios. After 12 months, reef-to-bay *S. siderea* transplants had a 100% survival rate and maintained calcification rates despite decreases in P:R ratios driven by increased respiration. This may indicate that *S. siderea* possesses high trophic phenotypic plasticity or energy management strategies to compensate for reduced P.

Conversely, we found evidence of negative physiological trade-offs for reef-to-bay *Porites* sp. transplants, as calcification rates and P:R ratios decreased significantly after 12 months. Although *Porites* sp. had a less favorable plastic phenotypic response, their high survival rate (90%) indicates acclimatization ability to survive extreme conditions at the cost of lower physiological fitness (low P:R ratios and calcification rates). *Siderastrea siderea* have remarkable tolerance to extreme conditions and high acclimatization capacity, making them potential candidates for coral restoration.

ID: 229 / Parallel Session 4-4: 16
Global Climate Change and Environmental Stressors

Keywords: submarine groundwater discharge, metabolism, pocillopora, biogeochemistry

Increase in submarine groundwater discharge may adversely affect metabolism of the tropical coral, Pocillopora acuta

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Submarine groundwater discharge (SGD) is an understudied environmental disturbance that may impact the health of corals in nearshore environments. SGD is the process of fresh or brackish water moving from terrestrial environments through the marginal seabed and into coastal zones leading to altered biogeochemistry. Our research investigated how SGD may affect the respiration, photosynthetic, and calcification rates of a tropical coral, *Pocillopora acuta*, that is commonly found within the fringing reefs of Mo'orea, French Polynesia. We analysed metabolic rates of *P. acuta* fragments (n=8 putative colonies per site, collected from ambient seawater) in response to a range of ecologically relevant SGD concentrations (0 - 4% SGD by volume across 9 dilutions). We collected groundwater from two sites with distinctly different sources and biogeochemistry. We tested the individual effects of SGD-associated environmental parameters (salinity, pH, nitrate, phosphate, and total alkalinity) on each of the three measured metabolic rates. Our results indicated that SGD significantly decreased calcification, but this relationship varied by site. For respiration and photosynthetic rates, there were no statistically significant effects of SGD treatment or the associated environmental parameters at either site. This is the first mechanistic study to assess the physiological responses of a range of SGD concentrations on adult corals. This is particularly important because as global climate change trends continue to intensify, the flux and concentration of SGD in coastal waters will subsequently increase. For virtually all coastal communities, but particularly in Mo'orea, the fringing reef holds a strong cultural, ecological, and economic significance. This further emphasizes the importance of understanding the impact SGD might have on the nearshore reef environment.

ID: 520 / **Parallel Session 4-4: 5**
Global Climate Change and Environmental Stressors

Keywords: global warming, local factors, nutrients

Testing Stress Antagonists for their Potential to enhance Coral Recovery after Natural Heat Exposure

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Hard corals are sensitive to heat stress, which often results in bleaching and mortality. Hence, it is important to investigate possible solutions that can help mitigate heat stress or aid the recovery of hard corals. Here, we compared a range of potential stress antagonists in a series of short-term experiments with *Acropora* spp. and *Pocillopora verrucosa*. Non-bleached colonies were collected after a massive heat stress event in the Central Red Sea in summer 2023. One fragment per colony was assigned to each of the five treatments: phosphate (2 µM), hydrogen (0.3-0.5 ppm), ammonium (3 µM), probiotics, and controls (no additives). After a 48 h exposure, ecophysiological endpoints were measured, including survival, coloration, chlorophyll content, oxygen fluxes, photosynthetic efficiency, and protein content. Compared to the control, phosphate increased survival in both hard corals by 20 % but had no significant effect on any other parameter. Hydrogen lowered survival by 30 % in *Acropora* spp. but increased it by 60 % in *P. verrucosa*. Ammonium increased survival by 20 and 40 % for *Acropora* spp. and *P. verrucosa*, respectively, and also increased their coloration significantly. Lastly, probiotics increased survival by 20 and 60 % for *Acropora* spp. and *P. verrucosa*, and also showed increased Fv/Fm by 11 % for *Acropora* spp.. Overall, these pilot experiments show a higher sensitivity of *P. verrucosa* specimens and a gradient of protective effect across treatments. The benefit of probiotics in mitigating heat stress and aiding the recovery of corals was shown for the first time in short-term experiments that also suggest the heat stress mitigating potential of ammonium, phosphate, and hydrogen.

ID: 661 / **Parallel Session 4-4: 19**
Global Climate Change and Environmental Stressors

Keywords: temperature size rule, climate change, metabolic traits, food consumption

Temperature induced metabolic constraints on food intake as an explanation for small fish sizes on the world's hottest reefs

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A phenomenon of increasing temperatures is that ectothermic species, such as fish, grow faster but attain smaller maximal sizes. This phenomenon known as the Temperature Size Rule (TSR) is predicted to result in fish size reductions and should be strongest at latitudinal extremes, including on coral reefs. Indeed, fish are predicted to be 14-24% smaller by 2050 compared to 2000 as oceans warm. Reductions in fish size have potential implications for fisheries yield and size-dependant trophic interactions. However, the physiological mechanisms that underpin these size reductions are still unresolved. Here we used the world's hottest coral reefs in the Arabian Gulf (AG), which reach 36ºC in summer, and the cooler adjacent Gulf of Oman (GO), as a model system to examine if temperature increases constrain fish size via metabolic limitations on food intake. Across three temperatures representing the annual median (27ºC), and summer maximum of the both the AG (35.5ºC) and GO (32ºC) we tested a range of metabolic traits relating to performance (standard metabolic rate, maximal metabolic rate, and aerobic scope) and digestion (specific dynamic action) in an ecologically and commercially important coral reef fish, yellowfin hind (*Cephalopholis hemistiktos*). Our results show that in the hotter AG fish reached smaller maximum sizes. Furthermore, increasing temperature resulted in a greater metabolic demand, while at the same time had a negative effect on food intake. At the highest temperature food intake was not only reduced but many fish refused to feed and some larger fish regurgitated what was eaten shortly after feeding suggesting that during summer months many fish struggle to feed and may explain why fish are smaller in the AG. Our results provide new insights into the proposed mechanisms explaining TSR as well the adaptive capacity for fish to survive under future climate conditions.

ID: 388 / **Parallel Session 4-3: 9**
Global Climate Change and Environmental Stressors

Keywords: Symbiodiniaceae, Photosynthesis, Chlorophyll fluorescence, Acute heat stress, Alternative electron transfer

Exploring the dynamic responses of Symbiodiniaceae to acute heat stress: insights into coral symbiosis and regulatory electron transport processes

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In this work, we investigated the impact of acute heat stress on the photosynthetic performance of Symbiodiniaceae, dinoflagellate algae, which live in a symbiosis with the coral host. This symbiosis is vital for the health of coral reefs. Through photosynthesis, algae transform sunlight into chemical energy, forming organic molecules that serve as a nutritional source for their coral hosts. In exchange, the coral host supplies a safe environment and crucial elements such as nitrogen and phosphorus, which aid in the growth and nourishment of algae. The escalating impacts of global climate change, particularly the rise in temperatures, threaten this symbiotic balance, leading to the expulsion of these algae and subsequent coral bleaching.

Our study focused on assessing heat tolerance across three distinct Symbiodiniaceae strains: *Fugacium kawagutii*, *Symbiodinium tridacnidorum*, and *Symbiodinium microadriaticum*. Employing a range of non-invasive chlorophyll fluorescence methods, we discerned strain-specific characteristics in a so-called wave-like phenomenon observed during fluorescence relaxation, which is associated with the decrease of the activity of Photosystem II (PSII) relative to the activity of Photosystem I (PSI) and the transient oxidation and re-reduction of the plastoquinone pool. Furthermore, through the application of various photosynthetic inhibitors, we characterized the interplay between linear and alternative electron transfer processes and revealed the role of key components such as the NAD(P)H dehydrogenase (NDH-2). Notably, our findings highlight the regulatory role of these processes in maintaining stability in coral symbiont algae under stress conditions.

In conclusion, this research provides valuable insights into the dynamic responses of Symbiodiniaceae to acute heat stress, offering a deeper understanding of the regulatory mechanisms that contribute to symbiotic stability in the face of environmental challenges. These insights are critical for developing strategies to safeguard coral reefs and their associated ecosystems in an era of rapidly changing global climates.

ID: 472 / **Parallel Session 4-3: 5**
Global Climate Change and Environmental Stressors

Keywords: Metabolomics, corals adaptation, bleaching mechanism

Metabolomics reveals different adaptation strategies to prolonged thermal stress in two coral species

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Coral reefs are facing an unprecedented decline due to the effects of marine heat waves that dramatically raise sea surface temperatures with increasing frequency and intensity, causing coral bleaching and extensive coral mortality. Although bleaching has been widely studied from various aspects, the involved molecular processes have not yet been fully clarified, and much remains to be done to understand the future adaptation trajectories of corals in a rapidly changing climate. In this study, we used an untargeted LC-MS metabolomics approach to detect the metabolic signature of two coral species, *Stylophora pistillata* and *Pocillopora damicornis*, during heat stress. After an acclimatization period at a control condition of 25 °C, the temperature was raised to 31 °C in experimental tanks. Corals were sampled before the onset of stress and after 24 h, 72 h, and 10 days. The two coral species exhibited a significant difference in their metabolic signature already at control conditions, relying on different pathways of metabolic energy supply. In both species, corals stressed for 10 days showed a significantly different metabolic signature than the control ones and those stressed for 24 and 72 h. Indeed, after 10 days of heat stress, *S. pistillata* showed significant downregulation of metabolites related to ATP synthesis and upregulation of critical metabolites of alternative pathways for energy production compared to control conditions. On the other hand, *P. damicornis* showed an upregulation of ammonia recycling pathways and an increased amino acid metabolism after 10 days of stress compared to control. Our results demonstrate that coral species may adopt different strategies to adapt to stress conditions by exploiting alternative metabolic energy production pathways (i.e., *S. pistillata*) or strengthening their cellular defensive mechanisms pathways (i.e., *P. damicornis*). Moreover, despite being underutilized, the metabolomic approach has proven extremely useful in understanding the molecular dynamics of coral bleaching

ID: 207 / Parallel Session 4-3: 7
Global Climate Change and Environmental Stressors

Keywords: coral reefs, Maldives, thermal anomaly, recovery, historical data

Recovery capacity of coral reefs from the effects of global warming: lessons to be learnt from a historical data series in the Maldives

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Historical data are essential for understanding the evolution of marine ecosystems under the effects of global climate change. Coral reefs represent a unique natural heritage in terms of biodiversity, ecosystem services and resources provided to humans and are very sensitive to sea water warming. Two main thermal anomalies affected the Maldives in 1998 and in 2016, causing severe coral bleaching and consequent mass mortality events. A precious uninterrupted historical series of data covering 26 years (1997-2023) has been collected during expeditions to the Maldives, which allowed evaluating the trajectories of recovery of Maldivian reefs after these two main bleaching events. Percentage of hard coral cover was used as indicator of the reef state, and non-taxonomic descriptors (growth forms) to evaluate change over time in the community composition.

The first bleaching event in 1998 caused approximately 90% of coral mortality, whilst after the 2016 event the coral mortality was comparatively lower, with a coral survival of about 30%. The two recovery patterns showed different trajectories: 16 years were needed to recover from the first thermal anomaly, whilst after the 2016 event the recovery proceeded at a double pace. Although the recovery of Maldivian coral reefs is going faster today, differences through time were observed in coral community composition.

Even considering a high geographical variability, we predicted a nearly full recovery of many Maldivian coral reefs by 2024, taking the half time (i.e., 8 years) compared to the recovery pattern after the 1998 mass coral mortality. Our long series of data provides a unique opportunity to evaluate resilience of Maldivian coral reefs to the effects of global warming. Predictions on climate change suggest that climate anomalies will inevitably be more frequent in the years to come, thus eroding the capacity of Maldivian coral reefs to further recovery.

ID: 149 / Parallel Session 4-1: 4
Global Climate Change and Environmental Stressors

Keywords: coral bleaching, turbid reefs, refugia, sedimentation, Southeast Asia

Ecological impacts and regional climatic drivers of coral bleaching on turbid reefs in Southeast Asia

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Coral bleaching often occurs following prolonged periods of anomalous ocean warming. Turbid coral reefs form in coastal sedimented waters and may benefit from the high levels of suspended particles during periods of heat stress, as elevated turbidity can reduce UV radiation exposure and corals may utilise greater heterotrophy for nutrition. However, our understanding of the response of turbid corals to thermal disturbance remains limited due to a scarcity of field bleaching observations. Here we present high-resolution ecological surveys of turbid reefs conducted during a major coral bleaching event in the Gulf of Thailand throughout May 2023. We combine data on coral bleaching occurrence and severity with in-water measurements of physical ocean parameters to quantify the impact on coral communities. Analysis of regional climate data during the bleaching event was conducted to identify the mechanisms driving the ocean temperature anomaly in Southeast Asia. Results show high coral cover (43-64%) and structural complexity on reefs ($R = 1.78$), with communities dominated by massive *Porites* spp. (19-61%), encrusting *Montipora* spp. (11-36%) and branching *Acropora* spp. (23%). Coral bleaching was widespread, but higher incidences and bleaching severity was observed at northwest-facing sites (43-50%, mostly non-focal bleaching) compared to northeast-facing sites (23%, paling and non-focal bleaching). Smaller colonies (<50 cm) which inhabited shallow water <4 m depths were more susceptible to full colony bleaching or fluorescence. Ocean warming in the Gulf of Thailand was likely caused by lower cloud cover that increased incoming solar radiation, and weaker wind speeds that reduced ocean-to-atmosphere heat exchange. Our data presents a unique account of coral bleaching in Southeast Asia and suggests that turbid corals remain susceptible to heat stress, despite reversals in the generic composition of bleached colonies compared to clear-water reefs.

ID: 625 / **Parallel Session 4-4: 12**
Global Climate Change and Environmental Stressors

Keywords: Coral reefs, Population dynamics, Scleractinian corals, Temporal variability, Maldives

Decadal change in coral recruitment and survival in a remote Maldivian atoll

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Coral reefs are declining worldwide as a result of global warming and human activity. Recruitment is a crucial process for the recovery of coral populations after large-scale disturbances causing mass mortality events such as coral bleaching. Recruitment success depends on complex, site-specific factors that are difficult to control, so understanding the dynamics of the early life stage of corals is critical to prevent future coral loss. In this study, the juvenile coral community of the remote and little anthropized Huvadhoo Atoll in the southernmost area of the Maldives (Indian Ocean) was investigated 11 years apart. The density of coral recruits (diameter ≤ 5 cm) and juveniles (diameter between 5 cm and 15 cm) was assessed in eight coral reef sites with different exposure (facing the lagoon or the ocean). The first survey was carried out in 2009, 11 years after the severe 1998 bleaching event, and the second survey in 2020, only 4 years after the 2016 bleaching event. The total number of recruits exhibited a slight increase from 25 individuals·m^{-2} in 2009 to 30 individuals·m^{-2} in 2021. However, *Acropora* populations, which represented 60% of juvenile corals in 2009, halved in 2020, particularly in oceanic reefs. The decrease in *Acropora* recruits seems to have favoured other corals: *Pocillopora* has doubled compared to the past, and massive species have become dominant. In all, the juvenile coral community structure has drastically changed between the two surveys. The comparison between the numbers of recruits and juvenile corals suggested higher survival of the massive corals, which apparently have adapted better to the bleaching events. Whether branching corals will also have the ability to adapt to increasingly frequent climatic disturbances deserves attention in the future.

ID: 830 / **Parallel Session 4-6: 6**
Global Climate Change and Environmental Stressors

Keywords: Coral Reef Resilience, Climate change impact, Bleaching events, Environmental stressors, Bleaching recovery

Dynamics and recovery of coral reefs in the Arabian/Persian Gulf under effects of repetitive bleaching and environmental stressors

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Coral reefs in the Persian/Arabian Gulf have adapted to one of the world's most extreme marine environments, enduring temperatures ranging from 15 to 35°C and salinities above 40 PSU. Despite these challenging conditions, the effects of climate change have not bypassed these unique ecosystems. Increasingly frequent bleaching events were observed in the falls of 2019, 2020, and 2021. To investigate the impacts of bleaching on Qatar's coral populations, permanent monitoring was established at five offshore reefs (40 to 100 km from the coast, depths of 11-20m). The monitored reefs showed a varied coral cover (3.71 to 38.2%) and colony density (54 to 592 colonies per transect). Dominant genera included *Dipsastraea* (33%), *Psammocora* (26%), *Porites* (10%), and *Platygyra* (7%). Notably, a 14% increase in colony numbers was observed, attributed to fragmentation from partial mortality. However, the proportion of healthy colonies drastically fell from 80% to 33%. Larger colonies (>500 cm2) were most affected, with an 87% loss, while smaller colonies (<20cm2) decreased by 46%. Proximity to the coast was a significant factor in bleaching severity, with sites closer than 100 km experiencing over 50% bleaching, compared to less than 20% at more distant sites. The rare *Acropora downingi* showed an 84% decline over the three bleaching years. Despite these setbacks, recovery was observed during cooler months, highlighting the resilience of these reefs. However, urgent action is needed to protect these ecosystems from irreversible damage

ID: 558 / **Parallel Session 4-5: 15**
Global Climate Change and Environmental Stressors

Keywords: coral reefs, thermal anomalies, community composition, recovery capacity, Maldives

The new face of the northernmost coral reefs of the Maldives revisited after 13 years

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Global warming and recurrent thermal anomalies are causing severe decline of coral reefs worldwide. Revisiting the same sites over time provides unambiguous information on the potentiality of marine ecosystems to recover after climatic disturbance.

Coral reefs in the northernmost atoll of the Maldives (Ihavandippolhu) have been monitored during 2011 to evaluate their recovery capacity after the major bleaching events occurred in both 1998 and 2010. Data showed a very low coral recovery in the lagoon reefs after the 1998 bleaching, as well as a high coral mortality in some sites after the 2010 thermal event, although still with a high coral cover in the ocean reefs of the atoll. The 'Up North Expedition' revisited the same sites after 13 years (2011-2024) and following the 2016 bleaching event, showing a promising high coral recovery in most of the reefs. Hard coral cover increased from 30±6% in 2011 to 48±5% in 2024 in lagoon reefs, and from 25±7% to 51±12% in ocean reefs. Despite the high resilience of these reefs, coral community composition changed through time, with reefs being currently dominated by massive corals (mainly *Porites*, followed by *Favites* and *Diploastrea*) rather than by branching and tabular corals, as occurred in the past. *Acropora* corals (tabular, digitate, and branching) almost disappeared in all the reefs in the last 13 years, whilst branching *Pocillopora* corals slightly recovered, although never exceeding 10% of the bottom coverage. Recent thermal anomalies led to a significant change in the northern Maldivian reefs, which are shifting towards more resistant coral communities. Although sensitive coral taxa are quickly disappearing after massive bleaching events, tolerant taxa are recovering fast, showing encouraging signs of increased coral cover and anticipating that the community composition in northern Maldivian coral reefs is changing.

ID: 509 / **Parallel Session 4-4: 3**
Global Climate Change and Environmental Stressors

Keywords: Coral Reefs, Bleaching, Iridocytes, RuBisCO, Vacuolar-type H+-ATPase

Physiological and molecular responses of the outer mantle of the fluted giant clam, *Tridacna squamosa,* to elevated temperature

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Giant clams live in symbiosis with phototrophic dinoflagellates (zooxanthellae) and can thrive in nutrient-poor seawaters where light is adequately available. The colourful and extensible outer mantle contains most of the symbiotic dinoflagellates inside a zooxanthellal-tubule system, and uniquely possesses iridocytes that can deflect light conducive for photosynthesis to the dinoflagellates. Iridocytes possess a mechanism, which involves vacuolar-type H^+-ATPase (ATP6V1), to facilitate the transfer of CO_2 from the host to the photosynthesizing dinoflagellates, and are therefore strongly ATP6V1 subunit A (ATP6V1A)-immunopositive. Climate change leads to rising seawater temperatures, which can result in a loss of symbionts and/or host's pigments in the outer mantle (bleaching) of giant clams. Exposure of the fluted giant clam, *Tridacna squamosa*, to elevated temperature (31 °C) for 57 days led to significant decreases in the quantity of dinoflagellates and the chlorophyll content in the outer mantle as compared to the control kept at 26 °C. The gene and protein expression levels of symbiont-derived form II ribulose-1,5-bisphosphate carboxylase/oxygenase (*rbcII*/RBCII) also decreased significantly in the outer mantle, indicating a decrease in phototrophic capacity. Notably, a significant decrease in ATP6V1A protein abundance in the outer mantle suggested decreases in iridocyte quantity and/or the capacity of CO_2 transfer. Immunofluorescence microscopy confirmed reductions in the quantities of dinoflagellates and iridocytes in the outer mantle. The plastids in the remaining dinoflagellates also displayed a weaker autofluorescence. After returning the temperature-treated clams to 26 °C for 11 days, the symbionts' quantity and chlorophyll content, as well as the transcript levels and protein abundance of symbiont *rbcII*/RBCII and host *ATP6V1A*/ATP6V1A in the outer mantle recovered partially to the control levels. These findings signify the importance of elucidating the effects of elevated temperature on the physiology of both the symbionts and the host so as to fully understand the process of temperature-induced bleaching in giant clams.

ID: 129 / Parallel Session 4-4: 10
Global Climate Change and Environmental Stressors

Keywords: coral population dynamics, marine heat waves, recovery

Unravelling the rebound potential of coral populations with increasing thermal stress

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Predicting recovery of coral populations in the aftermath of thermal stress and other major disturbances remain enigmatic. Despite an increasing number of longer-term studies on post-disturbance recovery, detailed data on coral population abundance, size structure and functional role are still rarely available thus limiting current ability to identify mechanisms behind recovery and assess long-term population viability. This study investigated early recovery dynamics focusing on key demographic processes driving coral population trajectories along Saudi Arabia's Red Sea coast and the Central Maldivian Archipelago following recent disturbances. Specifically, coral cover, coral juvenile abundance as proxies of recruitment rates, community composition, and size structure of focal taxa with contrasting life-history strategies were investigated in both geographic regions. This study provides evidence that size structure of focal coral taxa and demographic processes (e.g., juvenile abundance and composition) largely influenced recovery trajectories of coral populations and it is thus fundamental to include them in future studies. Understanding what influences the recovery and reassembly of communities in the aftermath of stressors, such as marine heatwaves, is critical for ecosystem management and conservation. Despite the potential for a full recovery, serious concerns remain that increased frequency, amplitude and return times of marine heat waves combined with localized ongoing stressors might not grant enough time for coral populations to reach full recovery.

ID: 707 / Parallel Session 4-5: 12
Global Climate Change and Environmental Stressors

Keywords: Stylophora pistillata, Red Sea, size frequency distribution, coral bleaching

Historical patterns of temperature variability on reef flats shape population trajectories of *Stylophora pistillata* following a marine heatwave

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The increasing frequency of marine heatwaves is impacting corals globally. Assessing the population structure of corals can reveal changes in demographic features that can shed light on population trajectories. Here, we assessed size structure and colony density of populations of the coral *Stylophora pistillata* inhabiting six reef flats in the central Red Sea, which are subjected to extreme temperatures. This study was conducted immediately following a widespread coral bleaching event between August and November 2023. Our surveys build on data collected from tagged colonies and semi-permanent transects in 2020, providing an opportunity to assess population dynamics before and after significant thermal stress. At each reef flat we surveyed nine 10-meter transects across three zones with distinct temperature regimes: the ocean-facing exposed edge, the midreef, and sheltered edge. At each location within a reef flat, temperature loggers have been maintained for four years, providing an extensive assessment of natural thermal regimes and specific levels of thermal stress during the bleaching event. Notably, despite broadly similar levels of thermal stress, changes in colony density and size structure varied substantially across locations, with some sites experiencing 100% mortality relative to 2020 while others exhibited stable or even increased colony density. Shifts in size frequency distributions were also highly variable and site-dependent, further emphasizing distinct population trajectories within and across reef flats. In situ temperature data revealed that populations inhabiting areas with historically lower temperature variability suffered the largest declines, while those in high-variable locations (e.g., midreef and sheltered sites) suffered less drastic declines even as maximum temperatures approached 38ºC. Our results indicate that *S. pistillata* inhabiting reef flats is generally resilient to extreme thermal stress, but that fine-scale variations in temperature regimes can shape population trajectories.

ID: 525 / **Parallel Session 4-4: 18**
Global Climate Change and Environmental Stressors

Keywords: Ecophysiology, Hypoxia, Metabolism

Physiological compensation to nocturnal hypoxia causes delayed energetic costs in a coral reef fish

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Oxygen availability on coral reefs shows strong temporal variation, peaking during the daylight hours and declining throughout the night. As the oceans continue to warm, hypoxia is predicted to increase in both frequency and severity, yet little research has explored its effects on reef fish ecology and physiology. Here, we expose wild-caught cryptobenthic reef fish (*Ecsenius pulcher*) to oxygen profiles measured on the world's warmest coral reefs (Arabian/Persian Gulf), showing that *in-situ* oxygen availability frequently reaches concentrations below the 'critical' limits of *E. pulcher*, causing lasting metabolic costs. These hypoxia-induced metabolic changes were not driven by behavioural differences, but instead relate to physiological compensation via a shift towards a greater reliance on anaerobic metabolic pathways. Transcriptomic analyses were used to further test this by assessing the long-term (> 6 hours post-hypoxia) effects of hypoxia on the expression of genes involved in anaerobic metabolism. Finally, utilising previously published oxygen logging data, we show that the conditions incurring such metabolic costs occur for 43 hours per month on average throughout the summer period, thus having the potential to cause substantial cumulative energetic costs and ecological consequences.

ID: 399 / **Parallel Session 4-3: 10**
Global Climate Change and Environmental Stressors

Keywords: coral disease, microbiome, Guam

What is the microbial role in acute tissue loss affecting *Acropora pulchra* on Guam's reefs?

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Staghorn corals play an essential ecological role on Guam reef flats, providing most of their three-dimensional structure. However, the populations of the eight staghorn *Acropora* species have significantly declined due to bleaching and acute tissue loss mortalities. While the physiological stress of bleaching is widely studied, there is a knowledge gap in our understanding of coral disease causation and dynamics. Most coral diseases in Guam are referred to as 'white syndromes' (WS) as they remain without investigated etiologies. To determine the possible role of bacteria in acute tissue loss of *A. pulchra*, we collected samples of apparently healthy and diseased tissue during a WS outbreak.The bacterial communities in the collected tissue samples were examined using two complementary approaches: metabarcoding and *in vitro* culture isolations. The results highlighted the critical association of *Endozicomonas* with healthy *A. pulchra,* representing 86-100% of the bacterial relative abundance. Conversely, in diseased coral tissues, the *Endozoicomonas*-dominance shifted toward highly heterogeneous communities composed of various bacteria genera belonging to different families, e.g.*, Rhodobacteracea, Alteromonadaceae, Vibrionaceae,* and *Flavobacteriaceae,* among others. The differential abundance analyses suggested that the bacterial assemblage in the *A. pulchra* lesion resembles that of a microbial dysbiosis or an opportunistic invasion of the dying tissue rather than an infection due to one bacterial pathogen. To test our conclusions, we currently use several cultured bacterial isolates from the diseased tissue in the challenge experiment to test whether any can initiate tissue loss lesions in healthy corals. With an ongoing histopathological examination, we aim to describe the microscopic morphology of *A. pulchra* tissue lesions. We suggest that future work on *A. pulchra* WS should also focus on host immunity response in response to disease, to evaluate the possibility of immune suppression, stress, necrosis, or programmed cell death triggering acute tissue loss iduring stressful environmental conditions.

ID: 747 / **Parallel Session 4-4: 7**
Global Climate Change and Environmental Stressors

Keywords: evolution, climate change, genomic vulnerability

Global coral genomic vulnerability explains recent reef losses

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As corals are in decline due to heatwave exposure, a key question in the field is whether corals can adapt to climate stress. Recent studies have tried to determine if coral genomes are evolving in response to recurring heatwaves by generating genomic datasets from coral reefs worldwide. By comparing these datasets, there is an opportunity to discover genomic regions that may contribute to heat adaptation across coral species.

Here, we conducted a meta-analysis using six existing datasets to associate the genetic diversity of *Acropora* corals across the world with past heatwaves. First, we compiled a genomic database of 635 *Acropora* corals from different oceanic regions - from the Great Barrier Reef to the Persian Gulf. Next, we used satellite remote sensing data to reconstruct the thermal history of the regions where these corals were sampled. Finally, we correlated coral allele frequencies with the thermal history of the reefs to find alleles associated with heat adaptation. Interestingly, we identified heat-associated alleles in the same genomic regions across different *Acropora* species from different oceanic regions. These genomic regions included genes encoding heat shock proteins and proteins associated with the heat-sensitive coral-algal symbiosis.

These heat-associated alleles were uncommon in *Acropora* populations exposed to less than three significant heatwaves since 1985, highlighting potential genomic vulnerability of these populations to future heatwaves. We predicted genomic vulnerability across the world's reefs and found spatial patterns matching local and global records of coral decline. We estimated that 20% of the world's reefs have been exposed to severe heatwaves while hosting genomically vulnerable corals. Because of the potential coral decline due to genomic vulnerability, *Acropora* populations might have already lost ~6% of their genetic diversity, reducing long-term adaptive capacity. Our work showcases the importance of understanding genomic vulnerability to predict global coral reef decline and inform conservation efforts.

ID: 791 / **Parallel Session 4-2: 7**
Global Climate Change and Environmental Stressors

Keywords: Climate change, Genetic differentiation, coral reef, pH.

Coral population resilience and connectivity in sub-optimal environmental conditions

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Climate change is threatening the future of coral reefs globally. Recent discoveries of diverse and high-cover reefs thriving in environments characterized by extreme environmental fluctuations suggest that some corals might subsist under hot, high- pCO_2, and deoxygenated seawater. However, whether these corals are acclimatized or adapted to these environments is a question that needs to be answered to understand if genetic adaptation is a pre-requisite for the persistence of corals in changing climates. Here, we present the preliminary results of an ongoing genetic study comparing corals in stable conditions with conspecifics living in a semi-enclosed lagoon characterized by extreme low values of seawater pH and dissolved oxygen at low tides. Our main objective is to determine whether corals (*Montipora stellata)* living in sub-optimal conditions are genetically selected and/or genetically connected to neighbouring reefs. We have sampled 50 coral colonies from four sites in New Caledonia; three located in the semi-enclosed lagoon of Bouraké, New Caledonia, and one at a reference reef adjacent to Bouraké (4 km away). We explore potential differentiations in their genomes, microbiome and associated zooxanthellae in relation to their habitat to test whether Bouraké corals may act as potential sources of stress-tolerant corals for adjacent reefs.

ID: 751 / **Parallel Session 4-6: 9**
Global Climate Change and Environmental Stressors

Keywords: disease, gene expression, immunity

Gene expression of corals throughout a stony coral tissue loss disease outbreak indicates varying mechanisms of resistance

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Disease outbreaks have caused severe declines in scleractinian coral cover in the Caribbean, particularly the recently described stony coral tissue loss disease (SCTLD). Coral disease ecology has been heavily studied in many aspects, but questions remain as to how and why some coral individuals and species develop disease while others do not. To assess these inter- and intra-specific differences in coral physiology before and during an outbreak of SCTLD on a reef, we have analysed gene expression data from samples of tracked coral colonies in Carrie Bow Cay, Belize. These corals were tagged and sampled in June 2019, before SCTLD was present, and again in May 2022, two months after SCTLD was confirmed in the area. We collected samples and analysed gene expression from ten individuals each of the species *Meandrina meandrites*, *Montastraea cavernosa*, *Porites astreoides*, and *Siderastrea siderea* across both time points. These species represent a range of SCTLD outcomes, from total mortality, to nearly 100% survival. We leveraged this range of outcomes to look for specific markers of susceptibility and/or resistance to SCTLD. Preliminary analyses reveal significantly different patterns of immune-related gene expression between moderately susceptible and resistant species. Further analyses of these differences in gene expression could reveal new insight regarding pathways involved in predicting disease phenotypes. Understanding the mechanisms through which disease affects not only corals that show phenotypic signs, but also those which remain apparently healthy, is crucial to predicting how reefs will fare long term and in the face of subsequent stressors.

ID: 757 / **Parallel Session 4-6: 11**
Global Climate Change and Environmental Stressors

Keywords: Macroalgae, coral cover, sand and rubble

Ecological assessment of coral reefs in the PSEPA-Primeiras and Segundas Environmental Protection Area: A decade-long analysis

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This work presents a comprehensive analysis of coral reef ecosystems within the PSEPA-Primeiras and Segundas Environmental Protection Area, spanning expeditions in 2005, 2010, 2020, and 2023. Despite the reefs not attaining pristine conditions, they exhibit overall robust health, characterized by high biodiversity and intricate structural complexity.

Our research reveals a concerning trend of accelerated decline, with a recorded 40% reduction in coral cover over the past 15 years. Past bleaching events have left a lasting impact, evident in the lingering effects on live coral cover. While the 2023 survey, conducted post-bleaching season, did not immediately detect signs of bleaching, historical data emphasizes the vulnerability of these ecosystems to such events.

A noteworthy shift in reef composition was observed in 2020, marked by an increase in macroalgal cover, typical after acute coral mortality events. However, the 2023 survey presented a surprising decline in macroalgae, coupled with an increase in sand and rubble.

Despite these challenges, there is optimism derived from the resilience of most reefs, which maintain live coral cover close to or above regional benchmark thresholds. Our findings underscore the potential for preservation and enhancement, contingent upon global emissions reduction in accordance with the Paris Agreement. Local management strategies also emerge as critical in securing the future of these vital coral ecosystems.

This research contributes valuable insights to the ongoing discourse on coral reef conservation. We propose that our presentation at the conference will foster dialogue among experts and stakeholders, emphasizing the urgent need for coordinated global and local interventions to ensure the sustained health of these ecosystems.

ID: 620 / **Parallel Session 4-5: 11**
Global Climate Change and Environmental Stressors

Keywords: coral restoration, CBASS, bleaching, thermal tolerance, Seychelles

Climate-proofing reef restoration: unlocking the preservation of coral thermal tolerance across restoration stages using acute thermal assays in the Cousin Island Special Reserve, Seychelles.

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The increasing thermal threats to coral reefs correspond with worldwide developments in coral restoration programs. To increase long-term survival, practitioners must consider the integration of genotypes that exhibit superior tolerance to increasing water temperatures. Research utilizing acute short-term thermal assays like the Coral Bleaching Automated Stress System (CBASS) have unveiled nuanced variations in thermal tolerances within species, populations, and sites, providing an avenue to systematically screen and select coral colonies. However, whether the thermal tolerance of coral genotypes is retained upon transfer into open-water-nurseries and subsequent transplantation to restoration remains unresolved. To determine the potential variation, we applied an experimental approach using the CBASS within the scope of the coral restoration program on Cousin Island Special Reserve (Seychelles). Here we will assess the thermal tolerance in four coral species (*Acropora muricata; A. irregularis; Pocillopora grandis; P. verrucosa*) across restoration stages (donor site, open-water nursery, outplant site). Fragments from each stage will be tested under temperature treatments (control, +4°C, +6°C, +9°C) and measurements of the photosynthetic efficiency (Fv/Fm) and bleaching rates will be conducted to derive standardized ED50 thermal thresholds. This analysis aims to better understand how thermal tolerances are maintained under different environments and how far pre-screening can inform and improve restoration efforts to offer insight for practitioners, researchers, and conservationists. Similar approaches elsewhere will facilitate a deeper understanding of coral health and resilience, paving the way for a more focused and effective global strategy to restore corals reefs in a warming world.

ID: 101 / **Parallel Session 4-6: 7**
Global Climate Change and Environmental Stressors

Keywords: coral larvae, carbon-13 and nitrogen-15 isotope labelling, carbon and nitrogen assimilation, ocean acidification, heat stress

Algal symbionts of *Pocillopora damicornis* larvae provide more carbon to their coral host under elevated levels of acidification and temperature

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Climate change is destabilizing the coral host-Symbiodiniaceae symbiosis globally. The effects of ocean acidification and warming on symbiotic interactions (i.e., carbon and nitrogen assimilation and exchange) during planula larval life stage, however, remains understudied. Here, we examined photosynthesis and the assimilation of carbon and nitrogen in larvae of the coral *Pocillopora damicornis* under conditions of acidification (1000 µatm) and elevated temperature (32 ℃). The larvae maintained stable symbiont densities across all treatments, showing no signs of bleaching or decreased survivorship. Both acidification and elevated temperature enhanced the net and gross photosynthesis of Symbiodiniaceae. Consequently, light respiration and C:N ratios in the holobiont were enhanced under the elevated pCO_2 and temperature treatment, respectively. This increase in carbon availability was primarily reflected in the carbon assimilation of the host, indicating an enhanced contribution of the algal symbionts to the host metabolism. We propose that such mutualistic symbiotic nutrient cycling may enhance coral larvae resistance to future ocean condition. Our findings indicate that the symbiotic relationship between larval coral host and Symbiodiniaceae may exhibit a greater dependency on carbon to maintain carbon-nitrogen feedback loop. This research extends our understanding of coral symbiosis, highlighting the importance of symbiotic interactions beyond adult coral holobionts.

ID: 440 / **Parallel Session 4-4: 2**
Global Climate Change and Environmental Stressors

Keywords: Global warming, giant clams, TEM, symbiotic algae, iridocyte

Impact of high temperature and high light on the symbiotic algae inside the mantle of giant clams

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Global warming has severely affected coral reefs through increased water temperature and solar insolation, resulting coral bleaching. Coral bleaching is a stress response toward the combination of high temperature and high light that led to deterioration of the symbiotic algae, resulting loss of colour in the corals. However giant clams, which also harbour symbiotic algae, are primarily found in the shallow water where they can be exposed to higher temperature and harmful level of solar radiation. Regardless to such stressful environment, giant clams show higher photochemical efficiency compared to corals and seem to be insusceptible toward the stresses. However, actual effects of increased water temperature and high light to the symbiotic algae in the giant clams have not been extensively studied. Therefore, this study is aimed to observe the resistance of symbiotic algae inside the mantle of giant clams toward high temperature and high light. Observation under a transmission electron microscope revealed notable degradations of chloroplasts and/or necrosis of the symbiotic algae in the giant clam individuals exposed to higher temperature; even under 28^{0}C which was assumed to be non-harmful temperature level. The experiment was conducted under a relatively higher light level (430 mmol photon m-2 sec-1) which was assumed to cause the symbiont deterioration even under such temperature. In this consequence, mechanisms underlying photoprotection was investigated. Ultrastructure of giant clam's mantle revealed numerous iridocyte cells containing multiple layers of crystallized guanine which may act as a Bragg mirror. The mantle colours and light reflectance well coincided with the thickness of each guanine layer, indicating the iridocytes with different thickness of guanine layers expressed the variations of the mantle colour. Interestingly, individuals with different mantle colours showed different properties of photochemical efficiencies under high light, insisting the iridocyte cells could be main drivers to control photoprotection in the giant clams.

ID: 270 / **Parallel Session 4-6: 14**
Global Climate Change and Environmental Stressors

Keywords: conservation, machine learning, climate change

Prediction of future environmental suitability of coral reefs via multimodal machine learning as a tool for optimising long-term efficacy of reef conservation

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Current levels of atmospheric greenhouse gases will result in significant geographic shifts in the regions that can support tropical coral species. Present-day resource-intensive reef conservation projects, such as coral outplanting, may therefore be ineffective in the long term if focused on areas in which environmental conditions will become increasingly unsuitable for coral survival. To address this, we need robust tools that can identify areas where future environmental conditions will be conducive to long-term coral survival. These tools could be used to guide where to focus reef restoration efforts, as well as implement complementary conservation techniques such as assisted migration, placement of genetically-altered corals, and static or mobile marine protected areas.

This work explores the application of multimodal machine learning to predict the present and future global distributions of shallow-water coral reefs using historic and forecasted environmental data. The input datasets are selected with guidance from domain experts and include earth system model outputs and bathymetry. The model outputs (e.g. performance metrics, communication of uncertainty, spatial resolution etc.) are based on the requirements of stakeholders in reef conservation projects. This work improves on past literature by improving spatial and temporal resolution of input data to scales relevant to ongoing conservation initiatives, increasing the quality of input data, and implementing more sophisticated machine learning models. This results in greater predictive performance and more useful outputs for reef conservation efforts.

The project aims to be directly applicable to the optimisation of coral reef conservation initiatives: the explainability of the methodology and results are emphasised, while the model outputs and uncertainty metrics are specifically targeted to be useful to key stakeholders. The project aims to provide invaluable predictive tools to aid the long-term preservation of the rich biodiversity and invaluable ecosystem services of shallow-water coral reefs.

ID: 150 / **Parallel Session 4-2: 2**
Global Climate Change and Environmental Stressors

Keywords: Turbid reefs, Photogrammetry, Rugosity, Habitat Function

Quantifying three-dimensional colony metrics and reef structural complexity of turbid coral reefs from underwater photogrammetry and light scanning

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Turbid coral reefs experience low light and chronic sedimentation. The ecological success and climate resilience of these marginal reef types can be partly attributed to physiological and morphological adaptations of corals to local environmental conditions. Indicators of reef health in turbid settings are often measured using coral cover values obtained through two-dimensional methods. However, as turbid reefs are dominated by low-profile coral taxa that grow horizontally across the reef surface (i.e., encrusting and plating genera), the values obtained from two-dimensional survey methods are frequently high, despite low structural complexity and habitat availability. Here, we utilize a combination of underwater photogrammetry and ex-situ light scanning to generate three-dimensional (3D) models for 247 colonies of 24 coral genera and their varying growth forms from highly turbid and light-limited coral reefs in Singapore. Models were used to quantify mesh metrics (e.g., mesh volume, convex hull volume) necessary for colony-level morphological traits. The relationships between the obtained trait values and colony diameter were determined. To evaluate the structural complexity of highly turbid reefs, the acquired data were then applied to phototransect surveys to generate absolute spatial refuge and colony rugosity values for reefs. Our results highlight the potential for photogrammetry in turbid coastal settings and provide greater insight into their habitat functionality. Specifically, data can be used to reconstruct historical reef complexity metrics of turbid reefs, resulting in a better understanding of their long-term resilience or recovery capacity following major disturbance.

ID: 794 / **Parallel Session 4-2: 4**
Global Climate Change and Environmental Stressors

Keywords: Florida, Thermal stress, stony coral tissue loss disease

Land-based nutrients and suspended solids may ameliorate coral bleaching but promote coral disease.

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Spatiotemporal patterns of tropical coral bleaching and disease are driven by a complex array of interactive environmental, anthropogenic, and host-specific factors, of which combinations can be beneficial or detrimental. The effects of anthropogenic eutrophication of coral reefs are dependent on the nutrient loads, ratios, sources, and temperature where high concentrations can increase susceptibility to bleaching and disease. However, certain ratios of high nutrients can decrease susceptibility. A southeast Florida population of the largest *Orbicella faveolata* colonies monitored monthly for 4 years was used to study these dynamics because of their proximity to nutrient-laden coastal water along a latitudinal gradient. SCTLD lesions on these corals were treated within a month of occurrence providing data on prevalence of new lesions over time. In 2023, an extreme thermal stress event caused many corals to bleach and die throughout Florida. In southeast Florida, SCTLD prevalence and incidence on the large *O. faveolata* colonies was the highest ever recorded leading up to the bleaching. In August, all colonies south of Government Cut bleached extensively, whereas no colonies further north visibly bleached even though temperature stress was equivalent. Unbleached colonies continued to acquire SCTLD lesions in the north, whilst SCLTD quiesced on bleached colonies. Multivariate analyses of monthly nutrient and suspended solids concentrations collected at reef sites and inlet mouths between 2018 and 2022 categorized by inlet exposures identified through hydrographic modeling elicited spatial differences in nutrient landscapes that aligned with the observed bleaching. Prior to bleaching, the southern colonies had higher densities of *Breviolum* and *Cladacopium* algal symbionts than the unbleached colonies further north that were historically exposed to nutrient-laden inlet waters. Research into the causes of this differential response continues, however this study exemplifies the complex nature of the coral holobiont response to thermal stress and disease in the context of anthropogenic influences.

ID: 749 / **Parallel Session 4-3: 11**
Global Climate Change and Environmental Stressors

Keywords: Coral bleaching, Computational model, Scleractinian corals

A computational study of the effects of environmental stress on coral calcification using spatio-temporal models

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Coral bleaching has emerged as an increasing concern over recent decades, with a notable rise in the frequency and intensity of bleaching events. Various hypotheses have been proposed for this phenomenon. The primary explanation attributes it to elevated water temperatures associated with climate change, as well as other stressors such as increased solar radiation, pollutants, and changes in ocean chemistry such as ocean acidification. However, the exact mechanisms of this process and the relationship between the coral's physiology and external stresses are still poorly understood. It is hypothesised that reactive oxygen species (ROS) play a pivotal role in the bleaching mechanism. These highly reactive species are by-products of photosynthesis and are closely controlled by anti-oxidants. It is thought that when corals are faced with environmental stressors, an overproduction of ROS occurs. The increased levels of ROS result in oxidative stress and trigger the bleaching response. Corals with intricately branched morphologies are more susceptible to mortality during episodes of elevated sea-surface temperatures, and their initial signs of bleaching are found in the inner part of the branches. These observations highlight the impact of coral morphology on the bleaching process. Computational models are useful tools for testing hypotheses within such complex biological systems. In this study, we present a spatio-temporal computational physiology model of photosynthetic calcifying corals. This model sheds light on the relationship between environmental stresses and localised bleaching events. This model is based on experimental data on localised bleaching in corals and incorporates their three-dimensional structure. It provides insight on the mechanisms underlying bleaching and allows to simulates the effects of various factors such as temperature, light intensity, and water flow around corals.

ID: 178 / **Parallel Session 4-2: 14**
Global Climate Change and Environmental Stressors

Keywords: Hard corals, Climate change, Diffusion Boundary Layer, Hydrodynamic conditions, pH

Hydrodynamic influence on coral physiology: insights into the role of diffusion boundary layers in mitigating ocean acidification effects

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Recent investigations suggest that a diffusion boundary layer (DBL) surrounding coral tissue may provide a potential buffer against the negative effects of ocean acidification. However, comprehensive studies on the DBL's role in supporting coral calcification are lacking, resulting in conflicting outcomes. This research analyses pH and oxygen dynamics within the DBL of reef-building corals (*Acropora tenuis*, *Montipora digitata* and *Pocillopora acuta*) developed at sites with different flow regimes. These corals underwent controlled indoor flume experiments with varying flow rates and pH levels to assess the impact on calcification, photosynthesis, and respiration. A cross-transplantation experiment further evaluated physiological responses to flow velocity changes in the naturally extreme semi-enclosed lagoon of Bouraké (New Caledonia).

The outcomes of this investigation elucidate the impact of hydrodynamic conditions on the establishment of a DBL and, consequently, on coral physiology. Water flow resulted as a determinant factor with distinct effects on metabolic processes, determining species-specific responses that further differentiate among populations within the same species. A slow flow leads to substantial pH increases within the DBL in all three coral species and, specifically in *A. tenuis*, it ameliorates the adverse impact of ocean acidification, allowing corals to maintain higher calcification rates than in fast flow conditions. Additionally, the in-situ experiment reveals that the growth of species can also be influenced by the flow conditions of their originating site, highlighting a potential adaptation of certain populations. Specifically, *P. acuta* corals originating from areas with slow flow exhibit a decrease in their growth when transplanted to fast flow areas.

These findings suggest that slow flow habitats, conducive to the formation of a DBL, may mitigate the adverse impact of ocean acidification and thus act as potential refuges for select coral species. Consequently, the DBL emerges as a species-specific potential buffering solution for corals under future climate change conditions.

ID: 607 / **Parallel Session 4-6: 8**
Global Climate Change and Environmental Stressors

Keywords: disease, in situ, treatment

Broadscale SCTLD intervention effectiveness on *Montastraea cavernosa* in an endemic zone.

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Disease intervention using CoralCure with amoxicillin is effective at stopping stony coral tissue loss disease (SCTLD) lesion progression, however, it does not provide protection against reinfection. Prolonging colony survival requires regular visits to treat new lesions as they appear. Hence, intervention activities in southeast Florida were allocated between regular treatment and monitoring of selected priority colonies and broadscale disease interventions without the intent to monitor. The latter involved striketeam divers, who worked in small groups to cover large areas of reef treating all SCTLD lesions observed, tagging the colonies, and recording their locations via a floating GPS. The aim of broadscale disease intervention efforts is to maximize the area covered and treat as many disease lesions as possible without the intent of returning to monitor treatment success. Between 2018 and 2023, over 1,800 colonies of 12 different species were treated with over 1,100 meters of treatment at over 280 sites. We evaluated this strategy's effectiveness by revisiting colonies treated one-time after a year or more prior and recording their condition. 266 corals were revisited to assess colony condition, 70% (178) of which were *Montastraea cavernosa*. 94% of all *M. cavernosa* colonies were still alive at the time of revisit. 2% of revisited colonies had active lesions and needed retreatment. Categorizing colonies into elapsed timeframes since treatment yielded high proportions of survival: 100% of colonies treated 1-2 years prior, 97% treated 2-3 years prior, and 87% treated 3-4 years prior. Average percent decrease in live tissue coverage was 18%, 20%, and 30% after 1-2, 2-3, and 3-4 years, respectively. Compared to reported natural SCTLD senescence of about 30%, broadscale interventions provide prolonged colony survival reducing the burden of post-hoc restoration. Coral cover and health will likely continue to decline until the underlying causes and dynamics of SCTLD are resolved.

Posters

ID: 172
Global Climate Change and Environmental Stressors

Keywords: reef islands, shoreline change, geomorphology, Southeast Asia, dynamics of coral reefs islands through climate change

Seasonal reef island shoreline dynamics in Southeast Asia:Exploring the physical drivers of reef island change

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Reef islands are low-lying, unconsolidated landforms that are particularly susceptible to the impacts of climate change. Changes in local physical boundary conditions can rapidly drive alterations in island shape and location on the reef platform. Quantitative measurements of short- to medium-term reef island shoreline modification are limited for Southeast Asia, despite these coastal features supporting high human population densities and infrastructure. Here we present a high-resolution seasonal analysis of shoreline changes and planform geomorphic adjustments from coral reef islands across Southeast Asia (Borneo Malaysia, Philippines, and Indonesia). Shoreline positions of 110 reef islands from the archipelago were mapped utilizing Sentinel 2, Maxar, and Planet Dove satellite data (spanning timescales from 2016 until 2023) to investigate variability in island morphodynamic behaviour under different biophysical conditions within differing geological settings. The spatial configuration of land masses within Southeast Asia, connected by deep-water passages and channels with the mean current velocity of 0.106 m/s, and shallow shelf environments, creates a complex oceanographic and physical environment for interpreting island change. Result revealed the average of End Point Rate (EPR) 0.018 +/- 0.609 m/yr, as the predominant mode of shoreline change in the circular islands had higher EPR 0.081 +/- 0.671 m/yr than the other shapes. The elliptical or triangular shape were typically more dynamic, particularly in triangulate elongated shape the EPR is -0.119+/-0.464 m/yr. Notably, we documented the dynamic formation style of multiple newly formed islands from emergent reef platforms in the western region of Sumatera as result of vertical land movement (28 +/-1.95 mm/yr) 2006 until 2022, and the complete loss of Lipan island following El Niño event and wave flux energy of 8.84 kW/m. Our findings provide empirical evidence of the morphological trajectories of reef islands in a previously understudied region and how variability in physical boundary conditions among reef island groups can influence morphodynamic behaviour.

ID: 427
Global Climate Change and Environmental Stressors

Keywords: corals, phenotype, susceptibility, GWAS, GEA

Identification of genes responsible for local adaptation in natural populations of *Pocillopora* corals

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Reef-building corals, known for their heightened susceptibility to environmental fluctuations, are expected to undergo adverse consequences in the face of escalating climate change. Despite the imminent threats, the current body of knowledge predominantly focuses on specific locations and does not thoroughly explore inter- and intraspecific coral sensitivity across diverse reefs. This leaves a significant gap in our understanding of the broader ecological panorama.

Through the TARA Pacific expedition spanning from 2016 to 2018, 450 samples of *Pocillopora* spp. were collected from 30 islands across the Pacific to assess phenotypic signatures using a multi-biomarker approach. Biomarkers such as animal and symbiotic dinoflagellate biomass were analyzed to study trophic status, mitochondrial DNA copies and total carbohydrate content as indicators of metabolism, as well as total antioxidant capacities, protein carbonylation and ubiquitination as indicators of redox status and cellular damage. In parallel, the genetic make up of the same individuals that were phenotyped was assessed using genome-wide SNPs.

Our findings unveiled a wide-range of phenotypes indicative of specific physiological states and large phenotypic plasticity. Furthermore, the exploration of allelic diversity linked with each coral phenotype (by genome-wide association analysis) and/or environmental conditions (by genotype environment associations) allowed the identification of specific genes that putatively explain the colonies' physiological state and their response to environmental variation.

ID: 814
Global Climate Change and Environmental Stressors

Keywords: corals, seasonal acclimation, thermal performances, Red Sea, symbionts

Contribution of algal, bacterial, and fungal symbionts to seasonal acclimation of thermal performances of two Red Sea stony corals along a depth gradient

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Warming oceans and changes in the El Niño Southern Oscillation cycle expose reefs to stronger and longer thermal stress periods. Rapid acclimation to such conditions may allow the fittest photosymbiotic corals to survive. The success of such acclimation depends on various factors, including changes in host metabolism and shifts in symbiont community composition and activity. Scleractinians from the Gulf of Aqaba (GoA) in the northern Red Sea are known for their exceptionally high thermal thresholds, yet their seasonal acclimation potential and their environmental memory have not been investigated. To better understand the dynamics of thermal performance variations and the species- and depth-dependency of acclimation success to extreme conditions, monitoring of two common GoA branching corals, *Stylophora pistillata* and *Acropora eurystoma,* began at the InterUniversity Institute of Marine Sciences in Eilat, Israel in 2022 at depths of 5m and 40m. This study compares their seasonal thermal performance during successive winter and summer periods and will continue until 2025. Thermal performance curve assays based on photosynthesis and respiration rates have begun to reveal species- and depth-specific shifts in optimum temperatures (t_{opt}) with higher values in summer, matching the local maximum monthly mean for most tested corals. Furthermore, seasonal changes in chlorophyll efficiency and concentration, algal symbiont density, and macro-molecular (proteins, carbohydrates, and lipids) content have been observed. Ongoing amplicon-sequencing targeting algal, fungal, and bacterial symbionts will soon allow us to determine the composition of these coral microbiomes and their seasonal dynamics. This comprehensive study will enhance the understanding of scleractinian seasonal acclimation strategies in the face of climate change and the possible contribution of microbial constituents to the acclimation process.

ID: 537
Global Climate Change and Environmental Stressors

Keywords: climate change effects, coral diseases, coral growth anomalies, SEM imagery

Morphological characterization of growth anomalies on coral genera *Acropora* and *Pachyseris*

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Outbreaks of coral diseases have recently emerged as a significant threat for the fitness and survival of corals, exacerbated by climate change effects. Factors like ocean warming and acidification are identified as significant environmental stressors that may heighten the susceptibility of corals to diseases. In recent times, attention is rising towards a particular type of coral lesion, growth anomalies (GAs) or skeletal tissue anomalies. Despite their increasing prevalence and global occurrence, the etiology of such lesions is still under investigation, with potential links to anthropogenic stressors and extreme temperature conditions. In particular, excess of UV radiation, environmental degradation and infectious agents such as viruses, bacteria, and fungi have been suggested as possible contributors to the onset of coral tumours. GAs are recognized as true tumours that not only impact the morphology of the polyps but also disrupt biological functioning, compromising the reproductive capabilities, feeding abilities and the capacity of defending against external agents. The use of Scanning Electron Microscopy (SEM) imagery is essential for analysing morphological differences between healthy and diseased coral colonies. In this study we compared by the use of SEM images, samples of tumoral and healthy skeleton of corals of the genera *Acropora* and *Pachyseris*. We investigated morphometrical parameters such as coenosteum porosity and thickness, corallite dimensions and general structure, such as presence of columella, number of septa, denticle appearance. The obtained results must be complemented by additional analyses, such as histological characterization, to gain a more comprehensive understanding of the specific implications for coral fitness and viability.

ID: 397
Global Climate Change and Environmental Stressors

Keywords: coral bleaching, marine heat waves, coral reef community, Caribbean Sea

Impact of the 2023 bleaching event on coral reefs of Martinique, French West Indies

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Rising sea temperatures have become one of the main threats to coral reef ecosystems worldwide. Stressed corals expel the coloured symbiotic algae living in their transparent tissue causing their white appearance due to their underlying calcareous skeleton. Bleached corals can either recover or die depending on the stress intensity and length, but also according to coral species or the taxonomic and genetic composition of symbionts. Mass bleaching events are globally increasing in severity and frequency. In 2023, the wider Caribbean experienced the longest period of marine heatwave ever recorded. Field surveys of twelve coral reefs around Martinique island, French West Indies, were carried out in October 2023, during the peak of the intense bleaching event, and in January 2024, two months after the temperature decreased below the bleaching threshold of 29,4°C when they were no more bleached corals observed on the reefs. The main objectives were to quantify the spatial distribution and level of impact of bleaching on the coral community, and to identify the most vulnerable species. Thermal stress during the 2023 event exceeded any stress ever recorded before. Around 80% of the coral cover was affected by bleaching, as well as some actiniarians, zoantharians and gorgonians. This severe event reached an unprecedented scale, impacting the reefs of Martinique which had already suffered from coral (Stony Coral Tissue Loss Disease, SCTLD) and Diadema diseases over recent years. Among the main species affected by bleaching are some of the most SCTLD resistant coral taxa. It will undoubtedly have long-term consequences on the reef ecosystems and suggests a distressed future under a warming climate. The reduction of greenhouse gas emissions is urgently required. Efficient local management should also focus on reducing human activities impacts on the environment (pollution, overfishing, etc.) to enable coral reefs' natural recovery and adaptation mechanisms.

ID: 369
Global Climate Change and Environmental Stressors

Keywords: Crustose coralline algae, Red Sea, thermal stress

Crustose coralline algae mortality during a marine heatwave in the central Red Sea

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Crustose coralline algae (CCA) play essential roles in the healthy functioning of coral reef ecosystems, including stabilization of the reef framework and production of chemical cues that induce settlement in reef-building corals. However, CCA are vulnerable to thermal stress and are threatened by warming ocean temperatures. Thermal stress in CCA can be visible through a "bleaching" of the thallus, which can signify the death of the individual. Although CCA "bleaching" in tank experiments has been alluded to in a handful of studies, there is little known about the mechanisms of this tissue loss or the occurrence of it *in situ*. Here, we describe the "bleaching" and recovery of CCA during and after a marine heatwave that occurred in the summer of 2023 in the central Red Sea. We tagged 19 individuals of a branching and an encrusting CCA morphotypes that were confirmed as separate species with molecular techniques. We quantified "bleaching" for both species through analysis of images collected regularly during and after the heat wave. We found that branching CCA were less susceptible to bleaching than the encrusting CCA, and that the encrusting CCA did not recover from the event. This research sets the stage for further investigations into the vulnerability of CCA to heatwaves on coral reefs and subsequent studies that should explore the mechanisms CCA "bleaching".

ID: 668
Global Climate Change and Environmental Stressors

Keywords: Great Barrier Reef, Benthic Communities, Foraminifera, Ecosystem Health

Benthic communities and foraminifera at Lizard Island (Great Barrier Reef, Australia): what can we learn about ecosystem health status?

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The Great Barrier Reef, the world's largest coral reef system, has been extensively studied at Lizard Island, a classical site for investigating reef ecosystems located 240 km north of Cairns (NE Australia). However, relatively few studies have focused on foraminifera, protists with biomineralized tests.

This study, conducted during August and September 2022 assessed coral reef ecosystem health. We simultaneously examined foraminifera and benthic communities (e.g., corals, calcareous coralline algae, bacterial mats), as well as nutrient and seawater physiochemical parameters.

We applied the *Amphistegina* Bleaching Index (ABI) to gauge photo-inhibitory stress during an Autumn/Winter season with average seawater temperatures around 25°C. The ABI revealed stress that was either chronic and mild, or recent and moderate, indicated by Photosynthetic Active Radiation (PAR) at the surface reaching 2268 µmol m^{-2} s^{-1}, approximately 1000 units higher than the averages measured in the Maldives during the same period in 2018.

The Foraminifera in Reef Assessment and Monitoring Index (FoRAM-Index or FI), shows that the Lizard Island reefs are overall healthy and growing. A mean FI value of 7 and a median value of 6.89 at North Point, together with a mean FI value of 7 and a median value of 7.19 at Watson Bay, indicate that these reef ecosystems support calcification and growth.

Data collected indicate that reefs at Lizard Island remained healthy without significant temperature-induced bleaching during 2022. We postulate that a thin ozone layer may still be present to explain the chronic mild and/or recent moderate stress. A further sampling campaign in February 2024 (summertime) will provide essential data, allowing for comparison with the same environment under substantially higher seawater temperatures and stressors.

We warmly thank Anne Hogget and Lyle Vail of the Australian Museum's Lizard Island Research Station for facility assistance and Swiss National Science Foundation Grant 200020_201106 for funding this research.

ID: 542
Global Climate Change and Environmental Stressors

Keywords: Bleaching, Coral Reefs, Dinoflagellates, Photosynthesis, Reactive Oxygen Species

Effects of exposure to elevated temperature or complete darkness on the expression levels of symbionts's manganese superoxide dismutase in the giant clam, *Tridacna squamosa*

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To overcome the scarcity of nutrients in tropical waters, giant clams live in symbiosis with phototrophic dinoflagellates (zooxanthellae) and obtain photosynthates from them. Dinoflagellates reside extracellularly in zooxanthellal-tubules located mainly in the colourful and extensible outer mantle. Rising sea temperatures due to global warming or increased turbidity with reduced illumination due to pollution can lead to the loss of symbionts or bleaching in giant clams. Dinoflagellates conduct photosynthesis during illumination and release not only O_2 that can affect both the symbionts and the host, but also reactive oxygen species such as superoxide radical ($O_2^{\cdot-}$), which can attack biomolecules. Therefore, the host and its symbionts must possess mechanisms to detoxify $O_2^{\cdot-}$, and the anti-oxidative defence must be more vigorous in light than in darkness. Superoxide dismutases (SODs) are metalloenzymes that scavenge $O_2^{\cdot-}$ to ameliorate potential oxidative damage. They catalyze the dismutation of two molecules of $O_2^{\cdot-}$ to H_2O_2, and H_2O_2 is subsequently detoxified to H_2O and O_2 by other enzymes. Five complete cDNA coding sequences of manganese (Mn) SOD (two from *Symbiodinium*, two from *Cladocopium* and one from *Durusdinium*) have been cloned from the outer mantle of the fluted giant clam, *Tridacna squamosa.* Exposure of *T. squamosa* to elevated temperature (31 °C) for 57 days had no significant effect on the gene and protein expression levels of *MnSOD*/MnSOD in the outer mantle as compared to the control clams kept at 26 °C, probably due to the usual photosynthetic activities in the reduced population of symbionts. However, exposure of *T. squamosa* to complete darkness for 45 days led to significant decreases in the expression levels of *MnSOD*/MnSOD in the outer mantle because of the complete stop of photosynthesis in the remaining symbionts. These results demonstrated that symbionts in the outer mantle of *T. squamosa* would respond differently to temperature-induced and darkness-induced bleaching.

ID: 677
Global Climate Change and Environmental Stressors

Keywords: Coral bleaching, artificial shading, ecophysiology, coral recovery

Recovery of bleached Fungia hard corals exposed to in-situ artificial shading at Sipaway Island, Central Philippines

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Hard corals are particularly sensitive to elevated water temperatures and high solar radiation. Artificial shading can reduce solar radiation during heat stress periods, but its effects on the in-situ recovery of corals after bleaching are not resolved. Additionally, coral reefs in the Central Philippines are highly under-investigated. Since summer 2023, this area has experienced comparatively high water temperatures. We thus assessed the ecophysiological response (mortality, pigmentation, growth, photosynthesis, respiration) of Fungia hard corals in a reef near Sipaway Island, Philippines, to different shading levels (25 %, 50 %, 75 % light levels and no-shading controls). The in-situ experiment started in December 2023 and will continue until March 2024. The experiment used both bleached and unbleached Fungia polyps to comparatively investigate the effects of shading on recovery after bleaching. We hypothesize that artificial shading increases survival potential and facilitates bleaching recovery. Six weeks into the experiment, mortality was only observed for bleached Fungia corals at 25 % shading and in the controls. For bleached corals, both 75 % and 50 % shading levels show increased pigmentation (mean intensity grey - MIG) by 9.3 % and 7.2 %, compared to no-shading controls. Similarly, for non-bleached corals, shading levels of 75 % and 50 % result in increased pigmentation, 12.1 % and 11.7 % respectively. Preliminary results indicate that shading levels above 25 % lead to lower mortality rates and higher recovery potential. This poster will present all results of this unique in-situ experiment from the Philippines and thereby importantly contribute to our knowledge about the use of artificial shading to mitigate the negative effects of ocean warming on corals.

ID: 846
Global Climate Change and Environmental Stressors

Keywords: Coral bleaching, Stylophora pistillata, ocean acidification, photosynthesis, symbiosis

Coral bleaching : Long-term exposure to low-pH moderately impacts photosynthesis in endosymbionts of *Stylophora pistillata*

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The symbiotic partnership between scleractinian corals and the Symbiodiniaceae they host may face hindrances leading to bleaching under the influence of stress factors, notably temperature and light. Despite ocean acidification (OA) being recognised for its adverse effect on corals calcification, it could potentially lead to enhanced photosynthetic activity of symbionts, owing to increased carbon dioxide availability and augmented Calvin cycle activity.

Stylophora pistillata coral samples have been cultured for several years under varying pH conditions (i.e., pH 8.0, 7.8, 7.4, 7.2) at the Centre scientifique de Monaco (CSM). Previous research conducted on these corals revealed an up-regulation of genes related to photosynthesis in corals endosymbionts, albeit accompanied by a decrease of their photosynthetic performances (Herrera et al., 2021).

Building upon these findings, we investigated the photosynthetic activity of the symbiotic algae (*Symbiodinium* spp.) within these coral colonies under different pH conditions. Photosynthesis induction and light saturation curves, coupled with oxygen level measurements, provide insights into the electron transport capacity (rETR) and non-photochemical energy quenching (NPQ) of the endosymbionts' photosynthetic machinery.

Our results indicate a moderate impact on photosynthesis, with minor variations observed in all indicators concerning pH at low illumination levels, but with a significant increase in NPQ observed below pH 7.4 under high illumination.

This suggests the possibility of a dynamic control over CO_2 supply by the host to its endosymbionts, indicating long-term coral acclimation to low pH at an energy cost to maintain homeostasis. The thresholds at which this control collapses and photosynthetic capacities are overwhelmed seem quite distant from predicted ocean pH values by the end of the century (IPCC scenario). OA alone appears less critical than temperature for inducing *S. pistillata* bleaching. Future research should explore combinations of stress factors and species for a broader understanding of coral responses to stress.

ID: 481
Global Climate Change and Environmental Stressors

Keywords: bleaching, heatwave, calcification, proxy, *Porites*

Signature of bleaching events in coral skeleton - A case study for *Porites* from Lizard Island, Australia

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El Niño-Southern Oscillation (ENSO) derived heatwaves can lead to coral mass bleaching events and death of bleaching-impacted corals. Therefore, the increasing number, duration and earlier annual onset of these events threaten tropical reef ecosystems and emphasise the necessity to investigate coral bleaching in detail.

Studying past hyperthermal events is important to estimate the future capacity of tropical coral reefs to cope with marine heatwave-derived bleaching events. To shed light on how often coral mass bleaching has occurred over geological time, we need a robust proxy for bleaching events in the coral skeleton.

To address this issue, we investigate geochemical signals in the skeleton of three massive corals (*Porites* sp.) from Lizard Island (Great Barrier Reef, Australia) in correlation with known bleaching events. The three coral skeleton samples, collected in August 2022, were scanned using micro-Computed Tomography (µ-CT), Laser Ablation-Inductively Coupled Mass Spectrometry (LA-ICPMS) and Confocal Raman Microscopy (CRM). Using the internal morphology and Li/Mg-thermometer results, an age model was generated and compared to years of known bleaching events. Preliminary data show a disagreement between the µ-CT and LA-ICPMS data. In addition, the well-established Sr/Ca thermometer shows a different cyclicity than the Li/Mg signal.

The growth and calcification of stony corals are important for reef accretion dominating over its erosion. Different element-to-calcium ratios and derived annual growth rates will be discussed concerning the bleaching events and evaluated on their capability to be used as a proxy for historical mass bleaching events. The first results indicate a reduced apparent growth rate after years of coral mass bleaching events. Finally, the calcification of the three colonies before and after known mass bleaching events will be evaluated using the CRM-derived aragonite saturation state of the calcifying fluid (Ω_{Ar}).

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ID: 617
Global Climate Change and Environmental Stressors

Keywords: CRISPR, corals, gene editing

CRISPR gene editing in corals for gene function discovery

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Climate change is threatening coral reefs worldwide. Understanding the genetic response of corals to environmental stressors, such as heat stress, is urgently needed. CRISPR/Cas9 gene editing in corals enables the study and discovery of gene function, and an increase in the knowledge of the molecular pathways underlying stress responses. The most common method of CRISPR gene editing in coral zygotes to date is microinjection. Chemically-mediated CRISPR gene editing is currently being developed for higher throughput editing. In this talk, I will give an overview of CRISPR/Cas9 gene editing technology in coral zygotes and discuss the challenges of microinjection and the promise of chemical transfection.

ID: 665
Global Climate Change and Environmental Stressors

Keywords: Fish community, Coral cover, Climate change, Health gradient, Bioacoustics

Something sounds fishy: Community drivers of the coral reef soundscape across habitat health gradients

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Coral reefs are under high threat from habitat loss due to increasingly common high temperatures. Capturing the ecological functioning of coral reef communities is crucial for informing conservation. Underwater visual census focuses on visible biota, and therefore overlooks some of the richness of reef communities; many species remain hidden or are nocturnal. Soundscape monitoring can enhance our understanding of biodiversity by capturing aspects of reef health and ecosystem functioning that may not be visually detectable. Whilst soundscapes are currently used to provide insights into habitat health, it is unclear what fish communities and habitat variables can be deciphered from soundscape characteristics. We are combining acoustic and visual surveys to disentangle the relationship between measures of reef health and soundscape variation by examining the Great Fringing Reefs of the Egyptian Red Sea, reefs with a gradient of habitat degradation due to coral bleaching and crown of thorns attacks. By comparing coral and fish transects to quantified soundscapes, we will determine the relationship between these ecological variables and how they vary with habitat health. Soundscape recordings will be compared along a quantified health gradient using historic coral disturbances, coral trends and abiotic factors, to reveal the drivers of soundscape variation. Our study will provide insights into how soundscapes vary across health gradients and relate to the ecology of reef communities. This will be beneficial in identifying biodiversity hotspots by using holistic community assessments, and in identifying useful metrics for the long-term monitoring of reef communities.

ID: 153
Global Climate Change and Environmental Stressors

Keywords: sponge disease, ocean acidification, seawater temperature

Impacts of multiple climate change stressors on a Caribbean sponge disease

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Climate change-associated stressors, including elevated seawater temperature and ocean acidification, are predicted to increase the incidence or prevalence of marine diseases. Whereas coral diseases have been studied more intensively, diseases of sponges have been reported with increasing frequency worldwide. Sponges are essential ecological components of coral reefs, and there have been predictions that coral reefs may transition to sponge reefs in the Anthropcene. Thus, understanding sponge disease dynamics under climate change scenarios is crucial to our understanding of the trajectory of coral reefs. *Aplysina* Red Band Syndrome (ARBS) affects sponges of the genus *Aplysina* and is widespread across the Caribbean basin. ARBS is readily transmitted by contact between neighbouring sponges. ARBS reduces sponge growth and typically progresses slowly, rarely killing the affected sponge. In a laboratory experiment, healthy and diseased sponges were exposed to ambient (8.1) and reduced pH (7.9) at low (29C) and high (31C) temperatures in a factorial design. ARBS lesions progressed significantly faster in low pH treatments at both elevated and ambient temperatures, whereas elevated temperature had no independent effect on lesion size. Lesions in the low pH treatment progressed so rapidly that the experiment was discontinued after 4 days. Effects of acidification and temperature on biochemical parameters and microbiomes in the healthy and diseased sponges showed variable effects. Ocean acidification may reduce resistance in the host sponge or enhance the growth rate and/or virulence of pathogens, enabling an otherwise slowly progressing disease to cause more rapid mortality. The impacts of acidification have rarely been assessed in non-calcifying species, but sponges, along with their associated microbial communities, can be affected by these changing ocean conditions. These data indicate that sponges need to be considered relative to management and conservation strategies as climate change continues to threaten reef ecosystems.

ID: 307
Global Climate Change and Environmental Stressors

Keywords: Bleaching, Mesophotic, Thermal Refuge, Cayman Islands

Mesophotic reefs act as a thermal refuge during the 2023 Caribbean mass bleaching event

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Corals are increasingly threatened by the impacts of global climate change and associated increasing seawater temperatures that result in dysbiosis, known as bleaching, and potential subsequent mortality. The frequency and severity of thermal anomalies has increased significantly over the last several decades with 2023 being the warmest year on record. In the Cayman Islands, shallow seawater temperatures exceeded 31ºC for an extended period, reaching an unprecedented 19.5 Degree Heating Weeks (DHW). In September 2023, during the 13th DHW, we conducted a series of vertical transects on the sheer wall in Bloody Bay Marine Park on Little Cayman Island. Transects ran from 50m up to 10m with all corals encountered within a 2m span identified and assigned a bleaching status (fully bleached, pale, or healthy), and temperature recorded every second. We found a significant correlation with bleaching prevalence and depth, with less bleaching at increasing depths. A marked transition from predominately bleached to healthy colonies occurred at roughly 36m, which coincided with a noticeable thermocline where temperatures dropped from 30.8 to 30.5ºC. However, refuge potential differed among species with *Agaricia* spp*.* showing no difference in bleaching across depth while *Stephanocoenia intercepta, Montastraea cavernosa*, and *Porites astreoides* showed significant declines in bleaching with increased depth. Interesting, the opposite trend was found for *Orbicella faveolata,* suggesting that individuals of this species may be strongly adapted to localized conditions such that shallow individuals have higher temperature tolerances than deeper colonies. Overall, these results suggest that several species capable of living at mesophotic depths may have a higher potential of persisting through climate change impacts via thermal refuge on deeper reefs.

ID: 623
Global Climate Change and Environmental Stressors

Keywords: cold-water corals, aquarium experiment, multiple stressors, ecophysiology, microbiome

Single and Combined Effects of Warming, Acidification, and Deoxygenation Reveal the High Plasticity of the Cold-Water Coral *Dendrophyllia cornigera*

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Cold-water corals (CWC), as ecosystem engineers, play a fundamental role in promoting deep-sea diversity. Cold-water corals are threatened by global change, due to the warming, acidification, and deoxygenation of the oceans. These stressors are likely to occur simultaneously, but the knowledge of their potential interactions is still very limited. Hence, by investigating their combined effects, a better understanding of the impacts of global change on the structure and functioning of CWC-dominated ecosystems will be achieved.

Here we present the results of a 9-month experiment to assess the single and combined effects of warming, acidification, and deoxygenation on the CWC *Dendrophyllia cornigera*, based on the current *in situ* conditions and the IPCC RCP 8.5 projections for the North Atlantic. During the experiment, survival, tissue extension, skeletal growth, and respiration were regularly monitored as response variables. Further, the biodiversity of the associated microbiome was also assessed.

No significant effects were found on any of the response variables for any treatment, suggesting the plasticity of this species to cope with different environmental conditions. A significant decrease in respiration (from 1.03 ± 0.29 to 0.82 ± 0.36 µmol O_2 cm^2 d^{-1}, mean ± SD) was documented in all treatments after 9 months, possibly reflecting a low food provision in the experiment. A dominant presence of Spirochaetes in the associated microbiome (~73 %) was found across all treatments, and we speculate that they could contribute to the observed resistance of *D. cornigera*.

Our results advance our understanding of the ecophysiological response of this CWC species under different climate scenarios, contributing to increasing the overall knowledge of the resilience and vulnerability of CWC to the ongoing global change.

ID: 776
Global Climate Change and Environmental Stressors

Keywords: Reef fish, Biomass, Prediction, Species distribution, Environmental-social-habitat relative importance

Satellite imagery and machine learning reveal the importance of environment, human and habitat for predicting reef fish species biomass

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Coral reef fishes are globally threatened by climate change, overexploitation and habitat loss, yet the net local outcomes of these interacting pressures depend on how the biomass of different species is independently affected. Here we investigate the relative importance of environmental, human and habitat factors for predicting the local biomasses of 552 reef fish species worldwide using a multi-model approach and a spatial cross-validation procedure. We found that environmental covariates such as primary productivity, salinity and temperature were the most important for more than half of species (57%), followed by habitat (32% of species) and human covariates (11% of species). Machine learning models perform best for 70% of species, suggesting prevalent threshold effects and interactions in relationships between biomass and predictors for most reef fish species. By revealing species-specific biomass responses to multiple gradients, our models can help identify species for which biomass can be more effectively managed through reduction of human impacts, and species that might be more affected by shifting habitats or climatic conditions. These results also pave the way towards spatial predictions of fish biomass where data are lacking, and where temporal forecasting may provide insight into different human-habitat-environmental scenarios.

ID: 167
Global Climate Change and Environmental Stressors

Keywords: heat stress, molecular biology, coral, proteomics

The past, present and future of proteomics in coral heat stress

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Corals are facing a variety of threats around the world, and one of the new tools developed over the last decade is proteomics. This presentation is a meta-review of how proteomics has been used for heat stress research specifically, including what we discovered and what is missing. There will also be a discussion of advances in the field and what it can be used for in the future.

ID: 790
Global Climate Change and Environmental Stressors

Keywords: tropical-temperate gradient, functional diversity, poleward range shift

Tropicalisation of mollusc assemblages leading to community reassembly on temperate, high-latitude reefs.

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Global warming is redistributing species on Earth causing topicalization, borealization and desertification, all of which disrupt ecosystem functions and their integrity. Mollusca can engineer their habitat through shell production and thus participate in the carbon cycle and coastal protection. They also provide important ecosystem services such as nutrient cycling and are significant fisheries resources. In shallow warm water reef communities, poleward range expansions of reef-building coral species have transformed former kelp ecosystems into coral-dominated reef communities. However, the effects of topicalization are largely unknown for most invertebrate groups, including molluscs.

Here we use trait-based analysis to assess the composition of mollusc communities across 34 coral communities along the tropical and temperate Pacific coast of Japan. We analysed changes in mollusc assemblages over an eight-year period, comparing datasets from 2015 and 2023.

We found significant community reassembly of molluscs in line with topicalization at most sites, along with a poleward shift in abundances of tropical species. We propose that the changes in mollusc community composition are mediated by habitat availability and availability of functional niches as opposed to competition with native temperate species.

Thus, changes in mollusc abundances collate with coral abundances, possibly due to a necessity for processes such as nutrient recycling. Ultimately, we observed an increase in species diversity at higher latitudes, on temperate reefs. However functional diversity remained relatively unchanged due to increases in functional redundancy. We provide evidence of the topicalization of mollusc species along a tropical-temperate gradient, and aid in understanding the ecological changes that may occur due to global warming.

ID: 174
Global Climate Change and Environmental Stressors

Keywords: turbid coral reefs, carbonate sediment, sedimentary dynamics, benthic communities, marginal reef systems

Ecological drivers of biogenic carbonate sediment across a highly turbid coral reef system

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Coral reefs have experienced the combined impacts of climate change, sea-level change, and anthropogenic stressors. As a result, there has been large-scale coral reef degradation and major decreases in the relative abundance of carbonate producers on reefs. Here, we examine reef-scale sedimentary dynamics of highly turbid reef systems in southern Singapore, to establish the contribution of carbonate sediment production to local sediment supply within a marginal reef setting. A total of 69 benthic sediment samples were collected at six reef habitats across a depth habitat profile (reef flat, reef crest, upper reef slope, deep reef slope). Particle size and composition analysis of sediment grains show that corals (mean: 57±1%) remain the dominant sediment contributor at all reef sites, despite chronic terrigenous inputs. Molluscan grains (e.g., gastropods, bivalves) were also a major sediment producer, comprising on average 21±1% of all sediment. Sediment composition varied significantly by location, with reefs positioned further from the main industrial area exhibiting a greater diversity of grain constituents and relatively fewer coral grains. Remarkably, average terrigenous mud content (< 63µm) in benthic sediments remained low at 7±1% and exerted no significant influence on the relative composition of carbonate grains. Benthic ecological surveys (photo quadrats) conducted at these same sites show that average live coral cover ranged from 15±4% (degraded site) to 65±3% (offshore site), with an average cover of 39±4%. Results show an inverse relationship between coral cover and coral constituents within the sediment. Our findings highlight the critical role of sustained coral cover for maintaining adequate sediment supply within marginal reef environments. Understanding the interconnections between benthic community composition and sediment production is important for identifying key sediment producers on reefs and projecting future trajectories of sedimentary dynamics in the Anthropocene.

ID: 308
Global Climate Change and Environmental Stressors

Keywords: long-term monitoring, stony coral tissue loss disease, southeast Florida, community structure

Twenty years of monitoring in a marginal reef system captures a severe coral disease event with limited recovery

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Coral reefs globally are rapidly changing due to increasing pressure from climate change and local anthropogenic stressors. Long-term coral reef monitoring of permanently marked sites can provide essential data on community dynamics and can quantify the impact of and recovery from disturbances, such as disease events. Stony coral tissue loss disease (SCTLD) was first widely observed on the marginal, highly urbanized reef system off southeast Florida in 2014 and has led to dramatic changes in the stony coral assemblage. Here we leverage data collected as part of the Southeast Florida Coral Reef Evaluation and Monitoring Project (SECREMP) to assess the spatiotemporal impacts of the SCTLD outbreak on coral community composition and demographics. SECREMP is an ongoing long-term monitoring project initiated in 2003 that annually surveys 88 permanently defined belt transects across 22 sites. Along each transect, data on adult and juvenile stony coral species abundance, size, and health condition (including the presence of disease) are collected. We documented active SCTLD in 11 stony coral species and across all reef habitats surveyed. Between 2012 and 2018, significant declines in stony coral cover, colony density, and live tissue area were observed. Regional SCTLD prevalence peaked in 2016 and has remained below one percent since 2018, with no further significant declines detected. Colony size did not preclude SCTLD infection or mortality which, coupled with subsequent high recruitment and limited growth, has led to a population size structure shift towards smaller colony sizes. Although coral density was significantly higher in recent years than in 2013-2017, this trend was driven predominantly by increases in non-SCTLD susceptible and low-relief species that only minimally contribute to reef structural complexity. This study demonstrates the usefulness of multidecadal long-term monitoring in capturing community-level impacts of disturbance events and highlights its importance for assessing reef resilience and predicting recovery trajectories.

ID: 102
Global Climate Change and Environmental Stressors

Keywords: Stylophora pistillata, Arabian Gulf, Local extinction, Long-term monitoring

Local extinction of *Stylophora pistillata* in coral reefs of the Saudi Arabian Gulf waters

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Coral reefs play a vital role as ecosystems by sustaining a diverse range of marine life and offering several benefits to humans. Unfortunately, coral reefs around the world are facing significant threats from anthropogenic activities, including climate change, pollution, and overfishing. In this study, we investigated the population status of *Stylophora pistillata*, a branching coral species that was common in the Saudi Arabian Gulf waters, which its lack of sightings during coral reefs surveys in consecutive years are suggesting that this species is locally extinct in the reefs of the region. We reviewed historical data from previous surveys and found that *S. pistillata* has not been recorded in visual surveys in the last decade. It seems that *S. pistillata* has experienced a local extinction from coral reefs in the Saudi Arabian Gulf. This decline is likely a result of multiple stressors, including changes in sea temperatures, ocean acidification, and overfishing. *S. pistillata* is an important coral species that provides habitat and food for a variety of marine organisms, and its decline has significant ecological implications for the Arabian Gulf. Conservation efforts in the Arabian Gulf focused on reducing stressors on coral reefs and promoting the recovery of *S. pistillata* and other threatened coral species is urgent.

ID: 632
Global Climate Change and Environmental Stressors

Keywords: Ocean acidification, transplants, adaptation, transcriptomics

Comparative transcriptomics of the coral *Astroides calycularis* from natural CO_2 vents

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The difference between phenotypic plasticity and local adaptation is essential in determining the survival and growth of species and populations in their environment. This is crucial under present and future climate conditions, including ocean acidification. Natural volcanic CO_2 vents cause local acidification of seawater and are used as natural analogues for future ocean acidification conditions. Calcifying species such as corals are considered to be especially sensitive to ocean acidification (OA) because their growth relies on the precipitation of calcium carbonate (calcification). This process is expected to decrease as acidification increases. Here we investigate the role of phenotypic plasticity and local adaptation using transcriptome approaches on *Astroides calycularis*, an azooxanthellate scleractinian coral endemic to the Mediterranean, that naturally occurs in a natural CO_2 vent system off Ischia (Italy). For this purpose, we reciprocally transplanted colonies from their native location in the CO_2 vent site with low pH (pH_T=7.6 - 7.8) and two ambient pH sites (pH_T= 8.0). In total, we aligned 1,816,147,895 reads to a newly assembled genome of 28,830 genes, successfully mapping 618,052,604 transcripts. From these transcripts, we evaluated which genes were significantly differentially expressed using various designs to retrieve those that might explain the adaptation to lower pH condition. Our results show unique differentially expressed genes in colonies transplanted to the CO_2 vent site than the pH ambient sites, indicating pH-regulation of gene expression. We also annotated the genes that help explain the higher fitness of native colonies from the CO_2 vent in these high and variable pCO_2 settings. Combined, our results shed new light on the local adaptation trajectories of corals in response to ocean acidification.

ID: 855
Global Climate Change and Environmental Stressors

Keywords: Environmental variability, Environmental history, Ocean warming, Ocean acidification, Trade-offs

The roles of environmental history and contemporary variability regime in shaping coral physiological performance to ocean warming and acidification

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Anthropogenic climate change is one of the biggest threats to coral reefs worldwide as ocean warming and acidification coalesce to cause repeated disturbances. In combination with increasingly frequent and intense marine heatwaves, ocean warming results in mass bleaching events that can lead to coral mortality on regional to global scales, while ocean acidification lowers the calcification rates of many reef-building corals. Not all corals, however, are equally susceptible to the ocean's changing abiotic conditions, with evidence mounting that some corals native to environments characterized by strong environmental variability possess enhanced stress tolerance. How this tolerance is shaped by a coral's environmental history and its present exposure to different variability regimes remains to be fully elucidated, particularly in the context of combined stress. We collected *Porites furcata* from two distinct habitats in Curaçao with markedly different environmental histories to test to what extent long-term acclimatization to local conditions affects physiological performance. Corals from the abiotically variable bay site diverged with regards to physiology and stress tolerance from their conspecifics originating in the comparatively moderate reef site. Using ex-situ experimentation, corals from both habitats were exposed to four variability regimes for eight weeks such that the amplitude and duration of the combined temperature and pH stressors were manipulated in a full-factorial design. Corals were preconditioned to increasingly stressful temperature and pH conditions during this period. We demonstrate that environmental life-history plays an important role in the ability of corals to implement physiological trade-offs. Adjustments in environmental exposure regime were met over time by changes in skeletogenesis and photobiology, depending on the nature of the manipulation. Overall, our findings suggest that coral physiological performance reflects environmental attributes, and may be altered only by certain types of abiotic variability.

ID: 295
Global Climate Change and Environmental Stressors

Keywords: reef-former, biomarkers, Mediterranean, heatwaves, microplastics

The effects of heatwaves and microplastics and their combination on the Mediterranean bioconstructor coral *Astroides calycularis*

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Shallow marine benthic environments are among the most affected by multiple anthropogenic threats. Here habitat former species, such as corals, exert an important role in maintaining biodiversity and ecosystem functioning, and their heightened vulnerability poses substantial risks to marine ecosystems. It is well-documented that rising sea temperature adversely affects organisms involved in coral reef formation. Specifically, the increased frequency and magnitude of heatwaves (HWs) is becoming a threat globally, particularly in the Mediterranean Sea. This effect of climate change may act synergically or in addition to other anthropogenic stressors, such as plastic pollution, determining further stress to benthic species.

This work aims to evaluate the response to HWs and the presence of microplastics (MPs), alone and in combination, on *Astroides calycularis*, an endemic habitat former Mediterranean coral. This species was already supposed to be affected by HWs and MPs. Here we test its response to both stressors from a biochemical point of view, thanks to a battery of biomarkers. The tested endpoints were antioxidant and biotransformation enzymes [superoxide dismutase (SOD), catalase (CAT), glutathione-S-transferase (GST) and reactive oxygen species content (ROS)], oxidative damage [lipid peroxidation (LPO)], cellular reserves [protein content (PROT) and glycogen content (GLY)], and mineralization [acid and alkaline phosphatases (AP and ALP, respectively)] responses.

Significant response regarding oxidative stress in *A. calycularis*, both at the level of the enzymes involved in the first line of defence and for the enzymes of detoxification of phase II, was observed in particular for HWs exposure and protein content reduction. MPs alone did not produce statistically significant results whilst the combined effect of MPs and HWs appeared enhanced with respect to HWs only for AP.

The biochemical response of bioconstructor species in response to stressors related to climate change and their combined effect with local stressors deserve further investigation.

ID: 693
Global Climate Change and Environmental Stressors

Keywords: Siderastrea stellata, thermal tolerance, global changes, environmental variability

Do environments with greater temperature variation select more thermally resistant corals?

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Global changes such as ocean warming and acidification have been threatening reef ecosystems by subjecting organisms to environmental conditions beyond their tolerance limits. More frequent and severe coral bleaching events have been contributing to the mass mortality of these organisms, resulting in reef degradation. Despite that, around the globe some corals have been experiencing less bleaching and higher survival rates, suggesting that corals have different susceptibilities to bleaching and distinct abilities to recover after stress events. This pattern may be related to local conditions, such as the natural temperature variability in the corals' origin site, which may influence different coral mechanisms to cope with thermal stress. We conducted laboratory and field experiments with colonies of *Siderastrea stellata* from habitats with high (tide pools), medium (shallow reefs; 2m), and low temperature variation (deep reefs; 28m) to investigate their response to a simulated heat wave and their ability to acclimatize when transplanted to different environments. In both experiments (heat stress and reciprocal transplant), we assessed coral response through changes in colour and photosynthetic efficiency. We observed that, under heat stress, tide pool corals bleached less and did not experience a significant decrease in photosynthetic efficiency, whereas corals from shallow and deep environments were more vulnerable to bleaching and suffered a significant decrease in photosynthetic efficiency. After the stress, tide pool corals recovered better, followed by corals from the shallow reef, while deep reef corals did not recover. Deep reef corals also bleached and reduced their photosynthetic efficiency when transplanted to reefs with wider temperature variation. Our results reveal that highly variable environments may favour more resistant and resilient coral colonies, by influencing tolerance mechanisms that enable corals' persistence in these locations. Under climate change, this increased tolerance could also prove advantageous, making these corals more prone to cope with ocean warming.

ID: 265
Global Climate Change and Environmental Stressors

Keywords: corals, biomarkers, susceptibility, environment, physiological state

Assessing *Pocillopora* species' phenotype variability across 30 Pacific islands

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Reef-building corals, known for their heightened susceptibility to environmental shifts, are expected to experience deleterious repercussions after escalating climate change impacts. Despite the looming threats, the existing body of knowledge concentrates mainly on specific locations and does not fully explore inter- and intraspecific coral sensitivity across various reefs, leaving a substantial void in our comprehension of the broader ecological landscape. Through the TARA Pacific expedition, 450 samples from *Pocillopora* spp. were collected on 30 islands across the Pacific from 2016 to 2018 to assess the phenotypic signatures using a multi-biomarker approach. The biomarkers analysed included biomasses of animals and symbiotic dinoflagellates to study the trophic status of the colonies, copies of mitochondrial DNA, and total carbohydrate content as indicators of metabolism and total antioxidant capacities and protein carbonylation as proxies for redox state and cellular damages. The results revealed a wide range of phenotypes reflecting specific physiological states and a large phenotypic plasticity. The analysis of the entire dataset allows us to answer the following questions: (1) How do biomarker profiles vary within and between different *Pocillopora* species across the Pacific? (2) Which environmental or genetic factors correlate with the biomarker profiles? (3) Which biomarkers can be used to monitor coral reefs?

ID: 771
Global Climate Change and Environmental Stressors

Keywords: Coral adaptation, Seascape Genomics, Environmental stressors, Red Sea, Conservation

Adaptative potential to environmental stressors of three coral species in the Red Sea.

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Coral reefs, the cornerstones of marine biodiversity, are threatened by climate change. Anomalous thermal oscillations have caused widespread coral bleaching resulting in the collapse of reef ecosystems worldwide. Nevertheless, Northern Red Sea corals show exceptionally high thermal thresholds and are attracting increasing attention in a reef conservation framework.

Recent research has found evidence of coral adaptation using the novel seascape genomics (SG) approach. Based on statistical associations between environmental variables and thousands of genomic markers, this approach aims to identify genetic variants that are predominant in corals persisting at reefs exposed to recurrent stress.

Using SG, this study investigates the adaptive potential of three flagship coral species (*Pocillopora verrucosa*, *Stylophora pistillata*, *Porites lobata*) in the Red Sea and Djibouti. A pre-fieldwork spatial analysis was performed on environmental data extracted from satellite images to delimitate reef clusters of highly contrasted environments in the Gulf of Aqaba, the Strait of Bab El-Mandeb and the Gulf of Tadjoura. During a research expedition with the Transnational Red Sea Center, coral colonies were strategically sampled at these reefs to maximize the potential for identifying adaptive genotypes using whole genome sequencing (WGS). To ameliorate statistical power, these data will be completed with existing genomic datasets across the Red Sea. Indeed, the adaptive potential of corals is associated with the connectivity between reefs exposed to heat stress in different regions. The said connectivity of individuals and populations is currently under characterization. Using genome-environment associations (GEA) the locally resistant genotypes will be identified and their distribution will be mapped across larger regions of interest. Subsequently, predictions on corals' adaptive potential across reefs will be made. The exposed adaptive patterns will empower bleaching predictive models and inform decision making for the preservation of coral reefs.

ID: 329
Global Climate Change and Environmental Stressors

Keywords: temperate coral, Mediterranean Sea, resilience, nutrients, warming

The Hidden Rescuers? Unveiling the role of nutrients in *Cladocora caespitosa* climate change resilience

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Over the last 25 years, the Mediterranean zooxanthellate and reef-building coral *Cladocora caespitosa* has been affected by recurrent mortality events triggered by marine heatwaves. Consequently, in 2015 the IUCN classified this species as endangered, underscoring the need for the description and monitoring of its populations to improve its conservation status. In this context, the *C. caespitosa* populations of Cap de Creus, Montgrí and Menorca (NW Mediterranean) have been studied in order to record the demographics and health status of coral colonies. The data of these surveys have shown, 1) a lower proportion of colonies affected by mortality and accumulated percentage of necrosis in corals sampled in Montgrí (15% and 9%, respectively) than in Cap de Creus (>70% and 33%, respectively), even if those in Montgrí are exposed to shallower and hence warmer waters; and 2) lower mortality values in highly sheltered sites in Menorca (e.g. 4.6 % average necrosis in Illa del Rei, within the Port of Mao, compared to the 29.4% average necrosis in Menorca). The common environmental characteristics among the locations showing lower mortalities are water turbidity, high sediment resuspension, and, therefore, presumably high nutrient concentrations. *Cladocora caespitosa* can both feed heterotrophically on suspended organic matter and enhance its photosynthetic activity when the availability of nutrients is higher (i.e. mixotrophic species). Therefore, elevated concentrations of nutrients may play a key role in overcoming the energy constraints associated with warming-related mortalities in the Mediterranean Sea, thereby increasing the resilience of this scleractinian. This hypothesis sets the basis for the UndResCoral project, which aims to understand the resilience of Mediterranean symbiotic corals to warming under different nutrient and food regimes. The outcomes of this research will contribute to develop future projections and establish effective management and protection measures.

ID: 292
Global Climate Change and Environmental Stressors

Keywords: adaptation, biodiversity, remote sensing, satellite data

Linking remote sensing and SCUBA to identify adaptive reefs

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The habitat heterogeneity hypothesis predicts that a highly heterogeneous habitat will support a community with high biodiversity. In turn, a highly biodiverse community is theoretically well placed to adapt to changes in environmental conditions, due to high response diversity, functional redundancy, and ecosystem functioning. This adaptive potential is key for survival under increasingly severe anthropogenic climate change. To overcome challenges with the poorly defined use of “adaptation” in the literature, we created a framework to conceptualise adaptation at various levels of ecological organisation, from individuals to ecosystems. We then apply the framework to data, bridging the disconnect between the theory and operationalising adaptive potential with accessible, widely-available data.

Coral reefs are naturally heterogeneous environments, composed of various habitat types including live taxa (corals, sponges and algae), and abiotic habitats including sand, rock and rubble. We have developed a novel metric of habitat heterogeneity based on the recently published Allen Coral Atlas that has mapped reef habitats from satellite imagery. Our metric classifies the beta-diversity of a site based on the habitat diversity within a surrounding radius. We then linked the satellite-derived metric to in-water biodiversity surveys by conducting SCUBA surveys in Ambon, Indonesia, and used linear mixed models to model heterogeneity with adaptive characteristics.

Using key traits and processes identified in the adaptive potential framework, we find a positive relationship between heterogeneity and adaptive characteristics, suggesting that reefs that are more heterogeneous may experience faster adaptation to the ongoing climate crisis. Our results demonstrate the applicability of a novel metric of habitat heterogeneity to predict the adaptive potential of coral reefs. Given the near-global extent of the Allen Coral Atlas, we can now estimate adaptative potential at a broad regional scale, and thus broaden our understanding of reef responses to climate beyond site-specific visual census or experimental approaches alone.

ID: 744
Global Climate Change and Environmental Stressors

Keywords: mass mortality, sponges, urchins

Mass mortality events as another factor shaping future reefs: Examples from a giant barrel sponge mass mortality event and the recent urchin mass mortality along the East African coast

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In the last two decades coral reefs have been facing unprecedented challenges at the global (climate change) and local level (e.g. nutrification, disease). Increased monitoring to identify and address these challenges has led to increased reports on bleaching events, diseases, and mortality events around the world.

Sponge mortality is often caused by fatal bleaching with massive tissue loss due to diseases or other environmental stressors such as changing environmental conditions and harmful algal blooms. Here we report on the first documented mass mortality event of the barrel sponge *Xestospongia* sp. in the lower Gulf of Thailand and its consequences on population dynamics and size distribution. Two anthropogenic impacted reefs of the island Koh Phangan and two anthropogenic non-impacted reefs were surveyed. Fatal "bleaching" ending up in mass mortality was observed for the impacted reefs, with *Xestospongia* sp. abundance decreasing by 80.6% and by 98.4% at the two sites. Sponges of all sizes were affected, and mortality occurred regardless of the survey depth (4 and 6 m). However, *Xestospongia* sp. population densities in the none impacted sites were at a constant level.

Diadema urchins are keystone species on coral reefs, where they are the main grazer of algae, especially in places where herbivore fish stocks have been diminished due to overfishing. Mass mortality events have been observed for *D. antillarum* in the Caribbean and western Atlantic, resulting in complete population collapses in the early 1980s. In 2022 another mass mortality was observed in *D. antillarum* caused by a scuticociliate. The observed urchin mass mortalities have led to pronounced phase shifts, changing benthic communities from coral dominated to algal dominated states. In 2022 mass mortalities have also been observed in the Mediterranean, the Red Sea and most recently Zanzibar, Tanzania. Effected species in Zanzibar included *D. setosum*, *D. savignyi* and *Echinothrix diadema.*

ID: 684
Global Climate Change and Environmental Stressors

Keywords: GFPs, confocal microscopy, photophysiology, Madracis, photosymbionts

Investigating the acclimatization potential of coral fluorescent proteins in the coral genus *Madracis* using reciprocal depth transplantations

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The ability of corals to synthesize various pigments is crucial to their fitness, however the ecological functions of coral fluorescent proteins (FPs) in reef habitats remain only partly understood; the two primary hypotheses for the ecological role of FPs are that they regulate light use by the coral's photoautotrophic endosymbionts either 1) by shading them from excessive irradiance in shallow water or, 2) re-emitting light at photosynthetically-active wavelengths in deep-water environments. To test these hypotheses this project studies the variation of coral FPs over depth on a reef slope on Curaçao and their acclimatization during a reciprocal depth transplantation experiment. Colonies of *Madracis decactis* (n=6) and *M. mirabilis* (n=6) were collected at 10 and 20 meters and split into transplantation and control groups. After five days of acclimatization the transplantation groups were moved across depths and their photophysiology (and that of control groups) assessed for 25 days. The study combined photo-physiological measurements performed in situ, histological techniques and confocal microscopy in order to investigate the combined response of coral FPs and coral-associated photosymbionts and their temporal dynamics. *In situ*, fluorescence responses to blue excitation light, reflectance patterns and the photochemical yield of photosymbionts have been measured with the DIVING-PAM-II (Walz). The tissue distribution of FPs was studied through laser scanning confocal microscopy, which was combined with measurements of symbionts cell densities, chlorophyll concentrations and total protein contents. Analyses of *in situ* measurements and histological techniques are ongoing and will allow establishing potential correlations between the variation in reflectance, fluorescence and yield over time and for the different light treatments (all measured *in situ*) and the composition of photopigments and distribution of animal FPs. Our work highlights the different functions of FPs in coral holobionts and the temporal dynamics involved in the response of coral and symbiont components to environmental variation.

ID: 582
Global Climate Change and Environmental Stressors

Keywords: corals, CO2 vents, ocean acidification, adaptation, Mediterranean

Coral populations naturally occur in high pCO_2 environments on the coast of Ischia

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Natural volcanic CO_2 vents cause local acidification of seawater and are used as natural analogues of future ocean acidification (OA) conditions. Populations associated with these high pCO_2 environments provide an unparalleled opportunity to assess the mechanisms of acclimatization and adaptation to climate variability and extremes. Here, we investigate two CO_2 vent systems on the coast of Ischia (Italy) and how elevated seawater pCO_2 exposure influences coral populations that naturally occur in these acidified environments. We studied two Mediterranean long-lived scleractinian corals of key relevance for conservation as habitat-forming species: the zooxanthellate *Cladocora caespitosa* and the azooxanthellate *Astroides calycularis*. We compare populations living near the vents (pHT = 7.6 -7.8) to reference areas with ambient pH (pHT = 8.0) hosting similar geomorphology but outside the influence of CO_2 venting. Our research addresses questions related to the physiology, ecology, and adaptive responses of corals to ocean warming and acidification. To achieve this, we integrate environmental data (carbonate chemistry), ecological field surveys and laboratory experiments, encompassing population demographics, skeletal characteristics, gametogenesis, and transcriptomic approaches. Further, we witnessed the spawning of *Astroides calycularis* in the field, allowing us to run an experiment on the effects of acidification on early life stages and explore whether differences in gene expression between populations and treatments exist. Through the study of these high pCO_2 environments and their populations, we gain new insight into how natural coral populations survive, as well as their adaptive strategies and resilience to high pCO_2 environments.

ID: 519
Global Climate Change and Environmental Stressors

Keywords: Turbid-water reefs, heat stress, global changes, marginal reefs, extreme conditions

Bleaching and recovery in turbid-water coral reefs in southern Mozambique

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Coral reefs confront escalating threats including rising sea temperatures globally, with bleaching events increasingly frequent and occurring on larger areas. Prolonged high temperatures, coupled with stressors such as low tide exposure, reduced light and sedimentation, can increase coral vulnerability. Nearshore, turbid-water coral reefs are well adapted to extreme fluctuations in environmental factors. However, how bleaching affects these reefs remains poorly understood compared to their counterparts in clear water. In March 2023, coral bleaching was observed in the turbid-water reefs of Inhaca Island, which borders the Bay of Maputo in southern Mozambique. Satellite data revealed that this event was likely triggered by a series of heat waves associated with an extreme low tide. To evaluate the impact of bleaching on the coral community and the relative importance of driving factors, we started monitoring monthly with photo quadrats, two turbid-water coral reefs: a well-developed 2-km-long reef extending down to 4 m depth, with higher coral diversity; and a less diverse 1-km-long reef that fringes a sand bank channel down to 2 m depth, formed mainly by large coral bommies and a mono-specific *Acropora* bank, which gets partially exposed during spring low tides. Our preliminary results show that the most developed reef had very low bleaching (<1%), while the less developed reef was severely affected (73%) and suffered high mortality of *Acropora* in the shallowest zone. The death of these corals resulted in a new semi-consolidated rubble substrate that may allow the recruitment of new species. These findings suggest that despite turbid-water reefs may be adapted to challenging conditions, heat stress, particularly when associated with low tide exposure, may be highly detrimental to key species. Monitoring is ongoing to detect and quantify recovery.

ID: 429
Global Climate Change and Environmental Stressors

Keywords: climate crisis effects, symbiosis, symbiont switching, qPCR, assisted evolution

Inoculating novel Symbiodiniaceae symbionts in the Large Benthic Foraminifera (*Sorites orbiculus*) following an artificial bleaching experiment

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Coral bleaching, intensified by global climate change, triggers potential adaptive mechanisms in coral organisms, such as symbiont switching to more heat-tolerant variants. Symbiotic large benthic foraminifera, important carbonate producers, associate with a variety of symbionts and represent an ideal system to investigate non-coral symbiont flexibility in tropical systems. In this study, we performed controlled menthol-induced bleaching (menthol/DCMU at 0.19 mM and 5 µM) followed by reinoculation experiments on *Sorites orbiculus*, a cosmopolitan reef foraminifer that can associate with dinoflagellates (Symbiodiniaceae). Post-bleaching, *S. orbiculus* specimens were reinoculated with *Symbiodinium microadriaticum* (strains CCMP2467 and KB8) and the more heat-tolerant *Fugacium kawagutii* strain F2, both individually and collectively. The reinoculation was performed for 19 days followed by a further cultivation for 14 days to test for any short-term effects. Monitoring through qPCR, confocal microscopy, and PAM fluorometry revealed a significant increase in the symbiont density and photosynthetic efficiency of all treated groups. While differences between reinoculation treatments were non-significant, control treatments showed no symbiont regrowth. The short time frame of observation did not reveal physiological differences between the strains. DNA of novel symbionts was detected in all strain-treated groups post-reinoculation, confirming successful uptake. Strain KB8 exhibited the highest gene copy number, followed by CCMP2467 and the mixed-strain treatment. Notably, *S. orbiculus* successfully associated with *S. microadriaticum* strains, which is the first such observation with Soritidae. This study illustrates the potential for symbiont flexibility among tropical foraminifera, indicating a possible path for adaptation to global climate change that warrants further investigation.

ID: 441
Global Climate Change and Environmental Stressors

Keywords: Environmental change, Tempreature treatment, Bioerosion

Responses of endolithic bioeroders to heat and cold

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Among other things, climate change and extreme weather events are causing significant ecological problems, notably for coral reef ecosystems. These ecosystems are vital for biological diversity and human communities, but worldwide they are endangered due to anthropogenic change. While reef builders increasingly fail, bioeroders are considered comparatively resilient, often survive adverse conditions and can accelerate coral reef degradation after disturbance. Previous studies looked into the effects of ocean acidification on internal bioeroders, but less attention has been paid to temperature effects on bioeroders. We conducted an experiment aiming to address this gap by investigating the response of internal bioeroders to temperature change. We implemented heat treatment as the main focal point, as well as cold treatment as a little-understood element, and a control group in ambient temperature. Natural live rock inhabited with internal bioeroders was sampled from Little Liuqiu Island, southern Taiwan and allocated to experimental units in this approach. Changes in buoyant weight were used to track bioerosion rates over two weeks of gradually increasing and decreasing water temperature and stable conditions. The highest rates of bioerosion were observed in ambient temperature of 25ºC, outperforming bioeroders in elevated (29 ºC), and in the cold treatment (21 ºC), where the lowest bioerosion was measured. Bioerosion rates only significantly differed in the cold treatment versus ambient and heat, not the latter two from each other. The heat treatment was not fatal to the bioeroders, indicating that they had not yet reached their critical limit. No evidence of necrosis or death was found in any treatment group. This highlights the temperature tolerance of bioeroders to thermal changes within a given limit and again suggests that the carbonate balance on reefs will further shift towards erosion with deteriorating calcification and live cover when bioerosion is unlikely to decrease at the same rate.

ID: 185
Global Climate Change and Environmental Stressors

Keywords: crustose coralline algae, CCA, temperature stress, climate change

Effects of temperature stress on central Red Sea crustose coralline algae

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Crustose coralline algae (CCA) are an essential component of coral reef ecosystems where they provide important ecological services. Red Sea coral reefs have abundant CCA communities and the warmest sea temperatures in the world. Yet, a large gap still exists in our understanding of CCA responses to warming ocean temperatures. To evaluate temperature effects on coralline biological functions, we conducted an aquarium experiment with different warming treatments. Two species of crustose coralline algae, *Lithophyllum* sp., a free-living CCA (rhodolith), and *Neogoniolithon* sp. an encrusting CCA, were exposed to 6 temperature levels for two months (26°C, 29°C, 32°C, 35°C, 38°C, and 41°C). At the start, middle, and end of the experiment, samples were buoyant weighed, photosynthetic efficiency was determined with a diving PAM, and light and dark metabolic rates were calculated based on changes in total alkalinity and dissolved inorganic carbon. All samples were stained with calcein at the start of the experiment for determination of linear extension.

CCA growth was significantly affected by temperature; *Lithophyllum* sp. continued to grow in the 26 °C, 29 °C, and 32 °C treatments, while *Neogoniolithon* sp. grew only in the 26 °C and 29 °C treatments. Maximum quantum yield of both CCA species in the 35 °C treatment was lower than other temperature treatments (excluding 38°C and 41°C samples). Temperature also had a significant effect on net photosynthetic rates however it did not affect instantaneous calcification rates. Our results shed light on the potential impacts of warming temperatures on physiology and growth rates of two important coralline species. Elucidating the relationships between temperature and ecological function of key algal taxa is becoming increasingly important as coral reefs shift towards dominance by fleshy and calcifying algae as ocean warming continues to intensify.

Session 5: Coral Reef Anthropic Pressures, Conservation and Restoration

Anthropogenic activities are altering the climate and ecosystems at a global scale, making it increasingly challenging for organisms to keep pace with the associated rapid ecological changes in their environment. Coral reefs are particularly affected due to the sensitivity of sessile and sedentary organisms that form the backbone of these ecosystems. The worldwide decline of coral reef ecosystems has made it imperative to better understand the mechanisms underpinning evolutionary processes and how they influence and are influenced by demographic processes, population connectivity, interspecific interactions, and the interactions of species with their abiotic environment. These ecological processes are important in directing and constraining evolutionary processes, and in turn such evolutionary change greatly affects coral reef conservation and restoration efforts. This session aims to bridge the gap between the fields of coral reef ecology and evolution, bringing together ecologists, evolutionary biologists, physiologists, molecular biologists, and modelers to give presentations on how ecological changes associated with climate change affect our ability to conserve and restore coral reefs now and into the future. Furthermore, this session aims to not only contribute novel data, but also robust experimental designs, innovative theories and synthesis talks to drive research addressing the conservation and restoration of coral reefs in the face of climate change.

Keywords: effects of tourism, overfishing, chemical pollution, plastics and other emerging contaminants, nature-based solution to coral reef restoration, the supercoral hypothesis, coral aquaculture

Session chairs

Timothy Ravasi, Okinawa Institute of Science and Technology (Japan)

James Davis Rimer, University of the Ryukyus (Japan)

Take home message

- Asides from global issues such as climate change, there is a clear need for longer and more comprehensive research into the full range of anthropogenic stressors and issues that affect coral reefs, from terrestrial runoff and pollution to disease, as well generating basic response and functional data for the whole diversity of scleractinian corals, fishes, and other organisms, in order to better predict the future of coral reef communities.

- Conservation efforts, such as the "30 by 30" agenda within COP28, are increasing, yet available data and subsequent conservation efforts remain unbalanced with regards to both the range of actions undertaken as well as geographic location.
- While conservation remains a top priority, there are numerous and rapidly increasing numbers of local- to large-scale restoration research projects and efforts, including the development of a wide variety of novel tools for coral reef managers to implement.

Regular oral presentations

ID: 583 / **Parallel Session 5-6: 4**
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: coral reef, hypoxia, photogrammetry, fluid dynamics, modelling

The importance of flow on small-scale oxygen distributions on a coral reef

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Eutrophication and the warming of marine coastal systems often result in decreased oxygen availability for benthic organisms. Ecological mechanisms, including microbially-mediated increases in oxygen consumption, act to further decrease oxygen availability. This is of particular concern in coral reef communities, where oxygen availability can become too low to sustain aerobic respiration in certain organisms. Corals are generally less tolerant to hypoxic conditions, compared to their benthic competitors, fleshy algae. This can result in weakened and suffocating califiers being outcompeted in these hypoxic zones. The extent and ecological significance of these presumed hypoxic conditions, especially in complex reef environments, are still poorly understood. Next to the solubility of oxygen in seawater (governed by factors such as temperature, salinity etc.) and metabolic rates of resident organisms, including microbes, fluid dynamics is emerging as a key factor driving the formation of small-scale hypoxic regions in a coral reef. Here, we combined Structure-from-Motion (SfM) photogrammetry, macro- and micro-organismal abundance estimates, and flow measurements collected from a coral reef in Curaçao with experimentally determined biogenic oxygen fluxes to develop a computational fluid dynamics (CFD) model aimed at predicting small-scale oxygen distribution in complex structural landscapes. Oxygen distributions predicted by the model approximated empirically measured *in situ* oxygen concentrations and revealed the common occurrence of hypoxic areas within the reef framework. These findings highlight hypoxia to be a structuring factor shaping benthic communities at small spatial scales. Our model could be further leveraged through the wealth of functionally annotated three-dimensional images to identify the biogeochemical settings that contribute to the demise, resistance or resilience of present-day reef communities across the world and potentially model responses of specific reef communities to projected future environmental scenarios.

ID: 785 / **Parallel Session 5-6: 8**
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: Cross-realm management, coral reef restoration, ecosystem monitoring, invasive species

Multi-scale monitoring of island restoration programs on coral reef systems

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Marine and terrestrial systems have been largely siloed in both the ecological literature and management practices, often treated as if they are not connected. However, ecosystem boundaries are porous and connected by the movement of materials and organisms. As such, threats, or conversely conservation actions, in one system can have substantial cross-realm impacts. Eradicating invasive species is a common management action that is now recognized for its potential to provide cross-ecosystem benefits. Recent evidence suggests eradicating invasive mammals (i.e., rats) from islands may benefit adjacent marine ecosystems, sparking calls to promote marine conservation via island restoration. Despite the promise of island-based eradications and restoration as cross-realm management solutions, we lack understanding of the spatial and temporal timescales over which benefits can be expected, and effective/efficient ways to monitor cross-realm outcomes. Here we developed a monitoring framework to evaluate the efficacy of island restoration on coral reef ecosystems using a case-study on Tetiaroa, a remote atoll in the South Pacific that hosts islets of various rat invasion histories to serve as proxies for differing recovery dynamics. By integrating data collected across multiple levels of biological organization (e.g., from isotopes and microbes to fish and benthic communities), we assessed instantaneous-, medium- and long-term indicators of cross-realm management outcomes. We found a strong correlation between rat status and bioavailable nitrogen levels in nearshore marine habitats, and have identified where we see both significant and non-significant impacts on microbial and macro-organismal marine communities. Understanding the interplay between land and coastal marine processes will be useful for restoration goal setting and, importantly, reducing the barriers to management implementation by minimizing monitoring cost and effort.

ID: 269 / **Parallel Session 5-3: 7**
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: Corals, microplastics, nanoplastics, symbiodiniaceae, nitrogen assimilation

Effect of nanoplastics on the photochemistry of the scleractinian coral *Stylophora pistillata*

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For several years, the health of corals has been threatened by plastic pollution. In particular, nanoplastics (NPs) are a new threat to corals and their photosynthetic symbionts (Symbiodiniaceae), as their very small size allows them to enter the cells. In this study, we first investigated the effect of polystyrene nanosphere (NPs, 0.026 µm), at environmental concentrations (0.005, 0.05, 0.5 mg/L), on the photosynthesis, photosynthetic efficiency, and chlorophyll concentrations of two clades of Symbiodinaceae (F1 and A1) maintained in culture, as well as on the scleractinian coral *Stylophora pistillata* (associated to clade A1). Our results show that *Symbiodiniaceae* in culture exhibited a significant decrease in the maximal electron transport rate when exposed to low NPs concentrations (0.005 mg/L) for 4 weeks, highlighting an impairment of the photosynthetic capacities. Exposure of *S. pistillata* to 0.5 mg/L NPs for 4 weeks induced significant bleaching (loss of symbionts and photosynthetic pigments).

In a second experiment, we assessed the effect of NPs but also microplastics (MPs) on the assimilation rates of organic nitrogen (15N-labelled artemia) and inorganic nitrogen (^{15}N-NH4) at 26°c and 32°C, the latest temperature being stressful for the corals. We observed a significant decrease in the assimilation rates of nitrogen in presence of plastics.

Overall NPs were detrimental for both Symbiodiniaceae in culture and the host-symbiont association

ID: 639 / **Parallel Session 5-6: 5**
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: coralligenous bioconstructions, MPA, quality index, Tirrenean sea, anthropogenic pressure

Conservation status of coralligenous bioconstructions within three MPAs of Tyrrhenian Sea

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Coralligenous bioconstructions are the most important habitat of the Mediterranean Sea. They are build up by a community characterized by sciaphilous and sessile organisms with high concretions of calcareous algae. European and National lows protect this habitat being considered a biodiversity hot spots; thus, monitoring activities of their conservation status is considered of primary importance.

Along the Campania coast, coralligenous bioconstructions of three MPAs (PC: Punta Campanella, SMC: Santa Maria di Castellabate and CIM: Costa degli Infreschi e della Masseta) for the first time were investigated applying the STAndaRdize coralligenous protocol (STAR: ISPRA 191/2020). STAR integrate three indexes: ESCA, focused on biocenotic aspects, COARSE, on the layered structure of coralligenous, and ISLA, focused on species sensitivity levels (SL) of taxa/morphological groups.

A total of 270 pictures, taken between 33 and 37 meters depth by scuba divers, were examined.

Better structured bioconstructions were found in PC (higher ESAC values), followed by CIM and SMC. In all MPAs low values of COARSE were found, accounting for "poor habitat conditions". Lowest values were found in SMC followed by PC and CIM. Finally, ISLA index was found to be “poor” in SMC sites and “sufficient” in PC and CIM. Most of taxa/morphological groups that better contribute to distinguish bioconstructions among MPAs show high values of SL.

Although the ESCA values show a well-structured community, the low COARSE and ISLA values indicated that Coralligenous habitat is particularly sensitive to anthropogenic pressures against which conservation measures have to be planned.

ID: 496
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: detritivore, sea cucumber, coral disease, microbiome, reef sediment

Overharvest of marine detritivores may increase coral disease on modern reefs

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Coral reefs are in dramatic global decline, with outbreaks of coral diseases playing a significant and increasingly frequent role in recent decades. This is especially true for Acroporid corals that represent ~25% of all Pacific coral species, were once dominant in the Caribbean but are now endangered, and that generate much of the topographic complexity on which many other species depend. Coral diseases commonly appear sediment-associated and could be exacerbated by the overharvest of sediment-feeding detritivores. Using field manipulations in both French Polynesia and Palmyra Atoll, we found that sea cucumbers, which have been overharvested for decades, strongly suppress disease among corals directly contacting reef sediments. Sea cucumber removal increased tissue mortality of *Acropora pulchra* (+370%) and *Acropora nasuta* (+124%) corals and altered sediment microbiomes—with microbiomes in removal plots containing more microbes associated with coral diseases. Sea cucumbers may historically have played a key role suppressing pathogenic microbes, and their overharvest during the past 200+ years may facilitate infectious diseases that have decimated coral reefs. Restoring the essential cleaning services of these once-abundant detritivores may help suppress coral losses to disease in a changing ocean.

ID: 105 / Parallel Session 5-1: 1
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: Coral cover, local stress, nursery, larval enhancement

Status, conservation, and restoration of coral ecosystems in Taiwan after the two strongest marine heatwaves on record

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Increasingly severe, frequent, and prolonged marine heatwaves are the greatest threat to the health and maintenance of reef-building corals worldwide. Taiwan experienced the two strongest marine heatwaves on record in 2020 and 2022 which resulted in prolific mass coral bleaching. In 2023, benthic community structure was monitored by photo-transects at shallow (3-5 m) and deep (7-10 m) depths across a total of 31 reefs in 7 regions around Taiwan. The results showed that the overall mean coverage (± standard error) of hard corals was 33.5 ± 4.5%, with ranges spanning 14.6 ± 1.9% to 45.3 ± 2.7% among regions. The major reason for decline in coral cover was not associated with marine heatwaves, but rather was related to local human impacts (e.g., pollution). Therefore, conservation efforts could be maximized by prioritizing management of coastal development, tourism, and sewage treatment. Two regions (Liuqiu islet and Kenting National Park) which have experienced the largest and second largest declines in coral cover compared to the 1980s, have been selected as sites for establishing heat-resistant coral nurseries for restoration. To support these efforts, the ex-situ complete life-stage culture of the thermally resilient coral, *Pocillopora acuta*, has been successfully established in both recirculating and flow-through aquaculture systems at the National Museum of Marine Biology & Aquarium. The stable availability of larvae almost every day throughout the year can enable larvae-based research, bioassay-based investigations, and restoration.

ID: 325 / **Parallel Session 5-3: 10**
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: Corallium rubrum, Coralligenous, Anthozoa, Reproductive biology, Connectivity

Understanding reproductive strategies to guide restoration and conservation: the case study of Mediterranean red coral (*Corallium rubrum*)

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Corallium rubrum is an octocoral endemic of the Mediterranean Sea, which suffers from population decline due to overfishing and warming-driven mass mortality events. For several years, scientists and managers have been interested in fostering the persistence of this resource, promoting conservation and restoration actions. Understanding how the mating system influences the spatial distribution of a species and knowing the parameters affecting its reproductive success is crucial to planning efficient restoration initiatives.

In this study, we will untangle some of the processes underlying the strong genetic structure of *C. rubrum*. Through two breeding seasons (summer 2022 and 2023), we analysed 1) the males' maximum fertilization distance and 2) the effect of sperm dilution on female fecundity by studying a population in a semi-controlled environment (i.e., submerged artificial caves) where the genotype, sex, and morphology of all individuals, as well as the population density, are known. Parentage analysis was performed through SNPs data, assigning each released larvae to its respective parents. Results show that polyandry is likely the norm in *C. rubrum* and that the species' potential fertilization distance can reach tens of meters. In addition, we observed a significant effect of sperm dilution on the fecundity of female colonies, recording significantly higher larval release from females placed close (cm scale) to male individuals than from those isolated (meters to tens of meters scale). Results suggest that male gamete dispersal capacity could buffer the genetic drift expected in a declining population affected by disturbances, offering an excellent recovery potential for the species.

ID: 528 / **Parallel Session 5-6: 3**
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: Marine pollution, Emerging contaminants, Microplastic, Marine animal forest, Marine environment

Assessment of emerging contaminant occurrence in key species of anthozoan in the Mediterranean benthic community.

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The biodiversity of the Mediterranean Sea is under severe threat from climate change and anthropic pressure, in particular pollution. Plastic and emerging contaminants (ECs) ever growing abundance and widespread distribution is raising concerns as one of the most important threats to the marine environment. Indeed, several studies have been conducted in recent year on various organisms, however, there remains a significant scarcity of studies concerning anthozoan, especially in Mediterranean region.

This study aimed to investigate for the first time the occurrence of emerging contaminants (ECs) in five key anthozoan species in the Mediterranean (*Cladocora caespitosa, Eunicella cavolini*, *Madracis pharensis*, *Parazoanthus axinellae*, and *Paramuricea clavata*). Specifically, we focused on phthalic acid esters (PAEs), active pharmaceutical ingredients (APIs), and UV filters molecules, analyzing coral tissues by solid phase microextraction (SPME) and liquid chromatography coupled to tandem mass spectrometry (LC-MS/MS) to detect contamination.

Our investigation revealed variable capacities for bioaccumulation among the species, indicating complexity in the absorption dynamics of these contaminants. We discussed inter- and intra-specific variability and their potential explanations in relation to growth form and life stage of the colonies, as well as the environmental conditions such as currents and habitat where they are usually found. It is important to notice that even low concentrations of these contaminants may have significant adverse effects due to continuous exposition. Therefore, we examined the potential sublethal impacts, including reduced energy production and photosynthetic activity, growth inhibition, compromised detoxification, and excessive immune system responses.

Further research is needed to fully understand the dynamics of accumulation and the biological consequences of these contaminants, especially considering the additional threats posed by climate change. This is important to develop more effective management strategies to mitigate their impact on the marine ecosystem, given the crucial role these species play in shaping habitats along the Mediterranean coast.

ID: 120 / **Parallel Session 5-1: 3**
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: CITES, export data, import data, coral fisheries, coral cultivation

Recent trends in the international coral trade

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The Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) has been keeping records on the international trade of live corals (Scleractinia) in the international aquarium industry. These records are reported by exporting and importing countries. The last three decades show important changes in the roles of the main exporting and importing countries. Indonesia was the most dominant exporter of wild-caught corals in the periods 1990-1995, 1999, and 2002-2017, Fiji in 1996-1998 and 2000-2001, and Australia since 2018. Indonesia has practically been the only exporter of cultivated corals since 2005. A worldwide record of 3 million wild-caught corals was reported for the year 2007. A record annual number of 570.000 cultivated traded corals was reported for 2017. The USA always had the highest import records of wild-caught corals. France was the major importing country of cultivated corals until 2012, when it was succeeded by the USA. *Acropora* is by far the most sold scleractinian genus worldwide. *Euphyllia glabresens* is the most popular aquarium species. Other species with fleshy polyps are also much targeted, such as those of the genera *Catalaphyllia*, *Cynarina*, *Duncanopsammia*, and *Trachyphyllia*, some of which are difficult to cultivate. Because little is known about the impact of coral fisheries on natural populations, there is always a risk over overfishing popular species. Therefore, better monitoring of coral populations is needed in areas were corals are fished. Harvesting of wild corals should become replaced by coral cultivation.

ID: 257 / **Parallel Session 5-3: 5**
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: ecosystem resilience, biodiversity conservation, restoration ecology

Application of conservation and restoration interventions in marine and coastal World Heritage Areas

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Climate change and human population growth are shifting Earth's biophysical environment and altering the structure and functioning of ecosystems. Globally, World Heritage designations recognise, and conserve, unique locations that have 'outstanding universal value' to humanity. In this study, we review the conservation and restoration interventions that have been applied in 48 marine and coastal World Heritage Areas (WHAs) around the world. We distinguish between 'enabling' actions (including regulations and governance, economic instruments and social instruments) and 'biophysical' actions (protected area designations, pest removal, and restoration responses for ecosystem recovery). Across these WHAs, invasive species, global climate change, uncontrolled tourism, and resource extraction are consistently highlighted as major threats, even in sites that are far removed from places with high human population densities. The majority of these WHAs are protected by multiple layers of enabling actions, ranging from cross-jurisdictional legislation and management plans, cooperative partnerships between government agencies and local rights holders, and economic instruments including entrance fees and nature markets that (partially) fund conservation actions. Active restoration interventions are also used in many WHAs, including removal of invasive species, construction of barriers to water flow, and scaled planting of flora and fauna. The extensive use of active interventions within WHAs demonstrates the scientific and social consensus that such approaches are an integral part of management for maintaining ecosystem functioning as the climate continues to warm, and land-use patterns continue to change.

ID: 184 / Parallel Session 5-1: 6
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: Microplastic, thermal stress, coral bleaching

Physical and cellular impact of environmentally relevant microplastic exposure on thermally challenged Pocillopora damicornis (Cnidaria, Scleractinia)

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Microplastic pollution is an increasing threat to coral reefs, which are already strongly challenged by climate change-related heat stress. Although it is known that scleractinian corals can ingest microplastic, little is known about their egestion and how the microplastic exposure may impair corals at physiological and cellular levels. In addition, effects of microplastic pollution at current environmental concentration have been little investigated to date, particularly in corals already impacted by heat stress. In this study, the combined effects of these two environmental threats on *Pocillopora damicornis* were investigated from a physical and cellular perspective. Colonies were exposed to three concentrations of polyethylene microplastic beads (no microplastic beads: [No MP], 1 mg/L: [Low MP]; 10 mg/L: [High MP]), and two different temperatures (25 °C and 30 °C) for 72 hours. No visual signs of stress in corals, such as abnormal mucus production and polyp extroflection, were recorded. At [Low MP], beads adhered to colonies, were ingested, but were also egested. Moreover, thermally stressed colonies showed a lower adhesion and higher egestion of microplastic beads. Coral bleaching was observed with increase in temperature and microplastic bead concentration, as indicated by a general decrease in chlorophyll concentration and Symbiodiniaceae density. An increase in lipid peroxidation was measured in colonies exposed to [Low MP] and [High MP] and an up-regulation of stress response genes cas3 and hsp70 was observed in *P. damicornis* subjected to both stressors. Overall, our findings showed that heat stress may represent the main threat to *P. damicornis*, while the effect of microplastics on coral health and physiology may be minor, at control temperature. However, microplastics could exacerbate the effect of thermal stress, even at [Low MP]. While reducing ocean warming is critical for coral reef preservation, effective management of emerging threats like microplastic pollution results equally essential.

ID: 514 / Parallel Session 5-6: 2
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: coral reefs, seabirds, rat control, nitrogen cycle, historical reconstruction

How seabird-derived nitrogen influences the nitrogen cycling in coral reefs through time: A case study from Surprise Island in New Caledonia

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Seabirds transfer nitrogen (N) from the ocean to their nesting sites into adjacent reefs through guano. This transfer provides nitrogen to the reef flat while enhancing the productivity, biomass and functioning of the recipient ecosystems. Invasive rodents can significantly impact seabird populations, through direct predation or habitat modification. The presence of rats causes decreases in seabird populations that can modulate the supply of N to the reef. Potentially, reef productivity, biomass, and functioning are lower near rat-infested islands than they are near islands with dense seabird populations, highlighting the importance of rat control as a crucial component of coral reef conservation and restoration efforts.

The timescales for the rebound of guano-N supply, and subsequent change in the coastal N-cycle, after a rat removal event, are currently unknown. This study explores the N-cycle through time by examining the nitrogen trapped inside a coral skeleton. As the coral grows and produces its skeleton, nitrogen is trapped inside the organic matrix, reflecting the isotopic composition of nitrate NO_3^--$\delta^{15}N$ at the time of growth, at a monthly resolution, while protecting it from processes of degradation.

Preliminary results from the southwest Pacific suggest that coral skeleton $\delta^{15}N$ do record seabird derived-N, indicating that coral skeleton-bound organic nitrogen (CS-$\delta^{15}N$) can be a powerful tool to reconstruct the history of N supply to the reef. Here, we explore the historical variability of guano input into a coral ecosystem after a rat eradication event in 2005 by analyzing the *Porites* CS-$\delta^{15}N$ at Surprise Island (New Caledonia) in the past 20 years. This reconstruction will allow to address the following questions: Does rat eradication on seabird islands influence N enrichment processes in the adjacent coral reefs? How quickly does the ecosystem recover after a rat removal event? What are the timescales for the return of guano-nitrogen into corals?

ID: 318 / **Parallel Session 5-3: 9**
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: Marginal reefs, benthic community dynamics, recruitment, size structure, water quality

Does Southeast Florida point towards the future of Caribbean coral communities under increasing local and global stress?

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The resilience of many coral reef communities has been diminished in the Anthropocene. Nowhere is this more evident than in the Caribbean, where coral cover rarely recovers following disturbance. Understanding community dynamics on marginal reefs, which are exposed to frequent disturbances and environmental stressors, may provide insight into the barriers to coral recovery and the future for coral reef communities. We quantified long-term changes in benthic community structure, and coral and octocoral recruitment and size structure in the marginal reef system off southeast Florida. We analysed these in relation to disturbances and local environmental conditions to elucidate the drivers of change and assess the resilience of benthic taxa. Significant changes in benthic community structure coincided with major disturbances, which impacted the region on average once every 3 years. Repeated heat stress and disease from 2014-2017 caused mass mortality of many reef-building coral species, reducing coral cover by up to 85%. These species showed limited recovery subsequently, but overall coral density increased significantly at some sites, fuelled by the substantial recruitment of weedy, non-reef building species. Spatial variation in recruitment was strongly influenced by the local temperature regime, with nutrient enrichment and sediment further reducing coral recovery potential by increasing macroalgal cover. Most colonies that did recruit remained small (<10cm), partly due to high partial mortality, constraining colony growth. In contrast to most coral species, gorgonians exhibited resilience, with the consistent influx of recruits and colony growth enabling recovery following disturbances and leading to stable size structure. We suggest changes seen in Florida may foreshadow those in the wider Caribbean, with small, weedy coral species and gorgonians becoming increasingly dominant under climate change. High disturbance frequency and chronic environmental stressors will continue to degrade coral populations, leaving much of the benthos dominated by sediment, turf algae and macroalgae.

ID: 118 / **Parallel Session 5-1: 2**
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: fear, reproductive behaviours, mating aggregations, behavioural trade-offs, risk-prone behaviours

Aggregating fish jeopardize reproduction and survival in response to human predators through risk-prone behaviours.

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Human disturbances can create stimuli akin to ‘fear’ or predation risk in animals. In response, animals may divert time away from fitness-enhancing activities like reproduction. We evaluated fear responses of male squaretail groupers (*Plectropomus areolatus*) at two spawning aggregation sites with varying fishing exposure in India's Lakshadweep archipelago. Through observational sampling and experimental simulations of predation risk, we analysed reactive (i.e. flight initiation distance and return time) and proactive fear responses (ie. time spent in contrasting activities like vigilance, courtship, and territorial aggression) in males at the aggregation site. Males at the fished site were twice as flighty as at unfished sites and exhibited a significant delay in returning to their mating territories after disturbance, unless paired with females. We observed that, territorial aggression was significantly lower in fished sites, with males primarily balancing vigilance with courtship, as compared to the unfished site where decline in vigilance led to increase in both courtship and territorial aggression. Our results suggest that squaretail groupers in spawning aggregations exhibit risk-prone behaviours, potentially jeopardizing their reproductive success and survival in response to human-induced predation risk, making aggregation fisheries even more insidious than we believe

ID: 240 / Parallel Session 5-3: 2
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: coral, sperm, crossbreeding, desynchronisation, climate change

The possible relationship between climate change and cryopreservation success in coral sperm

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Human activities negatively impact coral reefs, extending beyond bleaching events. Despite disruptive effects, some facilitate coral's natural defenses, such as the intriguing disruption of coral spawning synchronization by global warming (Shlesinger & Loya, 2019). Mass spawning events rely on synchronized gamete release, crucial for fertilization. Desynchronization challenges gametes, hindering access to compatible partners. Surprisingly, low sperm concentrations near eggs increase crossbreeding likelihood (Kitanobo et al., 2022). Our discovery building on our successful coral sperm cryopreservation techniques (Ohki et al., 2014) supports the hypothesis that crossbreeding leads to speciation (Ohki et al., 2015). Recent desynchronization may be a transitional period favouring reproductive mechanisms, accelerating evolutionary processes on coral reefs. Limited sperm choices heighten susceptibility to crossbreeding (Kitanobo et al., 2022). Extended spawning periods (Shlesinger & Loya, 2019) allow encounters between gametes of species with different spawning times, facilitating new hybrid formations. However, along with these facts, we find that the cryopreservation of coral sperm may be less successful, particularly in years when an increase in heat was observed over the ocean. We observed very good gamete quality in the years 2012 and 2015, whereas lower quality was noted in the years 2013, 2016, and 2017. Through retrospective analysis, we found that lower cryopreservation success and gamete quality were connected with years featuring higher climate anomalies over Okinawa Island. This suggests that, despite possible strong evolutionary mechanisms facilitating the creation of new hybrids on coral reefs, a better understanding of coral gamete biology is necessary to safeguard coral biodiversity. Additionally, adopting an assisted evolution approach may provide crucial support to coral ecosystems.

ID: 448 / Parallel Session 5-5: 2
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: coral restoration, coral nursery, artificial reef, competition, South Pacific

Optimizing nursery rearing, outplanting, sexual reproduction and innovative artificial materials for coral restoration in French Polynesia

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Coral restoration techniques are becoming increasingly diversified and sophisticated. Here, we provide an overview of methods trialed in Mo'orea, French Polynesia, to enhance the conservation of coral reef biodiversity. First, the growth of corals within suspended nurseries could be optimized by selecting certain species, the initial size of fragments but also the nursery site. A change in depth, luminosity and temperature from lagoon to fore reef induced an acclimation in photophysiology and a faster growth for 40% of species. Second, we outplanted nursery-reared *Acropora cytherea* fragments to several lagoon sites with distinct degrees of degradation, and observed that maturity was delayed, mortality was high and predation strongly limited the initial growth of outplants. Third, we revealed that the reproductive output of 2-year nursery-reared staghorn corals can be on par with that of wild corals of the same species. The fertilization rates at ambient and elevated temperatures could be further improved by selectively crossing certain parental lineages. We also demonstrated that the settlement rates of *Acropora cytherea* could be enhanced in the lagoon with the use of nets filled with laboratory-reared larvae. While this could prove to be more cost-efficient than transplanting coral fragments individually, the long-term survival of recruits remained extremely low on natural substrate (0.6%). Thus, we finally tested 8 innovative artificial materials, and different levels of complexity, for their efficiency as settlement substrates. Our results highlighted that cm-scale crevices increased settlement and survival on exposed materials, and that fiberglass, 3D-printed concrete, or flax with PLA had more success than other materials. Also, a high initial settlement was not associated with an improved survival rate during the post-settlement phase, underlining the importance to account for benthic competition when designing coral settlement substrates. These results could help finetune restoration practices and optimize their success by combining multiple techniques together.

ID: 243 / **Parallel Session 5-3: 3**
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: environmental DNA (eDNA), 3D biomimetic ceramic tiles, Coral Reef Ecobiome Transplant (aCRET), coral reef restoration

Health is significantly boosted in corals at degraded reef after receiving an ecobiome transplant from a healthy reef

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The coral reef ecobiome, comprising both living and non-living biological and chemical components, plays a pivotal role in reef health and corals' stress responses. This study explores the benthic ecobiome composition of a non-urbanized, healthy reef compared to a highly urbanized, degraded reef, with a focus on coral health. Using environmental DNA (eDNA) metabarcoding, we identified invertebrates via mitochondrial Cytochrome c Oxidase subunit I (COI) and assessed bacterial communities through 16S rRNA gene sequencing.

A novel aspect of our research involved transplanting 3D biomimetic ceramic tiles between the two reefs. After six months, scleractinian corals from each reef were attached to these tiles for an additional six months. The results, observed over a year, indicated that tiles from the healthy reef, when transplanted to the degraded reef, exhibited higher taxonomic richness and diversity in invertebrates. Bacteria indicative of healthy reefs were more abundant on tiles from the healthy reef, regardless of their location.

Significantly, corals from the degraded reef attached to tiles from the healthy reef showed improved photosynthetic capacity, increased algae symbionts per cm^2, and enhanced stress tolerance compared to those on the degraded reef's tiles. This highlights the direct impact of a healthy benthic ecobiome on coral physiology.

We propose the Coral Reef Ecobiome Transplant (aCRET) method, using eco-friendly, biomimetic substrates, as a viable approach for restoring health to degrading reefs. This method underscores the benefits of transferring a healthy benthic organismal community to enhance coral vitality in impacted ecosystems

ID: 729 / **Parallel Session 5-6: 6**
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: Corals, Superfood, antioxidants, oxidative stress, thermal stress

Enhancing coral resilience through superfood supplementation

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Anthropogenic stressors are the main drivers behind coral reef degradation and the ocean's rising temperature causes corals to bleach and eventually die. As these threats become more frequent, developing strategies to enhance the resilience of corals is urgently needed. The present study tested the use of "superfood" - *Artemia nauplii* enriched with antioxidants, essential metals, and lipids - as a way to increase the survival of corals exposed to thermal stress. In a 2-month laboratory experiment, we found that three Red Sea coral species (*Pocillopora damicornis*, *Turbinaria reniformis*, and *Stylophora pistillata*) fed with superfood showed more resistance or resilience to thermal stress. Physiological and biochemical analysis shows that corals fed with superfood exhibited higher photosynthetic efficiency than those provided with normal food (non-enriched *Artemia* nauplii). In addition, corals fed with superfood showed lower levels of reactive oxygen species (ROS) during recovery. We also tested how the microbiome of corals fed with superfood responds to thermal stress compared to those fed with regular food. We hypothesized that superfed corals would exhibit minor changes in the taxonomic and functional composition of microbial communities due to the enhancement of immune function and therefore reduced susceptibility to microbial infections. In conclusion, our results show that developing "superfood" for corals could be an effective tool for coral restoration as it may improve the coral's ability to resist thermal stress and enhance its antioxidant capacity.

ID: 254 / **Parallel Session 5-3: 4**
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: Artificial light at night (ALAN), Diurnal corals, Nocturnal corals, Coral tentacle behaviour, Coral spectral sensitivity

Spectral sensitivity of reef coral behaviour to the disturbance by artificial light at night (ALAN)

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Increasing levels of Artificial Light At Night (ALAN) alter the natural diel cycles of organisms at the global scale. ALAN constitutes a potential threat also to the light-dependent functioning of symbiotic scleractinian corals, the habit-founders of warm, shallow water reefs. Currently, the public lightning network is shifting to “broad white” LED lamps with spectral properties that differ significantly from those of the previously used metal halide or fluorescent tube technology. This shift in spectral quality of ALAN may have negative effects on the highly photosensitive reef corals. Here, we show that ALAN disrupts the natural diel tentacle expansion and contraction behaviour, a key mechanism for prey capture and nutrient acquisition in corals. We exposed four symbiotic scleractinian species to different ALAN treatments (0.4–2.5 µmol quanta m^{-2} s^{-1}). Exposure to ALAN levels of 1.2 µmol quanta $m^{-2}s^{-1}$ and above altered the normal tentacle expansion response in diurnal species. This response was less pronounce in nocturnal species indicating a greater tolerance to ALAN. The tentacle expansion behaviour showed distinct spectral sensitivity. The results of this work suggest that ALAN has the potential to affect nutrient acquisition mechanisms of symbiotic corals which may in turn result in changes in the coral community structure in shallow water reefs in ALAN-exposed areas. Furthermore, our results suggest that the impacts of ALAN could be partially reduced by changing the spectral quality of LEDs in the proximity of reefs.

ID: 753 / **Parallel Session 5-6: 7**
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: dissolved organic matter, untargeted metabolomics, microbiomes, nutrient cycling, anthropic pressures

Unraveling the chemical complexity of benthic-derived dissolved organic matter on a coral reef experiencing local stressors: overfishing and nutrient enrichment

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What exists in a small droplet of seawater? A microbiologist may respond, “about a million cells, made up of a diverse assembly of microorganisms.” Whereas an analytical chemist might answer, “a myriad of chemicals, many whose structural identity and origin are unbeknownst to us.” These answers act in consort, as diverse chemical structures, particularly those of organic form, are a key source of nutrition for the heterotrophic microbial community. This study employs untargeted metabolomics to unveil the origin and structural complexity of benthic-derived dissolved organic matter (DOM) collected in seawater from the forereef of Moorea, French Polynesia. Paired samples capturing DOM composition and microbial community structure were taken *in-situ* across experimental treatments for two local stressors: chronic nutrient enrichment and overfishing through caged exclusion. The taxonomic composition of the microbial community showed distinct variation between treatments. Additionally, sites excluding fish exhibited increased microbial species diversity. To contextualize this relationship, an experimental system was used to capture, extract, and characterize the organic photosynthate released by foundational coral and macroalgae species present in the *in-situ* treatments. The DOM released by each coral species contains a unique profile of the essential nutrients: nitrogen (N) and phosphorus (P). The total amount of dissolved organic carbon (C), and fluorescent DOM signal varied distinctly on a species level and across benthic functional groups: coral and macroalgae. Additionally, photosynthate derived from some foundational coral species exhibit variable C, N and P stoichiometric ratios compared their counterparts from ambient non-nutrified sites. Our working hypothesis suggests that variation in the community structure of the seawater microbiome results from modifications in the composition and nutrient content of dissolved organic photosynthate derived from distinct benthic community assemblages experiencing disproportionate nutrient enrichment.

ID: 836 / **Parallel Session 5-6: 10**
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: Coral larval settlement, microbial biofilm, coral aquaculture, reef restoration

Harnessing microbial inducers of coral larval settlement for reef restoration

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The Reef Restoration and Adaptation Program (RRAP) investigates active interventions to protect, restore, and build more resilient reefs. As part of this program, we aim to use prokaryote treatments to improve aquaculture production of corals through provision of settlement cues for sexually produced planktonic larvae. The current lack of reliable settlement cues is a major bottleneck for the sexual propagation of corals at the scale required for reef restoration. Microbial biofilms are effective inducers coral larval settlement, but the associated biochemical cues and specific bacteria that produce them remain largely unknown. Here, we used a novel approach combining larval settlement experiments with differently conditioned biofilms and shotgun metagenomic sequencing to identify the taxonomy and metabolic pathways associated with inducive biofilms. We show that light and biofilm age are critical factors in the development of settlement inducing biofilms, where distinct changes in biofilm composition were associated with high or low settlement. Several groups of taxa consistently correlated with settlement across multiple corals, including species classified as *Flavobacteriaceae* and *Rhodobacteraceae.* In addition, we identified genes positively and negatively correlated with coral settlement, such as those encoding the biosynthesis of secondary metabolites and bacterial secretion systems, respectively. To validate the inducing capability of taxa correlated with high settlement, over 200 bacterial isolates were cultured and screened for their ability to induce settlement across nine coral species. Approximately 25% of isolates tested induced a settlement response across multiple corals. Moreover, our results confirmed many of the strongest inducers were classified as *Flavobacteriaceae* and *Rhodobacteraceae*, while species belonging to other families, such as *Cellvibrionaceae*, may be lethal. Our work identifies novel inducing taxa that could be applied to improve settlement success in coral aquaculture for reef restoration.

ID: 171 / **Parallel Session 5-1: 5**
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: coral, settlement, seeding, restoration, post-settlement

Drivers of post-settlement mortality in seeded corals: implications for reef restoration.

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Recovery of coral populations is dependent on the successful recruitment of new individuals, yet increasingly frequent and severe bleaching events are disrupting the supply of coral larvae to many reefs. Coral seeding is a novel method being developed to increase numbers of sexually produced corals on reefs, to overcome naturally high post-settlement mortality and boost reef resilience. Knowledge of local drivers of early mortality is crucial to tailor methods to maximize seeding success and improve inshore reef management. Here we report the results from two deployments of engineered coral seeding units housing multiple species on turbid inshore reefs in Woppaburra sea Country (Keppel Islands, Southern inshore Great Barrier Reef). A hierarchical deployment design revealed that, at 1 year of age and approximately 10-months post-deployment, the largest variation in survival occurred at the smallest spatial scale tested (1-2 meters between seeding units). There were significant relationships between survival and the composition of benthic communities both on and surrounding the seeding units, and variations in survival and growth based on deployment orientation. We also identified consistent patterns in the performance of the three species tested across years, reflecting life-history strategies. We discuss the implications of these results for future coral seeding restoration efforts, particularly those on degraded inshore reefs globally.

ID: 263 / **Parallel Session 5-3: 6**
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: microplastic, chemical identification, tuna, shark, coral

The chemistry behind microplastic pollution in coral reefs

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Coral reefs are one of the most diverse and productive ecosystems on the planet, but their proximity to coastlines and the effect of climate change make them highly susceptible to anthropogenic disturbances such as microplastic pollution. In particular, the Asian-Pacific region has been identified as a hotspot for plastic pollution which makes the coral reefs of Okinawa, Japan an important location to study the pervasiveness and effect of microplastic pollution on marine organisms. However, the effect of microplastics on coastal regions, especially coral reefs, is still largely unknown because of the challenges in detecting and characterizing these increasingly small particles. To understand the effects of microplastics, it is necessary to understand the types of microplastics and the abundance of microplastics that occur in the environment. Some of the challenges in microplastic characterization are that microplastics are (1) composed of a variety of different polymers, additives, and plasticizers, (2) are physically and chemically modified through environmental weathering, and (3) are found alongside a myriad of other naturally occurring particles (e.g., sand, cellulose, etc.). Raman and Fourier transform IR (FTIR) microspectroscopy have gained attention as two complementary and non-destructive techniques for microplastic chemical identification. Herein, we assessed the presence and abundance of microplastics in a variety of coral-reef-reliant marine organisms (tuna, shark, and coral) in the Ryukyu Archipelago, Japan. Our initial findings in tuna (*T. albacares*) gut samples (n=11), indicated 113.8±100.2 microparticles/g of tissue ranging from about 20–500 µm in size and composed of polyethylene, polypropylene, nylon, and graphitic materials. Comparing the different species, we found different types and accumulation levels of microplastics in each species which may indicate that different marine organisms may have different responses or tolerance to microplastic pollution.

ID: 233 / **Parallel Session 5-3: 1**
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: Agricultural runoff, Herbicide accumulation, Maputaland high-latitude reefs, Hard coral, Soft coral

Accumulation of commonly used agricultural herbicides in coral reef organisms from iSimangaliso Wetland Park World Heritage Site, South Africa

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Coral reefs are amongst the most biodiverse ecosystems on earth, but are significantly impacted by agricultural runoff. Despite herbicides being commonly detected in coastal waters, the possibility of herbicide accumulation in coral reef species has largely been overlooked. We investigate the accumulation of several herbicides in five species of coral reef invertebrates collected from ten sites along the Maputaland coast, South Africa. Multiple herbicide residues were detected in 95% of the samples, with total average concentrations across sites ranging between 25.2 ng g^{-1} to 51.3 ng g^{-1} dry weight. Acetochlor, alachlor and hexazinone were the predominant herbicides detected at all sites, with atrazine and simazine detected less frequently. Significant interactive effects were detected between sites nested in reef complex crossed with species, based on multiple and total herbicide concentrations. In general, multivariate herbicide concentrations varied significantly between species within and across most sites. Contrastingly, the concentrations of the different herbicides and that of total herbicide did not differ between conspecifics at most sites nested in their respective reef complexes. On average, highest total herbicide concentrations were measured in soft coral (*Sarcophyton glaucum*; 90.4 ± 60 ng g^{-1} and *Sinularia gravis*; 42.7 ± 25 ng g^{-1}) and sponge (*Theonela swinhoei*; 39.0 ± 40 ng g^{-1}) species, while significantly lower concentrations were detected in hard corals (*Echinopora hirsutissima*; 10.5 ± 5.9 ng g^{-1} and *Acropora austera*; 5.20 ± 4.5 ng g-1) at most sites. Agricultural runoff entering the ocean via the uMfolozi-St Lucia Estuary and Maputo Bay are likely sources of herbicide contamination to coral reefs in the region. There is an urgent need to assess the long-term effects of herbicide exposure on coral reef communities.

ID: 165 / **Parallel Session 5-1: 4**
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: coral, acute toxicity, PAH, oil, dispersed oil

Sensitivity of six species of Atlantic scleractinian corals to petroleum hydrocarbons

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Coral reefs are keystone coastal ecosystems frequently at risk of exposure to petroleum hydrocarbons from a range of sources, including oil spill incidents and chronic runoff, and are usually one of the highest-valued natural resources for protection in Net Environmental Benefit Analysis or Spill Impact Mitigation Assessment of response methods and environmental impact. Partially due to the lack of standardized toxicity testing methods, many previous studies evaluating the effects of oil exposure on corals have not resulted in a clear characterization of impacts or relative sensitivity, and thus a significant knowledge gap exists regarding petroleum hydrocarbon impacts on the coral holobiont.

To address this, the relative sensitivity of six Atlantic corals (*Acropora cervicornis, Porites astreoides, Porites divaricata, Siderastrea siderea, Stephanocoenia intersepta*, *Solenastrea bournoni*) to toluene, 1-methylnaphthalene, phenanthrene, oil, and dispersed oil was assessed with standardized 48-h dose response assays. Effects were evaluated based on mortality, coral condition, photosynthetic efficiency, and gene expression; exposures were designed to determine high-level toxicity thresholds and low-level, sublethal effects that are more representative of real-world exposure scenarios.

A range of significant coral physical stress responses to hydrocarbon exposure were observed, with less significant effects on symbiont photosynthetic efficiency. Transcriptomic changes occurred at hydrocarbon concentrations 4-8 times lower than those which caused sublethal physical impacts. No latent effects were observed; corals that survived recovered to baseline condition within 1-4 weeks. The endangered *Acropora cervicornis* was the most sensitive species tested, however healthy corals were found to be relatively resilient overall to hydrocarbon exposure compared to other coastal marine species. These results provide a framework for a broader understanding of hydrocarbon impact pathways and thresholds in scleractinian corals, as well as the prediction of oil impacts and toxicity thresholds on the coral animal and related habitats, supporting science-based oil spill response decision-making in sensitive coral reef environments.

ID: 305 / **Parallel Session 5-3: 8**
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: phase shifts, soft corals, benthic regimes, community changes, reef functions

Soft-coral dominated reefs in the Indo-Pacific: detection and functional implications

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Increasing environmental variability as a result of anthropogenic stressors, is driving coral reef compositional and functional changes worldwide. In coral reefs, marked community changes between coral-dominated to algae-dominated communities have been globally reported. However, knowledge regarding reefs dominated by other alternate (i.e. non scleractinian corals) organisms is extremely limited. In a recent meta-analysis we found that 10-15% reefs in the Indo-Pacific were dominated by alternative communities, mostly soft corals. However, despite the potential detrimental effects of soft coral dominance on coral reefs, there is still fragmentary knowledge on their prevalence, diversity and implications on ecosystem functioning and services of soft coral-dominated reefs. Here, we discuss recent findings on different alternative benthic communities identified in reefs around North Sulawesi. We also illustrate the findings of recent studies showing different capabilities of abundant soft corals to overgrow and damage hard corals and their effect on associated fish communities. Our results highlight that soft coral-dominated reefs could have important implications for the functioning of coral reef ecosystems, potentially affecting associated ecosystem services.

ID: 490 / **Parallel Session 5-5: 3**
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: Coral restoration, phenotypic diversity, genetic structure, thermal tolerance, coral phenotyping

Phenotypic variability in coral thermal performance across diverse Great Barrier Reef sites independent of host genetic structure

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As anthropogenic and local stressors continue to impact coral reefs, stakeholders are increasingly turning to coral restoration to combat reef degradation and maintain coral diversity. However, concerns remain that corals will be unable to keep pace with a rapidly changing climate under traditional propagation approaches, and thus, selection of coral material that has beneficial emergent phenotypes has been identified as a strategy to increase future reef resilience. Unfortunately, practices that filter source material could unintentionally reduce genetic diversity and by extension population resistance. Thus, it is important to understand the potential consequences of colony selection based on phenotyping approaches. Furthermore, screening tools that allow us to characterise phenotypic diversity rapidly and cost-effectively in the field are lacking. In this study, we apply a novel, high-throughput phenotyping device to examine differences in photophysiological performance under a thermal gradient (24 – 37 ºC) of 186 coral colonies from 3 reefs and 7 sites across the continental shelf (250 km^2) of the Great Barrier Reef. Through a rapid (4 colonies/40 minute) assay, we assess maximum quantum yield, relative electron transport rate, saturating irradiance, and non-photochemical quenching. We further assess the genetic structure of the phenotyped corals to evaluate how emergent phenotypes related to the underlying genetic architecture. Our work shows that photophysiological responses varied significantly across unique reef communities and did not align with genetic structure which revealed a single, highly connected population. These findings suggest that selection of corals based on their photophysiological performance would not impact genetic diversity in this region. This work recognises the need to assess underlying drivers of emergent responses to mitigate impacts to genetic diversity and highlights the utility of high-throughput phenotyping to guide selection of stress-tolerant corals for future restoration efforts.

ID: 193 / **Parallel Session 5-1: 7**
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: sediment run-off, physiology, clownfish

The effect of suspended sediment on metabolic rate and recovery of a coral reef fish, *Amphiprion ocellaris*

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The escalating anthropogenic impact on coral reefs globally necessitates a comprehensive examination. While considerable attention has been directed towards researching aspects such as marine heatwaves and ocean acidification, there is a relative dearth of studies focused on the influence of terrestrial run-off and heightened suspended sediments on coral reef fishes. Moreover, the anticipated escalation in the intensity and duration of suspended sediment events, attributed to coastal development and increased storm frequency, underscores the urgency for further investigation. In regions dominated by fringing coral reefs, such as Okinawa, these events may have a substantial influence on the organisms inhabiting these ecosystems. In light of this, our study focused on elucidating the acute effects of elevated suspended sediments on *Amphiprion ocellaris,* a species of significant cultural and commercial importance. Through controlled exposure to acute suspended sediment treatments, mimicking sudden run-off and heightened suspended sediment events, we aimed to discern the physiological impact on individuals. Utilizing intermittent-flow respirometry, we assessed standard and maximum metabolic rates, excessive post-exercise oxygen consumption, aerobic scope, and recovery time was impacted. Additionally, we used microscopy through histological methods to access the morphological characteristics and potential impacts of suspended sediment treatments. These measurements, conducted both pre- and post-suspended sediment treatments, provided an insight into the physiological ramifications of these abrupt events run off events. The insights garnered from this study are crucial for the future management of these ecologically and economically vital coral reef ecosystems.

ID: 788 / **Parallel Session 5-6: 9**
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: reef-building corals, microplastic, deposition, growth, polyp activity

Beyond the surface: Understanding the impacts of microplastic pollution at different concentrations and mixtures on reef-building corals

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The pollution of marine environments with microplastic (MP, i.e., plastic < 1 mm) has become an increasing concern over the last decades. Despite its small size, MP affects a variety of marine species, including reef-building corals. Handling and adhesion of the indigestible particles has been suspected to be energetically costly, potentially leading to decreased growth rates, increased necrosis, and altered photosynthetic efficiency. Additionally, MP may become ingested and deposited in coral skeletons, making coral reefs environmental sinks for marine MP. Numerous experimental studies investigated the effects of MP on reef-building corals using single polymer treatments applied in unrealistically high concentrations. Hence, our project aimed to unravel the effects and underlying processes of realistic pollution scenarios on two common reef-building coral species (i.e., *Pocillopora verrucosa* and *Stylophora pistillata*). Therefore, we conducted a series of experiments (I) to explore coral polyp reactions when offered different types of MP, (II) to investigate concentration-dependent effects of a common MP mixture on coral growth and polyp activity, and (III) to assess how the deposition of MP is influenced by the MP type or concentration of the exposure. We found that (I) the reaction of polyps was influenced by the shape of MP and the availability of a biofilm and food, with MP fibers being taken in less frequently than particles. (II) Extreme MP concentrations resulted in decreased growth rates and polyp activity, which were less affected under realistic pollution scenarios. (III) MP concentration was a stronger driver of deposition rates, than the MP type. Our results provide detailed insights into the impacts of complex MP mixtures on reef-building corals, which contribute to a better understanding of the mechanisms by which this stressor affects corals. These results emphasize the need to take measures to curb MP pollution in the oceans.

ID: 362 / **Parallel Session 5-5: 1**
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: Depth zonation, contemporary ecological patterns, local human impacts, biophysical drivers

Spatial heterogeneity in coral reef benthic community depth zonation across the Pacific Ocean.

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The structuring force of depth is acknowledged as a key determinant of coral reef benthic communities. Patterns of zonation occur across gradients in water temperature, light attenuation, wave energy and primary production, all of which covary with depth. Despite advances in our understanding of these zonation patterns and their drivers, many historic zonation theories were derived from single-point location studies and therefore are potentially not representative of the wider seascape. Further, many of these studies observed communities which had not yet been degraded by human impacts, and may not be representative of contemporary reefs. The percentage cover of broad benthic groups was quantified from 2,357 forereef sites in the central and western Pacific Ocean across depth to determine whether, 1) depth zonation patterns are generalisable across ecoregions with known differences in environmental forcing, and 2) local human impacts across ecoregions disrupt observed zonation patterns. We compare benthic community structure within and across six ecoregions, comprising 33 Islands (15 populated and 18 unpopulated), across three depth strata (shallow 0–6m, mid >6–18m, deep >18–30m). We found a significant effect of depth on benthic community structure at three of six ecoregions, driven by increases in soft coral and Halimeda cover with increasing depth, while CCA decreased with depth. Results indicate benthic community structure varies with depth, but depth zonation varies across ecoregions, and with the human population status of islands. Comparing populated islands to their unpopulated counterparts, we found patterns of zonation across depth strata were inversed and less distinct at two ecoregions, suggesting local human disturbance can disrupt expected depth zonation patterns. Overall, our results highlight the spatial heterogeneity in benthic community-depth relationships on reefs, and add to a growing body of evidence that classic ecological theory sometimes fails to predict ecological patterns in this era of rapid change.

Speed talks

ID: 157 / **Parallel Session 5-1: 9**
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: ALAN, stable isotopes, carbon δ13C, nitrogen δ15N

Alterations in coral physiology and metabolic signatures due to artificial light at night (ALAN)

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Natural nighttime illumination, sourced from celestial bodies like the moon, stars, and the Milky Way, has profoundly influenced the behaviour and biology of Earth's organisms. Precise ecological timing is vital for survival. However, the widespread use of artificial light has introduced unintended consequences, including the sensory pollutant Artificial Light at Night (ALAN). ALAN significantly impacts coral reefs, particularly in the Gulf of Aqaba, Eilat, altering coral host and symbiotic algae metabolism as reflected in carbon δ^{13}C and nitrogen δ^{15}N stable isotopes. Our study assesses the impact of ALAN on *Acropora eurystoma* and *Pocillopora damicornis* in the Gulf of Aqaba/Eilat Red Sea, highlighting changes in energy and nutrient sourcing due to light pollution. Our findings further reveal disturbances in photosynthetic processes, particularly in *Acropora eurystoma*, suggesting carbon distribution or utilization alterations. *Pocillopora damicornis* also shows shifts in δ^{13}C and δ^{15}N, indicating disruptions in its nitrogen cycle and feeding strategies. These insights into the physiology of these corals, exposed to urban light pollution, emphasize oxidative stress and alterations in electron transport rate, chlorophyll, and algae density parameters we have measured. Notably, we also found that Blue and White LED lights have more extreme impacts than Yellow LED lights. This work underscores the emerging threat of light pollution to scleractinian corals and supports the development of mitigation strategies.

ID: 713 / **Parallel Session 5-4: 16**
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: Restoration, 3D printing, eDNA, terracotta, biodiversity

Coral survivorship, performance, and biodiversity enhancement using 3D printed ceramics in coral restoration

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Ceramics derived from clays are ideal substrates for marine life. They are naturally sourced, chemically inert, and porous - collectively enhancing their biocompatibility. Indeed, for more than a century marine scientists have censused marine life in the oceans using flat terracotta tiles for recruitment studies. Modern additive manufacturing technologies allow for the fabrication of this ancient material into highly complex structures via 3D printing. Here, we present data on the efficacy of 3D printed "reef tiles" for restoring degraded reefs in the South China Sea and Arabian Gulf. In Hong Kong, terracotta structures were found to host ~40% greater cryptic biodiversity while attracting a variety of macro-invertebrates and fishes. Mean coral survivorship exceeded 90% over 4 years, which was approximately 4x greater than conventional methods of attaching fragments to natural substrates owing to superior attachment and growth on reef tiles. Coral growth was consistent year on year, with 195%, 104%, and 92% increase in linear extension displayed by *Acropora*, *Pavona,* and *Platygyra,* respectively. At the same time, biodiversity was enhanced as determined by macro fauna surveys and eDNA. These promising results led to the formation of a spin-off company, Archireef, Ltd. which is undertaking coral restoration projects around the world.

ID: 246 / **Parallel Session 5-2: 5**
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: Ecological enhancement, Ecological engineering, Coastal protection, Complexity, Reconciliation ecology

Enhancing rrganism recruitment on coastal defense structures: transforming barriers into vital habitats

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As the global population increases and coastal urbanization expands, coupled with intensified currents, waves, and storms intensity and frequency, there is a rising necessity for the development of hardened coastal defence structures (CDS). These CDS, are typically comprised of rigid components intended to weaken and redirect waves and currents energy. CDS are often established right-on or near natural habitats, which might cause disadvantageous alterations to local ecosystems. Previous studies have shown that traditional CDS are inadequate in supporting diverse and abundant communities. Traditional CDS have demonstrated inadequacy in supporting diverse and thriving communities. To address this issue, eco-friendly approaches and designs are under experimentation and implementation to enhance the ecological significance of CDS. Some methodologies are applicable during construction, while others can be retrofitted onto existing structures like wavebreakers and seawalls. Effective techniques include: (a) Enhancing surface roughness through targeted perforations; (b) Incorporating artificial panels to elevate the surface complexity; (c) Deployment of additive "soft" engineering solutions like geotextile materials; (d) Substituting the traditional industrial construction materials with ecologically friendly mixtures into the CDS units; and (e) Pre-planning and the establishment of eco-friendly designed units as an artificial complex. This paper promotes the incorporation of ecologically sustainable techniques as obligatory procedures in CDS and coastal construction. Such integration aims to alleviate and hopefully prevent CDS negative ecological impacts and hopefully turn them into an important tool in coastal habitat ecological enhancement.

ID: 549 / **Parallel Session 5-4: 5**
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: light pollution, ALAN, damselfish, oxidative stress, brain

Ecological impacts of artificial light at night: a multi-organism, long-term study in a coral reef natural environment

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Pervasive artificial light at night (ALAN) perturbs the physiology and behaviour of terrestrial and marine animals worldwide. Despite considerable research into the short-term effects of ALAN, our understanding of its prolonged repercussions on diverse ecological groups in the natural environment remains limited. This study delves into the physiological effects of ALAN on damselfish (*Chromis viridis*) and corals (*Acropora* spp.) in the Gulf of Eilat's natural coral reef habitat. We investigated the effects of short-term ALAN compared to five months of continuous ALAN exposure using underwater white and yellow LED ALAN treatments, IR video recordings of behaviour, and multiple stress biomarker assessments. Short-term ALAN exposure revealed sleep disturbances associated with increased DNA damage in the fish forebrain. Long-term ALAN treatment uncovered enduring effects on fish species composition, nocturnal activity, and variations in antioxidant capacity and oxidative damage depending on the study organism and treatment wavelength. These findings offer crucial insights for future research and conservation strategies in the face of rising global light pollution.

ID: 507 / **Parallel Session 5-4: 3**
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: Durusdinium, endemic coral, Mauritius, Stylophora sp., Thermal stress

Differential thermal photo-physiological responses between *Stylophora* sp. morphs harbouring *Durusdinium* symbiont

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Stylophora species worldwide tend to be highly susceptible to ocean warming events and thus are among the first to bleach and die. In this study, we used morphology and genetics to characterize two morphs of *Stylophora*, Morphotype A from Ile aux Bernaches and Morphotype B from Ilot Longue, both located around Amber Island in the north of Mauritius. Their dinoflagellate symbionts were identified genetically and response to thermal stress, in terms of maximum quantum yield (F_v/F_m) at photosystem II (PSII) and visual bleaching observations, were investigated. The fine skeletal structures of both morphotypes appeared different as distinguished by scanning electron microscopy. However, genetic comparison of the mitochondrial open-reading frame (ORF), the mitochondrial control region (CR) and the nuclear internal transcribed spacer 2 (ITS2) revealed no apparent differences between the two morphs that were both identified as *Stylophora madagascarensis*. Both morphs harboured *Durusdinium* sp. (formerly Clade D). The photo-physiological responses, measured using a Diving Pulse-Amplitude-Modulated (D-PAM) fluorometer, of the *Stylophora* morphs were determined by exposing coral nubbins, in three replicates (n=3), to 28, 30 and 32ºC for a 12-hr duration. The F_v/F_m of Morphotype A and Morphotype B remained unchanged after a 12-hr treatment at 28ºC and 30ºC but declined significantly to almost zero and 80%, respectively, at 32ºC. Bleaching was visually observed only in Morphotype A treated at 32ºC. Difference in fine-scale morphological features is the one variable that could determine PSII functioning and bleaching responses to heat stress. Recognizing the existence of heat susceptible and heat tolerant morphs is imperative for management strategies to conserve, manage, and restore regionally rare and endemic reef-building corals exposed to ocean warming.

ID: 529 / **Parallel Session 5-4: 4**
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: ecotoxicology, test method, standardization, UV filters, pesticides

Addressing anthropogenic Impacts on Corals with an acute Toxicity Assay

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As coral reefs face global decline from multiple anthropogenic stressors, including chemical substances such as pesticides, pharmaceuticals or personal care products (*e.g.*, sunscreens), the need for an accurate toxicity assessment is essential. Many existing studies on coral toxicity lack consistency and reproducibility. Addressing this gap, we present a standardizable acute toxicity test method for the common reef-building coral *Montipora digitata*. By testing multiple substances (*i.e.*, BP-3, DCMU, Cu^{2+}), our study reveals that the endpoints bleaching, and mortality offer the most robust and reliable results. Aligned with international testing standards, our method promises to enhance toxicity assessments of substances that potentially enter the marine realm, paving the way for evidence-based regulatory decisions.

ID: 797 / **Parallel Session 5-4: 23**
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: Stony coral tissue loss disease, Symbiodiniaceae, Southeast Florida

Spatio-temporal mapping of algal symbiont communities in *Orbicella faveolata* and their associations with SCTLD

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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 to stony coral tissue loss disease (SCTLD) has not yet been studied in situ. This study tests for associations between lesion development and within-colony mosaics of Symbiodiniaceae taxa on *O. faveolata* colonies >2 m diameter in southeast Florida by mapping their distributions and monitoring over time. Five repeatable transects were set up on seven colonies in a radial pattern, where thirty-one biopsies per colony were taken at seven timepoints between 2022 and 2024. Quantitative PCR results showed the five northernmost colonies dominated by either *Breviolum* or *Durusdinium* and two southernmost colonies with variable distributions of *Breviolum* and *Cladocopium*, possibly relating to latitudinal or nutrient exposure differences. Symbiont to coral host cell ratios showed significant differences between colonies and across time points, with the greatest decline corresponding to a severe bleaching event, even in corals not visibly affected. Spatial analysis within colonies indicated significant clusters of symbiont genera in colonies with variable communities along with small shifts in proportions and distributions over time. However, there are no clear temporal trends or variation between the wet and dry seasons. During monthly monitoring, five colonies exhibited active disease lesions and bleaching throughout the sampling timeframe. Further analysis is in progress utilizing ITS2 sequencing and metabolomic analysis. These results provide further evidence of how environment influences algal symbiont communities in *O. faveolata* and how inter and intra-colony variation influences patterns of SCTLD severity and spread.

ID: 761 / **Parallel Session 5-4: 19**
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: coral reef, reef monitoring, eDNA metabarcoding, Ryukyus, Okinawa

An effective combo for reef monitoring: Observer-based and eDNA metabarcoding techniques to survey reefs exposed to different levels of anthropogenic pressure around Okinawa, Japan

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Shallow subtropical and tropical reefs are biodiversity hotspots and provide essential ecosystem services; however they are also vulnerable to anthropogenic pressures, which can cause shifts in their community structures and compositions. The coral reefs in the subtropical archipelago of the Ryukyus in Japan are highly impacted by urbanization, especially along Okinawajima's coast, and have experienced bleaching events. In light of these ongoing pressures and changes, monitoring and impact assessment are needed to inform conservation and restoration measures. Nevertheless, most monitoring efforts rely only on a single ecological metric, focus on a single taxonomic group (mainly fishes or hard corals), and/or consider the effect of a single impact, rather than offering a comprehensive view of reefs' benthic community and cumulative pressures. Here, a multi-taxa monitoring protocol combining observer-based techniques and eDNA metabarcoding was tested at two depths (<15 m deep) at twelve sites along Okinawajima and Akajima islands. Selected sites were classified according to their cumulative exposure to anthropogenic pressures using a score-based scale. Data from Line Intercept Transects for benthic cover, visual censuses for molluscs and echinoderms, and diver-operated videos for fishes were integrated with eDNA sequences of metazoans. This survey design allowed a wide characterization of community diversity and structure, including traditionally overlooked taxa, and to discriminate between different impact exposures. Although communities of the low-impact sites along the remote Akajima Island were notably different from Okinawajima's, hard corals were dominant at one site only. Our results suggest phase-shifts have occurred or are still occurring, and highlight the necessity and utility in broadening the taxonomic spectrum of monitoring and research efforts.

ID: 287 / **Parallel Session 5-2: 10**
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: artificial upwelling, marine heat wave, heat stress, coral reef, bleaching

Exploring the potential of pulsed artificial upwelling in mitigating coral thermal stress during marine heat wave: Upwelling duration versus depth

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As anthropogenic CO_2 emissions are still rising, the pressure of warming waters and marine heatwaves on coral reefs is now reaching an alarming state of regular mass bleaching worldwide. Artificial upwelling (AU), the uplift of cooler deep water to locally cool surface waters, could be a mid-term solution to reduce the impact of marine heat waves on shallow coral reefs. In this study, we explored the effect of pulsed AU, rather than continuous AU, on three Bermudian corals under a simulated 6-week heatwave (30.5°C, 2.5°C above mean summer SST). The AU scenarios tested followed a fully crossed design of three water depths - 30m (27°C), 60m (24°C) and 90m (21°C) - and four durations - 1, 2, 3 and 5 h. Coral response was assessed by measuring a number of physiological metrics that are known to respond to heat stress: metabolic rates via incubations, photo-physiology via PAM fluorometry, pigment concentrations via reflectance spectra and HPLC, bleaching via photography (grey-scale method) and cell counts, protein expression via proteomics, and energy reserves via lipid analysis. Initial results show that the simulated heat wave had a significant negative effect on all parameters measured. Corals exposed to AU showed a trend of improved physiological performance in particular under the more extreme AU scenario (90 m - 5 h). For most parameters, the increase in the AU duration had a more significant positive impact than the AU depth. Our temperature results show that AU has successfully improved the conditions of corals, going from a degree heating week of 10.7°C-weeks (heat wave condition) to 5.1°C-weeks (90 m - 5 h condition). Future AU applications should thus prioritize the duration over the depth and explore longer upwellings of shallower waters.

ID: 163 / **Parallel Session 5-2: 1**
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: Eco-friendly out-plantation, natural materials, hardening materials, underwater materials, coral restoration.

Underwater quick-hardening vegetable oil-based biodegradable putty for coral reef *r*estoration and rehabilitation

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Coral reefs are threatened by climate change and the effects of human activity on the marine environment. Researchers are attempting to rescue this fragile but essential ecosystem by restoring the reefs using several techniques, such as coral gardening, micro-fragmentation, etc., described as coral restoration actions. A common step in these procedures is out-planting the new coral colonies into their natural environment: the coral reef. To do that, commercial concrete or epoxy resins, also called putty, are utilized, highlighting different concerns about their mechanical and hardening performances and their impact and fate once released into the environment. Hence, this work shows a new biodegradable epoxidized soybean oil acrylate (ESOA)/zein-based Coral Putty capable of quick hardening underwater as an eco-friendly alternative for out-plantation of new coral colonies in the reef. Coral putty is composed of two components, containing one a radical initiator and the other a radical accelerator. Once the two components are combined, the ESOA starts crosslinking, and Coral Putty becomes hard with a compression strength comparable to a brick in 20-25 minutes underwater, showing a hardening timescale much faster than other commercial products. The Coral Putty is fully biodegradable in a biochemical oxygen demand (BOD) test and biocompatible when applied to the coral *Stylophora pistillata* in aquaria. Finally, it was used to out-plant *Acropora tenuis* corals on the reef in the Maldives, demonstrating how this new class of vegetable-oil-based materials can be a suitable, biodegradable, and eco-friendly alternative to epoxy resins and concretes commonly used in coral restoration procedures.

ID: 410 / **Parallel Session 5-2: 19**
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: coral restoration, conductive material, underwater biopaste

Underwater conductive paste for coral restoration

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Preserving coral reefs is of utmost importance as they serve as vital habitats for a myriad of marine species, constituting a fundamental pillar of our planet's aquatic ecosystems. Elevating the efficiency of coral restoration is crucial, not only for the well-being of the corals but also for the overall preservation of marine life and the delicate equilibrium of our oceans. Biorock has emerged as an efficient method to boost coral growth through mineral accretion driven by electrochemical processes. Biorock exploits a direct electrical current between two electrodes immersed in an electrolyte like seawater to precipitate and agglomerate calcium carbonates, magnesium hydroxides, and hydrogen at the cathode. At the same time, oxygen and chlorine are produced at the anode. Anchoring corals at the cathode significantly accelerates up to 5 times the deposition rate of their calcium carbonate matrix, leading to a substantial increase in resilience against bleaching and other adversities. Nowadays marine biologists grow corals in nurseries and subsequently transplant them onto the reef. The attachment is primarily facilitated using hardening bicomponent pastes, providing the corals with a substrate for ongoing growth and eventual permanent bonding to the reef. The bicomponent is usually an epoxy putty that must be mixed upon usage. Our research aims to formulate a conductive bicomponent hardening paste designed to facilitate the simultaneous application of electrochemical mineral accretion to corals underwater and the rapid transplantation of corals onto the reef. The conductivity of the paste is given by the usage of graphene nanoplatelets (GnPs) as filler, a graphitic material commercially available, with properties in between single-layer graphene and graphite, consisting of nanoflakes with micrometric lateral dimension and nanometric thickness. Our solution can offer versatility for application in aquariums and nurseries, does not require long-standing metallic structures underwater, and could also be employed directly on the reef, far from the shore.

ID: 407 / **Parallel Session 5-2: 17**
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: Anthozoa, Mediterranean Sea, RAD seqeuncing

Key strategies to restore marine animal forests using population genomic connectivity

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Organisms forming marine animal forests are considered ecosystem engineers due to their complex three-dimensional structure, hosting most of the biodiversity in benthic ecosystems and being essential for ecosystem functioning. Despite their ecological significance, marine forests are threatened by various human-related stressors. As such, it is fundamental to quantify the declines of these ecosystems and their resilience to disturbances, and genetic connectivity can provide valuable insight into the processes of population maintenance and replenishment following environmental fluctuations. Data on genetic connectivity can inform conservation and restoration strategies to enhance population resilience and originate new ecological corridors that may strengthen the recovery of neighbouring populations. Nevertheless, genetic connectivity is not always included in the latest restoration activity plans. Here we present how genetic connectivity data were used in three Mediterranean corals (*Savalia savaglia*, *Parazoanthus axinellae*, *Antipathella subpinnata*) to increase the knowledge of their reproductive behavior, to resolve phylogenomic disparities within taxonomically problematic groups, and to understand which populations could serve as a potential source of genetic diversity for adjacent populations. Then, we present a roadmap in which this information is used to develop an innovative and sustainable protocol for marine animal forests restoration, monitoring, and conservation.

ID: 552 / **Parallel Session 5-4: 13**
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: Coral reef restoration, Acoustic enrichment, Coral reef monitoring, Nocturnal fishes, Field experiment

Nocturnal predators drive community composition of acoustically enriched restoration reefs.

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Coral reef restoration is increasing in scale and ambition in response to current negative trends in reef health around the world. To date, studies investigating the interaction between coral reef restoration and coral reef fish have generally focused on changes in diurnal reef fish communities. However, the activity of nocturnal coral reef fish is crucial for ecosystem functioning, including predation and nutrient cycling, so could influence outcomes of restoration techniques. We have developed infrared cameras to monitor nocturnal fish communities with minimal disturbance and provide insight into nocturnal predation. Working with the 'Reef Song Project', which is experimentally investigating methods to enhance coral reef recovery in Australia, we investigated the influence of acoustic-enrichment and fish restocking restoration techniques on nocturnal fish communities at Lizard Island (Great Barrier Reef). Treatment differences in community composition were driven by predatory genera that occurred more frequently in nocturnal video surveys on the acoustically enriched patch reefs compared to those on control patch reefs. Our work has important implications for this restoration technique as the activity of nocturnal predators could influence net gains in fish abundance, and in restoration more widely. Moreover, we demonstrate the importance of varied monitoring techniques that investigate functionally important species to ensure that current restoration techniques are not hindered by the cloak of darkness.

ID: 409 / **Parallel Session 5-2: 18**
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: Microplastics, Nanoplastics, Polylactic acid, Plastic pollution

Effects of the Plastic Pollution to Sea Microfauna and Corals

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Over the last decades, a great increase in water pollution has been detected. Common and emerging water pollutants, such as micro- and nanoplastics, in combination with climate change, are among the most important pressures affecting marine environments.

Moreover, due to the lack of standard protocols in performing sampling, separation, concentration, and identification of real MPs and NPs environmental samples, studies on their environmental fate and on their interactions with living organisms require the use of model engineered particles. The aim of this work is twofold: first, the development a reproducible protocol to fabricate MPs and NPs representative models starting from poly(lactic acid) pellets; second, testing the effects of MPs and NPs on zebrafish's eggs and larvae, Vibrio Coralliilyticus bacterium and planarians.

The proposed fabrication method is the milling process. Two steps were followed: the dry and the ball mill of PLA pellets. The dry mill allows reaching micrometric sized particles, which are subsequently used as feeding material in the ball mill, which further reduces the sample size to NPs. To obtain NPs and MPs that resemble the main characteristics of those found in the real environment, the fabricated PLA particles were exposed to photooxidation processes. The PLA particles obtained are polydisperse and Nanoparticles Tracking Analysis revealed a concentration of 2.3*e*8±2.53e7 particles/mL with an average size of 146.0 ± 2.0 nm. Moreover, GPC analysis showed a decrease in the molecular weight of the photodegraded PLA particles confirming a successful break down of the polymer chain, as it would occur in the environmentally exposed PLA.

The study on biological models is ongoing, with the focus on investigating potential physiological impairments in organisms exposed to high concentrations of nanoparticles. However, there is currently a lack of understanding regarding the assessment of effects at very low concentrations, which may better reflect real environmental conditions.

ID: 658 / **Parallel Session 5-4: 14**
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: coral larvae settlement, settlement cues, coral reef restoration

The bacteria-derived pigment cycloprodigiosin is a multispecies settlement cue for scleractinian coral larvae

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The ongoing climate change is leading to frequent mass bleaching events, which represents the greatest threat to tropical coral reefs today. Sexually reproduction in scleractinian corals is a major driver of natural coral reef adaptation towards changing environmental conditions. A crucial and still not fully understood step in the life cycle of corals is the transformation of mobile larvae into sessile recruits, which is referred to coral larval settlement. Recently, the CCA-associated bacteria-derived pigment cycloprodigiosin (CYPRO) was identified as potent settlement inducing compound (cue) for larvae of the brooding species *Leptastrea purpurea*. In this study, we investigated whether CYPRO is a general settlement cue by testing eight different spawning and brooding scleractinian coral species belonging to the genera *Leptastrea* and *Acropora*. Competent larvae were exposed to purified CYPRO in different concentrations and their settlement success was then determined after 24 and 48 hours of exposure. All species tested were triggered to settle in a concentration-dependent manner, although success rates varied between 13 to 87% among species. Our findings suggest that CYPRO is a general settlement cue for scleractinian coral species. This makes the compound a promising candidate to deepen the understanding of coral larval settlement on a mechanistic level (see also ECRS contribution by Kellermann and colleagues). In addition, it should be assessed whether CYPRO could be used as a potent tool for novel approaches of coral reef restoration.

ID: 187 / **Parallel Session 5-2: 2**
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: Stony Coral Tissue Loss Disease, Mesoamerican Reefs, stony coral microfragmentation

Restoration of Stony Coral Tissue Loss Disease-susceptible species in the Arrecife de Puerto Morelos National Park, Mexico using colony microfragmentation

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The Arrecife de Puerto Morelos National Park (APMNP) has been a marine protected area in Mexico’s Mesoamerican Reef since 1998 and includes ~90 km^2 of coral reef. Significant declines in stony coral cover recorded within the APMNP, primarily due to increasing ocean temperatures and disease events, has precipitated the need for active restoration activities. This study addressed if current APMNP conditions, in relation to the recent Stony Coral Tissue Loss Disease (SCTLD) event, are appropriate for large-scale stony coral restoration efforts through an experimental framework of outplanting microfragments of SCTLD-susceptible species to multiple sites. This study was the first to outplant microfragments in the Mexican Caribbean. In September 2022, three APMNP important stony coral species (*Montastraea cavernosa, Orbicella annularis* and *O. faveolata*) were cut into 4 cm^2 microfragments (n = 1,504). These microfragments were epoxied onto plugs which were secured into 300 cement bases. An equal distribution of bases representing all parent colonies, species, and base densities (3 and 7 plugs) were outplanted at six reef sites. At each site, 50 bases were haphazardly distributed around a central pin. Microfragment outplants were monitored for survival, growth, and health conditions between species and site locations. Additionally, during each monitoring event, natural colony SCTLD prevalence was recorded at outplant and control sites to evaluate if outplanting SCTLD-susceptible species affected disease prevalence in the natural population. Although mean (±SE) survival for all species combined was 84.3% ± 3.3nine months post-outplanting, the microfragments exhibited minimal relative net growth at all sites suggesting chronic pressures currently limit the long-term potential for restoration via microfragmentation. However, introducing SCTLD-susceptible stony coral species did not increase disease prevalence in the surrounding natural colonies at any sites, suggesting that additional restoration activities could be implemented in the APMNP.

ID: 160 / **Parallel Session 5-1: 10**
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: Marine Animal Forest, coral reefs, carbon budget, floating coral nursery

Unlocking carbon sequestration potential for a coral-based marine animal forest

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While the urgency for nature-based solutions for climate mitigations in the face of current climate change scenarios is evident, comprehending the carbon removal potential of marine animal forest (MAF) ecosystems, like coral reefs, remains challenging. Both *ex-situ* and *in-situ* experiments yield variable results, complicating our understanding. Further, previous ecosystem approaches presented contradicting predictions, especially concerning the calcification-to-photosynthesis ratio, identifying reefs as either carbon sources or sinks. Indeed, the complex nature of these ecosystems, encompassing vertical and lateral carbon fluxes, poses significant challenges. This study introduces a Coral-Based Marine Animal Forest Module (CBMM) as a simplified model to calculate carbon budgets and as a tool to evaluate carbon sequestration potential. The CBMM, a scalable mid-water structure, populated with *Stylophora. pistillata* (a model coral species) fragments, develops into a MAF. As it develops, the CBMM attracts reef-associated organisms, fostering a diverse community that could sequester carbon, along with symbiotic algal photosynthesis. This simplified model helps mitigate complexities, establishing a clear starting point (time 0, almost zero carbon) and an endpoint (mature MAF), assessing the CBMM's carbon sequestration capacity. By assessing carbon fluxes and stocks between these two community developmental stages and by considering population structures, the study aims to present a simplified modular approach and to provide a clearer understanding of carbon dynamics in coral reef ecosystems.

ID: 627 / **Parallel Session 5-4: 12**
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: Coral restoration, Artificial reef, Technology improvement, Offshore, Subsea Construction.

Optimising table-like artificial reefs: Enhancing coral reef restoration strategies in offshore seabeds

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Coral restoration is an evolving scientific field with gaps in technologies and methodologies. This study focuses on refining permanent table-like artificial reefs for coral farming in soft seabeds, specifically addressing challenges associated with subsea construction and survival of transplanted corals. Two artificial reef models, the Marjan (three layers of tables) and Mushroom Forest (a single layer of tables), were utilised at offshore sites in Qatar. The research involved transplanting 4310 colonies of 10 coral species sourced from oil/gas pipeline corridors (donor site) from an environmental compensation program. Specifically, 843 colonies were transplanted in 21 packs (1 pack = 6 units) of the Mushroom Reef, averaging 40.1 corals per pack, and 3467 colonies were transplanted in 63 units of the Marjan, averaging 55 corals per unit. Five coral species dominated in both artificial reefs, collectively constituting over 80% of the total colonies, reflecting the biocenosis of the donor site. After a 2-year period, passing through two summers with temperatures reaching 36°C, the Mushroom Reef exhibited nearly 90% of colonies in a healthy state, 9.9% partially dead, and 0.49% totally dead. Conversely, the Marjan Reef displayed approximately 73% healthy corals, 25% partially dead, and 4% totally dead. Higher mortality on the Marjan Reef, particularly in the layers near the seabed, appeared to be influenced by sedimentation and shading. The presence of boring sponges covering the corals illustrates the mortality. Evaluating cost benefits related to coral survival, sediment prevention, available table area for outplanting, and deployment costs, the Mushroom Forest artificial reef emerged as a validated technology for coral farming in offshore soft seabeds. This study contributes valuable insights into the evolving field of coral restoration, offering practical implications for the subsea construction of coral farming assets and the selection and optimisation of artificial reef structures.

ID: 133 / **Parallel Session 5-1: 8**
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: Coral Sexual Restoration, Heterotrophic Feeding, *Acropora palmata*

Benefits of heterotrophic feeding on assisted coral propagation: A case study on *Acropora palmata*

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Assisted coral reproduction has become a powerful tool to support coral restoration efforts in an area characterized by rapid decline of coral health. In the Dominican Republic, sexual propagation of corals is increasingly being used owing to its potential to promote genetic diversity on corals. As our ability to harvest sexual corals in the laboratory, more research is needed to maximize survivorship of coral spats in the field. Coral feeding is perhaps amongst top research priorities, as coral spats might benefit from heterotrophic feeding during their early life cycle stages when zooxanthelae have not yet infected their tissues. In the paper we investigated the effect of heterotrophic feeding on *Acropora palmata* species. For this we designed a short-term experiment (25 days) in which three combinations of food were provided: (1) zooplankton, (2) phytoplankton and (1) 1:1 combination of both. Our results indicate that heterotrophic feeding is beneficial to increase growth of coral spats. We showed that combining zooplankton and phytoplankton for the first 25 days after fertilization is the best feeding strategy as we recorded a 37.17 ± 0.36 % significant increase in coral growth compared with the control. We conclude that programs aiming to sexually propagate *A. palmata* should include heterotrophic feeding to maximize the success of their intervention to restore coral populations.

ID: 819 / **Parallel Session 5-6: 13**
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: Parrotfish, herbivory, population dynamics

Spatiotemporal analysis of large parrotfish (Scaridae) on Florida's Coral Reef and their potential to control macroalgae.

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Parrotfish herbivory is a primary ecosystem function shaping Caribbean coral reef communities. Studies suggest that parrotfish ≥30 cm total length remove an exponentially greater macroalgae biomass of than smaller counterparts which opens space for settlement of new benthic organisms including corals. Although parrotfish take has been managed in Florida since the early 1990s from harvest for seafood, many of Florida's reefs remain dominated by macroalgae. Reef fish visual census data were compiled from 2012-2022 to assess parrotfish populations across Florida's Coral Reef to evaluate their potential to control macroalgae inside and outside of no-take reserves across three Ecoregions: Southeast Florida, the Florida Keys (Keys), and Dry Tortugas (DT). The global mean density of parrotfish was 1.13 (±0.09) fish 177 m^{-2}, however, 96.8% were below 30 cm. Four species dominated size classes ≥30 cm: *Scarus guacamaia*, *Scarus coelestinus*, *Scarus coeruleus*, and *S. viride*. Southeast Florida had the lowest mean density (0.20) and biomass (0.04 kg 177 m^{-2}) of fish ≥30 cm of any subregion and the Keys contained the highest. Density in the Keys significantly declined between 2016 (0.872 ± 0.113) and 2018 (0.499 ±0.439) likely due to hurricane Irma, but increased to 0.680 (±0.0721) in 2022. The Keys no-take reserves had similar mean densities to open areas but 82% higher mean biomass indicating larger fish. DT reserves had a higher density of fish than open areas but similar biomass. Mean density in the reserves was similar between the Keys and DT, but biomass in the Keys reserves was three times higher. The majority of Florida's parrotfish are small-bodied browsers not capable of controlling macroalgae growth. Continued analysis is underway to understand the regional and reserve differences in larger individuals and the factors limiting their densities.

ID: 838 / Parallel Session 5-6: 15
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: Coral rubble, sediment flux, reef restoration

Sediment flux on rubble dominated reef flats: Implications for reef island stability and coral reef recovery.

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Sediment and rubble flux in coral reefs is a key unknown factor that influences a range of ecological and geomorphic processes such as the trajectory of reef recovery after a cyclone event and the stability of reef islands in a future of sea level rise. The objectives of this study were:1) to determine the frequency of rubble movement which may directly influence the capacity of coral recruits to survive into adulthood and aid reef recovery; and, 2) to understand the annual flux of rubble and how this influences reef flat and reef island stability through time. Both objectives underpin critical research goals of developing interventions to aid coral reef recovery (i.e., rubble and reef flat stabilisation) and ensure reef island stability in a future of higher sea levels (i.e, reef flat and island sediment availability). Critical to this research is a knowledge of the near-bed velocities that initiate rubble motion and the long-term rate of rubble flux across the reef flats, both of which are mostly unknown. Here, we assess in situ coral rubble movement and the hydrodynamic processes driving this movement on a rubble dominated reef flat that supports a rubble island. Rubble was removed from their position, tagged and placed on the reef flats with the near-bed velocities measured each day. These data were used to calibrate a hydrodynamic model that simulated rubble movement at yearly scales. We find that annual rubble movement and flux far exceeds the frequency for which coral recruits are likely to survive and the required rate to maintain the rubble cay on the reef, respectively. However, over time coral rubble creates persistent deposits that are stable (e.g., imbricated deposits) which require far greater energy to initiate movement than the velocities determined here.

ID: 377 / Parallel Session 5-2: 14
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: Coral restoration, Florida, nursery, outplanting, survivorship

Sixteen years of coral restoration efforts in southeast Florida

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The decline of Caribbean coral reefs driven by local and global stressors has reduced diversity, structural complexity, and ecological function throughout the region. To promote conservation and recovery, coral restoration programs have been established with the goals of collecting, maintaining, propagating, and outplanting corals to depauperate reefs. In 2007, we established an offshore coral nursery in southeast Florida using 100 fragments collected from 10 local genotypes of the critically endangered *Acropora cervicornis*, with the objective to study and optimize coral restoration. Over the subsequent 16 years, the nursery has produced close to 30,000 fragments and currently holds approximately 4,000 corals from 17 different species and 352 genotypes, maintained on a combination of more than 100 floating and fixed structures spread between two sites. Approximately 17,000 corals from 14 species have been outplanted to 22 local reef sites. Mean survivorship for 2-year old *A. cervicornis* outplants between 2008-2018 across 11 sites was 69%. However, survival varied widely (0-100%), predominantly due to differences in sites, fragment size and density, attachment methods (nail, cable tie, epoxy), and major storm events. Lessons learned during the first 10 years, primarily relating to attachment techniques, have markedly improved outplant success, as post-2018 outplant survivorship for 2-year old *A. cervicornis* cement clusters at 4 sites was 84% (69-97%). These long-term research efforts have provided critical knowledge for understanding, developing, and expanding coral restoration in SE Florida and the greater Caribbean region. Recent outplanting efforts have expanded to non-acroporids, with mean 1-year survivorship from 2021 to 2022 at 78%, ranging from 11-100% depending on species, site, and attachment method. Detailed investigation is now underway to identify specific site characteristics driving spatial variability in survival, to optimize the success of restoration in SE Florida and ultimately improve the future viability of these valuable ecosystems.

ID: 709 / Parallel Session 5-4: 15
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: Bacterial produced settlement cues, bioactive metabolites, chemical settlement cue, structure-function of settlement cues

The mechanism behind chemically induced coral settlement: Applicability of single chemical cues for coral reef restoration?

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The climate change associated rise in sea surface temperatures is the major driver of worldwide coral bleaching and coral mass mortalities. A key mechanism for long term adaptation of coral reefs is the sexual reproduction of corals and successful recruitment of resulting 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. To date, *Pseudoalteromonas* is the only identified bacterial source that produces bioactive metabolites enabling coral larvae to attach onto a hard substrate and undergo the complex larvae-to-polyp transformation process. However, the physical, chemical and molecular processes involved in this complex settlement reaction with a single chemical substance are still poorly understood.

Recently, our working group identified cycloprodigiosin (CYPRO) as potent settlement inducer for larvae within the brooding coral *Leptastrea purpurea*. Subsequent assays with multiple spawning and brooding corals suggests CYPRO being a general morphogen for coral larval settlement (see also ECRS contribution by Fiegel and colleagues). Here we summarize the major underlying physico-chemical mechanism of the identified settlement agent CYPRO, which we compare with tetrabromopyrrole (TBP), the second bacterial-isolated settlement cue so far. Understanding the similarities and differences between the latter two morphogens will reveal the critical factors in the complex transformation of a free-swimming planula larva into a sessile coral recruit. A more detailed knowledge of the coral larvae settlement processes at the structural level is urgently needed to understand the effects of environmental factors on this critical transformation and to develop effective concepts for sustainable reef restoration.

ID: 418 / Parallel Session 5-6: 1
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: adaptation, resilience, coral reefs, restoration, marine heatwave

Enhancement of coral heat tolerance via selective breeding along the Ningaloo Coast World Heritage Area, Western Australia

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Western Australia's coastal reefs face escalating heat stress and bleaching since the 2011 marine heatwave. Insights into coral heat tolerance baselines and selective breeding to enhance resilience remain unexplored. To address this gap, wild coral colonies of reef-building *Acropora tenuis* and *Acropora millepora* from two thermally distinct reefs (22° S and 23° S) in the Ningaloo Coast (Western Australia) and their selectively bred larval offspring were subjected to 27.1 °C (control) and 31.0, 35.5 °C (heat stress), respectively. Heat tolerance was assessed through survival, necrosis, bleaching, and photosynthetic efficiency responses. Offspring produced with at least one parent from the warmer northern reef survived 1.5-2x better at heat than offspring from both parents sourced from the cooler southern reef. Adults of both species displayed high variability in thermal responses but overall, no significant differences in measured traits at heat between populations were found, potentially due to the homogenizing effect of symbiont communities. Unexpectedly, adult and offspring thermal responses at the population level did not align. This study provides crucial insights into coral responses on Ningaloo reefs, informing intervention tools for adaptation to predicted warming and marine heatwaves.

ID: 278 / **Parallel Session 5-2: 8**
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: Coral gardening, Coral predation, Coral recruitment, Long-term ecological monitoring, Structural complexity

Community-managed coral reefrestoration in southern Kenya initiates reef recovery using various artificial reef designs

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Monitoring of reef restoration and artificial reefs (ARs) has typically been limited to coral fragment survival, hampering evaluation of broader objectives such as ecosystem recovery. We aimed to determine to what extent AR design influences the ecological recovery of restored reefs by monitoring outplanted coral fragments, benthic cover, coral recruitment and fish and invertebrate communities. Four AR designs (16 m^2), unrestored controls and natural reef patches (n = 10) were established. ARs consisted either of concrete disks with bottles, layered concrete disks, metal cages or a combination thereof. A mixture of 18 branching coral species was outplanted at a density of 7 corals m^{-2}. After two years, 60% of all outplanted fragments had survived, resulting in coral cover on most ARs comparable to reference patches. Coral survival differed between ARs, with highest survival on cages due to the absence of predation. In total, 32 coral genera recruited on ARs and recruit densities were highest on reference patches, moderate on concrete ARs and low on cages. ARs and reference patches featured nearly twice the fish species richness and an order of magnitude higher fish abundance and biomass compared to control patches. Fish abundance and biomass correlated with coral cover on ARs. AR, reference and control patches all had distinct fish species compositions, but AR and reference patches had a similar trophic structure of their fish communities. Motile invertebrates including gastropods, sea urchins, sea cucumbers and sea stars were present at ARs, but more abundant and diverse at reference patches. Thus, all studied ecological parameters progressed towards reef ecosystem recovery, with varying influences of AR design and material. We recommend a combination of metal cages and concrete ARs to promote high fragment survival and natural coral recruitment. Ultimately, a longer period of monitoring is needed to fully determine the effectiveness of restoration.

ID: 798 / **Parallel Session 5-4: 24**
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: SCTLD, Disease Interventions, Longterm Monitoring, Orbicella Faveolata, Florida's Coral Reefs

Prioritization of monthly disease interventions prolongs colony life.

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Stony coral tissue loss disease (SCTLD) exemplifies that coral diseases are more devastating than ever before. When a virulent disease like SCTLD ravages a coral ecosystem, it significantly changes the population's demographics and can cause local extinctions. Landscape scale disease interventions during such an event is virtually impossible; therefore, priorities must be considered. Saving the largest, oldest colonies of reef-building species helps preserve the genetic stock of the most resilient corals with the highest fecundity and ecological functions. In May 2018, forty-two of 78 of southeast Florida's largest living *Orbicella faveolata* colonies were prioritized into a treatment group that received monthly monitoring, leaving 36 untreated controls. All SCTLD lesions were covered with a chlorinated epoxy before August 2019 or CoralCure amoxicillin paste once permitted with treatment success >80%. Failed treatments were retreated in subsequent visits. The untreated corals were reassessed in spring of 2021. After three years of interventions, none of the priority corals reached 99-100% mortality, whereas twenty-five (67.6%) of the non-priority corals did. However, three treated corals lost approximately 20% of living tissue once disease interventions began. Prior to interventions between 2015 and 2018, mean tissue coverage significantly declined in the priority corals by 6.0% (±6.15% SE), whereas during the treatment period (2018-2021), there was no significant difference. In contrast, untreated corals experienced significant tissue loss during both periods, indicating a positive treatment effect. These results indicate that regular disease interventions are highly successful at reducing the amount of tissue lost to disease, however, colonies continued to develop new disease lesions, requiring regular treatments. Projections of tissue loss indicated that the treated corals will die by the year 2052 if SCTLD persists. That's an additional 34 spawning seasons to which they would have not otherwise contributed.

ID: 260 / **Parallel Session 5-2: 7**
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: Artificial light at night (ALAN), Coral reefs, Light harvesting, Coral morphology, Bio-optics

Light pollution alters the skeletal morphology of coral juveniles and impairs their light capture capacity

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Urbanization and infrastructure development have changed the night-time light regime of many coastal marine habitats. Consequently, Artificial Light at Night (ALAN) is becoming a global ecological concern, particularly in nearshore coral reef ecosystems. However, the effects of ALAN on coral architecture and their optical properties are unexplored. Here, we conducted a long-term *ex situ* experiment (30 months from settlement) on juvenile *Stylophora pistillata* corals grown under ALAN conditions using light-emitting diodes (LEDs) and fluorescent lamps, mimicking light-polluted habitats. We found that corals exposed to ALAN exhibited altered skeletal morphology that subsequently resulted in reduced light capture capacity, while also gaining better structural and optical modifications to increased light levels than their ambient-light counterparts. Additionally, light-polluted corals developed a more porous skeleton compared to the control corals. We suggest that ALAN induces light stress in corals, leading to a decrease in the solar energy available for photosynthesis during daytime illumination.

ID: 309 / **Parallel Session 5-2: 12**
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: Coral reefs, microplastic pollution, heterotrophic feeding, heat stress tolerance

Unravelling the interplay of microplastics, heterotrophic feeding, and heat stress in coral resilience

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Microplastic (MP) pollution is an emerging stressor adding pressure to coral reef ecosystems already threatened by ocean warming. MP affects reef-building corals, causing bleaching, decreasing growth and photosynthesis. Under stress, corals may complement energy depletion through heterotrophic feeding. However, MP may interfere with feeding but its effects on coral energy reserves and heat stress tolerance are largely unknown. To fill this gap, we studied the responses of two reef-building coral species (*Pocillopora verrucosa* and *Stylophora pistillata*) in a six-week experiment, testing three different combinations of MP exposure and feeding regimes: CF (microplastic-free control + twice-weekly feeding), MP+CF (400 ppl mixture of MP + twice-weekly feeding), and MP+HF (400 ppl MP + daily feeding). To investigate the effect of food availability on coral tolerance to MP, we measured coral growth, photosynthetic efficiency, photosynthesis and respiration rates, and energy reserves. To study how the physiological response to microplastic and feeding are connected to bleaching susceptibility, we exposed the corals to short-term heat stress at the end of the experiment and assessed bleaching. We show that coral growth was similar under all treatments. *P. verrucosa* increased photosynthetic efficiency and respiration rates under MP with twice-weekly feeding, which were mitigated under the high feeding treatment. Accordingly, the MP treatment caused energy depletion under control feeding, which was mitigated under high feeding. Contrary, *S. pistillata* was not affected by MP under control feeding, but photosynthesis decreased when exposed to MP and high feeding. These findings highlight that the feeding regime impacts the response of corals to MP. All corals bleached in response to heat; however, they bleached less in the MP+CF treatment, suggesting that MP may inhibit the connection between energy reserves and heat stress tolerance. As stressors like global warming and microplastic pollution are increasing, further research is necessary to comprehend underlying mechanisms of coral stress tolerance.

ID: 225 / **Parallel Session 5-2: 3**
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: coral restoration, structural complexity, fish abundance, coral recruitment, reef resilience

Coral restoration increases structural complexity and fish abundance on a coral reef in Indonesia

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In recent decades, coral reefs have suffered unprecedented declines in habitat-forming hard coral cover due to anthropogenic stressors, with impacts on ecosystem functioning and the provision of ecosystem services. While some of these issues can be mitigated using active reef restoration, like coral transplantation, knowledge on passive benefits increasing the natural recovery potential and resilience of coral reefs following active restoration efforts remains scarce.

Over a 6-month field experiment in the Nusa Penida Marine Protected Area, Indonesia, we compared benthic recruitment patterns between a restoration site with gardened *Acropora* corals, a natural reef site, and a rubble site that showed potential for restoration. Using settlement tiles, our study assessed various response variables as indicators for the natural recovery potential and resilience capacity of the reef sites. The sites were also surveyed for their benthic reef cover, structural complexity, and fish abundance and community composition.

Active restoration efforts enhanced the structural complexity of the reef site, resulting in more than a two-fold increase in fish abundance compared to the rubble site. Additionally, there was approximately a two-fold increase in the abundance of herbivorous fish and more than a two-fold decrease in turf algae cover on settlement tiles when compared to the other two sites. While enhanced coral recruitment or crustose coralline algae abundance were not confirmed, a high coral spat supply observed at the restoration site suggested that local coral recruitment can improve over time as the transplanted corals have healed from transplantation stress and become fecund.

Our study highlights that active coral reef restoration can positively impact the benthic environment and may aid coral reef recovery and resilience at localized scales. Regular monitoring of passive restoration benefits is crucial to retain information regarding the overall success of coral reef restoration efforts.

ID: 733 / **Parallel Session 5-4: 17**
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: spawning, larvae, settlement, restoration, cryopreservation

Innovation for reef restoration: Recent CARMABI advances in coral breeding using materials engineering, cryopreservation, and good old natural history

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Decades of natural history work and fundamental research on coral spawning have made larval propagation feasible, expanding the potential to apply coral breeding in reef restoration. At CARMABI in Curacao, ongoing collaborations with engineers, physicists, and aquarists are improving restoration methods and expanding conservation options. With mechanical engineers and materials scientists, we are searching parameter space for novel coral settlement substrates that don't require preconditioning or live biofilms. We have induced settlement using lime mortar and natural hydraulic lime base materials with inorganic chemical additives known to support calcification and with fractionated metabolite pools extracted from crustose coralline algae. Meanwhile, recent collaborations with cryopreservation scientists, engineers, and aquarists have enabled the long-term preservation, long-distance transport, and fortification of coral genetic diversity. So far, our team has cryopreserved sperm from ten coral species, reared larvae of three coral species using thawed sperm, and completed a successful demonstration of cryopreservation-assisted gene flow in the Caribbean using endangered Elkhorn Coral. Cryopreservation of coral larvae is the next focal area as we formalize and expand a global network for coral cryopreservation. Coral restoration remains in its early stages, but collaborations across ecology, aquaristry, biotech, physics, and engineering have shown clear potential for coral breeding and gene banking to be applied at scale in the coming decades.

ID: 612 / **Parallel Session 5-4: 10**
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: aquaculture optimization, heterotrophy, temperature, climate change

Identification of an interactive effect between feeding and temperature on coral performance in *ex-situ* aquaculture

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Ex-situ aquaculture has become increasingly recognized as an important tool in response to the degradation of coral reefs globally due to climate change. The utility of coral aquaculture to support research and restoration efforts, however, relies on determining conditions conducive to effective long-term culture of each coral life stage. Here, we explore the influence of two important parameters – feeding and temperature – on coral health, reproduction, and recruitment. Colonies of the reef-building coral, *Pocillopora acuta*, were fragmented into four pieces with one piece from each colony being allocated to each treatment (fed 26°C, unfed 26°C, fed 29°C, unfed 29°C). Offspring produced in each treatment were subsequently settled and cultured at 26°C and 29°C; all offspring were fed. Over the course of this ongoing year-long experiment, we found similar photochemical efficiency across treatments but fed colonies in the 26°C treatment retained a darker colour than unfed colonies; no colour difference was observed between feeding treatments at 29°C. Similarly, fed colonies in the 26°C treatment generally produced more and larger planulae than unfed colonies, whereas reproductive output and planulae size did not differ between fed/unfed colonies at 29°C. Settlement, as well as recruit survival and size, was higher at 29°C than 26°C regardless of parent treatment. These preliminary results suggest that optimal culture conditions differ based on life stage, whereby culturing adult colonies at 26°C with food provision is preferential, and cultivation of offspring at 29°C can lead to higher recruitment and growth. Physiological (chlorophyll a, symbiont density, host protein concentration) and molecular (lipidomics and transcriptomics) investigations are currently underway to provide a more comprehensive assessment to complement the ecological metrics examined. Clear determination of species-specific culture requirements can increase both the cost efficiency of coral aquaculture, as well as maximize the capacity for *ex-situ* systems to benefit research and restoration.

ID: 567 / **Parallel Session 5-4: 7**
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: coral, toxicity testing, UV filters, sunscreens, ERA

Developing reliable, defensible, and relevant toxicity assays in the scleractinian coral *Acropora cervicornis*

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Coral reefs are directly or indirectly impacted by a combination of anthropogenic stressors including a diverse array of inorganic and organic chemical contaminants. Recent concerns over the impact of UV filter constituents contained in sunscreens and other products has brought to light the challenges of assessing the environmental risk of chemical contaminants to scleractinian corals. No standard test protocols for corals are currently available and it is unclear how representative standard test species (i.e. marine invertebrates and algal species) of coral sensitivity may be, given the complexity of the host-symbiont-holobiont system. Toxicity tests with corals have been conducted but the lack of a standard methodology has limited comparisons between studies and highlighted concerns on data reliability and quality. We provide guidelines and discuss considerations moving forward on designing standard toxicity tests for scleractinian coral species using results from flow-through exposures with common contaminants (e.g., copper, diuron and PAHs) and new emerging contaminants (e.g., UV filters). Factors discussed include choice of test species and life-stage, specific test designs and replication requirements, inclusion of appropriate parameters for quality control, timing of exposures, analytical verification, and the choice of appropriate biological endpoints for acute and chronic assessments to provide reliable, defensible and statistically appropriate measurements.

ID: 497 / **Parallel Session 5-4: 1**
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: Coral reefs, Marine Protected Areas, Functional traits

The level of fishing pressure and habitat quality alter the trait structure of Caribbean reef fish communities

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Fishing pressure and habitat degradation have changed the structure of reef fish communities but also altered the ecosystem functioning. However, most studies that aim to understand the effects of fishing and habitat degradation have focused on taxonomic approaches, and often fail to identify how and why certain species respond differentially to perturbations. For example, fishing pressure removes functionally important species whereas habitat degradation affects species adapted with close relationships to reef architecture. Here, we examined how changes in fishing pressure and habitat quality have affected the functional trait structure of reef fish communities. The mean coral cover was used as a proxy of habitat quality whereas the level of protection was used as a proxy of fishing pressure. 115 sites were classified into four scenarios: degraded with fishing, degraded without fishing, not degraded with fishing, and not degraded without fishing. Sites were unevenly distributed across scenarios, therefore we randomly resampled 1000 times each scenario with the same effort each time, and we compared the average of the number of species, functional richness, functional evenness, and functional dispersion of all iterations. Our results show that unfished sites with high habitat quality promote a higher fish species richness and trait diversity than sites with low habitat quality and fishing allowed. Still, they do not contribute to improving complementarity and having a better regularity of the distribution of trait abundances of reef fishes. Our findings suggest that the widespread degradation of Caribbean coral reefs could lead to a simplification of fish communities even in sites with high habitat quality and fishery protection. We expect that the loss of habitat quality and high fishing pressure will have a negative greater impact on the trait structure of reef fish communities in the future than if one or the other process acted separately.

ID: 248 / **Parallel Session 5-2: 6**
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: Ecological Succession, Parametric Design, Gulf of Aquaba, Marine Conservation, Long-term Monitoring

Long-term ecological succession of reef-fish and benthic fauna on designed 3D printed artificial reefs

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The global degradation of natural coral reefs requires innovative approaches to their conservation and restoration. This study investigates the efficacy of using parametric tools in 3D printed terracotta structures, towards artificial reefs (ARs) design and construction. Using adapted, ceramic materials in a Paste Based Extrusion 3D printer we develop a Gravity-Stimulated Printing Design method to fabricate bio-inspired reef designs. These led to highly complex shapes that assembled a spatial conglomerate structure with a uniqueness of each part, offering high structure complexity that constitutes variety of shelters and niches. Three separated ARs were deployed in the northern Gulf of Eilat Aqaba in 2019. Consecutive monitoring examined the recruitment and settlement of reef-fish, corals, and other marine benthic organisms onto the ARs. 12 months post deployment the three ARs were consolidated to one infrastructure at the same location. The results elucidate a pattern of long-term recruitment and ecological succession. The ARs facilitated complex communities. Fish populations reached equilibrium approximately one year after deployment. Soft corals (octocorals) were first observed 4.5 months post deployment and stony corals (hexacorals) settled in 5.5 months; neither of which reached a steady state within the study period. Furthermore, we observed that uniting the separated ARs units into a single complex, significantly affected the community assemblage composition and species richness. This study contributes to the understanding of AR design through the nuances of marine ecological succession, shedding light on the importance of long-term monitoring and opening avenues for future research.

ID: 568 / **Parallel Session 5-4: 8**
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: Persian Gulf, gametes, planula, hermaphroditic, gonochoric

Sexual propagation of native coral species as a reef restoration strategy in the Arabian Gulf

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Coral reefs are the most diverse, complex and productive marine ecosystems in the Arabian Gulf. However, they are being lost at such an alarming rate that several coral species are now threatened with regional extinction. Most corals in the Arabian Gulf are broadcast spawners, with only one annual spawning event, which constitutes a critical bottleneck for any restoration strategy relying only on natural reproductive cycles. In this project, we are developing the capacity to predict and manipulate the reproductive cycles of the dominant reef-building coral species in the region, in order to produce sexual offspring multiple times per year and enhance natural coral populations with this hatchery produced offspring. In this communication, we describe the main findings and achievements during the first two years of the project, including:

- Establishment of the first *ex-situ* coral hatchery in Qatar.
- Determination of the natural reproductive cycles and spawning periods for 4 local coral species (*Acropora dowingi*, *Platygyra daedalea*, *Coscinarea monile* and *Dipsastraea pallida*).
- Conditioning of gametogenic development and induction of out-of-season spawning events for the 4 targeted species
- Optimization and testing of protocols for fertilization, embryo rearing and larval settlement for the 4 targeted species

Good fertilization rates (up to 96%) were generally achieved for all targeted species. Settlement rates varied substantially among species and settlement cues tested. Survival and growth of coral spat were mainly driven by competition with algae and showed substantial variations among species and fertilization batches within the same species. Several trials are currently underway, to improve our husbandry techniques at this critical life-stage (e.g., co-culture with herbivorous snails, manual removal of algae, optimization of light levels and feeding regime, etc). The finding of this project will contribute to accelerate and strengthen the implementation of coral reef restoration initiatives in the Arabian Gulf region.

ID: 606 / **Parallel Session 5-4: 20**
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: Heat-resilience, genomics, staghorns

Using CBASS and Genomics to Identify Target Species for Coral Restoration on Guam

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Staghorn *Acropora* corals across the Southern Mariana Islands experienced severe mortality over the past decade and are the main focus of regional restoration efforts. Successful coral restoration relies on knowledge of species boundaries and species-specific genetic diversity to prevent local extinctions of cryptic species, outplant species back to their natural habitats, and preserve their adaptive capabilities. However, population-level variation, intermediate phenotypes, and phenotypic plasticity can blur species boundaries and impede systematic assessments of local adaptations and species-specific bleaching resilience. In the Southern Marianas Islands, species boundaries, genetic diversity, and species-specific heat tolerance remain understudied. Here, we address these knowledge gaps by using genome-wide sequence data and Coral Bleaching Automated Stress System (CBASS) studies of staghorn *Acropora* corals on Guam. Genomic data will be used to identify species boundaries and determine the amount of species-specific genetic diversity and predominant symbionts. Preliminary results indicate that the most heat-tolerant coral species are *A. aspera*, *A. muricata*, and *A. teres*. *Acropora virgata* was the least heat tolerant and *A. acuminata*, *A. vaughni*, *A. austera*, and *A. pulchra* were all mildly heat tolerant. These insights into heat resilience help restoration practitioners make more informed decisions, highlighting species that may be better suited for outplanting locations where heat stress is possible. In this talk, I will address the detailed results of this study and the potential implications for coral restoration and management on Guam.

ID: 412 / Parallel Session 5-2: 21
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: Coral Bleaching, Drug Delivery System, Sustainable Materials, Biodegradability

Biodegradable underwater films and silk microparticles as vehicles for curcumin delivery in coral bleaching treatment

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Climate change, such as enhanced UV-light exposure and ocean warming, are considered among the main causes of massive coral bleaching episodes, killing reef organisms over thousands of square kilometers. During these events, corals experience an overproduction of reactive oxygen species (ROS) and the breakdown of their symbiosis with the Zooxanthellae algae.

To mitigate these massive events, researchers have assessed several methodologies, from geoengineering approaches reducing the amount of solar light reaching the reef to coral's microbiome manipulation to isolate and administer heat-resistant bacteria in the form of probiotics.

Even if bright, these procedures do not seem to be decisive in solving the problem, due to high cost, low efficacy, and appropriate delivery systems for a large-scale application.

Being an unbounded environment, the ocean sets several limits in providing medical solutions. Supply drugs avoiding water contamination as well as developing a successful delivery system represent the main obstacles in oxidative stress' therapy. To overcome these restrictions, curcumin – an antioxidant polyphenolic compound derived from the *Curcuma longa* plant – can be a suitable candidate to employ in this scenario. Parallelly, biomaterials and bio-composites can be exploited to develop new sustainable, eco-friendly, and biocompatible promising tools for releasing molecules in small- and large-scale coral bleaching treatments.

Hence, a three-layered biodegradable film and silk-based microparticles will be presented as delivery systems. The two formulations were characterized in terms of morphological, chemical, mechanical, wettability, drug release, antioxidant, and biodegradability properties. Finally, both the films and the particles were applied *in vivo* on *Stylophora pistillata* corals at Genoa Aquarium. The efficacy of the two formulations in preventing bleaching was investigated by exposing "treated" and "untreated" corals to three fixed temperatures, simulating a heat-stress event. The obtained results suggest how these new strategies can give new hopes for saving corals during massive bleaching events.

ID: 286 / Parallel Session 5-2: 9
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: Nutrient fluxes, hydrodynamics, degrading reefs

Nutrient fluxes in degrading reefs: the effect of local hydrodynamics, benthic cover and dial cycles

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In-situ community studies are necessary to understand the integrated functioning of reefs and predict how they might respond to human-induced impacts. Although not often pursued, an analysis of the inorganic nutrients, (in)organic carbon chemistry and suspended particulate matter concentrations close to a benthic reef can reflect its functioning. In this study we aim to examine the interplay between benthic communities and water column biogeochemistry in reefs with different faunal assemblages located in a highly populated area around Curaçao (Caribbean Sea). We used a novel methodology, a gradient sampler that collects water samples at different depths above the seafloor at the same time. We combined it with current, light and temperature sensors to characterize the near-bed environmental conditions and net fluxes of nutrients, dissolved and particulate organic and inorganic matter into and out of the reef. Moreover, we quantified how these fluxes vary over diurnal cycles to capture the natural variability in these fluxes.

Fluxes were highly modulated by local hydrodynamics (i.e. tides and current speed and direction), time of the day and reef cover. Higher fluxes of inorganic nutrients towards the reef were found in the reef with higher coral cover, and enhanced when water speed was lower and during day. Water surrounding the highly degraded reef also presented higher inorganic nutrient levels and particulate matter, indicating that this reef is more subjected to run-off and land-derived material input. Understanding if reefs are a sink or source of nutrient is key to predict how already degrading reefs around Curaçao may react to future ocean scenarios.

ID: 565 / **Parallel Session 5-4: 6**
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: Marine Protected Areas, Spatial Models, Community, Species-specific

Rarity mediates species-specific responses of tropical reef fishes to protection

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Marine Protected Areas (MPAs) are the most widely applied tool for marine biodiversity conservation, yet many gaps remain in our understanding of their species-specific effects, partly because the socio-environmental context and spatial autocorrelation may blur and bias perceived conservation outcomes. Based on a large dataset of nearly 3,000 marine fish surveys spanning all tropical regions of the world, we build spatially explicit models for 658 fish species to estimate species-specific responses to protection while controlling for the environmental, habitat, and socio-economic contexts experienced across their geographic ranges. We show that the species responses are highly variable, with ~40% of fishes not benefitting from protection. When investigating how traits influence species' responses, we find that rare top-predators and small herbivores benefit the most from MPAs while mid-trophic level species benefit to a lesser extent, and rare large herbivores experience adverse effects, indicating possible ecological flow-on effects.

ID: 792 / **Parallel Session 5-4: 22**
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: metabolomics, chemical pollution, emerging contaminants

Distribution of xenobiotics across the land-sea continuum on a small Caribbean Island

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Coastal development, urbanization, and population growth in Caribbean coastal zones can cause unnatural fluxes of (potential) pollutants into nation's coastal seas. These pollutants include pharmaceuticals, oil, metals, plastics, trash, sediments, nutrients (fertilizers), pesticides, and microbes (including human pathogens), that may interfere with the functioning and health of coastal marine communities, including coral reefs. In this study we identified spatial differences across the land-ocean interface in the semi quantitative abundance of compounds associated with human presence, so called xenobiotics (e.g. pharmaceuticals, plant protection products or PMTs - persistent, mobile and toxic substances). To characterize the identify and distribution of xenobiotics in the waters of the Caribbean island Curaçao, we sampled the entire land-ocean interface at various locations around the Island, including groundwater, surface run-off, coastal waters and the open ocean using metabolomics (untargeted LC-MS/MS). Pharmaceuticals and drinking water chemicals (e.g. Cimetidine, Benzoylecgonine) were some of the most pronounced compounds/pollutants entering the ocean from land, as were surfactants (e.g. Nonaethylene glycol). These substances all accumulated foremost in coastal waters near the metropolitan and touristic areas of Curaçao's coast. The occurrence of xenobiotics often matched on shore land usages (e.g., residential vs. agricultural). This study demonstrates the usefulness of untargeted metabolomics analyses to assess the distribution and identity of various chemical forms of anthropogenic pollution that end up in coastal waters in Caribbean islands such as Curaçao.

ID: 505 / **Parallel Session 5-4: 2**
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: cold-water corals, aquaculture, chemical therapeutants

Effects of anti-sea-lice treatment in aquaculture on the behavior and respiration rate of the cold-water coral Desmophyllum pertusum

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In Norwegian finfish aquaculture, chemical therapeutants like emamectin benzoate coated on fish food pellets are being used to target parasitic sea-lice. Emamectin benzoate is relatively persistent in seafloor sediments and could impact non-target benthic fauna negatively. Along the Norwegian fjord coast, rocky hard substrate is the dominant habitat and in such environments sensitive ecosystems formed by corals or sponges are more frequently detected due to increasing monitoring efforts. The scleractinian reef-forming species *Desmophyllum pertusum* is widely present and is often co-occurring in the vicinity of finfish farms. The vulnerability of sessile species in response to aquaculture effluents is not well known. To date, there has been no published study on the effect of emamectin benzoate on cold-water corals. This study investigates the response of *D. pertusum* to emamectin benzoate. Two different emamectin benzoate concentrations were used to assess the bioaccumulation of this chemical therapeutant in the coral tissue. Metabolic responses after emamectin benzoate exposure were studied using respiration incubation in a recirculating seawater system. Additionally, polyp behavior and spectral responses were documented and analyzed using video footages obtained by color and hyperspectral digital camera systems, respectively. The results of this study will fill a gap in fundamental knowledge of how the anti-sea-lice therapeutant emamectin benzoate can potentially affect cold-water corals. The outcome of this work will contribute to a more sustainable management of aquaculture practices and the environmental footprint to sensitive benthic key species.

ID: 411 / **Parallel Session 5-2: 20**
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: coral restoration, coral disease, biomaterials, drug delivery, sustainability

Bi-phasic biosystem allows in-situ drug delivery in infected corals

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Coral reefs are endangered by climate change and human activities, which make corals more fragile and prone to disease outbreaks. To rescue them, coral restoration proceeds are ongoing worldwide, and the cultivation of coral colonies has been developed both *in-situ* and *ex-situ*. Specifically, *in-situ* cultivation exposes relatively small colonies to open fields, with consequent exposure to corallivores, pathogens, and uncontrolled conditions. Instead, *ex-situ* farms, mostly organized in tanks, offer a more protected environment with filtered and controlled seawater pumped directly from and to the sea, producing a higher rate of coral survival and growth.

Current approaches for treating coral diseases are based on mechanical removal and the use of probiotics or antibiotics. Especially regarding antibiotics, there are a lot of concerns connected to their proper use, diffusion, and application underwater. However, they remain the most effective way that we know so far. To improve their efficacy and reduce the impact on the environment, customized delivery systems can be produced.

In this work, an innovative therapy for facing coral disease will be presented. A bi-phasic system composed of a drug-loaded chitosan/polyvinylpyrrolidone-based film to be applied on the infected area, and a bio-derived thermosensitive based on beeswax and vegetable oils as sealing paste will be described. The materials were characterized in terms of morphological, chemical, and mechanical properties. The efficacy of the treatment was proved *in-vitro* against *Vibrio coralliilyticus,* and *in-vivo* on colonies infected with a Rapid Tissue Necrosis (RTN) disease, a vibrio-related infection. Finally, the low-cost production and the natural origin of this highly versatile tool make it scalable and suitable for massive applications.

ID: 806 / **Parallel Session 5-6: 11**
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: Fecundity, SCTLD, Florida's Coral Reef, Orbicella faveolata

Regional differences in the effects of stony coral tissue loss disease and antibiotic treatments on the fecundity of *Orbicella faveolata* in Florida

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Sexual reproductive success is a fundamental process that drives coral population dynamics. As coral populations continue to decline, it has become increasingly critical to understand how different factors impact coral fecundity. Eutrophication, thermal stress, and age can affect a coral colony's reproductive output and cause reproductive senescence. Additionally, the emergence of stony coral tissue loss disease (SCTLD) in 2014 was a massive mortality event on Florida's Coral Reef, from which came a disease intervention response that treated thousands of corals with antibiotic paste to stop lesions. This created an urgent need to investigate if the reproductive output of threated species like *Orbicella faveolata* was being affected by SCTLD or its treatments. In the summer of 2022, core samples were collected from 90 large colonies split between southeast Florida and the Lower Keys (Looe and Sand keys). In each region 15 colonies were sampled that never showed signs of SCTLD (no treatments), had a low disease incidence and number of antibiotic treatments, and had high disease incidence and treatments. Histological tissue analyses revealed that 91% of 89 colonies had ova and 85.4% had spermaries. The proportion of oocytes present was not significantly different between locations, however the proportion of spermaries present was significantly lower at Looe Key. Mean polyp fecundity was significantly higher in southeast Florida compared to the Lower Keys. In southeast Florida, fecundity, gamete presence, and oocyte size were not significantly different between affected and unaffected colonies, however there was a weak negative correlation (r^2=0.08) between fecundity and total historical treatments. In the Lower Keys, SCTLD affected colonies had significantly lower fecundity than unaffected colonies, but there was no relationship between historical treatments and fecundity where treatments were highest. Genetic analyses showed these populations are highly connected suggesting that local factors are creating regional fecundity differences.

ID: 241 / **Parallel Session 5-2: 4**
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: Restoration, Artificial reefs, 3D printing, Ecological engineering, Reconciliation ecology

Artificial coral reefs- from sunken ships and art to parameterized design

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Artificial coral reefs have become an integral practice in conservation, tourism, and research of coral reefs, being used by a range of agencies worldwide. Originally relying on sunken ships and on secondary use of different objects, the trend is shifting towards purpose-designed structures, including statues and art. However, it is often difficult to identify, evaluate, and replicate the principles used in these designs, as they are not mathematically defined. In our study, we sought to address this challenge by employing spatial and geometric principles in the design of 3D objects tailored for use as artificial coral reefs. Using a small number of well-defined parameters, we were able to control shelters for fish, spaces for invertebrates, connectivity between shelters and more. The designed structures were then 3D printed and subjected to comprehensive testing, including assessments of hydrodynamic flow and evaluation of their acceptance by fish. The results demonstrated the efficacy of our approach in creating artificial reef structures that were accepted as shelters to a diverse reef community. By applying spatial and geometric principles, our method allows for the development of intricate and tailored structures capable of providing optimal conditions for various marine species. This advancement holds promise for the future of artificial coral reef design, offering a systematic and replicable approach to examine and tests structures needed enhance ecological functionality and to contribute to the sustainability of marine ecosystems.

ID: 770 / **Parallel Session 5-4: 21**
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: Coral Reef, Florida, aquatic contaminants, water quality, environmental monitoring

Assesment and prioritization of aquatic contaminants of concern on Florida's Coral Reef

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Florida's Coral Reef (FCR) is the third largest barrier reef in the world and faces significant stress from localized, land-based sources of pollution. Several environmental contaminants have been found on reefs, including pesticides, organochlorides, hydrocarbons, and trace metals. However, for most current and emergent environmental contaminants, little to no consistent information exists regarding environmental concentrations or toxicological effects on corals. Assessment of contaminant exposure risk in coral reef environments is needed to guide management, restoration, and recovery strategies, and the coral reef resource management community has recognized the need for improved, readily available comprehensive information.

We have reviewed existing datasets to identify trends in the concentration and distribution of contaminants present on FCR and compiled available data on the sensitivity of corals to these contaminants. This cumulative information is used to identify regional contaminants of greatest concern, and highlight data gaps in contaminant occurrence and effects, informing the design of future toxicity studies and environmental monitoring efforts to elucidate impacts of priority contaminants on coral reef systems. This will significantly advance our fundamental understanding of the spatial and temporal occurrence and variability of relevant chemical contaminants which may contribute to water quality degradation and declining reef health on FCR. Subsequent assessment of chemical contaminant exposure risk based on this dataset will then identify and prioritize for further study the chemical contaminants that pose the greatest hazard to FCR, supporting informed decision-making critical to the development and success of effective coral reef management and restoration strategies. The data will be widely disseminated via incorporation into Florida's Department of Environmental Protection's (FDEP) coral reef decision support system (CRDSS).

ID: 815 / **Parallel Session 5-6: 12**
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: Coral settlement, Substrate biofilm, Recruit growth

Effect of cement tile composition of biofilm development, coral larval settlement, and post-settlement growth

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Coral restoration projects worldwide are increasingly focused on sexual reproduction efforts to boost genetic variation after stress events such as bleaching or disease outbreaks. However, their success is widely variable due to challenges inducing settlement and maximizing post-settlement survival. Many restoration projects use ceramic settlement tiles as recruitment substrates in ex situ facilities, but the composition of these tiles is rarely investigated as a means of promoting the growth of recruits. Here, we tested a total of fifteen different cementitious mixtures over three spawning events for their ability to promote larval settlement, recruit survival, and growth in Caribbean coral species. The first experiment conducted with *Orbicella faveolata* in September 2021 revealed that a mixture containing fly ash (FA60) attracted the most settlers (52% of settlers) and experienced the highest growth rate (2.2x higher than average). In May 2022, *Diploria labyrinthiformis* preferred another fly ash mixture (FA80; 23% of settlers) and the control made of Portland cement (PLC1; 20% of settlers).Two additional fly ash mixtures, FA60hp and FA40, promoted the highest survivorship at 92% and 91% respectively. In September 2022, crushed crustose coralline algae (CCA) was added as a settlement inducer. Although *Colpophyllia natans* larvae showed a slight preference for PLC1 tiles (20% of settlers), there was a more even distribution of settlers, and no mixture showed significantly higher settlement rates. The growth of these recruits was measured over 10 weeks following settlement, and a metakaolin-enhanced fly ash mixture (FA60MK10) fostered the highest growth rate (2x higher than average). Finally, four mixtures were selected based on settlement and growth results to be analysed for their biofilm composition using 16S and 18S after a 30-day conditioning period. This biofilm analysis will help better understand the possible bacterial cues that specific mixtures are cultivating to determine what microenvironments attract coral larvae.

ID: 739 / Parallel Session 5-4: 18
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: land-based pollutants, organic matter deposition, sedimentation, 13C and 15N stable isotopes, effect-based coral reef ecotoxicology

The role of inland bays in channeling land-based pollutants to neighboring reefs

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Inland bays likely play an important role in collecting on-shore pollutants and subsequent channelling to the coastal zone. Consequently, reef communities near the opening of these bays may experience (periodic) elevated concentrations of pollutants, nutrients, and suspended sediments, depending on bays' geomorphology and hydrodynamics. Here, we assessed seasonal (dry and wet season) differences in the transport of a variety of pollutants from inland bays to neighbouring reefs in Curaçao (Caribbean) by collecting sediments and suspended particulate matter (using sediment traps) at inland bays (Piscadera Bay, St. Michiel's Bay, and Santa Martha Bay). Material collected both close to the mouth of the bays and at adjacent up- and downstream reefs were analyzed to establish total fluxes of suspended material, as well as its composition (grain size, $\delta^{13}C$, $\delta^{15}N$ and C:N:P ratios). Additionally, time-integrative (30 d) organic chemical pollutants originating from the bays were sampled at all sites using polar organic chemical integrative samplers (POCIS) containing hydrophilic-lipophilic balance sorbent. POCIS extracts were subsequently dosed to *in vivo* (algal growth- and photosynthetic inhibition, crustacean- and cnidarian mortality) and *in vitro* (e.g. endocrine and metabolic disruption) bioassays to assess their toxicity to reef organisms. Additionally, the chemical composition of extracts was analysed using liquid chromatography-mass spectrometry to compare pollutant fingerprints among sites and identify potentially toxic (mixtures of) pollutants.

Preliminary results indicate that bay-to-reef fluxes were highest during the wet season and higher in the bay mouths compared to the adjacent reef sites. Local differences among bays also existed, for examples by high $\delta^{15}N$ values of sediments in Piscadera Bay likely caused by the presence of a local waste water treatment plant. Bioassay toxicity responses are currently analysed and will be presented at the ECRS to discuss to what degree and which land-derived pollutants transported from inland bays foremost affect Caribbean coral reef functioning.

ID: 580 / Parallel Session 5-4: 9
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: Orbicella faveolata, southeast Florida restoration, stony coral tissue loss disease

"Regional survivorship, predation and growth of outplanted fragments from resilient *Orbicella faveolata* in southeast Florida"

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Over 300 corals >2 m in length have been documented in nearshore habitats in southeast Florida, the majority being *Orbicella faveolata* dating up to 320 years old. Since 2015 many have died or lost over 90% of their living tissue due to environmental and anthropogenic stressors including stony coral tissue loss disease. Healthy-looking extant colonies that have persevered the conditions others did not indicates their resilience. Fragments of these colonies with a low probability of survival found during monthly visits were collected opportunistically to restore recently dead colony surfaces. Five genotypes of *O. faveolata*, were collected, held in an ex-situ nursery, and propagated onto 384 2 cm disks. 96 cement convex domes containing four fragment disks were outplanted on eight coral skeletons near Fort Lauderdale (n=4) and Key Biscayne (n=4). 43 domes included predation exclusion devices constructed of biodegradable polyhydroxyalkanoate. Predation, survivorship, and growth were analysed to determine the effect of genotype, regions, and monitoring periods. Preliminary results indicated that 99.7% of the fragments remained attached and 6.5% showed signs of minor predation with subtle damaged on a few polyps after 1 month. The predation was not significantly different between genotype, monitoring period, or region. The efficacy of the predation exclusion devices was not determined because initial predation was low and between weeks 1 and 2, 99.3 % of the straws were detached due to an extreme weather event. Monitoring will continue and be presented along with analyses of outplant tissue growth. These colonies are an important source of disease-resistant donors for future restoration of this threatened species. The hope is that outplanting fragments of several genotypes on old dead colonies that can quickly fuse to a reproductive size will increase sexual reproduction success to produce a generation of disease-resistant corals and restore the ecological functionality of this species.

ID: 402 / **Parallel Session 5-2: 16**
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: Reef restoration, Culcita schemideliana, Scleractinian corals, Corallivores, Maldives

Cushion stars (*Culcita* spp.) undermine coral restoration: assessing predation impact on Maldivian reef rehabilitation efforts

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Natural reef recovery and active restoration efforts are often impeded by ongoing, targeted feeding of corallivorous predators like crown-of-thorns starfish (*Acanthaster*) and *Drupella*. Cushion seastars (*Culcita*) are also predatory on corals, regularly favouring smaller colonies (< 10cm) from the genus *Pocillopora* and *Acropora*. In the Maldives specifically, natural predation levels have been exacerbated following two recent major bleaching events in the region. In addition, effective reef restoration and rehabilitation methods (which are increasing on a global scale) are dependent on the recolonisation and successful transplantation of corals often starting with members of these same genera and colony or fragment size. To date, the risk corallivores pose on outplant survivorship and restoration success at large-scale has not been assessed. Here, we aimed to initially document the population densities of *Culcita schemideliana* on a degraded reef system in the Maldives (Kunfunadhoo), and map their associated predatory effects on coral recruits and transplants, as well as explore the benefits of *Culcita* removal on the survival of these coral. Population densities ranged between 1.2 – 3.3 individuals per 100m² and resulted in relatively high predation rates on natural coral recruits (4 – 20%) and transplants (11 – 43%). Across all sites, *Culcita* predation accounted for most of the observed mortality (83%). In experimental plots, where *Culcita* were removed, we showed a significant trend in survivorship for both recruits (9.1% higher) and transplants (24.2% higher). Further field observations revealed that after starfish removal ceased, the same sites saw upwards of a 52% increase in predation again. These results clearly demonstrate the negative effects *Culcita* have on degraded Maldivian reef systems and indicate that they are significantly hampering restoration efforts. We therefore offer credible justification for the population management of *Culcita*, particularly when integrating a passive approach to an active restoration project in the Maldives.

ID: 304 / **Parallel Session 5-2: 11**
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: Coral Asexual Reproduction, Environmentally Friendly, Transplantation

Application of an efficient, environmentally friendly, and affordable coral asexual reproduction and transplantation technology in China

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The commonly used technique for coral transplantation in China involves fixing steel nails to coral reefs and attaching coral fragments to these nails. However, this method has several drawbacks, including difficulty in securely fixing the coral fragments and a low survival rate after transplantation (typically around 20-25%). To address these issues, our research introduces a new technique that employs perforated angle steel bars to quickly assemble a coral seedbed of appropriate size at the restoration site, thereby reducing transportation costs. This seedbed can be securely fixed to a sandy seabed with strong resistance against winds and waves. While on the ship, 10-15 coral seeding pods are first fixed onto the perforated angle steel bar using screws, before planting coral fragment (3-4 cm) into each device. Subsequently, the whole steel bar is screwed onto the designated coral seedbed underwater by divers. After six months, the perforated angle steel bar together with the attached seeding pods can be detached from the coral seedbed and transplanted onto the target coral reef in need of repair, either as a bar or as individual seeding pod. In our study, we planted 500 coral seeding pods with coral fragments onto the designed seedbed. After six months, we examined the growth condition of the corals and found a survival rate of 95.7%. Subsequently, 400 corals were transplanted with their pods onto coral reefs, and achieved a survival rate of 92% after six months.

ID: 624 / **Parallel Session 5-4: 11**
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: Oxidative stress, Restoration sites, Catalase, Glutathione-S-transferase, Superoxide dismutase

Coral restoration efforts: Understanding the oxidative stress enzymes response in restoration and natural sites

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The initial phase of corals restoration, the presence of rubbles and disturbed sedimentation can lead to an increase in reactive oxygen species (ROS) production. Algae and microorganisms in the sediments and also on the coral nubbins may respond by upregulating various antioxidant enzymes. As the restoration progresses and vegetation cover increases, the oxidative stress response may start to decline depending on the environmental status of the restoration sites. Establishment of algae communities and different organisms contribute to sediments stabilization, nutrient cycling, and the overall improvement of ecosystem health. This can lead to a more balanced redox state and a reduction in oxidative stress. This study investigates the oxidative stress responses in two coral species; *Acropora digitifera* and *Pocillopora* sp. in both restoration and natural sites at Pulau Bidong, Terengganu, Malaysia. Three different enzymes where measured which are Catalase (CAT), Glutathione-S-transferase (GST) and Superoxide dismutase (SOD) to access the oxidative stress response in those coral species. This approach is crucial for assessing the health and resilience of the ecosystems. Results indicated that the sites and species did not have significant impacts on enzyme response ($p>0.05$). Both selected corals species have similar thermos-resistance and resilience in both restoration and natural sites. This study has great potential to be expanded further and to support conservation work. Monitoring key antioxidant enzymes and their expression levels can provide insights into the adaptive strategies employed by different species of corals in response to environmental challenges.

ID: 385 / **Parallel Session 5-2: 15**
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: Coral cultivation, water treatment, OPO, holobiont, RAS

Safe applications of ozone in tropical marine RAS: determining impacts of ozonation on *Xenia* and *Stylophora* holobionts

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The maintenance of good water quality is crucial in recirculating aquaculture systems (RAS). Ozone (O_3) has seen an increase in interest among aquafarmers worldwide as a water treatment tool with a wide array of beneficial effects and is a common element in many tropical marine aquaria. Besides its germicidal properties, O_3 can enhance solid removal, degrade geosmin and other biogenic molecules, and oxidise toxic nitrogen compounds. While its application in freshwater is mostly unproblematic, ozonation of seawater creates secondary oxidants due to the oxidation of naturally occurring bromide ions (Br^-). These by-products of ozonation ('ozone-produced oxidants' = OPO) can be detrimental to animal health, and their impacts on tropical corals are still largely unknown. We aimed to define safe limits of ozonation for tropical hard – and soft corals (*Stylophora* sp. and *Xenia* sp.) by conducting an acute toxicity experiment in which mortalities were recorded following exposure to seven levels of ozonation over 96 hours. In a follow-up chronic exposure experiment we determined the impacts of three sub-lethal ozonation levels on animal health by monitoring respiration - and photosynthesis rates, as well as fluorescence signals over the course of four weeks. Since OPO have been shown to act on microbial biofilms, monitoring of physiological stress parameters was accompanied by 16S gene sequence analyses of coral surfaces. Early results of our study showed that *Xenia* is more susceptible to ozonation by-products, with first mortalities occurring after 48 h at 600 mV, while only after 72 h at 750 mV in *Stylophora*. Furthermore, chronic exposure to 500 mV resulted in higher net photosynthesis and lower photosynthetic efficiency in *Xenia*. Our study represents the first analysis of OPO-induced impacts on coral holobionts and can aid as a guideline for the safe application of ozone in tropical marine RAS.

ID: 827 / **Parallel Session 5-6: 14**
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: Coral, Regeneration, Coring

Orbicella faveolata core sampling impacts and tissue regeneration as an indicator of colony health in Southeast Florida

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Anthropogenic (anchors, scuba divers, tissue sampling) and natural disturbances (corallivory, storm damage) can wound living coral tissues, negatively affecting their life processes and impacting their ecosystem function. Wounding can impair coral growth, reproduction, and increase disease susceptibility, yet it can also increase growth rates through microfragmentation, which is the main principle behind asexual coral propagation. Tissue regeneration rates are indicative of a colony's condition, but they vary inter and intra-specifically depending on intrinsic factors (lipid stores, colony size, symbionts) and extrinsic factors (temperature, light, nutrients). Understanding the relationship between the factors that affect tissue regeneration is needed for it to be a useful indicator. Additionally, it is important to quantify the long-term impact that tissue sampling has on a colony. This study opportunistically assessed the tissue regeneration rates and impacts of core sample lesions between latitudes, stages of gametogenisis and terrestrial nutrient exposure on the reef-building species *Orbicella faveolata*. In 2021-22, eighty-seven colonies (45 in SE FL and 42 in the lower FL Keys) were sampled over three periods corresponding to different environmental conditions and stages of gametogenesis (1,717 cores). The difference in area (mm^2) between initial coring until Spring 2023 (410-951 days) divided by the interval were used to determine daily regeneration rates and assess the long-term effect of core sampling. Preliminary results found that 20.69% of cores almost healed, 24.14% were predated, and 3.45% were diseased. Mean regeneration rates were significantly lower in Looe Key (8.6 mm yr-1) than Sand Key (12 mm yr-1) or southeast Florida (12.3 mm yr-1). There was no significance between colonies with previous stony coral tissue loss disease lesions or nutrient exposures. Further analysis will examine differences in regeneration rates with histopathology and multiple omics datasets generated from the core samples to understand why Looe Key corals did not recover as quickly.

ID: 346 / **Parallel Session 5-2: 13**
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: restoration modeling, adaptation, future projections, coral resilience

Assessing coral intervention efforts in Hawaiian reefs under future climate scenarios

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Interest in active coral restoration is increasing as a local response to the escalating impact of climate change on coral reefs worldwide. These management strategies range from fragmenting and outplanting "corals of opportunity" to more experimental endeavors such as assisted migration or gene flow. The efficacy, ecological ramifications, and scalability of active interventions remain broadly untested. Furthermore, the success of interventions is likely site- and population-specific and might prove detrimental if unforeseen and unintended consequences occur. Therefore, designing intervention plans necessitates careful consideration of the targeted locations, coral populations, and stakeholder goals. Population modeling can help to inform the efficacy of intervention plans on a larger scale than experiments allow. Modeling approaches incorporating multiple population characteristics (i.e., demography and population genetics) are necessary to capture the complex array of potential interventions adequately. Here, we present a regional case study evaluating the effectiveness of various intervention strategies for three genera—*Porites*, *Montipora*, and *Pocillopora*—at multiple sites in the Main Hawaiian Islands. Employing a novel coupled demographic and quantitative genetic model, we forecast the site-specific coral populations under different future climate scenarios and test the viability of multiple hypothetical and proposed intervention strategies (i.e., outplanting, increasing survival of larvae, and assisted migration) on population persistence and growth. This work aims to provide a data-driven decision-support tool for Hawaii-specific reefs to inform reef managers on the intervention methods and frequencies that are most viable. Although climate change is global and requires large-scale changes in emissions, a "one size fits all" management approach may not work. Therefore, it is crucial to understand and adapt local interventions to local needs. Data-informed modeling approaches such as the one presented here will play an important role in determining how local reefs will persist into the future.

Posters

ID: 494
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: coral, recruit, aquaculture, light, spectrum

Influence of artificial and natural light spectra on the grow-out of Caribbean coral recruits.

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Coral populations globally have been declining due to numerous direct and indirect anthropogenic stressors, including rising sea temperatures, coral diseases, and pollution. To minimize this decline and preserve genetic diversity, land-based nurseries have been sexually propagating corals to repopulate reefs. While the methodologies to induce corals to spawn and rear their larvae are well established, the grow-out stage remains to be fully optimized. The quantity and time it takes corals to reach a size suitable for outplanting is affected by many factors, including light, as that is vital for supporting their symbionts. This study investigates the post-settlement survival and growth of the reef building corals *Colpophyllia natans* and *Pseudodiploria strigosa* under three light spectra: (1) radion aquarium lights with a blue-shifted spectrum peaking in 400-450nm, (2) radion aquarium lights to mimic light spectrum at a 10m (reef) depth; (3) natural sunlight spectrum at surface/shallow. All treatments had the same level of photosynthetic active radiation (PAR) with a gradual increase from 25 µmol photons.$m^{-2}s^{-1}$ at week 0 to 200 µmol photons.$m^{-2}s^{-1}$ at week 19. Through the course of seven months, the coral recruits will be checked for survival, and have their growth measured monthly. The blue shifted spectrum was expected to perform best as coral symbionts have shown higher photosynthetic rates under blue-shifted light; however, at week 15 its results are not very different from the reef-depth mimic. As expected, corals under shallow water sunlight spectrum are performing the poorest, likely because it induces oxidative stress. The findings from this study may help inform future aquaculture practices for coral restoration efforts by identifying a light spectrum that promotes the fastest growth rates while minimizing early life mortality.

ID: 586
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: Coral, Restoration, Bidong Island, Spawning, Malaysia

Successful spawning of transplanted coral at Bidong Island, Terengganu, east coast of Peninsular Malaysis

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In Malaysia, the tropical storm (Pabuk - January 2019) caused damage to the shallow water reef on Bidong Island, Terengganu. There was a significant loss of live corals and associated organisms. The population of live corals in Pantai Pasir Cina decreased from an average of 60% to less than 10% after the catastrophic storm. A total of one metre long pile constructions made of a combination of L-shaped stainless steel and PVC were installed. Corals were then transplanted by attaching selected fragments of different species to the cement on top of the PVC-R/pile structures using epoxy resin. The selected species include *Acropora digitifera* and *A. muricata*. The project started in July 2020 in Pantai Pasir Cina, which was severely damaged by tropical storm Pabuk in January 2019. The transplanted coral colonies were measured in terms of length and colour health code. The increase in length shows a positive result as the corals are growing. The discolouration of the corals (pale colour) shows that the corals are losing symbiotic algae and are under stress. However, a darker colour compared to the Coral Health Chart indicates a healthier coral as it contains more symbiotic algae that give the coral its colour. Mass spawning of the transplanted corals was observed in September 2023, indicating the success of the restoration efforts.

ID: 804
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: Artificial light at night (ALAN), Bioacoustics, Coral reef health, Herbivory, Soundscapes

Using bioacoustics to explore the impacts of artificial light at night (ALAN) on coral reef health.

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Natural day–night light cycles have been disrupted in many ecosystems by the presence of artificial light at night (ALAN). Increased urbanisation has led to the pervasive presence of ALAN on land, but this additional light has also encroached into coastal waters where coral reefs are often found. Since many biological processes are dependent on natural day–night light cycles, ALAN may have detrimental impacts on marine communities and ecosystem health. Bioacoustics are increasingly used to monitor marine habitats, including in assessing biodiversity and ecosystem function. We aim to use acoustic recordings and herbivory-rate measurements—herbivorous activity on coral reefs controls the overgrowth of benthic seagrass and algae, and thus marine community structure—to assess the impact of ALAN on coral reef health in the Red Sea. We will compare the soundscapes of naturally dark reefs to historically lit reefs and their un-lit outer peripheries. Additionally, we will conduct daytime fish community and benthic surveys to observe any differences in the spatial distribution and diversity between sites where night recordings have taken place. In the laboratory, we will compare the biomass of benthic seagrass and algae before and after long-term exposure to four different nighttime light treatments: dark (control), LED light, red LED light and dim light. This investigation will help to highlight the impacts of ALAN on coral reef health and suggest potential light mitigation strategies that could be established: this is a necessity as coral reef communities continue to face a plethora of anthropogenic stressors threatening their survival.

ID: 485
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: Coral reefs, Oil spills, Chemical herding agents, Dispersants, Toxicity

Acute toxicity of an oil spill herding agent to Atlantic shallow-water corals

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Oil spills pose a significant threat to coral reefs and other nearshore environments. Several emergency spill response methods can be deployed to contain and minimize the effects of spills, including mechanical containment and recovery, in-situ burning, use of sorbents, bioremediation, and application of dispersants. Chemical herding agents, which can contain and control the spread of oil, have emerged as a promising addition to the spill response toolbox as a potential alternative to other response agents. Herders are designed to be biodegradable and minimize potential harm to aquatic ecosystems. However, the oil spill response community needs data about the toxicity of herders to assess their usefulness in sensitive ecosystems such as coral reefs, where other chemical agents are not typically authorized for use. To address this knowledge gap, the acute toxicity of the herder Thickslick 6535 on two species of shallow water Atlantic scleractinian corals (*Acropora cervicornis* and *Porites divaricata*) was determined in two separate 96-hour static renewal tests. The corals exhibited a range of dose-dependent responses to herder exposure; low concentrations resulted in mild to moderate polyp retraction, while higher concentrations resulted in moderate to severe polyp retraction, bleaching, and thinning of tissue leading to mortality. The 96-hour acute exposure thresholds (LC50) were 285.1 mg/L for *Acropora cervicornis* and 329.5 mg/L for *Porites divaricata*. The LC50 values fall within the range previously reported for marine invertebrates such as *Tisbe battagliai* (copepod) and *Mysidopsis bahia* (shrimp). This study provides new data on the effects of herders on shallow-water corals to support spill-response decision-making and inform Net Environmental Benefit Analysis (NEBA)/Spill Impact Mitigation Assessment (SIMA).

ID: 446
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: Corals, Emerging contaminants, Physiological parameters, Red Sea, Sustainable development

Bioaccumulation patterns and potential effects of organic and inorganic contaminants in *Pocillopora verrucosa* in the Red Sea

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It has been universally acknowledged that coral reefs are threatened by climate change, whose effects can be magnified by local anthropogenic actions, such as the discharge of effluents from municipal, industrial, and agricultural activities. These effluents contain a broad diversity of dissolved and undissolved products that can have a direct impact on the health and function of coral reefs, since corals have a high capacity to accumulate and concentrate different compounds in their tissues. The distribution of contaminants has been studied worldwide in different ecosystems; however, there is still a lack of research and information regarding the concentration and distribution of contaminants in Red Sea coral reefs. Here, we investigate the concentrations of different organic compounds (pharmaceuticals) and inorganic elements (trace metals) in a scleractinian coral (*Pocillopora verrucosa*) and nearby waters in nineteen reefs in the central Red Sea. Reefs were selected, across three distinct locations, with various levels of anthropogenic pressure. Fragments from five colonies per reef were analysed for physiological parameters (e.g., total protein, chlorophyll, symbiont counts), whereas organic and inorganic contaminants were quantified in both the coral tissue and water samples to evaluate the bioaccumulation patterns of classical and emerging contaminants in a reef building coral. This study will contribute to a better understanding of the relationship between the intensity of human activities, the concentration of contaminants in the environment and their potential bioaccumulation patterns in a common Red Sea scleractinian species in a region experiencing intense coastal development. It will also provide baseline information for future scientific research, aiding decision-making, and the sustainable development of the Red Sea.

ID: 531
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: scleractinian, ecotoxicology, UV-filter, coral sensitivity

Assessment of the ecotoxicological effects of the UV filter benzophenone-3 on five different scleractinian corals using a standardizable test approach

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Coral reef systems are increasingly exposed to anthropogenic stressors such as chemical compounds from pesticides, personal care products and other sources. The potential effects of most chemical compounds on corals are still unknown. Organic ultraviolet (UV) filters such as benzophenone-3 (BP-3), commonly used in sunscreens, have recently attracted much negative attention worldwide. While studies have found that BP-3 can be harmful to corals, the effective concentrations have only been demonstrated for individual coral species, leading to a lack of consistency between test systems and ignoring coral species with different sensitivity. The quality of the data could be significantly improved with standardized test methods and an adequate analytical method for compounds quantification.

To compare the sensitivity of scleractinian corals to BP-3, we exposed five common coral species (*i.e., Acropora austera*, *Pocillopora acuta*, *Montipora digitata*, *Pavona decussata*, *Porites cylindrica*) to different concentrations of BP-3 for 96 hours in a semi-static acute ecotoxicological test system. To evaluate the observed effects, several endpoints, *i.e.* mortality, tissue loss, bleaching reduction in photosynthetic yield were measured consistently across all species. Tests included a positive control using diuron (DCMU), and a negative control with only artificial seawater.

The chosen concentrations of BP-3 impacted all tested coral species, albeit to varying degrees, establishing a sensitivity ranking from most sensitive to least sensitive as followed: *Acropora austera* > *Pocillopora acuta* > *Montipora digitata* > *Pavona decussata* > *Porites cylindrica.*

The use of a reproducible test system for all coral species leads to improved comparability of results and shows a spectrum of sensitivity to BP-3 in different species. Our results underline the need to develop standardized test methods with representative species to obtain results that could enable informed policy making regarding possible regulation of chemical substances used in agrochemicals, pharmaceuticals or personal care products.

ID: 714
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: deep reefs, assisted recovery, nature-based solutions

The restoration of deep reefs: the use of 3D-printed artificial reef structures (ARS) in the Life DREAM Project

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The use of 3D structures to support the recruitment of larvae and the growth of reef-forming species is the most common approach to assist and speed up the recovery of endangered reef habitats in the deep sea. These structures, known as Artificial Reef Structures (hereafter ARS), can be placed in sheltered areas and eventually relocated back to degraded reefs. In the framework of the EU-funded Life-DREAM Project, specific ARS have been designed to offer as much surface area as possible to corals' settlement. ARS have been produced using the 3D-printing technique, allowing the pozzolanic ceramic they are made of to mimic the rough surface of natural mound-shaped coral reefs, offering the larvae of the reef-forming species an eco-friendly substrate to recruit on. ARS will be deployed in the four project areas—Bari and Dohrn canyons in Italy, Seco de Los Olivos seamount in Spain, and the National Marine Park of Alonissos in Greece—at a depth range of 80–400 m with the support of a light-working Remotely Operated Vehicle (ROV) equipped with a manipulator arm for their correct and precise positioning. ARS will be strategically located to allow optimal exposition to suitable plankton-rich currents, increasing the chances of larvae settlement. Additionally, ARS will provide a complex physical structure, promoting the return of vagile benthic megafauna and fish, acting as a refuge for other species in the area and improving the success of ecosystem recovery. The long-term monitoring of the success of this action will be possible in each project area through the deployment of remote Deep-Sea Observatory Systems (DSOS) equipped with autonomous imaging devices.

ID: 281
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: coral bleaching, bleaching mitigation, pulsed upwelling, reflectance spectra, high-performance liquid chromatography

Pulsed artificial upwelling (AU) can reduce coral bleaching during thermal stress as indicated by elevated photo-pigment concentration (determined by reflectance spectra and HPLC) under strong AU scenarios

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As global warming intensifies, so does the need to find ways to mitigate coral bleaching (heat-induced loss of endosymbionts) and death. Artificial upwelling (AU), the uplift of cooler deep water toward the surface, could be a useful tool during a marine heat wave for thermal stress mitigation. Here, we experiment with short AU pulses (1-5 hours a day) rather than continuous AU to reduce potential negative side effects of AU. We conducted a 6-week outdoor experiment in Bermuda that assessed the effect of different AU scenarios (3 depths of water [30, 60, 90m] and 4 durations of pulses [1, 2, 3, 5 hr]) on 3 coral species (*Porites astreoides*, *Montastraea cavernosa*, and *Millepora alcicornis*) exposed to thermal stress in late summer 2023. To quantify the level of bleaching, we assessed pigment concentration (a) indirectly via reflectance spectra measurements (non-destructive approach) and (b) directly via HPLC tissue sampling. Both approaches were used to determine the relationship between the two methods, with the goal to use spectral measurements rather than destructive and costly HPLC measurements in future experiments that include these corals. Initial results show a strong relationship between the shape of the reflectance curve (between 300 and 850 nm) and visual signs of bleaching, in particular, the characteristic "dip" in the reflectance spectra at ~670 nm for chlorophyll-a. Using reflectance as an indicator for bleaching, we found less bleaching in corals that were exposed to more extreme AU scenarios with duration of AU resulting in a stronger effect than depth. Finalized results (spectra and HPLC) will be discussed in the context of AU efficacy and the context of spectral measurements being a tool for determining pigment concentration.

ID: 183
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: Nanoplastics, Alcyonaceans, Coral bleaching

Effects of polypropylene nanofibers on soft corals

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Current information regarding the effects of both micro- and nano-plastic debris on coral reefs is limited; especially the toxicity onto corals from nano-plastics originating from secondary sources such as fibers from synthetic fabrics. Within this study, we exposed the alcyonacean coral *Pinnigorgia flava* to different concentrations of polypropylene secondary nanofibers (0.001, 0.1, 1.0 and 10 mg/L) and then assayed mortality, mucus production, polyps retraction, coral tissue bleaching, and swelling. The assay materials were obtained by artificially weathering non-woven fabrics retrieved from commercially available personal protective equipment. Specifically, polypropylene (PP) nanofibers displaying a hydrodynamic size of 114.7 ± 8.1 nm and a polydispersity index (PDI) of 0.431 were obtained after 180 h exposition in a UV light aging chamber (340 nm at 0.76 $W \cdot m^{-2} \cdot nm^{-1}$). After 72 h of PP exposure no mortality was observed but there were evident stress responses from the corals tested. Specifically, the application of nanofibers at different concentrations caused significant differences in mucus production, polyps retraction and coral tissue swelling (ANOVA, $p < 0.001$, $p = 0.015$ and $p = 0.015$, respectively). NOEC (No Observed Effect Concentration) and LOEC (Lowest Observed Effect concentration) at 72 h resulted 0.1 mg/L and 1 mg/L, respectively. Overall, the study indicates that PP secondary nanofibers can cause adverse effects on corals and could potentially act as a stress factor in coral reefs. The generality of the method of producing and assaying the toxicity of secondary nanofibers from synthetic textiles is also discussed.

ID: 438
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: coral spawning, larvae settlement, larval enhancement, reef restoration

Monitoring coral spawning and larvae settlement to understand the reasons for rapid coral recovery on a lava flow

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The 'Lava flow' reef at Gunung Api, Banda Islands, Indonesia, experienced extremely rapid coral reef recovery after a volcanic eruption in 1988 had destroyed the former reef. Five years later, *Acropora* table corals larger than 90 cm and 124 different coral species were recorded on the cold lava stream. The reason for this rapid colonization was never studied after that. We started monitoring the timing of coral spawning at the reef in 2016 and recorded more than 20 multi-specific spawning events since then. Understanding spawning patterns provides opportunities for studies investigating the reasons for the rapid recovery of the reef. Here, we present results on settlement experiments with *Acropora* larvae, comparing porous lava rock, rocks with a smoother surface, and coralline crustose algae (CCA). Larvae were reared from gametes collected during mass spawning events at the water surface. Larvae development was monitored and when ready to settle larvae were transferred to Petri dishes (20 larvae each in 20 dishes) or released underneath fine nets into a formerly damaged reef (5200 larvae each in 17 nets). Petri dishes and nets contained the same combination of the 3 different substrates. Settlement was counted daily in the laboratory and weekly to monthly in the field. The preferred settlement substrate in the laboratory was CCA, followed by lava rock and then smooth rock. In the field, initially more larvae settled on the smooth rocks, but first signs after 3 months show that recruits on the lava rock grew faster. We will discuss these findings in the context of the role of the Lava flow as highly important reef for providing coral propagules to other reefs and show that larval enhancement for reef restoration can easily be conducted by local students in remote areas in Indonesia, given that a minimum of guidance is provided.

ID: 802
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: Pigment, Symbionts, Photo-physiology, Personal Care Product (PCP)

Arthrospira platensis' pigment based product and glycerin modify the *Cladocopium goreaui* photophysiology

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Personal Care Products (PCP) containing ultraviolet filters (UVFs) and emollients are known to be a threat for coral reefs. UVFs exposure can lead to toxicological disruptions such as oxidative stress or photo-physiological damages in corals. Some molecules (octocrylene, oxybenzone) are proven to be harmful and prohibited in certain countries (Hawaii, Palau). In order to develop safe and authorized PCP, cosmetic industry tries to find out new products to counteract these deleterious effects.

In our study, we tested the effects of a new pigment based product: extracted from the cyanobacteria *Arthrospira platensis*, as well as those of a widely-used solvent (glycerin) on the coral endosymbiont *Cladocopium goreaui,* in a 22 days batch culture. Symbionts were exposed to three concentrations (0,016 ; 0,16 and 1,6 mg.L^{-1}). The minimal concentration was chosen to represent a predictive environmental concentration (PEC). Algal physiological performances (growth rate, generation time) and photo-physiological parameters using PAM fluorometry (rETR, Fv/Fm, JIP-test) were assessed during growth and stationary phase.

Glycerin shows a concentration-dependent effect on ETRm and alpha values. After 12 days, the intermediate and highest glycerin concentrations result in a 6% and 9% reduction in ETRm values respectively, compared with the control ones. At the same time, alpha values also decrease by 5%. Other parameters, do not show any significant modification across glycerin concentrations. A-12 days high-concentration pigment exposure results in a 14% decrease in ETRm relative to the control. However, NPQ increases by 50% when exposed to the lowest concentration.

Our results demonstrate that both glycerin and *Arthrospira plantensis*' pigment impact the symbiont's photosynthetic system by inducing higher NPQ and lower ETRm values. At first glance, our study challenges the value of incorporating such products in PCP but before, these effects need to be confirmed by testing the same concentrations on coral colonies containing this type of symbionts.

ID: 849
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: coral restoration, coastal defense, engineering, biodiversity

Engineering rapid resilient coral reefs for coastal defense and biodiversity enrichment

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Coral reefs provide number of important ecosystem services, including protection of coastal erosion, increased biodiversity from structural complexity, and enhancing the natural beauty of the ocean that contributes to human enjoyment and well-being. Traditional approaches to coastal erosion prevention implement coastal hardening solutions like breakwaters, sea walls, or jetties. However, these approaches typically require long-term investments and repairs due to destruction from wave energy, biofouling, and material decomposition. The rapid resilient reefs for coastal defence project (R3D) is comprised of an array of submerged hybrid (man-made foundations with living reefs) structures modelled after a fringing reef. In addition to wave attenuation, the R3D reef is designed to increase recruitment of fish and coral, enhance coral growth, reduce the presence of invasive algae, and be populated with locally grown thermally tolerant corals to prepare for future ocean conditions, thereby supporting coral reef survival, reproduction, and self-recovery over time. The primary goal is to rapidly produce a reef that can support large and complex community of marine life as well as protect the coastline. These are the same benefits that are provided by naturally occurring reefs, which typically take decades or centuries to develop. Here we describe the R3D project being undertaken on the island of Oʻahu, Hawaii USA. Reef mimicking structures form an array 50 m across by 100 long, and is made up by 40 reef crest structures and 45 back reef structures. Ecosystem engineering and adaptive biology components enhance coral recruitment and reduce competitive algal growth, encourage coral settlement, and stimulate rapid coral growth. Selectively bred thermally tolerant corals enhance survivorship during warming events, and lighting is designed to attract plankton to enhance coral nutrition. Endemic herbivore introductions, playback devices to attract herbivorous fishes, and other project together contribute to a new standard for coral reef restoration projects.

ID: 368
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: cryopreservation, cryorepository, coral, long-term storage, cryojig

A breakthrough in novel cryopreservation technique applied to coral larval cryorepositories

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The establishment of cryorepositories plays a crucial role in achieving the paramount goal of preserving biodiversity. The rapid decrease in the population of coral species has emerged as a worldwide apprehension, with numerous species teetering on the verge of extinction. One approach to tackling the problem of preserving genetic material to prevent coral extinction is by creating cryorepositories and employing advanced vitrification and laser warming techniques. Current methodologies employing laser warming have primarily focused on conducting proof-of-concept trials. However, there are currently no established protocols or techniques that specifically address the issue of how to laser warm the samples that have been vitrified and stored in cryogenic conditions for an extended period of time in cryostorage or cryorepository facilities. In this study, a novel customized device was developed using a single-jig design with a self-made cryostick as a sample holder that allowed vitrification, long-term storage, and the subsequent rewarming of coral samples from a cryorepository. Before laser warming, the samples on the cryosticks were securely stored in dewars. The customized device and cryojigs exhibited a laser-hitting accuracy of 95% on the samples obtained from the cryorepository. Additionally, the device achieved a successful vitrification rate of 62% on samples with a volume of less than 1 µL. This novel technique signifies a promising initial advancement in using lasers to warm samples from the established cryorepository. The development of cryorepositories serves to address the urgent requirement of safeguarding coral species and aiding future coral conservation endeavours.

ID: 700
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: Acropora palmata, Restoration, Long-term monitoring, Tropicalization

Assessing the restoration potential of *Acropora palmata*, a critically endangered coral species, at its northern extent in southeast Florida

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Elkhorn coral, *Acropora palmata,* populations have experienced major declines throughout the Western Atlantic in response to disease, thermal stress, and storm events. Tropical storms and hurricanes can cause colony dislodgement and mortality, yet also induce asexual reproduction via fragmentation. Only a fraction of fragments naturally attach to reef substrate and survive. In southeast Florida, the northern limit of the species' range, restoration efforts have been undertaken to attach storm-produced fragments to aid population survival. Over a five-year period, this study monitored the health and survival of all known extant *A. palmata* colonies in Broward County, Florida, where very few extant colonies are found. In doing so, we assessed colony condition and the impact of storm events on *A. palmata*, and the success of attaching storm generated fragments to reef substrate adjacent to the parent colony. Between 2019 and 2023, we tri-annually monitored eight sites. Each site consisted of one parent colony (the largest colony at the site) and its associated fragments, if any. When loose fragments were found during the monitoring events, they were attached to reef substrate with marine epoxy within 0.5-1 meters of the parent colony. Due to low *A. palmata* abundance at each site and the distance between sites, we safely presumed that loose fragments belonged to the adjacent parent colony. Since 2019, the parent colonies experienced partial mortality due to disease and predation yet collectively had 100% survival. Across five of the eight sites, 34 fragments were attached, and 23 were alive one-year post-attachment. Three fragments were attached but died from causes not captured during the monitoring events, and eight fragments went missing, suggesting that dislodgement was the primary driver of the decrease in fragment survival. Nevertheless, with such a small population, facilitated attachment of fragments to the reef enhances the restoration potential of this species.

ID: 795
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: Reef Fish, Coral Reef, Maldives, Climate Change, Monitoring

Spatial diversity in reef fish assemblages across Central Maldivian Atolls

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This study investigates spatial variation in abundance, biomass and species diversity of reef-associated fishes at sixteen reefs within three atolls in the central Maldivian Archipelago. Specifically, we test for the effect of reef habitat (reef crest and slope), geomorphology and management regime (Marine Protected Areas vs unmanaged areas). The coral reef ecosystems of the Maldives have experienced numerous disturbances, including bleaching caused by El Niño, in recent decades. While changes in coral cover and composition have been documented, how these changes may influence spatial variability in fish diversity and abundance across different reefs and atolls is less clear. This study provides a comprehensive assessment of reef-associated fishes in the Maldives and a foundational framework for understanding reef fish community composition, and their potential drivers. Furthermore, this offers insights into the variations across diverse reef habitats and reef systems, and how fish abundance and diversity may impact coral reef functioning. The findings can be used to understand the connectivity between different atolls and inform marine environment stakeholders. Repeated monitoring efforts in the future are critical to determine if and how fish communities are changing in response to changes in abundance, community composition and size structure of coral populations, and other anthropogenic disturbances. This information will greatly enhance our understanding of coral reef resilience and provide valuable information for the strategic planning of Marine Protected Areas in the Maldives.

ID: 629
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: Coral reproduction, Restoration, Coral spawning

Spatial variation in spawning timing for multi-species *Acropora* assemblages in the Red Sea

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Sexual reproduction is a critical process for the resilience of coral populations, enabling genetic diversity and recovery from disturbances. Mass spawning events by *Acropora* species, as a key reef builder group, offer opportunities to maintain populations and biodiversity, and contribute to active reef restoration efforts. However, understanding the timing of coral spawning across the diverse thermal and environmental conditions of the Red Sea remains incomplete. Therefore, coordinated surveys were conducted at three locations in the Red Sea: Al-Fahal Reef (Thuwal, Saudi Arabia) representing the central region, Shushah Island (NEOM, Saudi Arabia) in the north-east, and Hurghada (Egypt) in the north-west. These surveys aimed to evaluate the gametogenesis and spawning timing of 21 *Acropora* spp. colonies (n=572) during the full moons of April and May 2023. We found synchronous spawning occurred in April and May for *Acropora* spp. in the central and northern Red Sea, respectively. Notably, corals in Shushah and Thuwal spawned on the full moon, while those in Hurghada were independent of the lunar cycle, spawning 7-9 nights before the full moon in May. Integrating our 2023 data with historical records revealed a correlation between spawning timing deviation from the full moon and Sea Surface Temperature (SST) metrics (earlier spawning with lower SST) and warming rates in the preceding 6 weeks (earlier spawning with more rapid warming). Temperature patterns, among other factors, likely influence gamete release and determine spawning day within the lunar month. The observed correlations between SST metrics and spawning timing provide a potential framework for predicting future *Acropora* spp. spawning dates. These findings highlight the importance of collaborative, cross-border efforts to gather essential data for effective management and conservation strategies in the ecologically diverse Red Sea region. This is particularly crucial amidst ongoing regional development and active reef restoration initiatives.

ID: 755
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: Mediterranean, ecological restoration, coral reefs, marine protected area, Dendrophyllia ramea

Ecological restoration of a temperate coral habitat and population (*Dendrophyllia ramea*) at Punta de la Mona Marine Protected Area in the Mediterranean (Spain)

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Understanding and mitigating local drivers of temperate coral ecosystems' degradation is crucial for effective conservation and reinforcing ecosystem resilience. Along the Mediterranean coast of Spain, the Marine Protected Area (MPA) of Punta de la Mona faced threats from pollution related to fisheries and anchoring activities, endangering the endemic coral population of *Dendrophyllia ramea*, compromising habitat quality for marine biodiversity, and impacting socio-economic activities. To address this degradation, an ecological restoration project was initiated in 2020 through collaboration between local and international stakeholders. The project sought to mitigate local stressors, reverse the decline of *D. ramea* coral habitat, and promote local reef stewardship to increase ecosystem resilience. This research seeks to answer the question: "How can the recovery of *D. ramea* habitat degraded by fisheries-derived pollution at Punta de la Mona MPA in the Mediterranean Sea be enhanced?". An initial assessment of the area was conducted through a bathymetric characterization and the analysis of rebreather diving video transects taken between 30-47 meters deep. Results revealed depth-dependent variations in the abundance of *D. ramea* colonies and types of impact, as well as the distribution of pollution. These findings informed the development of the ecological restoration strategy. Original restoration methods, including technical seabed cleanups, in-situ coral gardening, and coral transplantation onto natural substrates, were devised. With a mean coral survival rate of 92% over three years, this research provides detailed insights into the implemented restoration techniques.

Simultaneously, proactive restoration efforts included strengthening MPA protection involving the regional government. After three years, a revised MPA management plan is currently under review by the government to control local degradation drivers.

By sharing the methods and results of a three-year endeavour to restore a Mediterranean *D. ramea* coral habitat, this research contributes to the discussion on reinforcing resilience in temperate coral ecosystems, actively involving local communities.

ID: 829
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: Assisted Sexual Reproduction, Coral Propagation, Sex Systems, Coral Aquaculture

Induced sexual reproduction reveals bidirectional sex change of gonochoric coral *Montastraea cavernosa*

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Induction of gonad maturation and synchronously spawning corals ex situ has been common practice in propagated corals for restoration efforts, which provides a unique opportunity to study the reproductive biology of corals. The Marine Larval Ecology and Recruitment Laboratory at Nova Southeastern University has been able to induce *Montastraea cavernosa* corals to spawn synchronously in the laboratory over several years. This was achieved by mimicking the annual temperature and simulating the solar and lunar cycles experienced in the northern portion of Florida's Coral Reef. Similarly to field observations, M. cavernosa colonies in the lab commonly spawned 4-13 nights after the full moons of July, August and/or September, between 18 minutes before sunset to 184 minutes after sunset. This coral species is gonochoric, meaning colonies are either females (release eggs) or males (release sperm). Yet, four consecutive years spawning the same colonies in the lab revealed that these corals can change sex in both directions, sequentially, meaning they are anatomically hermaphrodites. Spawning observations and histology demonstrate corals can shift from male to female, shift from female to male, and can switch from male to female then in the following year switch back to male. Since these colonies were not moved and had the same "neighbours" in the tank throughout the four years, the sex change was not likely socially-driven. A greater number of colonies was observed to shift from female to male when food provision was reduced, meaning more research is necessary to determine the role of nutrition to drive sex changes.

ID: 842
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: Coral, transplant, restoration, parrotfish, PED

Protecting polyps from parrotfish predation; development and deployment of PHA predator exclusion devices

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Florida's coral reefs are in a state of near-constant degradation concomitant with ever-increasing coastal development and associated anthropogenic impacts. Government agencies, non-profits, and concerned citizens have spent significant time and resources combating these negative impacts. One primary method of mitigating damage to coral reefs is to replant degraded reefs with farmed or transplanted coral. While many challenges of reef restoration have been overcome, parrotfish predation on freshly transplanted corals remains a significant issue. Parrotfish are recognized as an essential species on healthy reefs but can also hinder reef restoration efforts by biting young, newly transplanted corals. This project endeavours to reduce the labour and costs of transplant operations by reducing the impacts of predation on transplanted corals. To minimize predation on newly transplanted coral fragments, this project utilizes a protective structure that coral fragments are attached to before transplant.

Three novel prototype parrotfish exclusion devices were tested *in-situ*; these prototypes deemed “Coral Castles,” have a barrier of biodegradable polyhydroxyalkanoate (PHA) tubes integrated with a concrete base. Two separate fragment outplanting trials, one using *Porites astreoides* and one using *Orbicella faveolata*, were monitored for several months. Corals used in this experiment were quarantined in an onshore nursery before fragmentation and subsequent mounting in one of three variants of the prototype before transplantation from the nursery to near-shore reefs.

ID: 694
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: gorgonian, pollution, microbiome

Effects of pollution on mediterranean gorgonian corals (*Leptogorgia sarmentosa*) at the microbiome level

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Anthropogenic-related disturbances such as water pollution impact marine habitats, which affects vulnerable ecosystems like coral-associated environments. However, the mechanisms by which nutrient pollution affects corals and the associated responses of the coral microbiome are largely unknown, limiting our understanding of coral health and its resilience capacity. In this study, we compared the microbiome compositions of a Mediterranean gorgonian population, *Leptogorgia sarmentosa*, residing in the harbour of Barcelona (Spain) with a population from a marine protected area (Cap de Creus, NW Mediterranean Sea) to understand the effects of water pollution in the health status of this gorgonian species. Visually healthy gorgonian samples from *L. sarmentosa* colonies (n=6 from Cap de Creus and n=13 from Barcelona harbour) were collected, and 16S rRNA gene amplicons were analysed to test for microbiome responses to water pollution. Additionally, we inspected colonies from both populations to identify any signs of disease, necrosis, or colony mortality. Colonies of *L. sarmentosa* from the marine protected area (i.e. less disturbed populations) showed microbiomes dominated mainly by Endozoicomonas strains, while colonies from the harbour showed a different bacterial consortium including distinct strains of Endozoicomonas. Moreover, the harbour colonies did not show any visual signs of compromised coral health (n=20 visualized colonies). Overall, our results indicate a shift in the gorgonian microbiomes associated with polluted environments that potentially contribute to maintaining the holobiont health status and may facilitate enduring gorgonian population in disturbed environments. These findings may provide crucial insights into understanding coral adaptability and suggest strong links between the microbiome composition and the resilience of corals to water pollution.

ID: 857
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: coral restoration, coral disease, biobased, transplantation, underwater hardening material

Development of an Eco-friendly Epoxidized Soybean Oil/Talc/Cocoabasedputty for restoration of coral reefs

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Coral reefs provide a habitat for almost one million of aquatic species and numerous ecosystem services. In the last century, a significant loss in global coral cover has led to the development of restoration techniques necessary to recover damaged areas. Among the range of materials used, epoxy resins are frequently employed to transplanting corals, despite their known toxicity for humans and harmful effects on the environment. They are often non-biodegradable and can contribute to plastic waste accumulation. Hence, employing innovative and specifically designed advanced materials for coral restoration is essential.

This project presents a new biodegradable coral putty developed as a two-component self-hardening material. The composition is based on naturally-derived components, including epoxidized soybean oil acrylate, talc, and cocoa powder. The development and fabrication of this new tool have considered the intention of being biocompatible and biodegradable to prioritize the operator's wellbeing and environmental safety. The newly developed materials underwent morphological, mechanical and biodegradability analysis, demonstrating that is stable in seawater, resistant to deformation under pressure, repels water and adheres well to marine substrates. Additionally, it degrades over time, providing a sustainable solution for coral restoration. The putty hardens quickly, ensuring the coral attachment process does not take too long while being strong enough to hold the corals firmly in place. It was also compared with three commercial epoxy resins currently employed worldwide.

The efficacy of the material is being tested in-vivo in the Genoa Aquarium through the microfragmentation technique and tested in-situ over a coral reef in the Maldives, through MaRHE Center facilities. It will be also evaluated whether the new material support a faster growth compared to inert substances and commercial epoxy resins. In conclusion, the cost-effective production and the natural origin of the material's components make it scalable and ideal for extensive applications underwater.

ID: 300
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: budding, polyps, restoration, Tubastraea aurea.

Enhancing Coral Reproductive Efficiency through the Separation of Polyps: Insights from the Asexual Reproduction of *Tubastraea aurea*

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Corals are invertebrates belonging to the phylum Cnidaria. Each individual coral entity is known as a polyp, and a coral group forms a colony consisting of genetically identical polyps. The colonies that give rise to coral reefs are termed hermatypic corals. However, some types of corals, known as ahermatypic corals, are not major contributors to reef construction and do not engage with symbiotic zooxanthellae. Coral populations expand through either asexual or sexual reproduction. Asexual reproduction occurs through methods like budding or fragmentation. In budding, new polyps emerge from parent polyps. The budded offspring are genetically identical to their parents. *Tubastraea aurea*, a type of ahermatypic and azooxanthellate coral, is heterotrophic, feeding on minute organisms and plankton. *T. aurea* reproduces both asexually and sexually. The aim of this study is to find new methods to multiply *Tubastraea aurea* polyps under laboratory conditions. We collected coral colonies and cut them into single polyps, these polyps were monitored from July 2022 to April 2023. The health, growth, and mortality of these polyps were tracked monthly. In the present study, a total of 236 polyps were examined, and by the end of the study, we had a total of 214 newly formed polyps. The number of new polyps showed a significant positive correlation with the weight of the parent polyps ($r = 0.28$, $p < 0.001$). The new method produced significantly more polyps than uncut colonies ($t = 4.16$, $df = 12$, $p = 0.001$, Student's t-test). This study introduces a method with the potential to increase *Tubastraea aurea* asexual reproduction. For the enhancement of efficiency, further studies are needed to optimize culture conditions under varied circumstances over extended periods of time.

ID: 499
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: hermatypic coral, ahermatypic coral, Tubastraea sp., sponges, decommissioning

Using oil and gas industrial imagery for biodiversity estimates: consequence for biodiversity patterns and decommissioning options

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The oil and gas industry needs to decommission ageing subsea infrastructure. Many companies intend to seek special permission to decommission "*in situ*" and need to provide assessments of the marine biodiversity present on subsea infrastructure. In this study, industrial imagery collected by the industry for operational purposes was used to estimate patterns of marine sessile biodiversity.

The percent cover of sessile epibiota was obtained in two ways 1) a quick eyeballing method with ranked abundance and 2) point intercept scoring of images uploaded into Reef Cloud (https://reefcloud.ai/), an online software with machine learning capabilities. More than 64% of points were scored by a human. The rest was identified by auto-classification.

A steel monopod, a concrete platform base with four pillars and other minor subsea structures were dominated by a high percent cover of sponges (54±34SD) and *Tubastraea* sp., a ahermatypic coral (16±20SD). Depth significantly structured the percent cover of sessile organisms such as hermatypic corals (0.4±1.8SD), hydroids (1.1±4.6) and algae (3.6±9) which occurred in highest abundance in the 0-20m depth range. Soft coral (1.8±3.7SD) and *Tubastraea* sp. (16±20SD) occurred most from 0-40m. Bivalves (2.6±3.1SD) were most abundant between 20 and 50 m. Non-metric dimensional scaling revealed weak overall data structure related to site, material and orientation, but those factors significantly influenced specific species. A permanova revealed that most of the variation in the samples stemmed from an interaction between depth and site (P (perm)= 0.029).

Both the quick ranking method and the point intercept method showed the dominance of sponges and *Tubastraea* sp. The a) rapid & b) point intercept methods took a) 29 & b)179 days (@8h/day) of effort, respectively to analyse 5.7Tb of imagery which produced 477 usable images. The lack of image replication across factors yielded very variable biodiversity estimates, which may have obscured patterns.

ID: 754
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: Coral species, Nurseries, restoration

Coral reef restoration in northern Mozambique: techniques, species, and challenges

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This work outlines two coral reef restoration initiatives in northern Mozambique. The first project evaluates the adaptability of four coral species—*Acropora austera*, *Acropora intermedia*, *Pocillopora eydouxi*, and *Porites* cylindrica—transplanted from healthy reefs. The second project employs a "corals of opportunity" approach, restoring over 10 species, primarily *Acropora* sp., obtained from damaged corals. These were nurtured in nurseries for nine months before attachment to rebar spiders. Results highlight variable success rates among tested species, with promising survival and growth rates in both nurseries and rebar spiders. Challenges include limited volunteers, small teams, and logistical hurdles. This research underscores the need for tailored restoration strategies, emphasizing the importance of addressing logistical constraints and community engagement for sustained coral reef restoration in the region.

ID: 544
Coral Reef Anthropic Pressures, Conservation and Restoration

Keywords: Coral transplantation, ship grounding, restoration, Benthic monitoring, Substrate stabilization

Can substrate stabilization and stony coral transplantation promote recovery at ship grounding sites?

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Ship groundings are acute disturbances that alter the benthic community and physical structure of coral reefs. Long-term effects, such as rubble mobilization and sediment accumulation, have been documented to prevent recovery at these sites. In Florida, remediation of ecological services lost at ship grounding sites has historically been attempted through mitigation reef creation with only limited efforts towards promoting recovery of the damaged sites. In recent years, site recovery has been promoted through structural rehabilitation of damaged areas using limestone boulders. Recent studies have demonstrated that stabilizing grounding sites using limestone boulders increased stony coral recruitment and recruit survival. However, it is unclear how biological intervention can further promote benthic biological community recovery at stabilized sites. In this study, we investigate how the transplantation of stony corals to a stabilized ship grounding site influences the benthic community composition and assess whether it further stimulates recovery. Study sites included two ship grounding sites in southeast Florida and four undisturbed reference reef sites nearby. Both groundings occurred in 2006 and damaged areas were stabilized in December of 2015. Stony coral demographic data and benthic community cover were monitored yearly from 2016 to 2023. Between late 2022 and early 2023, 172 corals were transplanted to one of the two grounding sites, increasing stony coral density by 83% and mean stony coral diameter by 52% within the study area. All transplanted colonies were tagged to distinguish them from naturally occurring colonies. In early 2024, transect data will be collected at both grounding sites, as well as reference reef sites, to determine the extent to which benthic community development differs between stony coral transplantation sites and stabilized sites left to naturally recover. The results from this study will elucidate how stony coral transplantation can influence the recovery of disturbed sites on coral reefs.

Session 6: Community-Based Monitoring and Ecosystem-Based Management

Coral reefs are one of the most species-rich and ecologically complex marine ecosystems, which provide food and livelihoods for hundreds of millions of people. However, they are facing global decline due to human-induced pressures, including overexploitation, land-use change, pollution, ocean warming and acidification. Rapid population growth and densely inhabited coastal areas increase dependence on marine resources, which, combined with exacerbating human pressures on coral reef ecosystems, threatens their conservation and the services they provide.

A more holistic management approach is advisable to address coral reef ecosystem threats and challenges. Ecosystem-based management incorporates the full range of interactions within ecosystems, moving away from traditional strategies focused on conserving individual species. It favours an integrated approach considering multiple impacts and all connections between species, ecosystem components and humans. This holistic approach aims to ensure sustainable ecosystems, thus safeguarding the goods and services they provide for future generations. However, as ecosystem-based management is applied to large and diverse areas and over large time scales, more spatial and temporal data are needed to help management make sound decisions for coral reef conservation. To bridge the gap, decision-makers and non-governmental organizations worldwide are increasing volunteers' involvement to improve their ability to monitor and manage natural resources through citizen science projects and other participatory approaches, at the same time increasing civil society's awareness on environmental issues and its involvement in decision-making processes. As a consequence, reliable scientific data are co-produced and can be used within the so-called quintuple innovation helix framework (academia-industry-government-civil society-environment) to address sustainable development.

This session aims to highlight actions and methods focused on ecosystem-based management and community-based monitoring of coral reefs and coral related habitats. Contributions may include, but are not limited to, studies that bridge the gap between management strategies and participatory approaches, provide new technologies that support long-term community-based monitoring, implement marine spatial planning resulting from ecosystem-based management approaches, apply nature-based solutions to habitats protection and restoration.

Keywords: marine spatial planning, stakeholder engagement, citizen science, people awareness

Session chairs

Fiona Merida, Great Barrier Reef Marine Park Authority (Australia)

Massimo Ponti, University of Bologna (Italy)

Take home message

- Well-informed Ecosystem-Based Management (EBM) are urgently necessary to implement proper marine habitat and biodiversity conservation strategies worldwide
- Environmental policies cannot do without robust data and effective involvement of local populations and citizens in general, as primary stakeholders
- Well designed, standardised and indefinitely planned Citizen Science projects can potentially provide both scientifically sound Community-Based Monitoring data and option to fill the gap from managing authorities and citizen

Regular oral presentations

ID: 456 / Parallel Session 6-1: 2
Community-Based Monitoring and Ecosystem-Based Management

Keywords: Citizen science, coastal temperate reefs, conservation, marine spatial planning, species distribution models.

Ensemble species distribution modelling of key octocoral species to support spatial planning and conservation of Mediterranean coralligenous assemblages.

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The pivotal challenge posed by marine spatial planning underscores the crucial role of species distribution knowledge in conservation ecology. This understanding is essential for optimizing management strategies aimed at conserving marine biodiversity. Ecological niche models facilitate the comprehension of how environmental factors may influence species occurrence, providing spatially explicit information relevant to species' conservation and management. In this context, modelling the distribution of key marine habitat-forming species becomes necessary, as it provides protection for a large number of co-occurring species, warranting priority in spatial planning strategies. Thus, we compiled information on the occurrence of the most abundant and representative octocoral species in Mediterranean coralligenous assemblages (*Corallium rubrum, Eunicella caovlini, E. singularis,* and *Paramuricea clavata*) using diverse sources, including peer-reviewed studies and technical reports (i.e. CorMedNet database), citizen science platforms (i.e. *Observadores del Mar* and Reef Check Med), local ecological knowledge initiatives, and the OBIS database. We then employed an ensemble approach to construct ecological niche models at both regional (i.e. Mediterranean Sea) and local (i.e. Costa Brava, north-western Mediterranean) scales. The model estimates at a regional scale are mainly influenced by seafloor roughness and temperature. At the local scale, we identified areas with high habitat suitability, particularly in locations characterized by steeper slopes and high roughness. Results indicate that the potential habitat distribution range for the four species may encompass about 25% of the entire Mediterranean coastal area, with 19% lying under existing protection regimes. However, these estimates reveal intermediate to high levels of uncertainty in distant areas, particularly those far from known species occurrences (e.g. south-eastern Mediterranean). Combining regional and local perspectives enhances our ability to develop comprehensive management and conservation strategies, highlighting focal areas for exploration and providing spatially explicit information to support the adaptation of conservation measures to the appropriate scale.

ID: 155 / Parallel Session 6-1: 1
Community-Based Monitoring and Ecosystem-Based Management

Keywords: Citizen science, stewardship, ecosystem

High frequency, long-term coral reef site monitoring informs effective restoration and intervention actions at twenty-six coral reef sites in the Great Barrier Reef

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The Australian government through the Great Barrier Reef (GBR) Marine Park Authority (MPA) has worked with tourism operations on the GBR for over 20 years through a voluntary eco-certification program to ensure the GBR Marine Park is protected and shared with visitors in an environmentally sustainable manner. The actions eco-certified operators take are informed by weekly Eye on the Reef health surveys and species counts. This long-term dataset is now guiding stewardship and intervention actions taken at tourism sites including crown-of-thorns-starfish control, *Drupella* control, assisted natural recovery measures and coral restoration programs. A well protected and healthy coral reef ecosystem is at the heart of a successful coral reef tourism business, restoration and rehabilitation projects that are poorly planned and implemented can reflect negatively on tourism businesses and be costly.

The GBR MPA has worked with tourism operators, scientists, environmental managers, and intervention practitioners to develop a Reef Site Stewardship Framework (the Framework). The primary aim of the Framework is to guide a whole-of-site understanding to improve evidence-based decision making for environmental stewardship practices. It is a systematic and transparent science synthesis process that integrates existing island and reef ecosystem data with expert scientific, localised site observations and historical knowledge (including First Nations Peoples) to develop site-specific Stewardship Plans that can be operationalised by Reef tourism businesses.

As the GBR faces increasing impacts from climate change, localised actions to enhance coral reef resilience and assist recovery at high value sites is critical. The challenge facing coral reef focused tourism businesses is to ensure that stewardship and restoration efforts are designed to be fit-for-purpose to each individual site and can be delivered effectively and efficiently with maximum return on investment. The success of this approach can be demonstrated, with twenty-six high value tourism sites spread spatially and temporally throughout the GBR implementing the Framework.

ID: 458 / **Parallel Session 6-1: 3**
Community-Based Monitoring and Ecosystem-Based Management

Keywords: citizen science, participatory approach, stakeholder engagement, Global Coral Reef Monitoring Network, conservation approach

What's going on at the core of the Coral Triangle? Results from over 10 years of Reef Check and CoralWatch community-based monitoring

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Coral reefs' health is declining worldwide, increasingly threatened by multiple stressors. These include local disturbances, which act synergically with thermal-stress events associated with climate change, triggering regional and global scale bleaching events. Preventing further decline and maintaining the resilience of these habitats requires implementing appropriate and timely ecosystem-based management actions and adaptive management policies, which rely on targeted, long-term, and integrated monitoring programs. Since 2011, two community-based monitoring protocols have been applied annually to collect data and provide baseline knowledge at six study sites at 6 and 12 m depth in Bangka and Gangga Archipelago, North Sulawesi, Indonesia, involving more than a hundred people, including students, researchers, and tourists: i) Reef Check Tropical protocol, based on the abundance of easily recognizable reef indicator organisms and substrates, able to reflect the condition of the ecosystem; and ii) CoralWatch protocol, which quantifies coral bleaching using a reference colour card, discriminating bleaching events from normal coral colour variation.

Study sites well reflected the range of coral reefs' health status in the area, which over the years remained generally good. However, some sites showed signs of coral diseases, excess *Diadema* sea urchins and local impacts, such as destructive artisanal fishing and overexploitation. However, they never showed major bleaching events until 2023, when a local bleaching event occurred at two sites on Gangga Island, affecting around 30% of the coral population at both depths.

The integration of these two protocols and the involvement of volunteers, students, and researchers from local and foreign universities and stakeholders (i.e., resorts) have proved effective in providing scientifically sound data and increasing public awareness. This report may represent a good example of how monitoring remote areas that are not specifically protected can be faced. However, conservation actions must be strengthened, and attention maintained high at the Coral Triangle core.

Speed talks

ID: 508 / **Parallel Session 6-1: 8**
Community-Based Monitoring and Ecosystem-Based Management

Keywords: Ecosystem-Based management, Ecosystem-Based Quality Index (EBQI), ecosystem functioning, Reef Check Protocol, standardised monitoring network

An Ecosystem-Based index for coral reef: a flexibe approach to process Reef Check data

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Coral reefs are complex and dynamic ecosystems that are crucial for their biodiversity and ecosystem services across the tropical coastal regions of the world. However, local human activities, combined with the increasing impact of climate change, are causing numerous damages on this ecosystem, often leading to abrupt shift in community structure and functioning. Monitoring changes in coral reef ecosystems status is therefore a kay management strategy for this habitat and its related ecosystem services. An Ecosystem-Based Quality Index for coral reefs (CR-EBQI) is here proposed as valuable management tool to assess the functioning and ecological status of the whole ecosystem. The structure of this index emulates the EBQI protocol already developed for several Mediterranean marine ecosystems in the frame of the EU 'Marine Strategy' and 'Habitats' directives. CR-EBQI prioritizes simplicity and adaptability, addressing the challenges of continuous monitoring with limited resources. The CR-EBQI is complemented by a Confidence Index (CI) that weighs the data reliability, enabling the use of data with different quality and resolution. The main descriptors used in the CR-EBQI assess the major functional compartments of coral reefs (e.g., builders, grazers, primary producers, predators), drawing upon the widely adopted Reef Check Protocol, that employs also non-specialised observers. The CR-EBQI was tested in the Maldives Archipelago (Indian Ocean) in 24 sites, encompassing lagoon and ocean reefs characterized by different levels of local human pressures. Surveys were conducted in 2016, when the last mass bleaching event occurred, in 2019 and in 2022. The CR-EBQI provides high operational potentialities to build a standardised monitoring network across a wide range of biogeographical regions.

ID: 657 / **Parallel Session 6-1: 10**
Community-Based Monitoring and Ecosystem-Based Management

Keywords: coral restoration, Arabian Gulf, fragmentation, long-term monitoring

An industry-academia partnership for coral restoration in the Arabian Gulf

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In the framework of an industry-academia partnership, we are developing and validating active restoration technologies for local coral species to enhance the recovery of degraded reefs in the Arabian Gulf. We have established and are operating the first land-based coral nursery in Qatar and are adapting procedures for asexual coral propagation (fragmentation), husbandry, and reintroduction (outplant) to carefully selected recipient sites, as well as their long-term monitoring.

All the corals used in this study were recovered from subsea construction sites. During phase 1 (2021 -2023) 9,621 fragments, from 7 coral genera and 979 donor colonies, were outplanted to 4 offshore locations in the EEZ of Qatar. A similar number of colonies will be processed in phase 2 (2023 – 2024). Monitoring of these outplants will continue for a period of at least five years, to assess attachment success, survival, growth, and health status.

Initial results show that attachment success was consistently high, with 92% to 99% of the outplanted fragments being detected during subsequent monitoring. Survival and health status after the first year varied substantially among recipient sites and coral genera. Deeper sites had significantly higher survival (up to 97%) and better health status, relative to shallower sites. Growth rates also varied substantially among genera. Fragments of the fastest growing genera (*Cyphastrea*, *Dipsastraea,* and *Platygyra*) typically re-merged into adult sized colonies within a few months. Laboratory experiments demonstrated that growth rates for fragments consistently exceeded congeneric whole colonies (up to 8X faster, for *Dipsastraea*).

The capacity to mass produce and successfully deploy coral propagules, under Standard Operational Procedures, will increase the ecological benefits, as well as reduce the costs and risks associated with future coral restoration efforts in Qatar and the Gulf region. These results advance the state-of-the-art restoration technology for the most heat tolerant coral biodiversity on earth.

ID: 478 / Parallel Session 6-1: 6
Community-Based Monitoring and Ecosystem-Based Management

Keywords: Cold-water corals, Spanish waters, mapping, SDMs, conservation

Mapping the spatial distribution of the cold-water corals *Isidella elongata*, *Dendrophyllia cornigera*, *Dendrophyllia ramea*, and *Desmophyllum dianthus* in Spanish waters

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Cold-water corals (CWCs) are structuring, habitat-forming organisms, which are considered Vulnerable Marine Ecosystems (VMEs) indicator species. As such, they are listed in several international marine environmental protection initiatives (MSFD, 2008/56/EC; UNGA Resolution 61/105). To better protect VMEs and assess the level of conservation required, basic information about their spatial distribution is essential.

In 2017, the Barcelona Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean included four CWCs: *Isidella elongata, Dendrophyllia cornigera*, *Dendrophyllia ramea* and *Desmophyllum dianthus*. These species are also included in the Spanish List of Wild Protected Species. To properly protect these four CWC species, having precise information of their spatial distribution to develop species distribution models (SDMs) is a fundamental prerequisite. Recently, the Spanish Ministry for the Ecological Transition and Demographic Challenge (MITECO) has commissioned the project BIODIV (full title in Spanish: "Asesoramiento científico – técnico para el seguimiento de la biodiversidad marina: espacios y especies marinos protegidos de competencia estatal (2022-2025)"). Within this project, the activity 5.1 aims to improve the knowledge of the spatial distribution of these four CWC species in the Spanish Mediterranean and Atlantic waters, combined with traits of their biology and ecology. The results of this study will inform and allow policy makers to design adequate management plans and conservation measures.

An exhaustive survey of the reported occurrences of these four CWCs species has allowed to elaborate preliminary maps of their presence in Spanish waters, highlighting important areas that will be used to predict their overall distributions and ecological preferences. Furthermore, the spatial outputs generated through predictive models will be used to investigate the geographical overlap of these CWC species and assess their exposure to pressures resulting from human activities. These results will greatly contribute to the conservation and management of such VME indicator species.

ID: 428 / Parallel Session 6-1: 5
Community-Based Monitoring and Ecosystem-Based Management

Keywords: hard coral community, coral health status, coral reef fish, coral reef management, marine spatial planning

Elucidating coral reef communities for marine spatial planning in Pulau Kapas Marine Park

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The scientific information related to coral reefs is commonly linked with coral reef management. In Malaysia, the establishment of Marine Protected Areas (MPAs) forms a crucial part of the strategy aimed at conserving the coral reef ecosystem. However, the utilization of scientific data for strategic coral reef management is not widespread. Notably, Pulau Kapas Marine Park, situated in Terengganu, has emerged as a popular tourist destination, leading to several physical developments to accommodate the rising number of visitors, despite its proximity to the mainland. As of now, both natural and anthropogenic disturbances are impacting the health of the coral reef ecosystem in Pulau Kapas Marine Park. Therefore, this study endeavours to enhance our understanding of the current situation by assessing the data related to coral reef communities. The evaluation focuses on two key components: 1) hard coral and 2) reef fishes, aiming to discern their distribution and health status in the study area. The ultimate goal is to employ this information to create suitable management zones in the marine park through Marine Spatial Planning (MSP). Based on the ecological data obtained from the MPA, three types of zoning have been proposed: 1) General Use and Recovery Zone (GR), 2) Conservation Zone (CZ), and Preservation Zone (PZ). The anticipation is that these zoning categories will pave the way for well-informed decisions, particularly in crafting policies related to sustainable island developments. Moreover, it is hoped that this ecological data will stimulate further scientific research explorations, fostering the effective management of coral reef areas in Malaysia.

ID: 502 / **Parallel Session 6-1: 7**
Community-Based Monitoring and Ecosystem-Based Management

Keywords: Great Barrier Reef, bleaching, multi-year dataset, citizen science

Coral bleaching from 2001 to 2017 on 12 sites of the Queensland coast, Australia

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In the last two decades many coral reefs in all oceans have experienced mass bleaching, yet there remain knowledge gaps about the impacts of warming ocean temperatures on coral reefs. Five Reef Check bleaching metrics were used to explore patterns of coral bleaching on the Great Barrier Reef (GBR) and in Southeast Queensland (SEQ). Twelve sites were used to examine the effect of year, region, reef habitat, and depth on bleaching patterns since 2001. More bleached corals were observed at the GBR sites than those in SEQ's, and the years 2013, 2016, 2017 saw the most coral bleaching. Recently killed coral was significantly more abundant on back reef slopes and in shallow water (< 5.9 m). The percentage of coral bleached in 2016 was high, but not statistically different to that in the years 2013, 2015 and 2017. The proportions of corals bleached were highest at sites on the back reef slope and lowest on the fringing reef on the leeward side of islands. The "percent of surface bleaching" indicator showed that the levels of bleaching in 2017 were not significantly different to those in 2002 and 2012 to 2016. The patterns reported here help contribute to our understanding of coral bleaching in Queensland at scales made possible by the community of citizen scientists.

ID: 227 / **Parallel Session 6-1: 4**
Community-Based Monitoring and Ecosystem-Based Management

Keywords: giant corals, citizen-science, maldives, awareness, conservation

Map the Giants: preliminary results in locating the largest coral colonies in the Maldives

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Coral reefs are suffering from both natural and anthropogenic stressors which are posing threats to the survival of countries that completely rely on them for their ecosystem services, such as the Republic of Maldives.

In the last years, Maldivian reefs have undergone severe mass bleaching such as the 2016 event which impacted 73% of the corals. This couples with threats posed by corallivore outbreaks, coral diseases, human activities, and pollution.

In this context, billions of coral colonies, potentially including the most enigmatic, resistant, and ancient ones—colonies over 5m, likely centennial—such as the giant corals, are at risk. These individuals hold unique information from biological, genetic, and paleoclimatic perspectives, having withstood environmental perturbations. They might hold the key to coral reef resilience. We present preliminary findings of giant coral colonies in the Maldives, located with the assistance of citizen scientists. The data provided was collected based on two levels of complexity, dependent on participants' level of expertise. Colonies have been identified across multiple atolls, with a seemingly higher abundance in the southern part of the archipelago. As expected, *Porites* sp. is the most common genus identified, with colonies exhibiting various growth forms, often found on slopes of channels and reaching lengths of over 10 m.

The objective of this work is to raise awareness about the importance and fragility of these organisms, moreover to provide the Maldivian government with a map of potentially sensitive areas worthy of protection. Additionally, the data serve as the foundation for future studies by experts in different fields.

ID: 597 / **Parallel Session 6-1: 9**
Community-Based Monitoring and Ecosystem-Based Management

Keywords: Spawning Hubs, allele effect, coral restoration, Southeast Florida

Coral Recovery Initiatives: Establishing stony coral spawning hubs in urbanized reefs offshore Southeast Florida, USA

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For more than 10 years, Stony coral tissue loss disease (SCTLD) has significantly impacted many Caribbean coral reefs, leading to significant declines in coral abundance which have isolated surviving colonies of severely impacted species. This has the potential to hinder successful sexual reproduction, potentially causing an allele effect which limits recovery potential. To address this in the highly urbanized and marginal reefs off southeast Florida, we initiated a restoration approach to enhance the chances of successful gamete interaction during spawning events. In July 2020, we began collecting and relocating sexually mature coral colonies to two targeted sites or “spawning hubs” offshore southeast Florida with the aim of promoting successful sexual reproduction. The sites were chosen based on site surveys, local knowledge, and a larval bio-physical dispersal model. We subsequently tracked the survival, percent partial colony mortality and incidences of bleaching, disease and predation on each colony and periodically monitored the sites for spawning activity. Between July 2020-Febuary 2024, 288 coral colonies of 15 species were relocated. Over the three-year study, colony survival was 76% in the northern hub and 98% in the southern hub. Additionally, wild SCTLD-susceptible colonies within a 30-meter radius of the site centre point underwent quarterly qualitative monitoring to observe any impact following the transplantation of coral colonies into the spawning hubs. Spawning activity was observed in May 2022. During this period, *Diploria labyrinthiformis* colonies transplanted between May and November 2021 were observed spawning, and gametes were successfully collected. This restoration effort not only supports species recovery through improving successful sexual reproduction but also facilitates recovery by establishing sites conducive to efficient spawning observations and gamete capture.

Posters

ID: 523
Community-Based Monitoring and Ecosystem-Based Management

Keywords: Thailand, sedimentation, bleaching, skeletal eroding band, coral disease

Results of 7-years coral reef monitoring at Koh Tao (Thailand)

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Over the past decade, the Gulf of Thailand has experienced a rapid and concerning decline in hard coral coverage, signalling a significant environmental shift in one of the world's most biodiverse marine ecosystems. Scleractinians, crucial for thriving coral reefs, are particularly affected, posing serious threats to the long-term health and resilience of the region's underwater habitats. Koh Tao, a swiftly growing tourist destination, grapples with unregulated and unsustainable fruition of natural habitats, disregarding planning guidelines. Effective management of coastal and land use remains insufficient, jeopardizing the coral reefs' health.

Data about hard coral coverage, sedimentation, disease prevalence and bleaching, collected from 2016 to 2023 along shallow (3-5 m depth) and deep (7-9 m depth) belt transects in selected sites in Koh Tao, are here presented to verify the effects of intense cumulative pressures on coral reefs.

Notwithstanding the touristic break in 2020 due to the Covid-19 pandemic, hard coral coverage reveals a significant decline, dropping from 52.07% in 2016 to 36.72% in 2023 for the shallow line and from 39.52% in 2016 to 22.1% in 2023 for the deep line. Health compromise issues show an increase, with sedimentation (cover % on corals) rising from 1.33% in 2016 to 14.46% in 2023. The Skeleton Eroding Band disease incidence escalates from 0.13% in 2016 to 2.33%, peaking at 5.38% in 2022. Bleaching events exhibit significant peaks in 2016 and 2018, correlating with subsequent declines in hard coral coverage. Besides the water temperature increase, most detrimental effects may be due to high sediment load driven by factors including infrastructure construction and land use changes.

A big effort is urgently needed to better understand the causes of the detected impacts and to involve stakeholders and policy managers in the preservation of the natural capital in Koh Tao.

ID: 588
Community-Based Monitoring and Ecosystem-Based Management

Keywords: stakeholder engagement, hotspot analysis, marine spatial planning, Natura 2000 sites

Assessment and mapping of ecosystem services provided by three Mediterranean octocorals

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Ecosystem services (ES) are the benefits people obtain from ecosystems. ES assessment and mapping are important instruments to guide marine conservation management and Marine Spatial Planning. This study aims to assess and map the ES provided by three Mediterranean octocorals: *Corallium rubrum*, *Paramuricea clavata*, and *Eunicella singularis*. The study approach consists in four steps: 1) ES assessment based on scientific literature review; 2) use of questionnaires to specifically assess stakeholder perception of cultural ES (CES); 3) development of a set of spatially explicit ES indicators and related spatial data search for the mapping exercise; and 4) hotspot and richness analyses implementation to identify zones where multiple ES are provided most and the opposite. While the literature review covered the whole Mediterranean Sea, the CES assessment was focalized in the area of Banyuls-sur-Mer (France), involving visitors of the public aquarium and scuba divers. The mapping exercise was implemented along the French coast, specifically within Natura 2000 sites.

We identified the ES provided by individual octocorals and assessed that aquarium visitors were more interested in the educational service, while divers perceived the aesthetic service more. With available open-access spatial data, the ES "biodiversity", "fishery and food", "diving spot" and all other CES investigated with questionnaires (i.e., "inspiration", "educational", "aesthetic", "pleasure", "spiritual/well-being") were mapped to identify hotspots and coldspots in the study area. We found hotspots extending far beyond the sites where octocorals are present, highlighting the ability of these species to provide benefits up to a great distance from where they live. We also found a higher percentage coverage of coldspots (55.2%) and 14.2% of areas with no statistical significance, mainly due to data deficiency linked to ES indicators. Overall, our study can help Mediterranean octocoral conservation and support the achievement of Natura 2000 network goals along the French coast.

ID: 426
Community-Based Monitoring and Ecosystem-Based Management

Keywords: Diving Tourism, Artificial Reefs, iEcology, Social media data mining, Human-Wildlife Interactions

Evaluating recreational diving pressure and diver-wildlife interactions on natural and artificial reefs utilizing social media data mining

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Recreational diving's rapid expansion worldwide and associated pressures are increasingly recognized as a significant local anthropogenic stressor to coral reefs. This trend necessitates innovative monitoring techniques, as the impacts of intensive diving tourism on reefs remain poorly understood and may hinder successful conservation and restoration efforts. This study focuses on Eilat's coral reefs, a prominent SCUBA diving destination located in the northern part of the Red Sea with over 500,000 dives conducted annually. We compared social media data with traditional methods (questionnaires and in-situ observations) from 2014-2016. A retrospective analysis of 407 dives shared on Facebook provided unique, user-generated insights. A z-test for proportions indicated no significant difference in dive distributions between social media and traditional data for key sites, representing 90% of dives, suggesting similar accuracy in capturing dive activities ($P>0.05$). Results revealed diver perceptions of different site types, diver demographics and reaffirmed the potential of artificial reefs for spreading divers' pressure from natural reefs. Certain species were found as diver favourites, shedding light on previously undocumented human-wildlife interactions, as 69.78% of posts featured marine animals as objects of interest with varying distances to wildlife: 14.50% at 3-10 meters, 42.02% closer than 3 meters, 1.97% beyond 10 meters, and 11.30% in macro shots (less than 50 cm from object). These findings highlight diver tendencies for close encounters, offering insights into sustainable diving guidelines. Additionally, the analysis revealed that dive frequency peaked during holidays and weekends (58.87%), contrasting with a significant decline in winter (16.22%), providing temporal insights not captured by traditional methods. We demonstrate this approach as a relatively accurate and inexpensive data mining procedure, allowing the quantification and normalization of multiple unrelated observations of dive events. This innovative methodology could be applied to other densely dived areas, providing valuable information for policymakers in marine conservation management and tourism.

ID: 778
Community-Based Monitoring and Ecosystem-Based Management

Keywords: climate crisis, satellite imagery, island dynamics, land reclamation

Coastal anthropization and shoreline dynamics: a Maldivian perspective

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The Maldives represents one of the most vulnerable nations to climate change. Over the next decades it will face severe consequences due to global warming and sea level rise, and the government will have to prioritize its resources for climate risk monitoring, management, and adaptation. Among the practices to face this challenge, land reclamation and artificialization of the shoreline are the most applied, even though the knowledge of their effectiveness and consequences is still scarce. To help fill this gap, we used Google Earth historical satellite imagery from 2001 to 2022 to assess recent shoreline changes in 153 vegetated islands over 9 different atolls. The temporal coverage and quality of the images allowed us to define areal changes over 13.76 ± 3.16 years for a total of 83 anthropized and 70 uninhabited islands. Despite a sea level rise of 4.24 mm/year (1969-2019), 57% of islands was considered stable (42 anthropized and 45 uninhabited) and 28% in accretion (36 anthropized and 7 uninhabited), while coastal erosion (reduction island surface) was prevalent in the remaining 15% (5 anthropized and 18 uninhabited), in agreement with the previous studies in the area. Although a general decrease of island planar surface area was not observed after the coastal artificialization, most islands suffered great variations in shape and sediment dynamics through the assessed period, potentially threatening the integrity and resilience of nearby coral reefs and undermining their role in the coastal protection. The exponential increase in the number and magnitude of humanly driven shoreline alterations through land reclamation, harbour construction as well as the deployment of coastal protection structures calls for the establishment of cost-effective long-term monitoring programs to evaluate potential alterations in local sediment dynamics and its detrimental impacts to natural reefs. This monitoring could represent a robust baseline to design tailored restoration actions.

ID: 228
Community-Based Monitoring and Ecosystem-Based Management

Keywords: card game, education, people awareness, biodiversity, threats

EcoChains: Coral Futures – An educational card game for all ages

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As local and global pressures on coral reefs are growing, the need for people's awareness and understanding is growing as well, in order to protect these ecosystems. One way to engage and teach the public is by playing games. Games can bring joy to all generations around the globe, can stimulate creative and strategic thinking, and can be effective educational resources. We developed a card game that teaches about the biodiversity and resilience of coral reefs, the threats coral reefs are facing, and the actions that can be taken to protect reefs. Players systematically build their reef ecosystems, which increase in diversity and complexity. At the same time, they encounter different stress events ("threat cards"; e.g., heat waves, ocean acidification, overfishing, diseases, etc.) throughout the game, which negatively affect the diversity and complexity of reef ecosystems. These stress events can be countered with "action cards" that either prevent a stress event or aid recovery from it. The goal of the game is to build ecosystems that are as diverse and complex as possible, which is directly reflected in the score. The game is currently available as a physical card game and is expected to be online by the end of 2024. EcoChains: Coral Futures is similar to its precursor EcoChains: Arctic Futures (https://askabiologist.asu.edu/games-and-simulations/ecochains) which is widely played in many classrooms and communities both within and outside of the Arctic.

Session 7: Shallow Temperate Reefs

Coastal temperate reefs are highly diverse and productive ecosystems that provide critical goods and services to our societies, including nutrient cycling, food and livelihood provision, and coastal protection. The intricate networks of species interactions formed by the vast taxonomic groups of reef species and associated organisms collectively contribute to the high-diverse temperate reef biodiversity. However, these ecosystems are particularly exposed to both global environmental change, such as ocean warming and acidification, as well as local stressors, including pollution, habitat destruction, bioinvasions, and overfishing. These threats reshape the structure and functioning of coastal reefs and have major consequences on marine biodiversity, species adaptation, and resilience, compromising their ability to support human sustainability and wellbeing. Despite the key role that temperate reefs play in coastal areas and their vulnerability to global change, our understanding of these ecosystems remains limited. This session welcomes ideas from across disciplines to ask the broad question: How are today's coastal temperate reefs shaping the reefs of the future in a changing ocean? This session aims to be highly interdisciplinary and integrative, combining work on biodiversity, community structure and dynamics, population connectivity, genetics, and ecosystem functioning to enhance the resilience of temperate reefs now and in the future. We also encourage abstracts aimed at identifying temperate reefs whose oceanographic setting provides resilience to climate change, and are therefore critical candidates for marine conservation efforts.

Keywords: biodiversity, connectivity, functioning and threats, biological invasions

Session chairs

Nuria Teixido, Stazione Zoologica di Napoli (Italy)

Jeremy Carlot, Sorbonne Université & CNRS (France)

Steeve Comeau, Sorbonne Université & CNRS (France)

Take home message

- Shallow temperate reefs are impaired by global change, including Marine Heatwaves and Ocean Acidification
- There is an increase of interest in the early-life stages and their responses to climate change
- Long-term observations, connectivity among populations, trait-based ecology, and using new technologies are important to better understand the dynamics of shallow temperate reefs

Regular oral presentations

ID: 382 / **Parallel Session 7-1: 4**
Shallow Temperate Reefs

Keywords: Functional diversity, Redundancy, Coralligenous reef, Mediterranean Sea

Maintained functional diversity but loss of redundancy in a temperate reef ecosystem over 60 years

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As widely recognised, biodiversity represents the variety of living organisms at all levels of complexity, from genes to entire ecosystems. Thus, species diversity alone is not a comprehensive descriptor of biodiversity: the functional roles of the different species are also crucial. Marine ecosystems worldwide are supposedly losing their functional diversity (i.e., the variety of roles), which makes the study of their change over time of fundamental importance. The analysis of functional diversity and redundancy (i.e., the diversity of species playing a given role) can provide information on the ability of ecosystems to maintain their integrity. Coralligenous reefs are among the most valuable coastal marine ecosystems in the Mediterranean Sea in terms of extent, biodiversity, and production. The present work aims at evaluating changes over time in the coralligenous of Punta Mesco (Ligurian Sea). Quantitative data - obtained by underwater photographic surveys - have been collected since the 1960s, representing one of the longest existing data series for Mediterranean reefs. Previous studies have shown that the composition and structure of the benthic community at Punta Mesco changed abruptly in the 1990s, resulting in a new configuration that remained stable until 2022. In this study, Biological Traits Analysis (BTA) was applied to analyse whether that change in species composition has affected the functionality of the ecosystem. As the BTA is based on the morphological and functional characteristics of species, three main functions were considered: trophism, three-dimensionality, and bioconstruction. Results showed that in the last 60 years, the functional diversity of coralligenous reef at Punta Mesco did not significantly change over time, indicating that ecosystem functions have been maintained. On the other hand, redundancy significantly decreased for all the functions considered, meaning little capacity to replace species lost, and thus highlighting a reduced resilience of this ecosystem.

ID: 571 / **Parallel Session 7-1: 6**
Shallow Temperate Reefs

Keywords: Bioacoustics, gorgonian, conservation, Mediterranean, biodiversity

The sound of gorgonian forests: use passive acoustic to plan biodiversity conservation

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Gorgonians are keystone engineering species characterized by arborescent morphologies. In high densities, their colonies form forests, which shelter numerous species, increasing local biodiversity. **Conservation programs should therefore focus on protecting the forest and its function (e.g. biodiversity maintenance) rather than the gorgonian as a species**. The relationship between forest demography and its associated biodiversity would give insights on the conservation targets. Still, its assessment can be challenging and time-consuming, especially in remote or poorly accessible areas. Passive acoustics is a non-invasive method that records the sounds produced by marine animals, providing information on their presence, activity, and diversity.

This study was conducted in two Mediterranean marine protected areas. We used passive acoustics to assess sound maps of the fauna associated to Mediterranean red gorgonian (*Paramuricea clavata*) forests characterized by different densities and size structures. We applied an acoustic localization approach based on multi-track recordings and time-of-arrival differences that allow to locate sound sources within a given surface. The established acoustic maps of sound density, abundance, energy, and diversity were associated with the respective gorgonian demography maps assessed by SCUBA diving. Results showed a clear link between gorgonian density (m^2) and sound density and diversity, suggesting a positive relationship between demography and function (biodiversity). Here we discuss the potential of using such acoustic footprints to estimate a target conservation demography for the conservation of gorgonian forests.

ID: 678 / **Parallel Session 7-1: 7**
Shallow Temperate Reefs

Keywords: Competition, benthic communities, growth, Palythoa caribaeorum, 3D models

Capturing change: Exploring spatiotemporal dynamics in zoantharian dominated habitats of the Canary Islands using photogrammetry

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In subtropical waters off the Canary Islands, ocean warming is favouring the proliferation of thermophilic organisms. Such is the case of zoantharians, which now dominate certain shallow benthic reefs and are inducing community-level changes due to their mat-forming growth. In this context, new methodologies such as photogrammetry enable to capture spatiotemporal changes and population dynamics of sessile benthic species with great precision. In this study, a *Palythoa caribaeorum* dominated area in Tenerife Island was surveyed every six months during a year using structure-from-motion photogrammetry techniques to build orthomosaic plots of 25 m^2, with the aim of studying zoanthid-algae interactions. Growth of *P. caribaeorum* colonies (cover and number of polyps) was measured, and the types of macroalgae neighbouring each colony were recorded, considering *Lobophora* spp., *Dictyota* spp., turf algae and crustose coralline algae. Overall, colony growth was mainly influenced by seasonality, exhibiting a higher mean growth rate during the warm season and a negative mean rate during the cold season. However, the mean net annual growth rate remained positive. Notably, colonies interacting with *Dictyota* spp. displayed the lowest growth rates during both winter and summer, representing the only conditions where colonies did not grow. Conversely, colonies neighbouring turf algae showed the only positive mean growth rate during winter and the highest during summer. These results suggest a potential inhibitory role of *Dictyota* spp., particularly during the winter biomass peak of these algae, while implying a facilitating role of turf algae on *P. caribaeorum* colonies. Nevertheless, a strong correlation between zoanthid growth rates and seasonal temperature oscillations was shown, evidencing that population outbreaks of zoantharians may be facilitated by climate change effects. Finally, this study achieved the first 3D virtual documentation of *P. caribaeorum*-dominated seabeds in the Canary Islands, establishing a baseline reference for future spatial-temporal monitoring of zoanthid populations in the archipelago.

ID: 177 / **Parallel Session 7-1: 1**
Shallow Temperate Reefs

Keywords: Dissolved carbon, Gorgonians, Heat stress, Dissolved nitrogen, Symbiosis

Nutritional ecology of temperate octocorals in a warming ocean

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Although octocorals play a central role in temperate Marine Animal Forests and contribute significantly to benthic and pelagic interactions, our understanding of their feeding ecology remains limited. However, the increasing effects of global warming on ocean temperatures pose a double threat to benthic organisms, pushing them to the limits of thermal tolerance while simultaneously subjecting them to starvation due to plankton scarcity during heat waves. In light of these challenges, dissolved nutrients emerge as a potentially crucial alternative food source in temperate regions, where their concentrations can reach peak values. Our study, conducted at both 17°C and 24°C, aimed to predict the effects of ocean warming. We investigated the uptake rates of dissolved inorganic (carbon, ammonium, nitrate) and organic (urea, amino acids) nutrients in the two predominant gorgonians of the Mediterranean Sea: the mixotrophic species *Eunicella singularis* and the heterotrophic species *Paramuricea clavata*, using ^{13}C and ^{15}N isotope labeling. In addition, we investigated the uptake of natural dissolved organic matter (DOM) at different concentrations. Our results revealed signs of heat stress in gorgonians, which manifested in increased respiration rates, loss of symbionts in *E. singularis* and reduced lipid reserves in *P. clavata*. In addition, the gorgonians showed strikingly low uptake rates of dissolved inorganic and organic nutrients at both temperatures. Surprisingly, despite the elevated temperature (24°C), no significant increase in the assimilation rates of dissolved inorganic or organic nutrients was observed, except for dissolved organic carbon in *E. singularis*. This study sheds light on the nutritional needs of temperate octocorals, revealing that dissolved nutrients, especially nitrogen, do not significantly contribute to their diet. Instead, these organisms should heavily rely on the capture of plankton and detrital material to meet their nitrogen requirements. Consequently, there is an increased risk of severe starvation for temperate octocorals in the foreseeable future.

ID: 331 / **Parallel Session 7-1: 3**
Shallow Temperate Reefs

Keywords: crustose coralline algae, Eunicella singularis, bacteria, holobiont, larvae recruitment

Unveiling larval settlement mechanisms of the Mediterranean white gorgonian under climate change

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Mortality events of the Mediterranean white gorgonian (*Eunicella singularis*), mainly caused by global climate change, have been observed at shallow depths the last years in the Mediterranean Sea. Since environmental changes are expected to increase in intensity and frequency in the future, related impacts might worsen. A better understanding of the dynamics that drive the early life stages of this species is needed to inform its conservation and restoration. In line with studies on tropical coral reefs, the settlement of *E. singularis* larvae is promoted in the presence of selected crustose coralline algae (CCA), presumably through the production of chemical cues in synergy with their associated bacterial communities. Here, we aim to understand 1) whether the microbiome and/or metabolites of specific CCAs may be drivers of higher settlement rate of *E. singularis* larvae, and 2) how the related mechanisms can be affected by ocean acidification and warming. First, we collected two phylogenetically identified CCA morphotypes, predominant and closely associated with *E. singularis* forests in Banyuls-sur-Mer (France, Western Mediterranean Sea). Prior to larvae arrival, CCA holobionts were exposed for three months to projected 2100 temperature and pH conditions for the area (+2.5ºC and pH 7.78), and to a heatwave (26ºC for three weeks). Then we used these CCAs as substrates in experimental aquaria in the presence of *E. singularis* larvae. The bacterial community composition of these holobionts and the production of metabolites were analyzed before and after the treatments, and at the end of the settlement experiment to disentangle their effects on *E. singularis* larvae. The potential transfer of bacteria from CCAs to gorgonian settlers was also assessed. The results shed light on *E. singularis* settlement capacity under different climate change scenarios.

ID: 434 / **Parallel Session 7-1: 5**
Shallow Temperate Reefs

Keywords: trait diversity, CO2 vents, ecosystem function, temperate reefs, ocean acidification

Functional changes across marine temperate habitats due to ocean acidification

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Global environmental change drives diversity loss and shifts in community structure. A key challenge is to better understand the impacts on ecosystem function and to connect species and trait diversity of assemblages with ecosystem properties that are in turn linked to ecosystem functioning. Here, we quantify shifts in species composition and trait diversity associated with ocean acidification (OA). We use field measurements at newly discovered CO_2 vent systems spanning four benthic habitats, including shallow reefs, semi-submerged caves, reefs, and deep reefs across different depths (from 1 to 40 m) along the coast of Ischia (Italy). These CO_2 vent systems locally acidify the seawater and are used as natural analogues for future ocean acidification conditions. We assessed changes in rocky benthic communities in four CO_2 venting sites and reference sites with ambient pH with no venting activity. In addition to conducting classic analyses of change in species composition and community structure, we assess the loss of trait diversity, *i.e.* the range of species' biological traits. For this purpose, we quantified the percent cover of 215 benthic species (algae and invertebrates) and characterized the ecology of each species using 7 functional traits describing (among others): morphology, longevity, growth rates, feeding characteristics, and presence or absence of calcareous skeleton. We find that species and trait diversity decreased, and that ecosystem properties (understood as the interplay between species, traits, and ecosystem function) shifted with acidification. Furthermore, shifts in trait categories such as autotrophs, filter feeders, herbivores, and habitat-forming species were habitat-specific, indicating that OA may produce divergent responses across habitats and depths. Combined, these findings reveal the importance of connecting species and trait diversity of marine benthic habitats with key ecosystem properties to anticipate the impacts of global environmental change.

ID: 310 / **Parallel Session 7-1: 2**
Shallow Temperate Reefs

Keywords: Temperate coral, Paleo-reconstruction, Boron Isotopes, pH-upregulation, ocean acidification

Seasonal variations of δ^{11}B in the Mediterranean coral *Cladocora caespitosa*: insights into pH-upregulation and resilience

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Human-induced elevated atmospheric CO_2 is responsible for ocean acidification and for the reduction of seawater carbonate saturation state, which are key processes that can affect calcification in scleractinian corals. Corals maintain optimal calcifying conditions by actively regulating the carbonate chemistry at their site of calcification via pH-upregulation, potentially conferring on them some resilience to ongoing ocean acidification. The boron isotopic composition (δ^{11}B) of coral skeletons can be used to reconstruct the pH of their calcifying fluid (pH_{cf}), which can serve as a proxy of seawater pH (pH_{sw}) when the effect of the biology is taken into account. The temperate coral *Cladocora caespitosa,* the only zooxanthellate reef-builder in the Mediterranean Sea, lacks extensive study regarding its responses to variations of pH_{sw} or thermal stress impacts on pH-upregulation on seasonal scales. Here, we assessed δ^{11}B in skeletons of *C. caespitosa* collected in two locations of the NW Mediterranean Sea (Columbretes Islands, Spain, and Villefranche-sur-mer, France). We measured δ^{11}B in the coral fragments at a bimonthly resolution to reconstruct seasonal variations of pH_{cf} over 7 years. For this, the corals were analyzed via solution chemistry, as well as *in situ* by laser ablation on an inductively coupled multi collector mass spectrometer (MC-ICP-MS). Ambient seawater temperature and pH data, together with growth parameters, were used to understand the sensitivity of pH-upregulation to environmental changes on a seasonal scale. With this study, we aim to offer insights into the resilience of *C. caespitosa* biomineralization to changes in pH_{sw} and temperature. Additionally, we aim to highlight the potential of using δ^{11}B as a proxy for seasonal variations of pH_{sw}.

Speed talks

ID: 175 / **Parallel Session 7-1: 11**
Shallow Temperate Reefs

Keywords: Coralligenous assemblages, Ecosystem-based approach, MSFD, Ecosystem-based quality index

An ecosystem-based index for Mediterranean Coralligenous assemblages: a standardized and easy method to assess a complex key habitat

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Coralligenous assemblages (CA) represent one of the most diverse and complex habitats of the Mediterranean Sea within the circalittoral zone. The CA bottom structure is shaped by the 3D development of the epibiota (e.g., coralline and other algae, sponges, cnidarians, bryozoans) developed on steep rocky walls or forming a bioherm when coralline algae are particularly developed. The complex stratification of these epibiota gives shelter to a very diverse mobile fauna and generates multiple functional compartments whose structure and composition display a great variability across geographic areas and local environments. The integrative assessment of the status of such a complex ecosystem is challenging. Ecosystem-based quality indices (EBQI) have been successfully applied to several coastal Mediterranean habitats (*Posidonia oceanica* meadows, UW caves, infralittoral rocky reefs, coastal detrital bottoms). Following a similar approach, this new index (EBQI-CA) includes the main functional compartments of the CA ecosystem. Each compartment was weighted according to its importance in the ecosystem functioning. Then, suitable descriptors were selected to define the limits of a 5-class status for each assessed compartment. A confidence index was developed to estimate the data quality (e.g., suitable method, expert judgement). To validate the method, initial data were collected on 61 sites along the French Mediterranean coast (e.g., Gulf of Lions, Provence, French Riviera, Corsica). Results showed ecological status varying from poor to very good according to (i) local environmental specificities, (ii) inherent bottom features (geomorphology) and/or (iii) the level of anthropogenic pressures (considering the level of management). The EBQI-CA is designed to fit the purposes of both Marine Strategy Framework and Habitats Directives of the European Union. In this frame, such a tool aims to be easily implemented in the perspective of future monitoring networks in the Mediterranean Sea.

ID: 134 / **Parallel Session 7-1: 10**
Shallow Temperate Reefs

Keywords: gorgonians, Maxent, marine protected area, distribution, habitat suitability

Modeling the habitat suitability of five gorgonian species in the North Western Mediterranean Sea

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Engineer species, such as gorgonians, provide several ecosystem services and play a significant role in the maintenance of biodiversity. We aimed to test an ecological niche modelling approach in the marine shallow environment and identify the ecological niche of gorgonian species for future conservation actions. We analysed a unique dataset of spatialized inventories on a regular grid (< 800 m) along 450 km of coastline of five gorgonian species commonly found in the Mediterranean shallow habitats (10-50 m deep). We replicated data collection in 2013 and 2020. Ten non-correlated environmental predictors derived from the most advanced geomorphological and hydrological data were used to assess the ecological niche of the five species using maximum entropy (Maxent). The difference in the spatial distribution of the five gorgonian species in the Gulf of Lion enabled us to differentiate the niche of the five species. The model confirmed that depth, rugosity, sea surface and bottom temperatures, flow speed and turbidity are significant drivers for gorgonian's distribution, but in different associations. The reduction of the number of presence observations did not alter the quality of the prediction as long as the observation points were spread over the entire variability range of predictors. The latter can be achieved by only including presence observations from highly protected zones of the marine protected areas of the region. Our results provide a greater understanding of the factors shaping the distribution of five gorgonian species commonly found in Mediterranean shallow areas.

ID: 361 / **Parallel Session 7-1: 14**
Shallow Temperate Reefs

Keywords: animal forests, β-diversity, functional traits

Paramuricea clavata forests support biodiversity and ecosystem functioning

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Coralligenous habitat is a biogenic temperate reef formed by complex and heterogeneous benthic assemblages, representing one of the most important biodiversity hotspots in the Mediterranean Sea. The iconic species *Paramuricea clavata* is an ecosystem engineer which increases the spatial complexity of the habitat, developing animal forests that support the persistence of other species. In the last decade, *P. clavata* suffered the increase of multiple stressors (e.g. fishery, heat waves, storms) which led to mass mortality events with substantially unknown consequences on associated benthic assemblages. We tested the hypothesis that *P. clavata* has the role of increasing local biodiversity, including both structural and functional components. The study was carried out in the Gulf of Naples in replicated sites, where benthic communities inside vs outside the forests were compared in terms of β-diversity (partitioned in its two components nestedness and turnover) and functional richness through the functional-trait approach. *P. clavata* forests are mainly represented by small size classes and show a wide range of both density (27 - 65 colonies/m^2) and biomass (100 - 505 g dry weight/m^2) across sites. The assessment of benthic assemblages reveals *P. clavata* forests support distinct communities, characterized by higher compositional and functional richness compared to the adjacent zones outside the forests. The analysis of functional groups reveals that *P. clavata* prevents the spread of algal species, favouring the growth of sessile invertebrates. Comparing β-diversity (inside vs outside), the turnover component is statistically significant at both taxonomical and functional level with higher values within the forest, highlighting the important role of *P. clavata* in modifying local environmental conditions and driving local species distribution. Our results provide new insights to the ecological relevance of this habitat and point out the importance of implementing its protection.

ID: 205 / **Parallel Session 7-1: 12**
Shallow Temperate Reefs

Keywords: physiology, gastric cavity, trace metals, iron cycle, metabolic response

Impact of dissolved iron enrichment on holobiont physiology and the gastric cavity of symbiont-bearing Mediterranean corals

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Iron (Fe) is essential for coral symbiosis, supporting vital processes like photosynthesis, respiration, and many other key enzymatic reactions. However, the impact of iron on corals and their metabolic responses to iron enrichment during ocean warming remains unclear. This study investigated the short-term (1 week) effects of increasing Fe(III) concentrations (20, 50, and 100 nM) and long-term (5 weeks) effects of low Fe(III) enrichment (20 nM) coupled with temperature increase (18 to 24°C) on three Mediterranean coral species: the scleractinian *Cladocora caespitosa* and *Oculina patagonica*, and the gorgonian *Eunicella singularis*.

Our results showed species-specific responses to iron enrichment. In *C. caespitosa*, short-term exposure to 50 nM Fe(III) increased respiration and photosynthesis rates, while the relative electron transport rate, rETR(II), decreased at 100 nM Fe(III). *O. patagonica* exhibited reduced respiration, photosynthesis, and maximum PSII quantum yield (Fv/Fm) across all short-term iron enrichments. Long-term exposure to 20 nM Fe(III) in *C. caespitosa* reduced Fv/Fm but not in *E. singularis*. Notably, all species experienced increased hypoxia (< 50 µmol O_2 L^{-1}) in the gastric cavity at night during short-term 50 and 100 nM Fe(III) and long-term 20 nM Fe(III) exposure, leading to increased polyp contraction time and reduced O_2 exchange.

These dynamics suggest *C. caespitosa* may be iron-limited for optimal photosynthetic capacity, while *O. patagonica* and *E. singularis* showed non-beneficial responses to iron enrichment. This study highlights the importance of microscale processes for micronutrient uptake in corals. Short-term exposure to low Fe levels (20 nM) may enhance coral photosynthetic capacity, while higher Fe levels (> 50 nM) and long-term low Fe enrichment (20 nM) can induce hypoxia and anoxia in corals´ gastric cavity, possibly linked to increased bacterial activity and Fe bioavailability. Understanding these trace metal and O_2 dynamics contributes to insights into coral health, informing effective conservation strategies amid environmental changes.

ID: 773 / **Parallel Session 7-2: 5**
Shallow Temperate Reefs

Keywords: ecological restoration, coral gardens, Octocorallia, sexual reproduction, larval settlement

Reproductive phenology and sexual propagation of the pink sea fan *Eunicella verrucosa* for coral restoration

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The widespread decline and functional impairment of coral-dominated ecosystems caused by human disturbances has focused the attention on the urgent need for active interventions of habitat restoration. Coral restoration using sexually-produced individuals is a pivotal approach to prevent further impact on donor populations, as well as to harness key processes such as genetic diversity and recombination, which are crucial to ensure corals' capacity to adapt to a changing environment. Yet, for the majority of coral species, especially those occurring in temperate and deeper (>50 m) regions, critical knowledge about reproduction and larval ecology that enables sexual propagation *ex situ* is lacking. Here, we report for the first time the spawning of a dominant species of octocoral in the NE Atlantic (*Eunicella verrucosa*) in aquaria and present preliminary data on larval development and settlement. The annual time of reproduction in SW Portugal was determined from the analysis of samples collected as fisheries' bycatch (2020-2022). In 2023, we observed spawning of colonies moved to aquaria prior to the predicted reproductive season. The species split-spawned over ~1 month (September 10-October 16), with three large spawning events observed on September 12-13 (3 days before new moon), September 30 and October 16. Oocytes and embryos were positively buoyant and developed into swimming larvae after 3 days. Preliminary observations and settlement trials using several substrates (natural rock, CCA and gorgonian skeleton) showed larvae testing the substrate ~2 weeks after spawning, with settlement peaking ~4 weeks. Fully developed recruits were observed after one month, with sclerite production starting before tentacle development. New settlement was still observed 3 months after spawning, indicating a protracted competency period. This study provides crucial new data required for actions of coral restoration using ex situ sexual propagation of a key structural species currently listed as vulnerable by the IUCN red list.

ID: 436 / **Parallel Session 7-2: 2**
Shallow Temperate Reefs

Keywords: coralligenous assemblages, thermal stress, marine noise, ascidians, non-native species

Responses to thermal stress and boat engine sound in ascidians from the Mediterranean Sea

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In the last three decades, the Mediterranean Sea experienced a rapid increase in sea surface temperatures and ocean heat content. How this affects its characteristic coralligenous assemblages is not understood. Marine anthropogenic noise also increased in intensity in the last decades and Mediterranean shallow coastal ecosystems are highly frequented by recreational motorboats during the European summer months. In this study, we investigated the effects of thermal stress and boat engine noise on ascidians from the Adriatic Sea. We i) compared the thermal tolerance limits (behavioural modulation, heat shock protein (HSP) production and survival) of a common native solitary ascidian of coralligenous assemblages in the Mediterranean Sea, *Halocynthia papillosa*, to a non-native solitary ascidian, *Styela plicata*, ii) investigated whether the sound perception of *H. papillosa* lies within the frequency range of sound produced by common boat engines, and iii) tested the responses (behavioral modulation and HSP production) of *H. papillosa* to boat engine sound in the laboratory and in the field. We found that *S. plicata* started to respond to thermal stress with behavioral modulation and HSP70 upregulation at lower temperatures in relation to its thermal limit than *H. papillosa*. Absolute thermal limits rose with higher acclimation temperatures in *H. papillosa*, and with slower rates of temperature increase in both species. The higher plasticity in response to thermal stress of *S. plicata* compared to *H. papillosa* may explain the species' success in establishing in non-native ranges. *Halocynthia papillosa* reacted with body contractions to sound of 100-400 Hz and with increased HSP70 production during exposure to engine sound, but not to an artificially created 100 Hz tone. Our findings suggest that impacts of anthropogenic noise on relatively understudied sessile filter feeders, such as ascidians, needs more investigation and attention, since these organisms compose a functionally highly relevant group in shallow water assemblages.

ID: 453 / **Parallel Session 7-1: 9**
Shallow Temperate Reefs

Keywords: global change, temperate coral, Mediterranean Sea, monitoring, long-lived

Long-lived corals require long-term observation: insights from 22 years monitoring global change impacts in a permanent *Cladocora caespitosa* transect

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Over the past decades, *Cladocora caespitosa*, the sole coral with reef building capacity in the Mediterranean Sea, has recurrently faced impacts from global pressures such as warming and invasive species. In 2002, as global change impacts were emerging in the NW Mediterranean Sea, we initiated the monitoring of a permanent transect of 250 *C. caespitosa* colonies. This transect has been monitored annually ever since. The long-term commitment has yielded valuable insights into the responses of this coral to global change, as well as recovery and adaptation processes. It has also enabled launching parallel research on topics like environmental and ecological paleoreconstructions using coral skeletons. The main lesson learned from this long adventure is that long-lived organisms require long-term observation because many crucial findings would not have been possible with shorter monitoring periods. This presentation will showcase key discoveries derived from 22 years of coral monitoring. We will emphasize the importance of studying global change impacts on corals through long-term permanent transects and outline future research directions.

ID: 443 / **Parallel Session 7-2: 3**
Shallow Temperate Reefs

Keywords: climate change, temperate corals, indicator species, Korean waters

Impact of climate change on distribution and diversity of shallow temperate corals in Korea

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170 species of corals have been reported from Korean waters by examining the specimens collected in the coastal areas of Korea from 1965 to 2023. This study aims to clarify the distribution of coral species along the coastal waters of Korea and to identify indicator species for the long-term monitoring of the changes in the distribution of coral species in response to climate change. Geographical analyses were performed to determine the distribution of coral species and to compare the species composition between regions in Korean waters. The 170 recorded coral species have been distributed in the following four regions, Korea: East Sea (28 species), Yellow Sea (21 species), South Sea (68 species), and Jejudo Island (124 species). As a result, it is shown that Jejudo Island has the highest diversity of coral species (73%) while the Yellow Sea has the lowest diversity of coral species (12%). The results reflect that most coral species in Korea are limitedly distributed along the Kuroshio warm Current.

In particular, given that scleractinian corals are significantly influenced by climate change in various ways, including because of their symbiotic relationship with zooxanthellae, the species composition and distribution of scleractinian corals as a key species provide critical baseline information to predict future environmental change in Korean waters. Most scleractinian corals in the tropical oceans are zooxanthellate. Six species of 35 scleractinian corals recorded in temperate Korean waters are zooxanthellate. As sea temperatures increase, the distribution of tropical zooxanthellate scleractinians expands northward. For example, we have found that one of the zooxanthellate scleractinian *Montipora efflorescens* Bernard, 1897 is dominantly expanding from the southern part to the northern part in Jejudo Island. In this respect, it is considered that this species would be important as an indicator species for monitoring environmental consequences induced by climate change.

ID: 396 / **Parallel Session 7-2: 1**
Shallow Temperate Reefs

Keywords: benthic ecology, climate change, thermotolerance, harbour, Marine Protected Area

Physiological responses to heat stress of harbour and natural populations of the Mediterranean gorgonian Leptogorgia sarmentosa

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Unexpectedly, dense aggregations of Leptogorgia sarmentosa (Esper, 1791) (Cnidaria: Anthozoa) were observed both in Genoa (Italy) and in Barcelona (Spain) harbors, thriving in urban marine environments with harsh conditions and in unusual shallow depths (less than 10 metres), in contrast to the usual bathymetric range of this species in coastal natural environments (usually found at depths greater than 20 meters).

Given the crucial ecological importance of gorgonians and their high vulnerability to both natural and anthropic impacts, it is essential to provide ecological knowledge of gorgonian species in various scenarios, including comparative studies between urban and natural areas, to better guide conservation and restoration initiatives. To address this knowledge gap, we compared the response to heat stress of colonies of *L. sarmentosa* from two major harbours in the Mediterranean Sea, Barcelona and Genoa, and two nearby Marine Protected Areas (Cap de Creus and Portofino MPAs, respectively). Fragments from different colonies at the four locations were maintained in experimental aquaria under different thermal conditions (Control: natural temperature, Scenario 1: a simulated marine heat wave up to 26 ºC and Scenario 2: a simulated marine heat wave up to 28ºC). Fragments from each colony were collected at the beginning and end of the experiment, and the quantification of total lipids, as well as the test for oxidative stress (lipid peroxidation), were performed on each fragment to test the hypothesis of a differential response to stress between natural and urban populations.

We will present the results of the first comparative thermotolerance experiment conducted for this species, addressing a current knowledge gap that is crucial for a better understanding of the ecology of gorgonians in the Mediterranean and their adaptation and response to changing anthropic environments.

ID: 779 / **Parallel Session 7-1: 8**
Shallow Temperate Reefs

Keywords: population connectivity, temporal variation, genomics, gorgonians

Temporal changes in population connectivity of the gorgonian *Paramuricea Clavata* in the northwestern Mediterranean Sea

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Connectivity (the exchange of individuals between fragmented populations) has a major impact on metapopulation regeneration and persistence. It is therefore increasingly taken into account in biodiversity conservation programs. In coral ecosystems, connectivity is mainly ensured by larval transport, and therefore depends on species life history characteristics (spawning time, duration of the larval stage, larval behaviour...) and ocean currents. These two factors are strongly influenced by the environmental context, which varies not only on an inter-annual scale, but also on a much longer timescale due to climate change. The extent of these variations on different time scales is largely unknown. However, connectivity is usually assessed as a one-shot study, resulting in a screenshot of the connectivity at a given time and not always representative of the connectivity over a longer period of time. Here, we used a time-structured sampling scheme of *P. clavata* in the northwestern Mediterranean Sea : each population was sampled in 2014 and resampled in 2022 in 4 size classes (cohort representatives). This allows us to estimate the connectivity of *P. clavata* populations at different times and on different time scales. As a first result, we show that while the population genetic structure is stable across time, the proportion of exchanged individuals shows large variations across the sampled years. This highlights the need to study the extent of connectivity variation at different timescales in order to evaluate the long-term effectiveness of current management actions and anticipate necessary updates of connectivity assessment.

ID: 823 / **Parallel Session 7-2: 6**
Shallow Temperate Reefs

Keywords: coral, Balanophyllia, population, water flow

The solitary coral *Balanophyllia elegans* in the Salish Sea (Washington State, USA): habitat, population density and size distribution

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The solitary coral *Balanophyllia elegans* is strictly subtidal in the Salish Sea, with a depth range of 0 to 293 m along the Pacific coast (-1.8 to -38.0 m MLLW in this study) and is found on all substrate inclinations. We examined coral size and number in photographic quadrats from 12 sites in the San Juan Archipelago, at depths to 38 m, including measurement of over 26,000 coral polyps. Maximum density was 262 polyps.m^{-2} with an average subtidal density of 26.6 polyps m^{-2}. This species was the most abundant and evenly distributed hexacorallian in our study and was found at every site except those with the lowest tidal flow speeds. We used a statistical model including depth, substratum slope, and flow speed to examine distribution; *B. elegans* was found to be significantly more abundant with greater depth, steeper substratum slope and higher flow conditions. Sites with greater flow speed, and greater depth, also had the largest polyps. Previous studies found that polyp sizes measured in 2007-2000 were smaller than those in photographic quadrats from 1969-1972, and that corals were growing more slowly during the former dates, which may be due to regional ocean warming over the past half century. The depth distribution quantified in our study suggests that conditions are less favorable for this species above about 10 m depth; warmer water with lower salinity could be having a negative effect on coral growth or survival at the shallowest depths, although it is also possible that interactions with macroalgae in the shallow zones may be important as well.

ID: 645 / **Parallel Session 7-2: 4**
Shallow Temperate Reefs

Keywords: Temperate coral, northward migration, climate change, *Symbiodinium*, *Acropora*

Corals change symbiotic partnerships at the forefront of northward migration in response to climate change

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Coral reef ecosystem harbors high biodiversity, although corals are highly threatened by elevated water temperature by climate change. Several species of corals, on the other hand, are expanding northward and expanding their distributions in the northern areas in Japan. The marginal populations of species distribution created by northward migration, however, would be harsh environment for the species and might have lower genetic diversity and/or have specific adaptative strategies. In this study, to test these hypotheses genetic diversity of coral itself and the genetic composition of *Symbiodinium* have been assessed. Genomic diversity of two dominant temperate zone species (*Acropora* cf. *glauca* and *Acropora solitaryensis*) was estimated using the MIG-seq method and ITS2 regions were sequenced. As a result, genetic diversity of two coral species was comparable in all the areas examined in this study, suggesting that they are not particularly vulnerable to environmental changes in the northernmost areas in terms of genetic diversity. On the other hand, the genetic compositions of *Symbiodinium* in the northernmost two populations, Tateyama and Tsushima, were strikingly different from those in other temperate areas, suggesting that corals may have selectively adapted to the cold-water environment by having unique *Symbiodinium* composition. This study demonstrated that corals dramatically change their symbiotic partners in the front-lines of northward migration for their survival. These findings imply special adaptation strategies by dramatically changing symbiotic partners can be found in corals at the marginal populations and thus caution is required when predicting future coral distribution and resilience associated with climate change.

ID: 282 / Parallel Session 7-1: 13
Shallow Temperate Reefs

Keywords: Mediterranean gorgonians, Mechanical properties of gorgonians, Canopy effect, Hydrodynamics

Mechanical properties of three Mediterranean gorgonian species, *Paramuricea clavata*, *Leptogorgia sarmentosa* and *Eunicella singularis*

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Gorgonians are octocorals with arborescent shapes. When their populations are dense enough, they form forests similar to terrestrial ones (animal forests) which modify the physical environmental conditions inside and around them. This near bed hydrodynamics modification could improve food and larvae retention, resulting in higher resilience of the gorgonian forest. To investigate this small-scale modification of the flow by the canopy effect, measurements can be performed in a hydraulic flume using surrogates and optical measurement techniques. To ensure relevancy of these experiments, similarity between open ocean and laboratory conditions is required. The dimensionless similarity parameter associated with flexibility is the Cauchy number, which compares the flow drag on the gorgonian to its elastic resistance to reconfiguration. Young's (E) and Shear (G) moduli characterizing the stiffness and rigidity of gorgonian material, respectively, are necessary for the calculation of relevant Cauchy numbers. Here Young's (E) and Shear (G) moduli are measured experimentally for three common Mediterranean octocoral species, *Leptogorgia sarmentosa*, *Paramuricea clavata*, and *Eunicella singularis*, along with their geometrical characteristics. Measurements on both living specimens and on rehydrated axial skeletons are performed to investigate if there is a significant stiffness variation and thus, modifications of the hydrodynamics between alive and recently dead colonies. These measurements are performed using both classical protocols (beam deformation) along with new ones based upon modal analysis. The measurement of the mechanical properties for different branching orders along the gorgonians allows to account for the variability of stiffness and rigidity among branches of different sizes. The acquired knowledge on the mechanical properties of Mediterranean gorgonians will contribute to a better understanding and modelling of the local flow conditions inside and above gorgonian forests.

Posters

ID: 503
Shallow Temperate Reefs

Keywords: Trophic behavior, MixSiar, SIBER, Carbon, conservation

Dietary and isotopic niche patterns across *Paramuricea clavata* colony colorations and filter feeding species inhabiting near a fish farm

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The gorgonian *Paramuricea clavata* is a keystone Mediterranean species that can exhibit a wide range of colours including red, yellow and the combination of both within the same colony. Here, we assess the isotopic ($\delta^{13}C$ and $\delta^{15}N$) and nutrient (percent C and N) composition of *P. clavata* (branch tissue and polyps), and we evaluate potential dietary contributions (plankton fractions of 1 and 20 mm and sediment) and isotopic niche for each coloration, as well comparisons with other local filtration feeders such as the gorgonian *Eunicella* sp. and the mussel, *Mytilus galloprovincialis*. Samples were collected from a single population area located at ca. 50 m depth near a tuna farm where gorgonians populations were available, whereas sediment and water were sampled at increasing distances from the fish farm and in a control site to assess potential effects of the activity. Results evidence significant differences in both $\delta^{13}C$ and $\delta^{15}N$ between tissue and polyps of *P. clavata*, with higher $\delta^{13}C$ and %C, but lower %N values in the red coloration. For species comparisons, significantly higher $\delta^{13}C$ and $\delta^{15}N$ values were observed in *P. clavata* and *Eunicella* sp. compared to mussels. Sediment samples evidenced lower $\delta^{13}C$ and higher $\delta^{15}N$ values near the fish farm, whereas plankton fractions showed no significant variation across sites. MixSIAR models indicated that the largest component of the *P. clavata* diet (all colours) was based on sediments available at the gorgonian site (45 to 58%) and SIBER results also evidence a similar isotopic niche with *Eunicella* sp. and a clear trophic segregation with mussels. Despite subtle differences in dietary contributions for each coloration, they not appear significant enough pinpoint diet as a determining factor. These findings provide valuable insights into the feeding ecology of these gorgonians, suggesting that the fish farm may positively affect their nutritional status.

ID: 462
Shallow Temperate Reefs

Keywords: Marine heatwaves, sponges, microbial symbionts, thermal stress, Mediterranean

Summer is not a sponge spa: Heatwaves impact *Petrosia ficiformis* (Poiret, 1979) populations and their microbial partnerships

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Global climate change exacerbates the incidence of marine heatwaves (MHWs), which increased in intensity and frequency over the past years, causing severe impacts on coastal ecosystems. MHWs have already caused massive coral bleaching events in the tropics and mass mortalities of habitat-forming species, including sponges and gorgonians, in temperate and polar seas. In the Mediterranean, these abrupt enhancements of temperature have been shown to cause tissue necrosis, accompanied by microbial dysbiosis in several temperate sponges, facilitating the entrance of opportunistic microorganisms. During the summers of 2022 and 2023, populations of the sponge *Petrosia ficiformis* were conspicuously observed with signs of thermal stress linked to MHWs around the Gulf of Naples, Tyrrhenian Sea (Italy). These included depigmentation spots (bleaching) and tissue texture alterations, which often evolve in necrotic processes and eventual death. In the peak of both MHWs, though, apparently thermoresistant sponges co-occurred with sensitive unhealthy specimens. In order to explore potential microbial drivers correlated with these divergent thermal stress tolerances, visually healthy and affected individuals were sampled along the coast of the Island of Ischia in September 2022. Prokaryotic community characterization based on the 16S rRNA gene revealed dissimilar compositions in affected versus apparently healthy sponges. Increased alpha richness and low evenness in thermosensitive sponges were due to an extensive presence of rare taxa and to the introduction of pathogenic groups (e.g., *Vibrio* spp.). Major microbial families regularly associated with *P. ficiformis* –SAR202, Caldilineaceae, Poribacteria or TK17, were replaced in thermosensitive specimens by seeming opportunistic groups within Lentimicrobiaceae, Rhodobacteriaceae or Flavobacteriaceae. Our results show that the preeminent association between healthy sponges and Rhodothermaceae microbes could provide heat tolerance during these disrupting events. The existence of stress-resistant phenotypes leaves a shade of hope for species persistence, and their study may allow us to forecast the structure of future ecosystems.

ID: 359
Shallow Temperate Reefs

Keywords: the Moroccan Atlantic Coast, Gorgonian corals, Shallow-water habitats, Habitat mapping, Seabed mapping

Shallow-water habitats along the Moroccan Atlantic Coast: Gorgonian communities' distribution and biotopes

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The current work describes the distribution and fauna of gorgonian habitats at 27 to 111 meters on the Atlantic Coast of Morocco, based on 37 ROV stations conducted as part of a coral mapping survey held in 2020 by the FAO-NANSEN programme. Observed megafauna and substrate along 400 m long video transects performed at each station were annotated using the software (VideoNavigator). Diversity was measured using the Shannon`s index (H´) and species richness (S). Fauna patterns were identified using the Two-way indicator species analyses (TWINSPAN) and Detrended Correspondence Analysis (DCA), and 11 environmental variables were compared with the DCA ordination axes to find the main drivers behind the patterns. Analysis was conducted on entire video lines (37) and on 113 transect subsamples. In total 28919 organisms and 143 taxa were recorded, and the highest diversity was related to the presence of hard substratum. Five station-groups (I-V) with related fauna were identified and the fauna variation along DCA Axis 1 was correlated with bottom type (bedrock, mud and gravel) while depth, temperature, and position were related to Axis 2. Station-groups (I-III) had presence of hard substratum and gorgonian gardens. I, 7 stations at 76-111m depth, were characterized by sponges and *Ellisella paraplexaurides*. II, 6 stations at depth 27-72m depth, where dominated by *Leptogorgia* species, e.g., *L. violetta* and *L. viminalis*. III, 18 stations at 42-67m depth, had *Eunicella* dominated coral gardens e.g., *E. verrucosa* and *E. cf. labiate*, and encrusting sponges. Two station-groups (IV-V) had only mud sediments: IV, 2 stations at 53-75m depth, had sea pen community dominated by *Pennatula phosphorea*. V, 4 stations at 71-75m depth, was characterized by a community comprising both *P. phosphorea* and *Veretillum cynomorium*. This first comprehensive documentation of gorgonian gardens in the region indicates that sand burial and fisheries are treats to these habitats.

ID: 756
Shallow Temperate Reefs

Keywords: Greater Bay Area, population genetics, reef-building corals, endosymbiosis, resilience

High genetic diversity in endosymbionts contribute to resilience of subtropical reefs in China's Greater Bay Area

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The Greater Bay Area (GBA), China's most prosperous economic area, harbours long-lasting subtropical reef-building coral communities, yet their population connectivity is still unknown. In this study, we selected resilient corals *Platygyra carnosa*, one of the dominant species in GBA, as research object, and obtained transcriptomic-based SNPs data of coral host and endosymbionts from more than 120 fragments collected in 16 sites. Results of population genetic analysis revealed a simple structure of coral hosts across 16 sites, indicating a high population connectivity of coral host *P. carnosa* in GBA. However, a complicated structure was detected in endosymbiont populations, suggesting that Symbiodiniaceae is more susceptible to environmental conditions, and thus forms different subpopulations. These observations highlight that establishing a symbiosis relationship with a partner of high genetic diversity may contribute to coral resilience.

ID: 342
Shallow Temperate Reefs

Keywords: habitat, classification, monitoring

Uncovering hidden treasures: mapping of geogenic reef biotopes in the SE Baltic Sea using underwater Imagery

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Currently, less than 1% of marine areas are strictly protected in the EU (European Commission, 2020). In line with the European Union's Biodiversity Strategy for 2030, which aims to restore our oceans and seas, the EU intends to implement strong protection measures for a minimum of 10% of the EU sea area. Yet, in order to protect and restore areas with unique biodiversity, it is necessary to understand the current state of habitats within our national borders. With this in mind, we conducted the first national reef monitoring program with the aim of mapping underwater reefs (EU-Code 1170) in Lithuania that are currently protected under the European Union's Habitats Directive and the NATURA 2000 network.

During the 2021–2022 summer–autumn sampling season, we filmed 408 video transects within a 300x300-meter grid, covering all the coastal reefs located in the Lithuanian marine area. Transects were divided into 10 m segments, which resulted in a total of 1658 underwater video segments. Underwater imagery data was collected using a drop-down video camera system between 3 - 16 m depth. In the SE Baltic, several reef-associated species were quantified: perennial red alga *Furcellaria lumbricalis*, *Vertebrata fucoides*, and green algae *Cladophora* spp., as well as epibenthic fauna such as blue mussels *Mytilus edulis/trossulus*, and barnacles *Aphibalanus improvisus*. Furthermore, the composition and coverage of substrate types (boulders, pebbles, cobbles, and sand) were also estimated.

As a result, detailed reef biotope maps along the Lithuanian coast were created based on the HELCOM biotope and habitat classification system (HUB). Up to 23 biotopes until Levels 5–6 were delineated, of which the Baltic photic mixed substrate characterized by epibenthic crustacea (AA.M1I) was the most dominant. Additionally, shaping factors and distribution patterns of key species within the reefs will be presented.

ID: 280
Shallow Temperate Reefs

Keywords: Hexacoral, Ligurian Sea, Conservation, Cladocora caespitosa, Oculina patagonica

A new coral reef site in the Ligurian Sea composed by the endangered species *Cladocora caespitosa* and the cryptogenic species *Oculina patagonica*: first assessment.

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Cladocora caespitosa is the main Mediterranean coral species able to create bioconstructions and, at some particular sites, monospecific reefs of particular conservation value, while less information are available for biogenic structures made by *Oculina patagonica*. As suggested by conservation assessments and red lists, information on distribution, population trends and status is a priority to contrast the current general decline of these benthic assemblages. The Ligurian coast pertaining to the municipality of Borgio Verezzi is characterized by the presence of shallow natural beach-rocks (from 1 to 3 m depth). This habitat was investigated in August and September 2022 and in June and October 2023 and, overall, in less than 1 km of linear coast 489 colonies of coral species were registered: *C. caespitosa* representing the 79% and *O. patagonica* the remaining 21%. The colonies of *C. caespitosa* and *O. patagonica* with dimensions less than 20 cm in diameter are between 68% and 55% respectively, while those with diameter larger than 20 cm are 45% for *O. patagonica* and 32% for *C. caespitosa*. There are also some large colonies that cover a surface area from 1 to 3 m^2 for *O. patagonica* and from 0,5 to 1 m^2 for *C. caespitosa*. Some of these colonies showed interspecific competition. During the study some important cases of stress were observed for many colonies related both to phenomena of sedimentary imbalance due to the construction of physical barriers to contrast coastal erosion, and to strong heatwaves. Overall, *C. caespitosa* was found to be more sensitive to these problems (24% of colonies bleached >75% or with sediment or filamentous brown algae that cover the corallites), while *O. patagonica* showed higher capability to adaptation (73% not affected). Future monitoring activities are required to define and implement specific management actions for the conservation of this coral reef species.

ID: 561
Shallow Temperate Reefs

Keywords: restore, biogenic substrate, benthos, transplantation

BORA, a modular multi-habitat artificial reef for the restoration of damaged areas. The study case of Mediterranean coralligenous habitat.

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Due to the prioritisation of shallow coastal areas for the implementation of conservation and restoration actions, certain habitats have been highly overlooked and, consequently, exposed to human activities for many decades now. One of these habitats is the coralligenous, a typical Mediterranean bioconcretion that forms unique landscapes built by calcareous algae frameworks growing in dim-light conditions. Although it is recognized as the second most important biodiversity hotspot in the basin and listed as natural habitat of community interest by the EU Habitats Directive (92/43/EEC), it still lacks effective habitat- and species-based management measures. Among the many stressors impacting coralligenous communities, climate change and artisanal fishing are considered the main threats. Vertically structuring species, such as gorgonians, are especially sensitive to these impacts causing a steep decline in their populations, and thus, overall coralligenous' structural complexity over the past years. In this context, the development of efficient restoration actions interesting those species and contributing to the preservation and enhancement of benthic three-dimensional complexity is paramount to maintain the resilience of this habitat. In the framework of the Italian National Plan of Recovery and Resilience (PNRR), this study presents the first application of BORA, a new kind of multifunctional artificial reef that supplies a customized hard substrate that mimics the terraces and overhangs typical of coralligenous bioconcretions. Its innovative modular shape contributes to the creation of a wide range of micro-habitats and environmental gradients that provide the optimal niche for different species along the same structure. To test its efficiency, 3 typical coralligenous species were selected and transplanted to the structures (*Paramuricea clavata*, and *Corallium rubrum*). Transplanted specimens' survival and growth rates were monitored by means of photogrammetry and compared with explants located over natural substrates in the nearby area.

ID: 650
Shallow Temperate Reefs

Keywords: Microbiome, Cold-Water Corals (CWCs), Resilience, Bacteria

Investigating microbial communities associated with temperate coral gardens in the context of marine restoration

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Microbes contribute to the functional homeostasis of the coral holobiont and drive acclimatization and resilience of corals under changing environmental conditions. Coral gardens, a dense coral formation, are essential for marine species diversity and benthic-pelagic-coupling, and suffer ongoing degradation from overfishing and climate change. Yet, fundamental parameters of their microbiome remain poorly understood. This study represents the first large microbiome analysis across coral garden taxa in the NE Atlantic. Octocorals, scleractinians, and one black coral species were opportunistically collected from fisheries' bycatch at 60-480m depth around Sagres (SW Portugal) to (1) assess natural microbiome diversity and composition; and 2) investigate microbial changes under aquarium conditions in three dominant octocoral species, *Eunicella verrucosa, Paramuricea grayi* and *Leptogorgia sarmentosa* (Malacalcyonacea). *E. verrucosa and P. grayi* were kept under standardized laboratory conditions (Faro, Portugal) and sampled over 45 days (n=33 samples, 7 colonies). All three octocorals, held in two public aquaria (Oceanario Lisboa n=8, Zoomarine n=10) were investigated for comparison. Third-generation 16S-rRNA gene sequencing revealed high microbial host-specificity and supported the importance of Endozoicomonadaceae (mean relative abundance 28.3%±10.5%), Spirochaetaceae (8.2%±5.8%) and Spongiibacteraceae (4.6%±1.8%) in the natural coral garden microbiome. Endozoicomonadaceae was particularly dominant in the order Malacalcyonacea (67.7%±14.5%). The low microbial alpha diversity and limited interspecies differences among the Malacalcyonacea species suggest a conserved microbiome within this group, as compared to other orders. In addition, we revealed differences in the responses of two octocorals to laboratory and aquarium conditions, with *E. verrucosa* displaying higher microbial flexibility to short-term captivity, in contrast to greater microbiome stability in *P. grayi*. However, the long-term captivity led to microbiome shifts in both species. Our results reveal that restoring coral gardens, not only requires coral garden-specific conservation strategies, but also species-specific strategies based on the microbial diversity, flexibility, and stability of each coral species.

ID: 555
Shallow Temperate Reefs

Keywords: Portofino, Western Mediterranean, mitigation strategies, sessile organisms

Pump it…Harder! Mucilage removal from coralligenous assemblages in an Italian MPA

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The rapid warming of the Mediterranean Sea is increasing the frequency and intensity of mass mortality events and mucilage outbreaks are now spreading on deeper depths and for longer periods than in the past. Mucilage was found to induce oxidative stress at cellular level in the red gorgonian *Paramuricea clavata*, partially explaining the pattern of tissue necrosis. In this context, an innovative vacuum pump designed by SUEX S.r.l., called Discovery – diver operated dredge (DOD), for the removal of mucilage from benthic sessile organisms has been here applied. Thanks to the engagement of technical divers, the vacuum pump collected mucilage covering *P. clavata* colonies in two sites (Isuela and Testa del Leone) inside the Portofino Marine Protected Area. At a depth of around 30 m, twelve quadrats of 50 x 50 cm were deployed and tagged at each site. The mucilage removal occurred in July 2023 (T_0) in both locations, with pictures taken before and after the removal and a second monitoring was carried out 50 days later (T_1). From a total of 134 colonies, the 88% was affected by mucilage at T_0, and only a 9% at T_1 (Friedman test: df =1, $\chi 2$ = 12, $p < 0.001$), with only 1 colony affected at Isuela. The collected mucilage was also tested as a potential tool in metal bioremediation, demonstrating to be a good candidate in the biosorption of palladium, iron, and aluminium. Considering the current climate crisis, the increasing frequency of such events asks for urgent and effective solutions to mitigate the impact as the design of experimental circular exploitation of algal biomasses for promising and innovative applications.

ID: 223
Shallow Temperate Reefs

Keywords: Octocorallia, invasive, shift in community structure, anthropogenic effects, biogeography

The xeniid octocoral *Unomia stolonifera*: unprecedented case of an invasive to coral reefs

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Since the first appearance of the invasive xeniid soft coral *U. stolonifera* on the Venezuelan reefs in 2007, it has dispersed immensely while overgrowing any natural hard substrate, including stony corals, sponges and seagrass. Taxonomic and phylogenetic studies revealed that this species is indigenous to the Indonesian reef system and it is likely that the source of introduction in Venezuela is aquarium release. The soft coral was assigned to the new genus *Unomia* and it is the first record of an invasive xeniid to be found in the Caribbean reefs, away from its native biogeographical region of natural occurrence. Quantitative surveys revealed that *U. stolonifera* dominated all the studied Venezuelan sites, featuring an average percentage cover of 30 - 80%, far above that of the native corals or any other coverage of benthic taxa recorded prior to the invasion event. The spread of *U. stolonifera* in places where it has become established while displacing native benthic species has led to a dramatic decrease in the benthic community diversity. Dispersal of this invasive along the Venezuelan reefs has been intensified by drifting of detached colonies, by colonies settled on detached fragments of the sea grass *Thalassia testudinum* and additionally by colonies entangled on fish nets and consequently translocated. The current findings explicitly demonstrate that this progressing invasion is causing severe ecological damage to the Venezuelan marine ecosystem. Its biogeographical expansion has been further recorded in other Caribbean reefs, such as Cuba, and in addition in Pearl Harbor, Hawaii. Undoubtedly, *U. stolonifera* should be considered a harmful invasive species that requires monitoring and management programs, especially in the vicinity of already invaded reefs. The current findings demonstrate the invasiveness and spreading nature of octocorals in general and of xeniids in particular.

ID: 646
Shallow Temperate Reefs

Keywords: Semper larvae, Palythoa heliodiscus, zooxanthellae, settlement

An unexpected presence: zooxanthellae Semper´s larvae (Zoantharia) in the Canary Islands closely related to those in the Pacific, settlement, and growth.

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In recent years, zoantharians outbreaks on shallow reefs of tropical and subtropical regions around the globe have increased. These colonial cnidarians can occupy large areas, smoothening rocky surfaces, and modifying entire benthic communities. So far, in the Canary Islands, seven zoantharian species have been recorded, some of them already altering coastal ecosystems. In this study, we identified a previously unreported Semper larvae species in the archipelago, along with its dominant endosymbiont. Additionally, we documented their settlement and growth in the laboratory. Larvae were collected in the water column at two different locations of Tenerife Island (Canary Islands, Spain) in March 2023. Specimens were maintained in the laboratory under the same conditions registered at the time of collection (i.e., 21-22 ºC; 37,0 PSU). Larvae successfully settled in the aquarium and their development was followed for 9 months, registering, and describing the complete metamorphosis from larvae to polyps. Semper´s larvae were consistent with the zoanthella form characteristic of the genus *Palythoa*, and zooxanthellae were abundantly present in their tissues. Morphological and morphometric characteristics were recorded weekly, while genetic analyses were performed to identify both the host and the endosymbionts species. The mitochondrial cytochrome C oxidase (COI) and ITS-rDNA molecular markers identified the larvae as *Palythoa heliodiscus*, and phylogenetic analyses supported its strong relation to Pacific Ocean specimens. Furthermore, the ITS2-rDNA and $psbA_{ncr}$ markers of the zooxanthellae identified the dominant endosymbiont as *Cladocopium* C3, particularly from the same linage previously detected in *P. heliodiscus* in Okinawa (Japan). This study constitutes the first report of *P. heliodiscus* settlement under laboratory conditions and the first record of these species in the Canary Islands and the Atlantic Ocean. Our findings suggest that current environmental conditions in the archipelago seem sufficient to allow the settlement and growth of this tropical species, previously reported exclusively in the Pacific Ocean.

Session 8: Mesophotic and Cold-Water Coral Ecosystems

Mesophotic Coral Ecosystems (MCEs) are deep reef communities that occur from ~30–150 m, and have been estimated to encompass more areal reef habitat (i.e., ~60-80% global cover) than shallow reefs. These deep reefs are typically further offshore from anthropogenic stressors (e.g., coastal development and point-source discharges) and below the depth limits of most natural stressors (e.g., storm events and thermal effects), which led to the hypothesis that MCEs could provide a refuge for many coral reef species and might potentially replenish degraded shallow reefs. Mesophotic reefs represent a challenging frontier for direct underwater research that can be only partially explored with ROV studies. The observations and sampling performed during technical dives are unveiling unexpected aspects both regarding biodiversity and ecosystem functioning. In temperate and tropical areas, the connectivity between mesophotic-shallow and mesophotic-deep habitats is still an open debate that cannot be solved by looking for general rules. Studies focused on the controversial "refugia hypothesis" need to be discussed considering the peculiarity of each site, both from a temporal and spatial point of view. The climate crisis, even if dramatic in its effects on the marine environment, is offering a unique opportunity to test the role of the mesophotic zone in coastal benthic assemblage dynamics. While a general understanding of MCE structure and function may be impossible to develop giving apparent site-specific differences, with increasing knowledge, and depending on the considered taxa, we can likely identify patterns which future research can test globally.

This session will focus on all aspects of mesophotic reefs. Contributions may include studies on the biodiversity, ecology, and physiology of mesophotic species to highlight how the experiences coming from tropical mesophotic reefs can contaminate and inspire the research on temperate reefs, and vice-versa.

Keywords: biodiversity, connectivity, functioning and threats

Session chairs

Marc Slattery, University of Mississippi (USA)

Carlo Cerrano, Polytechnic University of Marche (Italy)

Take home message

- Continued exploration has demonstrated that Mesophotic & Cold Water Reefs are broadly distributed
- Data indicates that these reefs vary with location (ie, not all deep reefs are the same, site specific processes)
- Conservation & Management will require additional research on structure & function, species assemblages, and oceanographic patterns, & ecological interactions (including facilitation, predation & competition)

Regular oral presentations

ID: 190 / **Parallel Session 8-1: 4**
Mesophotic and Cold-Water Coral Ecosystems

Keywords: Scleractinian cold-water corals (CWCs), ROV-imaging, Italian monitoring, entanglement

The monitoring of Mediterranean upper bathyal biogenic reefs within the marine strategy framework directive

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The main objective of the European Marine Strategy Framework Directive (MSFD, 2008/56/EC) is the achievement of the Good Environmental Status (GES) in the EU's marine waters, including the deep sea, and the protection of the marine biodiversity. Due to the ecological importance and vulnerability of cold-water corals (CWCs), Italy has extended the implementation of the MSFD monitoring to deep-sea reefs, by carrying out specific programmes on scleractinian CWCs, using a non-invasive Remotely Operated Vehicle (ROV)-imaging methodology. Eleven areas, known for the presence of upper bathyal CWC reefs and representative of diverse seabed morphologies, environmental conditions, and anthropogenic pressures have been identified to be monitored every three years, starting from 2020, in each of the three MSFD Italian marine subregions. To assess the GES of benthic habitats, the Italian MSFD requires the combination of data sets relating to three different descriptors: D1 – Biodiversity, D6 – Habitat integrity, and D10 – Marine litter. The monitoring activities are carried out applying standardized protocols based on specific criteria, used as a proxy for evaluating habitat health status and quantifying the extent of anthropogenic impacts on the biological components. A multi-parametric ecological index is currently under development to assess the environmental status of CWCs over time employing a robust and structured numerical method. This index integrates both the Index of Status (Is) and the Index of Impact (Ii). It includes ten metrics, targeting conspicuous species diversity, canopy composition, biogenic substrate, sedimentation level, entanglement, and marine litter occurrence. This approach improves scientific knowledge on CWC reefs enabling the definition of threshold values useful to compare data on a large scale. Furthermore, it is pivotal in defining the need of new specific management measures, as the MSFD requires.

ID: 602 / **Parallel Session 8-1: 8**
Mesophotic and Cold-Water Coral Ecosystems

Keywords: photogrammetry, genomics, mesophotic, biodiversity

Reefscape genomics: leveraging 3D-imaging to assess fine-scale genomic variation on coral reefs

Pim Bongaerts

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Molecular ecological studies have been instrumental in advancing our understanding of coral reefs. Although initially focused primarily on broad-scale connectivity patterns, they have gradually uncovered the prevalence of local genetic structuring and cryptic diversity in these ecosystems. Genome-wide sequencing approaches have provided new opportunities to understand both neutral and adaptive contributions to this largely unexplained diversity, but in terms of exploring environmental or phenotypic associations, have been hampered by methodological challenges specific to marine environments. Here, I discuss the potential of "reefscape genomics," leveraging recent advances in underwater imaging to enable spatially explicit genomic studies in marine ecosystems, allowing for fine-scale spatial mapping, environmental characterization and simultaneous in situ mass-phenotyping. Using examples from our CoralScape project in Curaçao –where we are gradually characterizing the genomes and phenotypes of ~20,000 corals across a large depth gradient (5-60 m depth) – I discuss how this approach can offer new insights into the spatio-temporal drivers and adaptive potential of local genetic diversity. Reefscape genomics represents a promising advancement of our molecular ecological toolkit to help inform how we can most effectively conserve and restore threatened marine ecosystems into the future.

ID: 643 / **Parallel Session 8-1: 9**
Mesophotic and Cold-Water Coral Ecosystems

Keywords: Desmophyllum pertusum, reef morphology, reef habitats, currents, food

Influence of Water Currents, Food Supply, and Topography on the Growth Morphology of Cold-Water Coral Reefs on the Norwegian Shelf

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Cold-water corals depend on food particles transported horizontally by currents and vertically by zooplankton migration, and particle sinking. Reefs built by *Desmophyllum pertusum* are found in areas with a stable and good food supply provided by strong currents or concentrated by turbulence. Reefs grow both vertically and horizontally, and growth direction depends on the dominating direction of food supply and the underlying terrain that results in different shapes e.g. circular, elongated, carpet forming, and banana shaped. We study how the growth morphology is controlled by current direction and terrain using fine-scaled seabed topography (multibeam echosounder data), visual surveys, and environmental data from 595 coral reefs on the Norwegian shelf and shelf break (62 to 71°N). The distribution of habitats including surface area and volume of live and dead coral framework is compared between reefs of different size and shape. The ratio between height and horizontal extension of reefs varied in relation to seabed topography and current patterns. In steep terrain reefs cover a wider depth range than on level bottom. On ridges or elevations with tidally driven bi-directional currents, reefs tend to be circular and tall, whereas in areas with uni-directional currents the reefs are more elongated (cigar-or droplet shaped). For instance, on fjord sills with a typical east-west current, or in the Hola area (northern Norway) where the main food transport is related to the tidal current from east to west the reefs have colonies growing mainly towards the current. We discuss how currents and food supply shapes and structure reef morphology and the impact from climatic related change in temperature, oxygen, and turbidity. The growth morphology of Norwegian reefs is compared with the morphology of reefs in other regions of the world where growth has been continuous during last Ice age and environmental settings differs.

ID: 107 / **Parallel Session 8-1: 2**
Mesophotic and Cold-Water Coral Ecosystems

Keywords: MCEs, Red Sea, Palaeoecology, Long-term monitoring, Coral ecology

Historical and contemporary evaluation of Eilat's mesophotic coral ecosystems

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The mesophotic ecosystems of Eilat, situated in the northern Gulf of Aqaba (Red Sea), have been studied by marine scientists and conservationists for a long time due to their unique biological ecological characteristics. In this study, I will present a comprehensive examination of the historical and contemporary factors influencing the health and resilience of Eilat's mesophotic ecosystems with some future points for consideration for the management and protection of these unique habitats.

Our palaeoecological reconstructions and historical assessments delve into past ecosystem dynamics, environmental conditions, anthropogenic impacts, and natural disturbances that have shaped the trajectory of these coral communities. It explores the phase shifts and resilience mechanisms that have allowed mesophotic corals to adapt to changing conditions over time and the fragility of some species. In the contemporary context, we focus on the current state of Eilat's mesophotic coral ecosystems, employing long-term advanced monitoring techniques, ecological surveys, and physiological analyses.

In this study, we investigated the impacts of global climate change, pollution, and other local disturbances on the health and biodiversity of these northern Red Sea ecosystems. Additionally, it explores ongoing conservation efforts and management strategies implemented to mitigate threats and enhance the resilience of Eilat's mesophotic ecosystems with some global perspectives.

ID: 332 / **Parallel Session 8-1: 5**
Mesophotic and Cold-Water Coral Ecosystems

Keywords: Deep reef refugia hypothesis, Population genetics, La Réunion, Mayotte, Microsatellites

Genetic connectivity of mesophotic hydroids from French overseas territories in the southwestern Indian Ocean.

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In the context of global warming and anthropogenic pressures that threaten coral reef ecosystems worldwide, scientific interest on the mesophotic zone has increased considering its potential for shallow-water reef resilience. Located between 30 and 150 meters of depth, mesophotic coral ecosystems (MCEs) remain largely unknown, in terms of their biodiversity as well as their relationships with euphotic ecosystems. In the Deep Reef Refugia Hypothesis (DRRH), MCEs were proposed to act as potential sources for recolonization of degraded shallower reefs. However, the prerequisite to this hypothesis is the existence of connectivity between shallow and deep reefs: a vertical connectivity along the depth gradient.

This study aims to test the vertical genetic connectivity among hydroid populations, a neglected group with a high diversity of traits in terms of morphs, skeletons, habitats, and reproduction modalities. Through 50 dives at mesophotic depths in the French overseas territories of the southwestern Indian Ocean (La Réunion & Mayotte), more than 2600 samples were collected. These samples were genotyped using microsatellite libraries for 8 target species (6 newly developed for this study) to perform a comparative population genetics approach. A combination of several methods (estimation of genetic differentiation indexes, Structure and AMOVA analyses, Mantel tests and estimation of gene flow and its directionality) were used to investigate population genetics patterns at different scales of complexity. Results show contrasting patterns of connectivity depending on species and reproduction strategies. This study brings new information about the links between mesophotic and euphotic populations which could contribute to the conservation of reef ecosystems.

ID: 722 / **Parallel Session 8-3: 1**
Mesophotic and Cold-Water Coral Ecosystems

Keywords: Canary Islands, Biodiversity, Mesophotic zone, Marine Animal Forests, latitudinal gradients

Underwater forests: distribution and ecological patterns of black coral communities across an oceanic archipelago

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The Canary Islands and their adjacent seamounts represent a unique biodiversity "crossroad" within Atlantic and Mediterranean. The geographical separation of *ca.* 1000 km between the Western and Eastern volcanic islands and seamounts, generates a high variability of biodiversity scenarios, which are currently under threat due to the overexploitation of coastal areas, natural resources, and global environmental changes. Despite these challenges, unexplored marine animal forests, particularly black corals, appear in the shallow, mesophotic and deeper zones. We took advantage of the geomorphological configuration of the archipelago to assess whether patterns in the occurrence and abundance of black corals varied between groups of islands (western, central, eastern), depth, slope and sea bottom types. Data collection encompassed a range of depths, from shallow to mesophotic, as well as deep waters using SCUBA diving (< 15 to 203 m) and remotely operated vehicle deployments (*ca.* 1000 m).

More than 1600 observations of black corals were recorded across the 10 islands surveyed (87 sites) including at least 13 species grouped in 9 genera. Globally, depth conditioned the species occurrences, although the differences in the spatial distribution patterns of coral communities, especially *Antipathella wollastoni*, *Stichopathes* spp., *Antipathes* spp. and *Parantipathes* spp., also showed the importance of slope, sea bottom and island group. In addition, *A. wollastoni and Stichopathes* spp. appeared widely distributed in the mesophotic zone (60 to 200 m) composing dense aggregations, with a major occurrence on rocky bottoms and mixed mud-sediment banks, respectively.

Overall, the results provided insights into the distribution and ecological patterns of black coral communities in relation to the diverse environmental factors, revealing the significance of the Canary Islands and neighbouring seamounts as an important black coral hotspot in the world. These findings provide a fundamental basis for the protection of mesophotic and deep-sea coral assemblages in this biogeographical region.

ID: 110 / Parallel Session 8-1: 3
Mesophotic and Cold-Water Coral Ecosystems

Keywords: trophic ecology, sponge loop, water flow, sponges

The functional ccology of sponges on Mesophotic Reefs

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Mesophotic Coral Ecosystems (MCEs) are low-light adapted deep reef communities that occur from ~30-150 m; representing 2-3 times the percent cover of worldwide shallow reefs. MCEs are typically further offshore from anthropogenic stressors (*e.g*., coastal development and point-source discharges), and below the depth limits of most natural stressors (*e.g*., storm events and thermal effects). This has led to the hypothesis that MCEs provide a refuge for many coral reef species that could replenish shallow reefs impacted by climate change (*i.e*., the Deep Reef Refuge Hypothesis). While recent studies have addressed molecular evidence for MCE connectivity with shallow reefs, few studies have examined ecological interactions on deep reefs and the functional roles of various species within these ecosystems. Within the Caribbean Basin there is a consistent faunal break at a depth of ~60 m. At depths above this faunal break (*i.e*., the upper mesophotic zone: ~30-60 m), the benthic communities are ecologically similar to those of nearby shallow coral reefs and represent a transitional fauna. In contrast, at depths below this faunal break (*i.e*., the lower mesophotic zone: ~60-150 m), the communities are unique with many endemic species and there are significant increases in percent cover and biomass of sponges. Worldwide, sponges are an important component of benthic-pelagic coupling and are a means to transform dissolved organic matter (DOM) to particulate organic matter (POM) via the "sponge loop", that then becomes available to higher trophic levels. Utilizing a functional ecology approach we will characterize the importance of sponges on MCE trophic dynamics, and the effect that climate change may have on MCEs as food (*i.e*., picoplankton) potentially becomes limiting, changing the functional roles of sponges in these unique deep reef ecosystems.

ID: 533 / Parallel Session 8-1: 7
Mesophotic and Cold-Water Coral Ecosystems

Keywords: cold-water corals, deep-sea ecosystems, habitat mapping, seamounts, VMEs

Machine learning approaches to map unexplored cold-water coral communities in Cabo Verde (NW Africa)

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Cold-water coral (CWC) dominated communities contribute to habitat complexity and diversity of deep-sea ecosystems, and they can be key indicators of Vulnerable Marine Ecosystems (VMEs), according to international fisheries guidelines. Due to their remoteness, it is challenging to investigate the occurrence of CWCs and, consequently, the presence of VMEs, hampering the implementation of marine spatial plans.

The iMirabilis2 expedition, as part of the European project iAtlantic, took place in 2021 on board the Spanish Research Vessel *Sarmiento de Gamboa* (UTM-CSIC), where the deep-sea off Cabo Verde (NW Africa) was explored. For the first time, the bathyal hard-bottom benthic communities of Cadamosto seamount (SW Brava Island) and the slopes of the islands of Fogo and Brava were surveyed, from 2100 to 1450 m depth, with the Remotely Operated Vehicle (ROV) Luso (EMEPC). In this study, we aimed to investigate the spatial distribution of CWCs in Cabo Verde, using species spatial data and environmental variables (terrain and oceanographic). At local scales, we used multivariate regression trees to identify benthic communities and a random forest classification to create a predictive habitat map for the SW of Cabo Verde. At a regional scale, we applied an ensemble species distribution modelling approach to predict the presence of the most conspicuous CWC taxa, indicators of VMEs, on five unexplored seamounts in the Cabo Verde archipelago.

Our results show that at local scales, community composition and distribution are driven by depth, water column chemistry and terrain geomorphology, whereas the presence of CWCs on the seamounts of Cabo Verde is driven by large-scale features related to terrain slope and orientation, illustrating the importance of hydrodynamic-topography interaction to provide increased food supply for CWCs. Our work demonstrates how predictive habitat mapping techniques can be used to assess data-poor and remote deep-sea regions for the likelihood of VMEs.

ID: 103 / Parallel Session 8-1: 1
Mesophotic and Cold-Water Coral Ecosystems

Keywords: Octocoral, Genomics, Ocean dynamic modelling, Histology, Life history

Factors limiting range edge populations of the pink sea fan (*Eunicella verrucosa*)

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The pink sea fan (*Eunicella verrucosa*) is a cold-water gorgonian octocoral with a distribution ranging from northwest Ireland to the Mediterranean. Recognised as a priority species in Great Britain under the UK Wildlife and Countryside Act 1981, many marine protected areas (MPAs) have been designated to safeguard priority species like the pink sea fan. However, for MPAs to achieve their goal of protecting marine biodiversity, a comprehensive understanding of population connectivity and limiting factors at range edges is critical.

We aim to address the knowledge gaps in pink sea fan life history and connectivity using a multidisciplinary approach that harnesses molecular ecology, life history aquaria experiments and histology, and ocean dynamic modelling. Whole genome sequencing captures genetic variation across the species' range; preliminary analysis has revealed fine-scale patterns of connectivity and potential evidence of adaptation at range edges. Life history analyses are ongoing to understand gonadal development timing and elucidate reproductive processes, growth rates, and temperature-related pelagic larval duration. These novel data will allow us to build species-specific particle tracking models to simulate connectivity across the species' range, offering insights into settlement locations and population dynamics within and between MPAs and non-MPA populations and how the species' range may shift under climate change.

In summary, our research aims to evaluate the current effectiveness of the MPA network in preserving connectivity within the Pink Sea Fan populations. By integrating genetic insights, biological data, and modelling techniques, we strive to contribute valuable information for the conservation of this remarkable species and the preservation of marine biodiversity in the UK and beyond.

ID: 379 / Parallel Session 8-1: 6
Mesophotic and Cold-Water Coral Ecosystems

Keywords: Vulnerable Marine Ecosystems, Species Distribution Models, Climate Change, Climate Refugia

Identifying climate refugia for Vulnerable Marine Ecosystem indicators under future climate change scenarios

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Vulnerable Marine Ecosystems (VMEs), such as cold-water corals, hold substantial conservation value due to their ecological significance and vulnerability to disturbances like climate change and fishing. One approach to managing these ecosystems, especially in difficult-to-reach environments such as the mesophotic and the deep sea, involves generating spatial predictions for VME indicator taxa – species, communities or habitats signalling the potential presence of VMEs. This study employed Species Distribution Models to evaluate potential alterations in the distribution and density of 14 VME indicator taxa within the New Zealand Exclusive Economic Zone, spanning depths from 100 to 1500 meters, under current environmental conditions and future climate change scenarios (SSP2-4.5 and SSP3-7.0). Our models performed well for all taxa (mean AUC = 0.82; r = 0.40) but predicted a considerable reduction in the density (54%) and habitat extent (61%) by the end of the 21st century under both climate change scenarios. Such declines pose threats to ecosystem functionality and increase susceptibility to additional stressors like bottom trawling, elevating the risk of local extinction. However, under both future climate change scenarios, most taxa will maintain high densities, albeit lower than current-day predictions. Furthermore, these species are projected to expand into new areas within the study zone, potentially acting as climate refugia as they are predicted to persist under future climatic conditions. Our findings carry significant implications for ecosystem management and spatial planning since current marine protected areas may not offer adequate protection to VME indicator taxa against additional impactful activities, such as bottom trawling, either in the present or the future. Consequently, we suggest an assessment of cumulative effects on these ecologically relevant habitats should be undertaken to identify and establish an effective level of protection for potential climate refugia, thereby safeguarding the provision of essential ecosystem services.

Speed talks

ID: 273 / **Parallel Session 8-2: 9**
Mesophotic and Cold-Water Coral Ecosystems

Keywords: growth, respiration, ocean acidification, warming, deoxygenation

Physiological response and skeletal dissolution of the cold-water coral *Desmophyllum pertusum* to multiple environmental stressors

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The cold-water coral (CWC) *Desmophyllum pertusum* (syn. *Lophelia pertusa*) is an important ecosystem engineer, forming complex three-dimensional reefs in the deep sea. These reefs consist of both live corals and dead skeletons and are associated with high biodiversity. However, CWCs are threatened by climate change. Previous laboratory studies mainly focused on the effects of individual environmental factors, especially elevated temperatures and reduced pH. So far, little is known about the effects of reduced oxygen concentration and food availability on CWCs and the combined effect of all these stressors. Therefore, we have conducted a long-term aquarium experiment with *D. pertusum* under end-of-century conditions. We have investigated the combined effect of increasing pCO_2 (400 and 1000 ppm), elevated temperature (9 and 12 °C), reduced oxygen concentration (80 % and 100 %) and reduced food supply (25 and 50 mg C m^{-2} d^{-1}) on coral mortality, calcification, respiration, and energy reserves over one year. In a parallel experiment, we also examined dissolution rates of live and dead skeletons at different pCO_2 levels (750, 1000 and 1250 ppm) using buoyant weighing and micro-computed tomography scans to better predict how ocean acidification will affect the structural integrity of CWC reefs in the future. Calcification rates were lowest in the multiple stressor treatments, reaching negative values after more than three months, presumably because the dissolution of skeletal parts not covered with tissue exceeded the growth rate of live polyps at aragonite undersaturation. In addition, the dissolution rate of dead coral skeletons increased with reduced seawater pH. Therefore, we assume that live CWCs may be able to cope with future environmental changes to a certain extent, whereas increased skeletal dissolution due to ocean acidification may lead to structural weakening of the dead skeletal framework and potential crumbling of CWC reefs in the long term.

ID: 121 / **Parallel Session 8-2: 1**
Mesophotic and Cold-Water Coral Ecosystems

Keywords: community stability, depth gradient, refugia

The stability of Caribbean reef fish communities across shallow and upper-mesophotic reefs

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According to the 'deep reef refugia hypothesis (DRRH)', fish communities on deeper coral reefs (mesophotic coral ecosystems - MCEs) will be better protected from disturbances than those at shallower depths. If this were true, we would expect fish communities at depth to have higher levels of constancy in community composition overtime (i.e., greater community stability). On the other hand, greater species richness of fishes on shallow-water reefs could promote stability - in line with the 'diversity–stability relationship'. Here, we explore whether fish communities in the upper-mesophotic zone (40m) have greater levels of stability than those in shallow reefs (<30m) and explore how biodiversity influences community stability across depth. We hypothesize that the stability of fish communities will decrease with greater depth and sites with higher initial levels of fish diversity will exhibit greater levels of stability. We used diver operated stereo-video surveys to record fish communities around the island of Utila, Honduras in two time periods: 2014-2015 and 2022-2023. These surveys were conducted at four depths (5m, 15m, 25m, and 40m) spanning shallow-water and upper-mesophotic reefs. We determine fish alpha, beta and functional diversity, as well as biomass, for each depth and time period. Using these data, we employ piecewise structural equation modelling (pSEMs) to evaluate the direct and indirect effects of each diversity metric and depth on community stability. From anecdotal observations during data collection and initial analysis, we anticipate that our findings will highlight that depth does not provide a universal refuge for fish communities

ID: 826 / Parallel Session 8-3: 2
Mesophotic and Cold-Water Coral Ecosystems

Keywords: Laminaria, Paramuricea, VME, remote sensing, temperature

Benthic community zonation from mesophotic to deep sea: Description of first deep-water kelp forest and coral gardens in the Madeira archipelago (NE Atlantic)

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The Madeira archipelago has a unique underwater landscape that is characterised by narrow shelves, steep slopes and a large submarine tributary system that boosts primary productivity in oligotrophic waters and thus offers a potential for hotspots of biodiversity. Despite this, there have been limited deep-water exploration activities with less than five expeditions since the 1960s. Here, we investigated the seabed on the southern side of the Madeira-Desertas Ridge using a manned submersible along a 3.8 km long transect starting at 366 m depth up the ridge shelf until its top at 73 m. Benthic habitats and community composition were documented with video along a depth gradient from mesophotic to deep sea. Six distinct biotopes were recognised (three deeper, and three shallower than 115 m depth). Our results showed a rich biodiversity with deep biotopes characterised by sponges and non-reef-building corals (e.g., *Pachastrella*, *Viminella flagellum*, *Eunicella verrucosa*) and shallow biotopes comprising macroalgae and the gorgonian *Paramuricea* cf. *grayi*. The pronounced benthic zonation reflects the steep environmental gradient that includes high topographic variation, heterogeneous substrates, and bidirectional regular wave-motion at the shallow mesophotic part. Together with biotic factors, such as low density of sea urchins and presence of predatory fish, this environment with unusual deep light penetration, a mesoscale cyclonic eddy, and deep wave-motion, has allowed the establishment of a mature deep-water kelp population of *Laminaria ochroleuca* in the plateau (max. >100 individuals p/100 m^2). At the same time, a conspicuous coral fauna was observed on a wide range of soft to hard bottoms with several species taking advantage of the favourable hydrodynamic regime and seawater properties together with substratum availability to create coral gardens. These habitats were previously not known from Madeira, and their newfound discovery in the archipelago merit further investigation and protection.

ID: 516 / Parallel Session 8-2: 14
Mesophotic and Cold-Water Coral Ecosystems

Keywords: Parazoanthidae, animal forests, Adriatic Sea, Mediterranean Sea

Diversity associated with a *Savalia savaglia* (Bertoloni 1819) forests related to freshwater vents in Boka Kotorska Bay (Montenegro)

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The environment of Boka Kotorska Bay, on the eastern coast of the Adriatic Sea, is characterized by a huge amount of freshwater flowing into the sea from small rivers, and numerous streams and karstic underwater springs - *vrulja* - that are more common in the inner parts of the bay system. These freshwater outflows are largely intermittent due to the meteorological conditions: in raining periods, the flow is estimated at 15-20 m^3s^{-1} also visible from the surface while in summer it is strongly reduced. Around these vents, rich benthic assemblages mainly characterized by anthozoans and sponges were found between 9-25 m depth. The most abundant species was the gold coral *Savalia savaglia* with colonies up to 1.2 m high and organized in dense intricate patches reaching values of about 0.6 col. m^{-2}. Additionally, bioconstructions mainly formed by the two non-symbiotic scleractinians *Polycyathus muellerae* (Abel, 1959) and *Phyllangia americana mouchezi* (Lacaze-Duthiers, 1897), exceeding 1 m high, with a volume greater than 1 m^3 were recorded. The high quantity of freshwater, coming both from superficial coastal runoffs and submerged springs upwelling, has the consequence of a strong reduction in light penetration which explains the observed vertical compression of the bathymetric planes. Due to the *vrulja* outflows, these assemblages can tolerate reduced salinity levels for extended periods, undermining the traditional idea that salinity is one of the limiting factors for anthozoan development. The impressive flourishment of these assemblages cc 200m in diameter around *vrulja* was putatively put in relation to the action of vents producing a substantial upwelling of organic matter from the sediments over long periods across the year.

ID: 689 / **Parallel Session 8-2: 21**
Mesophotic and Cold-Water Coral Ecosystems

Keywords: mesophotic zone, coral habitats, Photosynthetically active radiation, Climate change

Benthic mesophotic coral habitats in a changing global marine lightscape

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The mesophotic zone hosts a highly diverse ensemble of habitats, stemming from the gradual transition from communities thriving in full light conditions to those tolerant to shade. This diversity is mainly controlled by the gradient of solar radiation with depth.

The depth range of mesophotic light conditions varies with latitudes: 30–150 m in the tropical belt composed of ‘mesophotic coral ecosystems’, and at more variable depths depending in temperate and higher latitudes on geographical location.

Determining the current distribution of benthic mesophotic habitats poses a significant challenge, as it relies upon estimating the amount of light at seafloor. This becomes even more complicated when considering temporal variation in the underwater light field over time.

Recent studies using satellite-based modeling revealed a global-scale spatial reorganization of the benthic mesophotic zone over the past two decades, with potentially major implications for mesophotic habitats requiring specific light conditions.

Here, we explore the impact of ongoing changes in underwater light conditions on the presence and distribution of benthic mesophotic habitats through four case studies in different geographic and climate zones: The Mediterranean Sea, a semi-enclosed temperate basin with peculiar oceanographic settings, where mesophotic habitats are formed mainly by algae, cnidarians and sponges; The Red Sea, a uniquely warm and oligotrophic tropical basin, inhabited by scleractinians, anthipatharians, and gorgonians at mesophotic depths; The northern Gulf of Mexico, a marginal subtropical sea of the Atlantic Ocean hosting macroalgae and cnidarians at mesophotic depths; and the Hawaiian Archipelago, an isolated and highly-productive tropical archipelago populated by macroalgae, scleractinians, and anthipatharians at mesophotic depths.

Our contribution aims to explore how changes in underwater light conditions affect the distribution of mesophotic habitats in our selected case study areas. Furthermore, it seeks to establish a reference baseline for investigating the fate of benthic mesophotic habitats on a global scale.

ID: 841 / **Parallel Session 8-3: 4**
Mesophotic and Cold-Water Coral Ecosystems

Keywords: protected natural area, biodiversity, population ecology, Gulf of California

Differences between shallow and mesophotic ecosystems in the Espíritu Santo archipelago, BCS Mexico.

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The study of mesophotic reefs has become relevant because they can function as refuges for both human activities and the effects of global change. In this study we aim to improve the knowledge on the structure of these ecosystems by focusing on the local ichthyofauna. An analysis of the ecological structure of shallow and mesophotic fish was carried out in three areas of the Espíritu Santo Archipelago National Park, to determine if there were differences among three locations: El Bajo, Punta Lobos, Los Islote. The data was obtained by means of a remotely operated vehicle at depths from approximately 20 to 65 meters through video recordings of 5 minutes from which the abundance of each fish species was determined; from there we calculated species richness, abundance, Simpson dominance, equitability, richness Margalef and Fisher's alpha diversity. The results show that a total of 90 species belonging to 67 genera and 38 families were recorded joining the three sites. The highest dominance was found in Punta Lobos (Simpson D=0.859) due to the abundance of the planktivores *Chromis atrilobata* (Pomacentridae) and *Paranthias colonus* (Serranidae), while Los Islotes and El Bajo presented lower values because the abundance of the resident species was more balanced. When comparing bathymetric levels, the mesophotic zone in general had more abundance and richness, and the effect was more evident in Punta Lobos. The differences in ecological indices of mesophotic reef fish faunas at different sites of the same protected area is due to the combined effect of a higher bottom tridimensionality (high at Punta Lobos, low in the remainder sites), and the high number of planktivores therefore, it is ideal to extend the studies to continue evaluating the influence of bathymetric factors, as well as determine the amount of oxygen and chlorophyll present.

ID: 557 / **Parallel Session 8-2: 16**
Mesophotic and Cold-Water Coral Ecosystems

Keywords: antipatharia, marine animal forests, conservation, Marine Protected Area, Mediterranean

Hopes and dreams for the conservation of coral forests in the Mediterranean Sea: insights from two archipelagos

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Most of the mesophotic coral taxa in the Mediterranean Sea have an arborescent habitus (e.g., black corals and octocorals), able to form dense populations known as coral forests which enhance the morphological, structural and functional complexity of the seabed. These vulnerable marine ecosystems host unique communities and represent true hotspots of biodiversity, which led to the currently growing attention by both scientists and policy makers toward appropriate conservation actions, as well as to find non-invasive ways to study and monitor them. Recent explorative efforts are highlighting the presence of extensive coral forests in the Mediterranean Sea, where no conservation measures are currently in place to protect such a pivotal ecosystem. This study reports the finding of large, mesophotic coral forests structured by the black coral *Antipathella subpinnata* and a suite of octocorals species in two different Mediterranean archipelagos: Tremiti Islands (Adriatic Sea) and Egadi Islands (Sicily Channel). Both ROV and technical diving explorations revealed coral forests characterized by a colony density up to 8 colonies m-2, over 1000 to 5000 m2 of continuous coral cover. A correlation between the local distribution of coral forests and the main oceanographic features confirmed the fundamental role of currents in shaping the presence and distribution of the corals in presence of hard substrata. Local conservation initiatives aiming at avoiding significant adverse impacts related to bottom-contact fishing gears are a priority to protect these ecosystems and enhance their resilience towards the impacts of global stressors such as global warming. These initiatives include the enlargement of nearby marine protected areas or the institution of ad-hoc fishery restricted areas. Ocean literacy and dissemination activities including local community involvement and the production of documentary films represented an effective support to raise awareness and achieve conservation measures in a suitable time scale.

ID: 573 / **Parallel Session 8-2: 18**
Mesophotic and Cold-Water Coral Ecosystems

Keywords: black corals, time-lapse technique, mesophotic, behavior

Home sweet home: the use of *Antipathella subpinnata* (Antipatharia, Myriopathidae) colonies as foraging, shelter, and resting areas

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The study of animal behaviour and interactions between organisms in mesophotic and deep environments is a challenging task due to logistic and technical constraints. Using time-lapse devices may help overcome this issue by providing this kind of data without disturbing the investigated communities. A time-lapse device was used to describe the behavioural ecology of the fauna associated with an adult colony of *Antipathella subpinnata* (Ellis & Solander, 1786) of 90 cm height. The device was deployed at 72 m depth, at the Giannutri Island, Tuscan Archipelago. It was set to take a picture every 3 minutes for a total of 12 days of recording. The fauna associated with the black coral colony was analysed on 2560 randomly selected pictures and identified to the lowest possible taxonomic level. Additionally, the behaviour description, the circadian activity, the presence-absence and direction of the main current was obtained from the image analysis. At specific level, 17 fishes and 8 invertebrates were observed, with the former more active during the daytime and the latter starting their activities generally after the sunset. There was evidence that the monitored colony represents an important shelter and resting area for fishes and the regular appearance of different invertebrates taxa suggests a potential use of the black coral forest as a feeding ground. The colony is often under strong currents whose intensity was estimated and related to the associated fauna behaviour. These results highlighted that the presence of the black coral forests can play a key role as foundation species, regulating the activity of the recorded species, likely including their trophic relationships.

ID: 338 / **Parallel Session 8-2: 11**
Mesophotic and Cold-Water Coral Ecosystems

Keywords: Black coral forests, species richness, mesophotic ecosystems, rebreather diving, Santo Antão

Mesophotic Black Coral Forests in Santo Antão, Cape Verde: Biodiversity, distribution, and ecological characteristics.

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The Republic of Cabo Verde heavily relies on marine resources for its sustenance. Its coastal areas play a crucial role in ensuring the well-being of local population by providing essential resources like food and employment opportunities. Nevertheless, coastal regions are facing significant threats, due to global warming, natural hazards, and various anthropogenic pressures. Thus, there is an urgent need for sustainable development of activity sectors linked to the sea, but the lack of a comprehensive baseline knowledge regarding the environmental condition of Cabo Verde's marine ecosystems poses a considerable obstacle.

Black coral communities create high-diverse forests in shallow and deep bottoms. Serving as "ecosystem engineers", these corals provide suitable habitats, acting as feeding, reproductive, nursery, and refuge areas for a wide variety of associated species, many of which are of commercial interest. Using advanced rebreather diving, we have mapped and characterized black coral communities in 2 locations around Santo Antão (Cape Verde) for the first time in depths until 60m. We used the Mackinnon List Technique (MLT) to compute biodiversity indices for benthic and fish communities shedding light on the intricate relationships between various species inhabiting these mesophotic depths. Preliminary findings indicate a rich and complex ecosystem with unique biological communities, which vary in depth and location.

By providing baseline data on the biodiversity and distribution of black coral forests in Santo Antão, this research will contribute to its protection with efficient management plan recommendations, in line with the needs of stakeholders and local communities.

ID: 250 / **Parallel Session 8-2: 7**
Mesophotic and Cold-Water Coral Ecosystems

Keywords: Mesophotic coral ecosystems, species distribution modelling, central Indian ocean

Predicting mesophotic coral ecosystem distribution in the central Indian Ocean.

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To support conservation efforts, the development of accurate maps depicting the spatial distribution of marine benthic communities, has become more critical than ever before. While previous mapping endeavours have primarily focused on easily accessible shallow-water habitats and species, there remains limited knowledge about the ecosystems lying beyond SCUBA diving depths, such as Mesophotic Coral Ecosystems (MCEs, 30-150 m). MCEs are important habitats from an ecological and conservation perspective, yet there is limited knowledge about the environmental factors that shape these ecosystems and their distribution, particularly in the Indian Ocean region. Here, we test the effectiveness of a range of environmental and topographically derived variables to predict the distribution of MCEs around Egmont Atoll and the wider Chagos Archipelago. In addition, we compare the predicted extent of MCEs in the region using models derived from high-resolution multibeam and low-resolution GEBCO bathymetry data. Using maximum entropy modelling, all models resulted in excellent (> 0.9) performances, for AUC and threshold-dependent metrics, predicting extensive and previously undocumented MCEs across the entire Archipelago. However, differences were observed in the predicted extent of MCEs between the high- and low-resolution models. Photosynthetically Active Radiation (PAR), temperature, chlorophyll α and topographically derived variables were identified as the most influential predictors. In conclusion, this study provides the first prediction of MCE distribution in the Chagos Archipelago, highlighting the significance of MCEs in terms of coverage extent. The results serve as a target for future MCE research and monitoring in the Archipelago.

ID: 763 / **Parallel Session 8-2: 23**
Mesophotic and Cold-Water Coral Ecosystems

Keywords: species delimitation, phylotranscriptomics, reproductive isolation, prezygotic, Octocorallia

Speciation in recently diverged lineages of Atlantic *Paramuricea*: complementary insights from phylogenomics and reproductive biology

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The accurate delimitation of species boundaries in anthozoan taxa is notoriously difficult, with consequences for many studies in ecology and evolution. While molecular species delineation has revolutionized the assessment of species diversity, reproductive isolation is the key criterion of biological speciation, thus an integrated framework combining molecular approaches with reproductive biology is required. We have recently investigated lineage diversification in a gorgonian species complex of the genus *Paramuricea* occurring along the coast of Portugal (Atlantic) in two color morphotypes (purple and yellow), which were previously considered marginal populations of the Mediterranean *P. clavata*. That study showed that there are 3 genetic entities, with mitochondrial genes clearly distinguishing the Atlantic and Mediterranean as separate sister species. Species-tree estimations based on single-copy orthologues provided support for a second putative (or ongoing) speciation event between the two Atlantic colour morphotypes (not supported by mtDNA), consistent with the parapatric distribution with contact depths observed along the west coast of Portugal and virtual absence of the purple lineage in the south coast. Here, we provide additional transcriptomic data on lineage segregation of these two Atlantic *Paramuricea* that are coupled with observations on reproductive and larval biology. Congruent with the molecular evidence suggesting reproductive isolation, we observed strong prezygotic barriers between the two lineages: 1) different reproductive modes, surface brooding (purple) vs. broadcast spawning (yellow); and 2) temporal isolation, with the two lineages reproducing 1.5 months and 3 weeks apart in late Summer/early Fall of 2022 and 2023, respectively. Furthermore, early-life traits such as propagule buoyancy, phototaxis and larval swimming behaviour were also markedly different. The asynchronous timing of reproduction and contrasting reproductive traits reported here for the two *Paramuricea* colour morphs lend further support to the genomics-based hypothesis that the lineages represent two reproductively isolated entities.

ID: 125 / **Parallel Session 8-2: 3**
Mesophotic and Cold-Water Coral Ecosystems

Keywords: Helicolenus dactylopterus, Cold water corals, North West Africa, Essential habitat, behavior

Do cold water corals provide an essential habitat for *Helicolenus dactylopterus* (Delaroche, 1809) in the Northwest Africa?

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Cold water corals (CWC) support a high diversity of marine organism and play an important role as habitat for these organisms including demersal fish. *Helicolenus dactylopterus* is known as a typical deep-water fish. Several observations, based mainly on data from bottom trawl and longline fishing gears, have indicated a co-occurrence between *H. dactylopterus* and CWC. However, the role of CWC for this fish remains unclear.

To better understand the nature of this relation we have analysed 85 video-lines from ROV dives conducted at 25-1700m depth off Morocco, Mauritania, and Senegal in 2020 and 2021 with the research vessel Dr. Fridtjof Nansen. The detailed analyses of these videos and images that includes, abundance, size, and behaviour of this species showed a clear association of *H. dactylopterus* with CWC habitats that involves both juveniles and adult specimens. In total, 552 individuals of *H. dactylopterus* was observed (32% of juveniles and 68% of adults), 82% of theme occurred in a coral reef habitat, most encounters were related to coral rubble and live corals. The vast majority of *H. dactylopterus* were standing on their fins on the substratum and in most case completely inactive. Both juveniles and adults were more frequently observed in low rugosity settings, however, adults are slightly more frequent at medium to high rugosity compared to juveniles.

Our observations are discussed considering available knowledge on feeding ecology and life cycle of *H. dactylopterus*. Our findings show that CWC provides an essential habitat for this species at least during parts of its lifecycle, however, more behavioural studies are needed for an in-depth understanding of this association.

ID: 380 / **Parallel Session 8-2: 12**
Mesophotic and Cold-Water Coral Ecosystems

Keywords: Biodiversity, taxonomy, gorgonians, benthos

Deep-sea octocorals from bathyal cold-water coral ecosystems of the Ligurian Sea(W Mediterranean Sea)

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In the last decades, several studies have focused on bathyal cold-water coral reefs, allowing for a better understanding of their ecology, functioning, life-history traits, connectivity, and the anthropic pressures burdening on these ecosystems. However, the taxonomical identity of the associated species, including habitat-forming octocorals, remains often understudied, negatively influencing the ability to disentangle among similar and closely related species.

A series of remotely operated vehicles (ROV) explorations conducted along the “Di Levante Canyon” in the Eastern Ligurian Sea (Western Mediterranean Sea) recently led to the discovery of a flourishing cold-water coral province. During the explorations, a total of 11 octocoral samples were collected (from 474 to 724 m) using the ROV’s three-jaw grabber for taxonomical identification. Corallum features, polyps' architecture, as well as dissociated sclerite morphology, size, and ornamentation were examined under a stereomicroscope, optical microscope, and scanning electron microscope (SEM).

Six species have been identified. Some of them are considered common for bathyal ecosystems, including *Muriceides lepida* Carpine & Grasshoff, 1975 and the stoloniferan *Rolandia coralloides* de Lacaze Duthiers, 1900, both observed growing on coral rubble as well as plastic debris. Other records are rare for the Mediterranean Sea, including *Placogorgia coronata* Carpine & Grasshoff, 1975, *Placogorgia massiliensis* Carpine & Grasshoff, 1975, and *Acanthogorgia armata* Verrill, 1878. In addition, the taxonomy of a bamboo coral of the genus *Acanella* Gray, 1870 is discussed, highlighting the status of confusion affecting Mediterranean isidids.

ID: 251 / **Parallel Session 8-2: 8**
Mesophotic and Cold-Water Coral Ecosystems

Keywords: Mesophotic Coral Ecosystems, automated identification, object detection models, Red Sea

Automated identification of benthic organisms of the lower mesophotic zone of the Saudi Arabian Red Sea using deep learning object detection algorithms

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Mesophotic Coral Ecosystems (MCEs) remain largely unexplored due to the challenges and high cost of accessing them. Modern equipment, including Remotely Operated Vehicles (ROV) and submersibles (SUBs), enables effective surveying of biodiversity through video transects, increasing data volume. This extensive data poses challenges for analysis, creating a 'bottleneck-effect' in the manual processing workflow. The primary reasons for this bottleneck are the extensive time required for analysis and the necessity for expert scientists. Consequently, there is a need for automated identification and analysis of marine video data.

The Saudi Arabian Red Sea MCEs are particularly understudied and have developed in unique environmental conditions. Over three years, four major expeditions have embarked on a comprehensive mission using state-of-the-art technology, allowing extensive sampling and studying of MCEs, covering both the depth and latitudinal gradients of the Saudi Arabian Red Sea.

Targeting MCEs between 75 and 220 meters, we have collected over 1000 hours of underwater footage using 69 videos from ROVs and SUBs. This extensive video library allowed us to identify and label more than 13,000 organisms, across 2,000 images, providing a training dataset for object detection models using deep learning algorithms. These models are designed to identify families from three major cnidarian groups: Octocorallia, Scleractinia, and Antipatharia.

These annotated datasets play a key role in improving our understanding of the diverse taxa within the lower mesophotic zones of the Saudi Arabian Red Sea. By employing deep learning algorithms for object detection, our approach aims to reduce processing time and increase prediction accuracy compared to manual labelling.

Our research provides fundamental knowledge on mesophotic coral habitats biodiversity and distribution, serving as a foundational reference for future conservation and management plans of the Saudi Arabian Red Sea's mesophotic coral ecosystems.

ID: 162 / **Parallel Session 8-2: 5**
Mesophotic and Cold-Water Coral Ecosystems

Keywords: Corallium Rubrum, Sarcophyton sp., biomineralisation, injection, exogeneous molecules.

An adapted methodology for in vivo injection of exogenous molecules in octocorals to study calcification

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Calcification is the mechanism by which corals build biomineral structures through the deposition of calcium carbonate and organic molecules. Despite information at the cellular and physiological level, knowledge of the mechanisms controlling coral calcification remains elusive in corals as in other marine invertebrates.

The limitation of the knowledge is mainly due to a gap in the available techniques for these organisms. Indeed, *in vivo* study of the effects of molecules of interest in aquaria facilities is very challenging due to the exposure time, the high costs of compounds, their quantity and diffusion in seawater. Here, we provide a viable alternative methodology by *in vivo* injection using a vehicle which solidifies upon injection. Our research focuses on corals belonging to the subclass Octocorallia, which elaborate sclerites and/or axial.

Our experimental study evaluated a novel method for delivering an internal emulsion of either hydrophilic or lipophilic compounds. The local diffusion and slow release of the injected products inside the organism was followed using visual tracers: two classes of fluorescent markers were used, the first one investigated internalisation into cells, while the second monitored the process of calcification. This method was optimised and validated on the soft coral *Sarcophyton* sp. (order Malacalcyonacea) before being validated on the precious coral *Corallium rubrum* (order Scleralcyonacea) (Forin et al., submitted).

As we have validated the method, ongoing studies are investigating compounds which are either promoting and/or inhibiting calcification. Monitoring is achieved both by following incorporation of the fluorescent markers for calcification and measuring calcifying gene expression by qPCR analyses on *Corallium rubrum*. This approach represents an advanced methodology for coral research that aims to enhance our comprehension of coral biology, with focus on the physiological mechanisms that controls coral calcification.

ID: 805 / **Parallel Session 8-2: 24**
Mesophotic and Cold-Water Coral Ecosystems

Keywords: Leiopathes glaberrima, Mass mortality, Deep Sea, Strait of Sicily, ROV-imaging

Leiopathes glaberrima populations in the strait of sicily: occurrence of a deep mass mortality

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The black coral *Leiopathes glaberrima* is a key component of deep-sea animal forests of Mediterranean and North-Atlantic hard bottoms. Due to its ecological role, biological characteristics and sensitivity to fishing activities, it has been included in the Annex II of Barcelona Convention and among the indicators of Vulnerable Marine Ecosystems. During a survey conducted in the Strait of Sicily, 140 ROV transects were carried out allowing us to characterize the environmental preferences, associated fauna and the population structure of *L. glaberrima* in the study area. 1020 colonies were distributed between 165 and 672 meters and arranged in 17 patches and isolated colonies. The average height was determined to be 40.9 ± 1.0 cm, with the range spanning from a minimum of 5 cm up to nearby 200 cm. Pristine colonies accounted for 62.9%, mainly constituted by small-sized individuals densely aggregated (up to 1.6/m^2 on average) in the eastern part of the area. 24.5% of the specimens were dead and localized in the western part of the area where we reported a rare case of mass mortality in the deep-sea environment and the first ever described for black corals. The triggering causes of this event are currently unknown, but a possible explanation could be reconducted to changes in physical and chemical conditions caused by past hydrothermal emission. However, it is not to be excluded that, sooner or later, a similar effect could potentially result from anthropogenic climate change as sadly observed for tropical corals and temperate mesophotic ecosystems.

ID: 816 / **Parallel Session 8-2: 25**
Mesophotic and Cold-Water Coral Ecosystems

Keywords: Marine Park, Espíritu Santo Island, Deep refugia hypothesis

Assessing the influence of oceanographic factors on the abundance of the dominant fish species resident at mesophotic reefs in the southern Gulf of California

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Mesophotic reefs, due to their depth are relatively protected from natural disturbances and anthropogenic impacts, and may serve as faunal refuges. The study of biological communities inhabiting these ecosystems is in an early stage, and there is still limited information for the Mexican Pacific. The objective of this study was to analyze the influence of five oceanographic factors (temperature, salinity, oxygen concentration, primary productivity, and percentage of incident light), and of on the 20 most abundant species present at the mesophotic zone of three reefs off Espíritu Santo Island, in the Gulf of California, Mexico (Punta Lobos, El Bajo and Los Islotes). Using a remotely operated vehicle, about 20 hours of video were taken at depths of 16-68 m, and for the analysis the recordings were divided into 5-minute intervals to be used as sampling units to determine species abundance. Simultaneously, information on temperature, salinity, oxygen, and incident light percentage were taken at 1-minute intervals with a multiparameter probe, and satellite information on surface chlorophyll concentration were obtained for the same day and site (precision of 1 km) and later transformed to integrated productivity. A series of generalized linear regressions revealed that temperature was the key factor explaining the abundance level of 12 species, followed by oxygen concentration (7 taxa). The models were highly efficient to explain the distribution of five species: the damselfish *Stegastes rectifraenum* and the butterflyfish *Chaetodon humeralis* increased their numbers in areas with low oxygen, while the angelfish *Holacanthus passer* decreased its abundance proportionally with oxygen and surface chlorophyll concentration. Finally, the damselfish *Chromis atrilobata* and the porcupinefish *Diodon holocanthus* were associated with warm conditions. For the remaining 15 fish species, the models did not have good explanatory power, indicating that these taxa are tolerant to changes in conditions along the studied bathymetric gradient.

ID: 136 / **Parallel Session 8-2: 4**
Mesophotic and Cold-Water Coral Ecosystems

Keywords: meosphotic, trophic ecology, photosymbiosis, Agariicidae

The trophic ecology of photosymbiotic corals in the lower photic zone

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Photosymbiotic corals create the structural foundation of coral reef ecosystems which support high biodiversity and productivity in oligotrophic waters throughout tropical and subtropical oceans. These light-dependent, coral can extend to extreme depths (i.e., 172 m). However, knowledge about coral reef ecosystems is primarily gleaned from shallow water studies within the limits of normoxic SCUBA diving depths. While new studies of mesophotic coral ecosystems (MCEs) have proliferated in recent years, most are limited to depths <60 m and restricted to descriptive data. Almost no information about the physiological function or ecology of photosymbiotic corals in the lower half of their depth range exists. Based on early studies, coral heterotrophy has long been assumed to play a vital role in enabling them to thrive at deep depths where light attenuates to very low levels. Despite this widely held belief, reliable *in situ* data/evidence from the lower photic zone supporting this traditional dogma is lacking, and indirect evidence undermining this assumption is steadily accumulating (reviewed in Kahng et al. 2019). Here we report the first direct measurements on the trophic ecology for *Leptoseris fragilis* from 70 & 100 m. Species of the genus *Leptoseris* within the family Agaricidae dominates the photosymbiotic coral community in the lower photic zone throughout Indo-Pacific. After separating host and symbiont tissue, the $\delta^{15}N$ for individual amino acids (AA-CSIA) were measured via gas chromatography/combustion/isotope ratio mass spectrometry (GC/C/IRMS), and trophic position (TPaqua) was calculated using established methods (Takizawa et al. 2020). Results indicate that these corals are nearly 100% autotrophic (TPaqua = 1.14, 1.16) and significantly more autotrophic than their shallow water counterparts. These data are consistent with the physiology of *Leptoseris* spp. which have very few polyps that completely lack tentacles for catching plankton. These initial results reflect only our first two samples measured to date.

ID: 473 / **Parallel Session 8-2: 13**
Mesophotic and Cold-Water Coral Ecosystems

Keywords: Porifera, metabarcoding, taxonomy

Do different sponge species sample different benthic communities?

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Sponges are ubiquitous ecosystem engineers with a wide bathymetric range which play a key functional role increasing the complexity of the substrate and providing refuge to a wide variety of species. Furthermore, they are efficient filter-feeders, filtering massive volumes of water every day and trapping particles inside their tissues, including environmental DNA. They are indeed natural and non-invasive sample collectors and can be used to monitor temporal changes of their associated communities. This is especially useful in the mesophotic environments, where sponges can become predominant and where benthic communities' characterization is challenging. However, it is unclear whether different sponge species are able to sample different communities. In this study, we used integrative taxonomy (skeletal architecture and DNA barcoding) to describe different sponge species collected in Tenerife (Canary Islands) at shallow and mesophotic sites. We then investigated their associated communities through morphological identification and eDNA metabarcoding recovered from the sponge tissue. The results will provide information on the poorly studied benthic communities of the area across depth to help decision-making for conservation and restoration frameworks.

ID: 123 / **Parallel Session 8-2: 2**
Mesophotic and Cold-Water Coral Ecosystems

Keywords: Antipatharia, reproductive cycle, gametogenesis, sexual maturity size, Gulf of California

Reproductive cycle of the black coral *Antipathes galapagensis* in the Bay of La Paz, Gulf of California, Mexico

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The black coral *Antipathes galapagensis* has been object of an intensive fishery in the Eastern Tropical Pacific area. Despite its importance as a habitat-forming species, there is few information about its basic biology. The objective of the present study is to describe its reproductive cycle and strategy. The sampling was carried out over 22 months period at the dive site in the La Partida, Archipelago Espiritu Santo, La Paz Bay, Mexico. 197 colonies were collected from 2018 to 2019, on which histological analyses were performed. Slides stained in Hematoxylin-eosin were observed under the microscope and photographed for analysis. Different stages of gonadal development in males and females are described for this species for the first time, where the mean diameter and the size range of oocytes for each oogenesis stages was determined. The species is an external spawner, adopting the partial spawning strategy, since a polyp in state III (mature) presents at the same time previtellogenic, vitellogenic and postvitellogenic oocytes. *Antipathes galapagensis* shows evidence of sequential hermaphroditism, recorded for the first time in Antipatharia. The gonadic development begins in the month of May (development and maturation), reaches the reproductive peak in the months of September and October, where the highest frequency of mature females and males are observed, as well as partial spawning. The period of maximum reproduction was similar for both females and males, indicating that the reproductive period in *A. galapagensis* is synchronous. The reproductive cycle of the species shows a correlation with the increase of sea temperatures in the study area that reached the maximum around September to October. The estimated height for sexual maturity (L50) is 102 cm for females and 93 cm for males, indicating a late maturity in the species. The present study provides fundamental information for the protection and conservation of the species.

ID: 834 / **Parallel Session 8-3: 3**
Mesophotic and Cold-Water Coral Ecosystems

Keywords: precious corals, jewelry, genetic, phylogeny

Analysis of trace-DNA from polished coral objects as a tool to reveal the diversity of coral species used in jewelry

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Precious corals from the genera *Corallium*, *Hemicorallium* and *Pleurocorallium* (Corallidae, Octocorallia) have been used to produce jewellery objects for centuries. Identification of the producing species of cut and polished precious coral objects is difficult, as these specimens lose all their taxonomic identification characters except for the colour of the axial skeleton. Moreover, an exact list of potential species used by the jewellery industry has hitherto been lacking.

Here, we present our framework to discover the species diversity of corals used in jewellery objects based on their genetic analysis. First, we developed methods to extract trace-DNA from processed skeletal material following minimally destructive sampling. Specific barcoding DNA regions are then sequenced and analysed in a phylogenetic framework together with a curated reference data set. To create the reference data set, it was necessary to analyse a large number of samples including some holotypes to generate data for all previously not analysed species and to clarify the taxonomy of species with dubious identity.

Results of coral objects submitted to us by owners or confiscated by customs authorities show an unexpected abundance of *Pleurocorallium niveum*, a species from the Emperor Seamounts and Hawaiian Archipelago, which was formerly not considered to be used by the jewellery industry. Furthermore, we discovered *Pleurocorallium* objects that do not show a match with any DNA sequences in our reference data set and thus likely originate from species that are unknown to science.

ID: 297 / **Parallel Session 8-2: 10**
Mesophotic and Cold-Water Coral Ecosystems

Keywords: Marginal reefs, Mesophotic, Cabo Verde, Black corals, Octocorals

Characterization of marginal mesophotic coral communities in Santo Antão (Cabo Verde, East Atlantic Ocean): combining demographic and community approaches

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Marginal reefs are typically dominated by low coral cover and/or species richness in areas characterised by ‘suboptimal’ or fluctuating environmental conditions. Increasing interest in these reefs is due to their potential as “analogues” for future ocean conditions and/or resilience hotspots that may harbour naturally stress-resistant coral species and/or communities. Therefore, the study of these ecosystems is crucial, especially in regions such as Cabo Verde, where current information and biodiversity baselines are very scarce. In this talk, we will present a first comprehensive characterization of marginal reefs at mesophotic depths (30-40 m) of the island of Santo Antão, combining population and community approaches. Specifically, we will provide results on the density and population size structure of the main mesophotic coral species found in this area (mainly the black corals *Stichopathes* sp., *Tanacetipathes spinescens*, *T. wirtzi* and *Antipathella wollastoni* and the octocorals *Eunicella papilifera, Leptogorgia capverdensis* and *L. gaini*), as well as a biodiversity assessment of main benthic functional groups inhabiting these reefs. The study of the composition, structure and conservation status of these marginal mesophotic reefs may contribute to improving our understanding on the functioning and vulnerability of these systems at the local (i.e., Santo Antão), regional (i.e., Macaronesia) and global scales.

ID: 560 / **Parallel Session 8-2: 17**
Mesophotic and Cold-Water Coral Ecosystems

Keywords: Antipatharia, mesophotic, drop-cam, Madagascar

Discovered and already going? The first exploration of the mesophotic communities of the Great Reef of Toliara (SW Madagascar)

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The Great Reef of Toliara, a barrier reef in SW Madagascar, is separated from the coast by two passes both located in front of rivers. These areas have particular hydrodynamic regimes and experience high turbidity events throughout the year. Historically, efforts began in the late 1960s and have mainly focused on the shallow parts up to 40 metres deep. After a gap of several decades, recent studies highlighted significant changes in community structure and diversity of scleractinian corals over the past 50 years. In parallel, recent diving explorations have documented unique assemblages of antipatharians and sponges in the upper limit of the mesophotic zone of the reef. This area is facing increasing pressures such as overfishing, deforestation, and cyclones; but recently, a new threat has emerged with the proposed construction of a large harbour in the north pass. Therefore, there is an urgent need to explore and understand the mesophotic zone of the reef to prevent the irreversible loss of biodiversity resulting from this industrial project. To overcome the challenges associated with field work, such as logistics and the lack of a decompression chamber for deep diving, we developed a low-cost drop-cam to investigate deeper areas and assess the diversity and distribution of benthic communities. We combined this data with visual observations of the substrate and temperature records obtained using a CTD sensor. Detailed bathymetric maps of the areas were created using a small echo-sounder mounted on a small boat, which efficiently gathered data for large surfaces in a short amount of time. Abundant communities of sponges and antipatharians were discovered in both passes until a depth of 120m, including new records for the entire Indian Ocean. These results represent important steps towards shedding light on this hidden biodiversity and should encourage future research and funding in this threatened area.

ID: 242 / **Parallel Session 8-2: 6**
Mesophotic and Cold-Water Coral Ecosystems

Keywords: Environmental Niche Models, Marine Animal Forests, Spatial distribution, Bio-Oracle, Red Sea

Predicting and understanding the distribution of mesophotic and deep coral taxa across the Red Sea

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Mesophotic and deep zones of the world's oceans have been shown to support extensive and biodiverse Marine Animal Forests (MAFs), dominated by filter feeding benthic organisms such as Scleractinia, Antipatharia and Octocorallia. MAFs form vital habitats for associated species, but are threatened by anthropogenic activities such as deep-sea fishing, or oil and gas exploration and mining. The Red Sea is a unique environment with temperatures above 21°C and salinities over 40 PSU even at depths of 3000 m. Despite recent technological advances, extensive surveys of the deep sea remain costly and time consuming, however, environmental niche models represent a more effective method to increase our understanding of the ecology and spatial distribution of mesophotic and deep species. Here, bathymetric data was used to extract geomorphometric variables, and to model temperature, salinity and oxygen concentration at the bottom layer across the Red Sea basin. These models were then verified by *in situ* measurements and combined with occurrences of five common, MAF-associated coral species obtained from georeferenced video transects. Boosted algorithms were used to generate both explanatory models to understand the drivers of coral distributions, and predictive models to estimate the potential presence across the whole Red Sea basin. The explanatory models revealed the importance of depth and seafloor complexity to the distribution of these species, reflecting the influence of food availability in MAF distribution. Further, the predictive models demonstrated that these species are abundant not only along the Saudi Arabian Red Sea from where they have been described, but also along the west coast of the basin. These species may serve as indicators for biodiverse MAFs, and a better understanding of their distribution can be used in conservation planning. Crucially, further knowledge on the drivers of distribution for these species can indicate how they may respond to changing climatic conditions.

ID: 664 / **Parallel Session 8-2: 20**
Mesophotic and Cold-Water Coral Ecosystems

Keywords: coral, mesophotic, scientific diving, canakkale strait, marmara sea

New Habitats of *Savalia savaglia* form mesophotic depths in the Sea of Marmara (Turkish Straits System, Türkiye) and adjacent waters with the additional rare records.

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Savalia savaglia, a keystone bioconstruction species in the marine environment, forms biodiversity hotspots. This Mediterranean-originated coral facies can occasionally establish species-rich ecosystems far from its native waters. This study delves into four uncommon reef sites of *S. savaglia* in Turkish seas. Assemblage assessment of several rocky and wreck sites in the Turkish Straits System uncovered the presence of large *S. savaglia* individuals, reaching a maximum height of 117 cm in the Çanakkale Strait (42 m, trunk circumference: 13.2 cm) and 96.4 cm in width in Marmara Sea (Avsa-Cinarli region, Marmara Island, 38-47 m), respectively. In a 2023 project, 80 benthic invertebrate species were detected around *S. savaglia* colonies in the Marmara Sea, with two (Phoronida, Porifera) being new records for the eastern Mediterranean Sea from the region. Several sites exhibited a Neopycnodonte cochlear community as the most prevalent structural facies encircling *S. savaglia* colonies. Moreover, an engulfment scenario was observed on separate healthy colonies of *Paramuricea clavata* at depths between 38-44 meters on wreck sites. This study marks the first recorded occurrence of *S. savaglia* colonies in the Aegean Sea at mesophotic depths on an offshore rocky bank off Babakale-Assos. Additionally, a recent severe impact from seine nets was documented from a monitored area for the first time. Despite Marmara Island's distinctive habitat for healthy gorgonian forests, there are currently no specific conservation measures in place to safeguard coral reefs in the region. In light of ongoing fishing activities, illegal catch, and anchoring, this study aims to underscore the need for a coral-based marine protected area in the site, address knowledge gaps, highlight the crucial role of *S. savaglia* at the local level, and showcase its ecological significance for other marine life.

ID: 551 / **Parallel Session 8-2: 15**
Mesophotic and Cold-Water Coral Ecosystems

Keywords: CWC, Desmophyllum pertusum, microbiome, metagenomics, restoration

Exploring the composition of microbial communities associated with the cold-water coral *Desmophyllum pertusum* in Skagerrak reefs

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A multitude of associated microorganisms such as bacteria, archaea, protists, fungi, and viruses, form complex synergies with corals. In tropical corals, it is hypothesized that microorganisms provide important cues that induce larval settlement and promote the transition to the polyp life-stage. In cold-water corals (CWCs), however, it is still unknown what members of the microbial community contribute to the success of larval settlement and metamorphosis. Our ultimate goal is to identify microbes that can potentially contribute to larval settlement and presently we are characterizing the natural variation of bacterial communities in CWCs. For this task, we collected 102 samples from different anatomical coral compartments (mucus, tissue, skeleton) and different life stages (gametes, embryos, larvae, juveniles, adults) of the CWC *Desmophyllum pertusum* from the Tisler and Väderöarna reefs in Norway and Sweden, respectively. We characterized the bacterial microbiome of these samples through 16S-rRNA gene sequencing using Nanopore technology. Samples of unhealthy and dead corals, as well as surrounding seawater and sediment were used for comparison. We found that the CWCs were dominated by the bacterial classes Alpha- and Gammaproteobacteria, and less frequently by the phyla Bacteroidota, Planctomycetota, and Verrucomicrobiota. Coral mucus samples were found to contain members of the genus *Pseudoalteromonas*, which are known to induce larval metamorphosis in some tropical corals. Sediment samples and dead corals exhibited the highest microbial alpha-diversity. Multivariate analyses revealed that the microbial composition of the various compartments and life stages was highly distinct. Analyses indicated a vertically-transmitted microbiome from parent to offspring and a horizontally-transmitted microbiome acquired from the environment. Further investigations based on shotgun metagenomics are ongoing to unravel the functional potential of these microbial communities. Our results will be pivotal to assess and interpret the important role that microbiomes may play in the restoration of highly endangered CWC reefs.

ID: 743 / **Parallel Session 8-2: 22**
Mesophotic and Cold-Water Coral Ecosystems

Keywords: Cold-water corals, Desmophyllum dianthus, feeding, plankton

Wall of Mouths: *in situ* depletion of plankton and particulate organic matter near a cold-water coral wall

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Cold-water corals (CWC) are known to be voracious carnivores gorging on plankton and krill, but to the best of our knowledge, heterotrophy near CWC walls has never been assessed *in situ* using minimally invasive techniques. Here, we close this gap for a *Desmophyllum dianthus* - dominated CWC wall in Comau Fjord in northern Patagonia, Chile, taking advantage of the phenomenon of emergence that permits divers to access these deep-sea organisms in shallow water. We deployed two moorings with self-recording instruments at 20 m depth, one in the boundary layer of the CWC wall, in the vicinity of the tentacle crowns, the other in the boundary layer of a CWC-free wall, some 50 m away. Each mooring was fitted with an Underwater Vision Profiler (UVP6lp), an Aquadopp profiler and a CTD to record particles, currents and water mass properties, respectively, at 1 Hz. The CWC mooring carried an additional IR time-lapse camera and IR flash to record tentacle exposure every 5 min, as a measure of CWC feeding disposition. UVP-data were analyzed to provide bulk estimates of the abundance, size and volume of particles >0.1 mm and ground-truthed with push-net and Niskin bottle samples taken by divers. Simultaneous one-day measurements, on repeated occasions, allowed us to detect differences between the CWC and CWC-free control site, and relate these to currents, CWC abundance and feeding disposition. We found a remarkable up to one order of magnitude drop in total particle volume at the CWC site compared to the CWC-free control, consistent between the repeat deployments. It was accompanied by a reduction of larger (>2 mm diameter) particles, indicating selective feeding by CWC. Flux calculations provide the first comprehensive *in situ* evidence on strong bentho-pelagic coupling near a CWC wall.

ID: 626 / **Parallel Session 8-2: 19**
Mesophotic and Cold-Water Coral Ecosystems

Keywords: Mediterranean, mesophotic reef, reef-building corals, reproductive cycle

Reproductive cycle of reef-building scleractinians from a Mediterranean mesophotic coral reef

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Coral reefs are typically widespread in shallow waters from tropical seas, while in Mediterranean Sea they were widely distributed in the past but currently have a very reduced extension. Indeed, coral banks here are mainly represented by cold-water coral formations and bioconstructions built by endemic shallow-water species such as *Astroides calycularis* (Pallas, 1766) and *Cladocora caespitosa* (Linnaeus, 1767). Only recently, a true coral reef has been identified on mesophotic bottoms along the coasts of Apulia (SE Italy). The reef was mainly built by non-symbiotic scleractinians belonging to the family Caryophylliidae, namely *Phyllangia americana mouchezii* (Lacaze-Duthiers 1897) and *Polycyathus muellerae* (Abel 1959).

Reproduction is a fundamental aspect of an organism's life cycle and investigating the reproductive cycle of a scleractinian is a useful tool for assessment and conservation purposes, especially in the case of engineering species that play a key role in biogenic habitats. In Mediterranean Sea, reproductive biology has been studied only in a minority of the 33 species of scleractinians recorded so far. This contribution represents the first attempt of describing the sexual reproductive cycle of *P. a. mouchezii* and *P. muellerae*, taking into account its possible relationship with budding and water temperature.

In general, the study revealed that both species are oviparous and fundamentally gonochoric. They showed an irregularly cyclical trend of gametogenesis, with a greater energy investment during Summer. There was a substantial stasis of oogenesis during Winter and the concentration of spermatogenesis in Spring/Summer. *P. muellerae* showed a slight advance in gametogenesis, with peak production one month before that of *P. a. mouchezii*. Budding did not seem to interfere with sexual reproduction. Finally, the study allowed to intercept the emission of gametes in some colonies of the target species sampled and reared in tanks under controlled conditions.

Posters

ID: 510
Mesophotic and Cold-Water Coral Ecosystems

Keywords: cold-water corals, microbiome, salmon farms, Mycoplasma, SUP05 cluster

Mycoplasma and SUP05 cluster dominance in the cold-water coral *Desmophyllum dianthus* - friend or foe?

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Previous studies on cold-water corals (CWCs) have characterized their associated microbiome and identified key taxa. In particular, two members, *Mycoplasma* and SUP05 clusters, are recurrent and may serve as beneficial partners. Both members occurred in relative high abundance in the CWC *Desmopyhllum dianthus* from Comau Fjord in Patagonia, Chile – a remote region subjected to increasing aquaculture activities. Here, we examined the coral microbiome using 16S rRNA amplicon sequencing and assessed how these two important microbes relate to known environmental gradients, aquaculture activity, and coral health. We took advantage of a suite of coral traits (growth, energy content) analysed along natural environmental gradients and at different distances from salmon farms in the fjord.

We found an inverse correlation between the relative abundance of the SUP05 cluster and *Mycoplasma*. Corals near salmon farms had a high proportion of *Mycoplasma* (58.5% ±25.6 (mean ±sd) and a low SUP05 cluster (7.2% ±13.3) in their microbiomes, at more distant locations SUP05 cluster predominated over *Mycoplasma* (39.1% ±23.1 vs. 2.42% ±6.6). The undisturbed populations consisted of corals with enhanced performance traits and a generally healthier appearance. In addition, the best performing corals at deeper sites of the fjord were found to have a microbiome with a high relative abundance of the SUP05 cluster (52% ±23.4) and the absence of *Mycoplasma* in all samples.

Our results support the role of the SUP05 cluster taxa as beneficial partner, in contrast, to *Mycoplasma*, which replaces SUP05 cluster in anthropogenically disturbed environments. We hypothesise that the dominance of *Mycoplasma* may be due to salmon farm activity with its introduction of food-pellets and antibiotics into the environment. Our study provides indications that continued uncontrolled increase in aquaculture will clearly leave its footprint in the environment on *D. dianthus* populations and may challenge other benthic organisms.

ID: 672
Mesophotic and Cold-Water Coral Ecosystems

Keywords: Antipatharia, VME, Macaronesia, megafauna, benthic habitats

Mesophotic to twilight zones of Madeira are home to dense black coral (Cnidaria: Antipatharia) forests

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Madeira is one of the least explored areas in the Macaronesia archipelago, with a considerable underestimate of total marine benthic biodiversity, particularly at deeper depth zones, beyond 30 m. However, the archipelago is surrounded by oligotrophic waters and hosts mountainous terrain with a dense drainage system combined with steep underwater topographies that are strongly linked with an encouraging hydrodynamic regime that includes transport of deep rich-nutrient waters to surface waters. These features have the potential to enhance biological productivity in the vicinity of the slopes, leading to the formation of unique and species-rich deep-water ecosystems in this region.

We conducted deep-water (50-250 m) habitat surveys using multi-year drop camera and human operated vehicle surveys across 24 locations in the Madeira archipelago. Here, we report substantial coral forests, dominated by whip black corals, just a few hundred meters from the coastal areas, extending from mesophotic depths to the twilight zone, beginning at 70 m depth and peaking at ~100 m. Here, thousands to millions of *Stichopathes* colonies were observed, with densities occasionally reaching as high as 120 colonies per m^2 - representing the densest black coral forest ever reported globally to date. The trade of black corals is forbidden under Appendix II of the Convention on International Trade in Endangered Species (CITES), and these communities are considered Threatened and/or Declining habitats under OSPAR, thus their vulnerability and uniqueness are recognized and recommended for protection. Exploration of these lesser-known deep-water depth zones are critical to identify biodiversity hotspots such as the one reported herein, but also to assess their role in shallow-water biodiversity recovery.

ID: 317
Mesophotic and Cold-Water Coral Ecosystems

Keywords: Tropical deep reefs, Maldives, mesophotic coral ecosystem, rariphotic

Finding the fish: new depth range extensions for reef fish in the Maldives

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Mesophotic (30-150 m) and rariphotic (150-300 m) reefs are some of the least explored habitats in the ocean, particularly those within the Indian Ocean. The Maldives is a Large Ocean State situated 475km south of India with a vast exclusive economic zone (916 000 km^2). Most previous research has focused on shallow water environments (<30 m). Using deep-reaching technology investigations to these deeper ecosystems are now possible providing new information on the fish species that inhabit them. In 2022, snorkellers, remotely operated vehicles and manned submersibles we conducted video surveys of the demersal fish communities of five atolls across a wide depth gradient (2, 10, 30, 60, 120, 250, and 500 m). We recorded depth range extensions for 60 fish species, most (43) extending to deeper depths. Majority of the species recorded are listed as Least Concern according to the IUCN Red List assessment the remaining species were either Data Deficient (3) or Not Evaluated (4). Eight species are considered to be commercially important to fisheries and aquarium trade in the Maldives. An increase in the known living space of these fish is important as it allows informed decision-making on their sustainable management and conservation. For example, fish with wide depth ranges have more opportunities to find refuge from disturbances thus aiding their overall resilience. We conclude that stakeholders and managers should focus management and conservation efforts on protection across depths not just geographic ranges.

ID: 801
Mesophotic and Cold-Water Coral Ecosystems

Keywords: Dendrophyllia, Portuguese continental shelf, Cryptic species complex

A cryptic species complex of stony corals (*Dendrophyllia*, Scleractinia) at mesophotic depths in northern Portugal

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Cold-water corals play a crucial role in the structuring of marine benthic communities, particularly in the deep-sea where they can form vulnerable marine ecosystems (VMEs) such as coral reefs and gardens. The genus *Dendrophyllia* de Blainville, 1830, comprises 31 species of brightly colored azooxanthellate stony corals, of which four are reported for the Lusitanian and Mediterranean Sea biogeographic provinces - *D. alternata* Pourtalès, 1880; *D. cornigera* (Lamarck, 1816); *D. laboreli* Zibrowius & Brito, 1984 and *D. ramea* (Linnaeus, 1758). However, the recent discovery of colonies with variable morphological characteristics in the Eastern Mediterranean has raised questions regarding the specific status of *D. cornigera*, a species with a wide Atlanto-Mediterranean distribution. In this study, we investigated the identity and phylogenetic relationships of *Dendrophyllia* specimens obtained on the northern continental shelf of Portugal as bycatch from local artisanal fisheries, at mesophotic depths. Morphological analysis and phylogenetic reconstructions performed using mitochondrial (COI) and ribosomal (ITS1, 5.8S, ITS2) markers, reveal the presence of *D. ramea* and an additional *Dendrophyllia* species in the area. This second species is morphologically similar but phylogenetically distinct from *D. cornigera*, supporting the idea of a species complex. Our findings call for the need of a detailed taxonomic revision and larger scale phylogenetic and phylogeographic study of this species complex in view of better delineating the status and geographic distribution, as well as connectivity (or lack thereof) between the respective populations. These findings are of even greater relevance taking into account that both *D. cornigera* and *D. ramea* are listed as VME indicator species, as well as Endangered and Vulnerable, respectively, on the IUCN Red List, warranting them a high management and conservation priority.

ID: 303
Mesophotic and Cold-Water Coral Ecosystems

Keywords: Coralligenous, MSFD, Monitoring, MACS, Mediterranean Sea

Main results of coralligenous monitoring within the implementation of marine strategy framework directive in Italy

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Coralligenous is an endemic benthic assemblage of the Mediterranean Sea, considered a hotspot of biodiversity. Due to its key functional and ecosystem roles, and its high sensitivity to human activities, coralligenous reefs are monitored in Italy within the Marine Strategy Framework Directive (MSFD) to evaluate the maintenance or achievement of good environmental status (GES). The monitoring activities at national scale requires the application of a standardized protocol based on multibeam echosounder, side-scan sonar and ROV surveys.

The present study provides the results of the first two cycles of MSFD monitoring (2015-2020) in the sixty-five areas belonging to eight Italian Regions, where the reefs are more abundant. The quantitative analysis of video transects allowed to characterize the megabenthic communities in terms of species composition, abundance, size, and health status of habitat-forming species, and to evaluate the abundance and occurrence of marine litter. The environmental status of coral reefs was then evaluated through the application of the Mesophotic Assemblages Conservation Status (MACS) index, which compared to other indices shows a greater ability to distinguish natural and anthropogenic factors obtaining a better interpretation of local situations.

Overall, most of the monitored areas were found to be in a moderate environmental status (46%), 34% good, 15% poor, and 5% high. No areas were found to be in bad environmental status. The three areas assessed in high status were found in Apulia and Tuscany.

It will be important to carry out specific analyses at the level of the various Regions, to identify the possible need for specific management measures to effectively promote the GES attainment or maintenance for this benthic assemblage of extremely high conservation value at both European (Habitat Directive) and Mediterranean (Barcelona Convention) level.

ID: 847
Mesophotic and Cold-Water Coral Ecosystems

Keywords: coral reef, oyster reef, bioconstructions, mesophotic

Exploring mesophotic invertebrate bioconstructions from the Adriatic Apulian seabed (Southern Italy, Central Mediterranean Sea)

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Mesophotic environments host diverse benthic communities dominated by a variety of organisms, including algae, sponges, cnidarians, bryozoans, molluscs and polychaetes. In the Mediterranean Sea, biogenic substrates occurring at mesophotic depths are typically built by calcareous red algae (coralligenous), although recent findings have highlighted the presence of mesophotic bioconstructions mainly built by invertebrates such as cnidarians and molluscs along the southern Adriatic coast of the Italian Peninsula. These bioconstructions, which develop at depths between approximately 40 and 65 meters, are mainly built by the non-symbiotic scleractinians *Phyllangia americana mouchezii* (Lacaze-Duthiers, 1897) and *Polycyathus muellerae* (coral reefs), or by the bivalve *Neopycnodonte cochlear* (Poli, 1795) (oyster reefs). We investigated the diversity patterns and substrate covering of the benthic assemblages associated with these mesophotic invertebrate bioconstructions. By employing both qualitative and quantitative analysis, we characterised the biotic communities and described the key patterns of substrate covering of their main megabenthic assemblages. These latter showed remarkable heterogeneity in terms of both species composition and abundance, probably depending on morphological differences of the seabed and life traits of individual species. Primary bioconstructors appeared to play a role in shaping the patterns of the associated communities. Studying the variations in taxonomic patterns in mesophotic habitats is essential to test the potential role of these latter as a refuge for shallow communities. In addition, it appears fundamental to include mesophotic ecosystems in future conservation planning.

ID: 546
Mesophotic and Cold-Water Coral Ecosystems

Keywords: reefugia, sediments, mesophotic

Shedding light on the causes and consequences of turbidity on coral reefs in Darvel Bay, NE Sabah, Malaysia

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There is increasing evidence that corals living in turbid water habitats can be more resilient to heat stress and experience lower rates of bleaching than populations in more typical clear water settings. Turbidity is a measure of the relative water clarity and can be caused by a variety of factors related to water quality, sediments, biogenic, among others. Different sources of turbidity may have different consequences for reef health. Thus, in this study, we characterized turbidity in a mosaic of turbid reefs in Darvel Bay (Sabah, Malaysia) that contain diverse coral communities which were not severely impacted by a regional bleaching event in 2020. Light data were obtained from in-situ light meters, multi-spectral depth profiles, water quality profiles, and remote sensing. To address the role of suspended matter we deployed two types of sediment traps to measure sedimentation rates and studied the composition and grain size of sediment samples. There was a range of turbidity among our study sites but two with relatively low light levels were influenced by different mechanisms. Sakar is permanently turbid because of the resuspension of seafloor sediments caused by tidal currents and the Triangle site is seasonally turbid due to changing river influx. One important lesson from this study is the need to combine data from multiple sources as each data type has particular strengths and weaknesses. Therefore, analysis of combined data facilitates distinguishing multiple sources of turbidity and light limitation on the studied reefs.

ID: 820
Mesophotic and Cold-Water Coral Ecosystems

Keywords: Mesophotic, Mediterranean, Behavior, Conservation

Red hot chili coral: two time-lapse case studies

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To establish effective conservation and protection plans, it is crucial to address gaps in our understanding of the dynamics, biological rhythms, and interactions among species. However, direct observations are constrained by underwater limitations such as time constraints and equipment availability. Time-lapse systems can offer a solution to overcome these challenges. Within the Coral Hidden Life (CHILI) project, we developed a time-lapse device featuring a digital GoPro8 camera with eight different time configurations, ranging from 3 to 30 minutes. The system, operational up to a depth of 100 meters, is compact and lightweight, making it easily transportable and deployable by scuba operators.

This study focuses on observations of *Corallium rubrum* (L., 1758) colonies, with a total of 44 colonies analysed, 26 over a four-day period and 18 for 18 hours. Image analysis revealed distinct rhythms between the apical and basal parts of the same colony. The former remained closed for the majority of the time, while the latter exhibited a circadian rhythm, demonstrating a synchronized and consistent decrease in activity across the population after sunset.

Polyp opening and closing transitions were observed in all colonies, with increased inactivity at night, suggesting a circadian rhythm influence. In one instance, the interaction with *Lysmata seticaudata* (Risso, 1816) led to the closure of several colonies. However, post-disturbance, these affected colonies synchronized once again with the rest of the population.

This study contributes to our understanding of *C. rubrum* ecology, revealing not only the presence of circadian rhythms in individual colonies but also the synchronization of these rhythms across the population. Enhancing our knowledge of red coral behaviour in its natural habitat establishes a crucial foundation for interpreting data from laboratory observations, particularly in the context of urgently studying the effects of thermal anomalies on both physiological parameters and behavior.

ID: 799
Mesophotic and Cold-Water Coral Ecosystems

Keywords: biodiversity, scleractinians, octocorals, community structure, UAE

Mesophotic coral communities of the Gulf of Oman

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While numerous coral studies in the Indian Ocean have focused primarily on shallow waters accessible via SCUBA diving, attention is increasingly expanding toward mesophotic corals, found at depths ranging from 30 m to 150 m. These deeper corals are garnering interest from scientists and managers dealing with coral reef research due to their unique biodiversity and distinct ecosystems that are vulnerable to pressure arising from human activities despite their depth. Recent advancements in deep-sea exploration and engineering have significantly reduced the barriers to explore these greater depths, making research both more feasible and cost-effective. The Gulf of Oman and the Arabian Sea, characterized by their distinct hydrography and climate conditions shaped predominantly by seasonal monsoons, offer unique habitats. These regions appear to have high levels of endemicity, particularly along the coastlines of the United Arab Emirates (UAE) and Oman. While the shallow hard coral communities in these areas have been relatively well-documented, the mesophotic and deeper zones remain largely unexplored. In December 2023, a groundbreaking survey was conducted off the coast of Fujairah, UAE. Utilizing the *OceanXplorer* research vessel, equipped with submersibles and remotely operated vehicles (ROVs), depths of up to 1200 m were explored, with a particular focus on the mesophotic zone. This expedition marked the first specialized deep-water survey in the region. Our findings unveiled several rarely known coral assemblages of azooxanthellate hard and soft corals within mesophotic depths. The presentation will delve into the overall diversity and community structure of these habitats, underscoring how they are intertwined with the region's complex hydrography and environmental conditions.

ID: 390
Mesophotic and Cold-Water Coral Ecosystems

Keywords: Spinimuricea, octocorals, taxonomy, molecular phylogeny

A Morphological and Genetic Exploration of *Spinimuricea* genus in the Mediterranean Sea and NE Atlantic Ocean

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Spinimuricea klavereni (Carpine & Grasshoff, 1975) is a Mediterranean endemic gorgonian congeneric with the Atlantic species *Spinimuricea atlantica* (Johnson, 1862). Although there has been an increase in recent records of *S. klavereni* at mesophotic depths, mainly due to increased use of ROVs, this species is still considered a relatively rare encounter in the Mediterranean Sea. On the contrary, it is considered a common species in the Marmara Sea between 15 and 40 m depth, especially around the Prince Islands, where it forms patches on hard substrates or on soft substrates attached to cobbles or shells. There is very poor information on the ecology and biology of this species, and for this reason, it is categorised as "data deficient" in the IUCN Mediterranean Red List. Therefore, to shed light on the systematic, biology and ecology of the species, specimens from three populations of *S. klavereni* (Marmara, Montenegro, Sicily) were compared both morphologically and genetically with specimens of S. *atlantica* from the NE Atlantic Ocean (Galicia). Morphological analyses covered various biological features of the species, including sclerites, anchorage structures of colonies inhabiting both hard and soft substrates, and gonad analyses. Genetic analyses included DNA isolation, PCR amplification of mitochondrial (MutS) and nuclear (28S) markers, and DNA sequencing. Sequences for each marker were analysed, and data analysis tools were utilised to compare genetic variability and structure. No significant morphological and genetic differences have been observed between *S. klavereni* populations. However, the taxonomical status of the two congeneric species, *S. klavereni* and *S. atlantica*, is brought into question by the disparity between the existing literature and our findings.

ID: 683
Mesophotic and Cold-Water Coral Ecosystems

Keywords: Mesophotic coral ecosystems, Refugia, Ryukyu Islands

Hidden lineagaes and potential deep to shallow connectivity of the brooding coral, *Seriatopora hystrix*

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Coral reef ecosystems are now severely threatened by anthropogenic stresses including climate change. In 1998 and 2001, most shallow Scleractinia corals such as *Seriatopora hystrix* went locally extinct due to high seawater temperature in Okinawa. However, healthy *S. hystrix* populations were reported at a nearby upper mesophotic site (40 m depth) in the recent years. Such mesophotic coral ecosystems may release larvae that help the recovery of nearby shallow populations. This study aims to elucidate if mesophotic habitats can supply larvae to shallow habitat for recovery.

In this study, we collected 195 *S. hystrix* samples from different depths (1 to 51 m) in the Ryukyu Islands. Clones were identified using seven microsatellite loci, and we analyzed the remaining 179 samples. We then applied a genome-wide SNP analysis called MIG-seq to examine their genetic structure. STRUCTURE analysis (483 SNPs) and phylogenetic tree analysis(14,312 SNPs) first indicated at least three hidden clade (named α, β, and γ clade) that are not correlated with depth or geographic distance along with the Ryukyu Islands. Within each of the three lineages, we found some detailed clades associated with the locations.

To further examine genetic connectivity between shallow and deep sites within a location, phylogenetic tree analysis was performed on cladeα in Shigeo (18 samples) and clade γ in Nagura (5 samples), which has samples at a wide range of depths. The results suggest overall genetic separation between shallow and deep-water habitats, and that gene flow is weak between shallow and deep water. However, phylogenetic tree suggested some genetic mixing between the individual from the middle depth habitats (10-29 m) with shallower and deeper habitats, implying the possibility of stepping stone like connectivity between different depth, supporting the hypothesis shallow population recovery by the larval recruitment from the deeper survived population.

ID: 730
Mesophotic and Cold-Water Coral Ecosystems

Keywords: Eunicella cavolini, gametogenesis, anthropogenic impact, mesophotic communities

Reproductive Pattern of the Mediterranean Yellow Gorgonian in a peculiar environment: the Sea of Marmara

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The Sea of Marmara harbours remarkable mesophotic communities despite facing significant anthropogenic impacts. This inner sea features a two-layer current system flowing in opposite directions, perpetually separated by a halocline layer. The mesophotic communities at depths of 25 to 45 meters around the Prince Islands primarily consist of four Mediterranean gorgonians: the yellow gorgonian *Eunicella cavolini*, the red gorgonian *Paramuricea clavata*, *P. macrospina*, and *Spinimuricea klavereni*. Below the halocline layer, an environment akin to depths below 50 meters in the Mediterranean promotes the occurrence of these Mediterranean species due to relatively stable conditions throughout the year (14°C and low light). However, these communities have significantly diminished due to increasing human pressure in recent years. Restoration efforts may be necessary for some species, but the bioecological characteristics of the species in the region are not well understood. The most common species in the region, *S. klavereni*, is a gonochoric broadcast spawner with continuous gametogenesis, exhibiting high male and female fecundities year-round. In contrast, most Mediterranean octocorals, including the yellow and red gorgonians, reproduce on an annual cycle after reaching maturity. Regardless of the reproductive type, spawning occurs in early to mid-summer, with increased water temperatures being a primary factor. However, in the Sea of Marmara's lower layer, which experiences minimal temperature changes throughout the year, the timing and trigger factors for regional spawning remain unknown. To investigate gametogenesis in the yellow and red gorgonian, 30 and 10 tip fragments of 10 cm were sampled per month, respectively. Gametogenesis was studied in 10 polyps per sample. Preliminary results indicate that the red gorgonian colonies, significantly reduced around the Prince Islands, may not be reproductively active. On the other hand, the yellow gorgonian appears to follow a more or less similar pattern to that in the Mediterranean.

Session 9: Technological and Methodological Innovation in Underwater Surveys and Data Analysis

Underwater surveying through images acquired by divers and unmanned underwater vehicle has been used for many applications in oil industry, archaeology, and biology. There was a significant improvement in integrated applications using photogrammetry, acoustic surveying, laser-based methods, hyperspectral sensors. The accuracy needed for the applications changed from some cm level till high accuracy level requirement (less than 1 cm accuracy), like for multi-temporal analysis for change detection purposes, depending on the instruments and camera settings used and the distance to the imaged object. Consequently, to new instruments development, a significant evolution has been realized on methods, algorithms, datasets and their applications to underwater objects and structures 3D modelization.

We would like to invite you to submit memories even on to new methods using deep learning and machine vision to different wavelengths including hyperspectral, acoustic, and laser-based methods.

We also want to address problems related to the semantics of generated 3D models: to gather original research on application and background issues arising from the design of conceptual models, ontologies and semantic web technologies applied to coral reefs and more generally corals related habitats and species.

Keywords: precise survey, unmanned and deep surveys, image semantic segmentation, data FAIR

Session chairs

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Take home message

- An increasing attention to surveying, measurements and monitoring with different techniques and methodologies has been observed; the interdisciplinary approach is quite consolidated.
- Use of machine learning algorithms and Artificial Intelligence application are diffused.
- Transfer of knowledge and skills to other disciplines and society (citizen science, citizen awareness) and tools for decision makers are given… We strongly suggest maintaining a technological and surveying session at next ECRS.

Regular oral presentations

ID: 706 / **Parallel Session 9-1: 4**
Technological and Methodological Innovation in Underwater Surveys and Data Analysis

Keywords: underwater geomatics, photogrammetry, VSLAM, monitoring, mapping

Geomatic techniques for underwater mapping and monitoring

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Geomatic techniques, such as photogrammetry, have been applied to marine ecology studies for many decades but have become a common practice only recently. In this contribution we will provide an overview of the current trends in underwater geomatics focusing on the evolution of the techniques from underwater surveying with classical direct methods to the more recent vision-based underwater mobile mapping. Indeed, the latest developments in underwater photogrammetry, bridging computer vision and marine robotics make it possible to process the image data captured by the cameras in real-time directly underwater using visual SLAM algorithms. These capabilities enable a new set of safer, more efficient and lower cost surveys providing guidance to the SCUBA divers or to the remote support vessel at the surface. Underwater photogrammetry provides high spatial resolution products such as ortho-photomosaics and three-dimensional models more and more used for in depth analyses to detect and monitor over time the impacts of natural and anthropogenic disturbances on underwater live structures.

Depending on the specific scientific aims of the project and their metric requirements, different methods of rigorous control for validation and traceability may be demanded. Nevertheless, the standard approach of ground control implemented for above the water surveys are often unaffordably expensive to be implemented underwater. For this reason, surveying procedures that limit the permanence underwater and require minimal ground control measurements are to be preferred. In this contribution we will show some of our latest developments that use pressure and inertial sensors to minimize the use of ground control point and scale bars in underwater photogrammetry. Laboratory and in the field tests have shown significantly lower time, costs and risks associated with the presented methodology. The contribution will conclude with current and possible future perspectives benefitting from artificial intelligence methods.

ID: 271 / **Parallel Session 9-1: 1**
Technological and Methodological Innovation in Underwater Surveys and Data Analysis

Keywords: drone, habitat mapping, multispectral camera, RTK, bathymetry

The impact of UAV navigation and sensor technology on bathymetry reconstruction and mapping live coral cover

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In recent years, Unoccupied Aerial Vehicles (UAVs) have emerged as an efficient tool to map shallow, spatially heterogeneous coastal ecosystems such as coral reef flats. However, refraction of light at the air-water interface interferes with the Structure-from-Motion (SfM) algorithms that are used to stitch UAV imagery together. Moreover, the variable attenuation of light by the water column obscures the reflectance signal of the seafloor, hampering the subsequent habitat classification. Technological advances such as UAV-integrated Real Time Kinematics (RTK) navigation systems and multispectral cameras may help to overcome these challenges, however, such systems can be prohibitively expensive. It is therefore paramount to evaluate whether employing UAVs with multispectral cameras and RTK navigation systems results in ecologically meaningful improvements to coral reef habitat maps. Here we investigated the capability of five representative UAV set-ups to reconstruct bathymetry and map live coral cover. We compared a DJI Mavic 2 Pro (RGB, non-RTK), a DJI Phantom 4 RTK (RGB, RTK), a DJI Zenmuse P1 (RGB, RTK), a MicaSense RedEdge-MX Dual (multispectral 10-bands, non-RTK) and a MicaSense Altum-PT (multispectral 5-bands, RTK). Preliminary results demonstrated that integration of RTK navigation systems significantly improved bathymetry retrieval when evaluated against in-water RTK elevation measurements ($R^2 \geq 0.79$ vs. $R^2 \leq 0.68$). Bathymetry retrieval was improved further by combining SfM-derived bathymetry with Stumpf's spectral bathymetry indices from the multispectral cameras ($R^2 = 0.95$). However, the increased spectral resolution of the multispectral cameras only marginally improved separation of live coral from spectrally similar classes like turf algae. Our results demonstrate that the inclusion of both RTK navigation and multispectral imagery improved the accuracy of UAV-derived bathymetry, while their impact on classification of live coral is limited. Our findings provide important insights into the marine mapping capabilities of different UAV configurations, aiding decision-makers to effectively allocate coral reef monitoring resources.

ID: 404 / **Parallel Session 9-1: 3**
Technological and Methodological Innovation in Underwater Surveys and Data Analysis

Keywords: underwater photogrammetry, fluorimetry, biometry, marine bioconstructors

Underwater fluorescence imagery and photogrammetry for the detection of fine-scale changes in marine bioconstructors.

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Marine communities are facing both natural disturbances and anthropogenic stressors. Bioconstructor species are endangered by multiple large-scale and local pressures, making the early identification of impacts and damages a primary goal for the preservation of coral reefs. These operations, generally performed by SCUBA divers, have to cope with safety and logistic constraints and require a considerable observation time if high-quality data are needed. Additionally, the manipulation of corals and the destructive sampling of colonies for further laboratory analyses are often required; and the on-field evaluations are affected by inter-observer variability.

In this work, the use of photogrammetry and fluorimetry was combined to design, test, and validate in the laboratory a multi-sensor measuring system for the assessment of the health status of corals and the detection of relevant biometric parameters with high accuracy and resolution. The system has been tested with fragments of the endemic coral *Cladocora caespitosa,* the sole zooxanthellate scleractinian reef-builder in the Mediterranean. The proposed methodology led to the following results: 1) achievement of a sub-centimetric resolution for measuring relevant biometric parameters (polyp counting, colony surface areas, and volumes); 2) set up of a reliable and repeatable strategy for multi-temporal analyses capable of quantifying changes in coral morphology with sub-centimeter accuracy; 3) changes detection in coral health status at a fine scale and under natural lighting through autofluorescence analysis.

The novelty of the present research lies in the combination of emerging techniques that could be applied to different habitats and species, thus paving the way to innovative opportunities in ecological research and more effective results than traditional in-situ measurements. Moreover, the measuring system could be easily modified for integration with different sensors, exploited in open water by SCUBA divers, or installed on underwater remotely operating vehicles.

ID: 313 / **Parallel Session 9-1: 2**
Technological and Methodological Innovation in Underwater Surveys and Data Analysis

Keywords: deep learning, machine learning, mapping, monitoring

Scalable 3D semantic mapping of coral reefs with deep learning

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In light of the critical threat to coral reefs worldwide due to human activity, innovative monitoring strategies are demanded that are efficient, scalable, and low-cost. Existing methods are commonly very labour intensive, creating a bottleneck for large-scale applicability. We present a method for rapid 3D semantic mapping from video transects using low-cost underwater cameras, in which both the 3D reconstruction and the benthic classification are created by neural networks trained on field data. The 3D reconstruction neural network is trained in a self-supervised scheme from a large dataset of videos, learning to tackle the challenges that conventional computer vision methods face under water. To train the semantic segmentation neural network, we create a dataset of annotated video frames with over 80'000 polygons from 36 benthic classes, down to the resolution of prominent visually identifiable coral genera found in the shallow reefs of the Red Sea. This initiative was carried out in Djibouti, Sudan, Jordan, and Israel, with over 150 hours of collected video footage for training the neural network for 3D reconstruction. We then process over 30 transects using the deep-learning based mapping system, characterizing their benthic composition, and demonstrate the method's accuracy as well as the consistency over time (evaluated after re-visiting sites in Israel and Djibouti). This research pioneers the use of deep learning in 3D underwater mapping and semantic segmentation for rapid, practical, and implementable reef surveying from cheap underwater cameras, paving the way for affordable and widespread deployment of the method in monitoring.

Speed talks

ID: 638 / **Parallel Session 9-1: 11**
Technological and Methodological Innovation in Underwater Surveys and Data Analysis

Keywords: Machine learning approach, Unbalanced dataset, Loss functions, Microborings abundance, Massive corals

Machine learning approach to quantify microboring assemblage dynamics in two living massive corals

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Coral hosts comprise various micro-organisms including those in their skeleton. Within this latter, microboring communities are mainly composed of filamentous cyanobacteria, algae, and hyphae of fungi. They produce specific traces (microborings) by dissolving $CaCO_3$ skeletons through various metabolic processes. Those traces are important as they can be seen as instant fossil traces that are well preserved during the lifespan of their coral host. The study of the variability of their abundance within skeletons of living massive slow-growing corals has been overlooked. Still, it is of great interest to better understand the long-term effects of climate change on their communities and coral resilience. Microborer traces can be observed using scanning electronic microscopy (SEM). To date, only a few highly time-consuming methods relying on the observer allow their quantification on SEM images. This greatly limits the number of samples that can be analysed. Recently, a machine-learning approach based on a Convolutional Neural Network (CNN) model was developed to study accurately and quickly traces' abundance along a core of the massive coral *Diploastrea* sp. (Mayotte). Here, we tested this CNN model on a massive coral, *Porites* sp., and found that the accuracy which was initially 93% dropped down to 88%. We adapted it and showed that optimized loss function can significantly improve the accuracy (from 88% to 95.2%). Finally, we suggest improvements to our CNN models to allow the analysis of microborer traces in all kinds of coral skeletons.

ID: 151 / **Parallel Session 9-1: 6**
Technological and Methodological Innovation in Underwater Surveys and Data Analysis

Keywords: Acanthaster, crown-of-thorns starfish, population outbreak, Great Barrier Reef, novel survey method

Increasing densities of Pacific crown-of-thorns starfish (*Acanthaster* cf. *solaris*) on the Great Barrier Reef, resolved using a novel survey method

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Recurrent population irruptions of Pacific crown-of-thorns starfish (CoTS, *Acanthaster* cf. *solaris*) are among the foremost causes of coral mortality on Australia's Great Barrier Reef (GBR). Early intervention during the initiation of new population irruptions represents the best opportunity to effectively manage this threat. However, traditional survey methods are not sufficiently sensitive to detect changes in CoTS densities during the early onset of population irruptions as they either have constrained spatial scales or limited capacity to detect cryptic individuals. This study demonstrated the utility of a novel scooter-assisted large area diver-based (SALAD) visual survey technique as a superior monitoring technique for resolving the most accurate abundance estimates of CoTS, prior to outbreaks becoming fully established. Surveillance with this new method ultimately revealed increasing densities of CoTS at Lizard Island from 2019 to 2022, providing strong evidence that the anticipated renewed fifth population irruption of CoTS on the GBR, has already commenced. The novel monitoring approach has allowed the renewed outbreak to be identified 2 years before it was predicted to occur and provides an important opportunity for early intervention, as well as enabling improved understanding of the patterns and processes involved in initiation of CoTS population irruptions. Furthermore, this new method has potential applications for fine-scale surveillance of other cryptic invertebrate species in both tropical and temperate reef ecosystems.

ID: 681 / **Parallel Session 9-1: 12**
Technological and Methodological Innovation in Underwater Surveys and Data Analysis

Keywords: Coral reefs, Ecoacoustics, Passive acoustic monitoring, Machine learning, Marine Biology

Towards more standardization in the use of Ecoacoustics for coral reef monitoring across ocean basins

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Coral reef ecosystems, facing severe threats, demand effective large-scale monitoring solutions. Ecoacoustics is emerging as a potent complementary monitoring method. While awaiting the development of artificial intelligence tools capable of swiftly processing vast acoustic datasets, ecoacoustic indices have been formulated, linking ecosystem characteristics to acoustic metrics. However, the parameters applied for computing these metrics, and their usefulness for ecosystem description, vary widely among coral reef studies, along with the results and conclusions that stem from them. Thus, acoustic metrics and their use for reef monitoring need further validation and standardization. This study aimed to identify the most relevant acoustic metrics in distinguishing coral reef soundscapes, irrespective of islands or ocean basin.

To achieve this, ambient sound was continuously recorded for 24 hours on 98 sites around three islands in two ocean basins: Reunion and Mayotte (western Indian Ocean) and Guadeloupe (Caribbean). Recordings were denoised using automatic detectors for boat, diver, and breaking wave sounds. Eight commonly used metrics (ACI, ADI, BI, NDSI, SPL, M, Hs, and Ht) were calculated on all remaining 1-minute recordings. Parameters and frequency bands were systematically varied, resulting in a total of 503 metrics calculated. Machine Learning algorithms (Random Forest and GLM) were employed to identify the most discriminant metrics among sites. These analyses were conducted for four distinct times of the day (dawn, day, dusk, night) on each spatial dataset. Sites were then classified using clustering based on the selected metrics, and the relevance of the clusters was analysed.

Results identify the minimal set of metrics that distinguish coral reef soundscape sites across oceanic basins, islands, and times of the day. Rarely applied on coral reefs so far, the spectral entropy index (Hs) proves useful for reef soundscape studies. These findings contribute to a more robust methodology for large-scale coral reef acoustic monitoring.

ID: 384 / **Parallel Session 9-1: 9**
Technological and Methodological Innovation in Underwater Surveys and Data Analysis

Keywords: Cold water corals, Marine imaging, Copmputer vision, Data science, Environmental monitoring

Combining machine vision and stationary observatories for next generation in-situ visual monitoring of *P. arborea*

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Paragorgia arborea is a gorgonian cold-water octocoral with a wide geographical distribution. Such habitat forming cold-water corals and their environments can be monitored in-situ using stationary observatories equipped with cameras and other sensors (e.g. temperature, currents, etc.). Here, ee investigate data collected with the Lofoten – Vesterålen (LoVe) ocean observatory, located at approximately 250 m depth and 12 km off the coast of Norway (N 68°54.474′, E 15°23.145′). A series of 2222 images (2206 x 2752 pixels) were collected at LoVe between 12th December 2018 and 6th April 2019 showing one *Paragorgia* colony with a temporal resolution varying between minutes and hours. We present new machine learning tools to automatically a) estimate the polyp activity in the colony and b) estimate the branch diameter. The latter was done at nine pre-selected branch positions in the colony with two deep learning architectures, Yolov5 and ResNet50. The networks were applied to detect and track branch positions in consecutive frames (step 1) and estimate branch diameters in these frames (step 2). Training data annotations of branch positions and diameters were collected using the annotation software BIIGLE. The computed branch data was compared to gold standard annotation data obtained from manual assessments using the BIIGLE tool. We report a mean absolute percentage error (MAPE) of 0.049 for the branch diameter and an average position shift of 1.57/1.70 pixels. The resulting time series of the colony's average branch diameter shows a strong correlation with the time series of polyp activities. We observe a period of low-to-no polyp activity starting in late February 2019 and lasting until mid/late March 2019. During this "dormant" period the individual branch diameter is reduced and shows less variability. Throughout the observation period, the variables, branch diameter and polyp activity, showed little to no correlation with other sensor data.

ID: 541 / **Parallel Session 9-1: 10**
Technological and Methodological Innovation in Underwater Surveys and Data Analysis

Keywords: fish identification, memorisation of species names, diagnostic field traits, underwater photography

Improved field identification of fish species in biodiversity hotspots

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Visual identification of reef fishes in the field poses four challenges: (1) the extreme number of species (ca. 4000 on or near reefs in the Coral Triangle), (2) the similarity between congeneric species, (3) the strong variation and rapid changes in colouration a single species shows, and (4) the discrepancy between pictures in ID-books (using a flash) and a fish's colour underwater. We offer three solutions:

a. The Reef Fish Trainer is a digital flashcard system with multiple pictures per species showing colour variations. It allows users to quickly memorise species names and their appearance ***before*** going into the water. It contains 420 (Red Sea) and >1000 species (Indonesia). Most common and some rare species are covered, making it possible to allocate "unidentified, new" species to the most fitting higher taxon, facilitating a posteriori identification if needed.

b. Flash-free UW photography to assure that fish are shown as they appear to the human eye - often revealing surprisingly conspicuous, diagnostic traits that are remain inconspicuous in flash-illuminated pictures in field guides.

c. Finding new diagnostic field traits by analysing the literature on taxa that are difficult to identify, and comparing them to thousands of pictures (own and internet). This reveals novel diagnostic traits that can facilitate visual field identification.

The procedure allows quick and correct field identification, and produces proof of each observation in the form of pictures that can be re-checked later. Pictures are stored following FAIR standards and shared with GPS coordinates in Citizen Science projects (e.g. iNaturalist).

We illustrate this strategy by presenting data from a 2-month survey of fish species diversity in diverse marine shore environments in North-Sulawesi. Approaches like these yield more reliable data faster, which is essentials in the face of climate change and overfishing.

ID: 147 / **Parallel Session 9-1: 5**
Technological and Methodological Innovation in Underwater Surveys and Data Analysis

Keywords: structural complexity, rugosity, photogrammetry, habitat functionality

Effects of habitat configuration on coral reef structural complexity across Southeast Asia

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Coral reef health and habitat functioning is closely associated with the structural complexity and three-dimensionality of reefs. Through habitat and niche partitioning, more complex environments are considered to sustain higher biodiversity and biomass, with greater functional redundancy and overall functional resilience. To date, estimates of reef structural complexity have typically utilized rugosity index measurements (i.e., chain method) to calculate surface roughness and habitat availability. Such methods have limited applications to whole reef-scales as they capture only a small subset of reef complexity that may not represent larger reef extents, and do not distinguish between the different biotic (e.g., coral) and abiotic (e.g., sand, rubble, etc.) factors contributing to reef rugosity. Here we employed novel underwater photogrammetry techniques to construct large-scale orthomosaics and digital elevation models (3 x 5m plots) at three sites in Southeast Asia. Three-dimensional reefscape models were combined with benthic cover data to quantify reef structural complexity values for a variety of reef habitat configurations and determine the key drivers of reef rugosity at different spatial scales. Our findings demonstrate the capabilities of photogrammetry for high-resolution surveying of complex coral reef systems, even within low visibility (<5m) turbid settings. Furthermore, data suggests that despite coral cover and morphotypes playing a critical role in reef structure at finer-scales, abiotic factors also contribute to overall complexity and habitat functionality at larger-scales and should not be overlooked.

ID: 374 / **Parallel Session 9-1: 8**
Technological and Methodological Innovation in Underwater Surveys and Data Analysis

Keywords: space use, animal movement, reef structure, 3-dimensional space

Linking fish movement and coral reef structure in a 3-dimensional space

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Human-induced environmental change is altering the composition of coral reef assemblages, with drastic consequences for reef structure and function. The structural complexity and functioning of coral reefs are inextricably linked to patterns of movement and space use by reef inhabitants. Animal movement plays an integral role in shaping community dynamics, population persistence, and even individual behaviour. One key avenue that has remained elusive is the tracking of fish movement across coral reefs in 3-dimensional space. Here, we present methods linking fish movement and behaviour to coral reef structure in three dimensions, featuring case studies highlighting the potential uses of these methods. Specifically, we use stereo video surveys to map fish movement alongside structure-from-motion generated reef surfaces. Using territorial farming damselfish as a study species, we first explore how reef structure shapes territoriality and individual behaviour, as well as interactions between neighbours. Secondly, we employ the landscape of risk framework to explore how reef structure affects the perception of predation risk and subsequent responses in prey species. Evolution of 3D technology has unlocked new avenues of exploration for many important ecological issues relating to coral reefs, and we build on these new technologies to address our questions. By linking fish movement and behaviour to coral reef structure, we can deepen our understanding of the effects of habitat structure on animal space use, allowing us to better predict how environmental change may influence communities.

ID: 339 / **Parallel Session 9-1: 7**
Technological and Methodological Innovation in Underwater Surveys and Data Analysis

Keywords: data analysis, underwater remote sensing, coral reef monitoring, historical changes

Potential of remote sensing for mapping coral reef cover and historical changes in shallow coastal waters of Bonaire

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The degradation of coral reefs is a well-documented and unfortunately worldwide ongoing process. This process is caused by increasing human and non-human stressors that have a large impact on the coral reef. Stressors effect on different scales, such as locally (i.e., tourism), regional (i.e., rivers of South America) and globally, such as climate change. One of the main difficulties in the monitoring of coral reefs is the lack of historical data with a large spatial extant. The use of historical aerial photographs in combination with more recent very high-resolution satellite imagery can provide a powerful tool in these difficulties. The benefits of those RS techniques have been discussed in different areas in the world. This thesis applies RS techniques on historical time series of imagery on the shallow coastal waters of Bonaire's leeward side, to evaluate its potential in supporting future monitoring processes. It is shown that analyzing satellite images can produce reliable spatial information about coral cover and sand patches in the shallow coastal waters in combination with in-situ measurements. With in overall accuracy of 70% the classification provides reliable information, that especially apply to corals and sand. Additionally, this thesis uses historical airborne imageries to detect changes of the coral reef over the past 60 years and compare them with different sources of information. The historical analysis of imagery proofs the strong changes in the coral cover, with a loss of 40% over the last decades and visualize them in a spatial context. It is shown that the degradation of the reef varies a lot between different areas and goes along with an increase of sand patches. This research shows the benefits and prospects of remote sensing for mapping aquatic habitats and points out, what is necessary to improve the workflow in the future.

Posters

ID: 449
Technological and Methodological Innovation in Underwater Surveys and Data Analysis

Keywords: ecotoxicology, cell cultures, cnidarian, symbiosis, marine bioassays

In vitro marine ecotoxicity tests: an innovative method to assess the environmental contaminations impact on coastal reef

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The increasing ocean contamination strongly threatens marine ecosystems. Pollutants and floating wastes lead to a multitude of malfunctions and eventually death of marine organisms. Coastal ecosystems are particularly impacted by anthropogenic activities. Among them Cnidarian-Dinoflagellate associations, which represent the most distributed symbioses in the marine environment, are experiencing high levels of anthropogenic perturbations (climate change, pollution) contributing to the symbiosis breakdown, known as "bleaching", and even mortalities. Thus, the response of symbiotic cnidarians to environmental contaminations is considered as to be a relevant benchmark for the health status of the coastal reef and represents a major societal challenge.

Marine bioassays were designed to preserve marine ecosystems by evaluating the impact of anthropogenic activities on seawater. However, these ecotoxicity tests are usually conducted on living organisms and are therefore costly and invasive. Thanks to *in vitro* marine invertebrate cell cultures, we propose a more sustainable and efficient alternative solution, requiring no animal sacrifice.

Using animal and algae cell cultures obtained from a symbiotic cnidarian study model, the sea anemone *Anemonia viridis*, this *in vitro* marine ecotoxicity test allowing: (i) to measure the toxicity from raw material to final products (pollutants, industrial products), (ii) to assess the level of coastal pollution and its impact on reef biota by measuring cellular parameters on cultivated cells. The performance of the test has been successfully demonstrated on sunscreen products, by identifying a reliable wide range of solar products toxicity from weak to irreversible impact.

This innovative approach provides a relevant methodology for monitoring the coastal environment. In addition, by respecting the concept of "3R": refinement, reduction, replacement it represents a sustainable solution contributing to the preservation of coastal reef biodiversity.

ID: 279
Technological and Methodological Innovation in Underwater Surveys and Data Analysis

Keywords: Coral polyps, restoration, photogrammetry, Corallium rubrum, fecundity.

Coral polyps number estimation through photogrammetry: the example of *Corallium rubrum*

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Mediterranean red coral (*Corallium rubrum)* is a gonochoric colonial octocoral. Colonies are composed by polyps, which are the reproductive units, developing male or female gametes. The heavy harvesting due to its high economic value, depleted most *C. rubrum* populations. In the last decades, conservation and management measures have been implemented, but in some cases, restoration actions could be necessary. To ensure its long-term success, restoration should be based on the biological characteristics of the species, to secure the survival and reproduction of the restored populations. In the framework of the development of restoration protocols based on sexual reproduction, *C. rubrum* male and female colonies are maintained in semi-controlled conditions at 30 meters depth, to study the reproductive biology and the mating system. In this context, the number of polyps can inform on reproductive potential and fecundity of male and female colonies. Despite the number of polyps is expected to depend on the colony surface, methods for estimating this value, developed 20 years ago, are based on the relationship between colony basal diameter and number of polyps, due to the lack of tools to measure colony surface. Here we present a new method based on polyp density and colony surface. First, we applied photogrammetry to produce 3D models of 26 *C. rubrum* colonies and we measured their surface. Second, we estimated polyp density by counting the number of polyps on sections of known surface of 1st, 2nd, and 3rd order branches of the 26 colonies. Finally, the number of polyps is obtained by multiplying polyp density by colony surface. Comparisons showed a better performance of the new method, probably because the morphological variability of the colonies is linked to surface more than to basal diameter. Further investigations will focus on the applicability to other *C. rubrum* populations and other coral species.

ID: 353
Technological and Methodological Innovation in Underwater Surveys and Data Analysis

Keywords: Coral bleaching, marine heatwaves, temperature sensors, restoration

Widespread inconsistency in logger deployment methods in coral reef studies may bias perceptions of thermal regimes

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Warming ocean temperatures are driving an unprecedented deterioration to coral reef health, prompting an emerging need for better and affordable instruments to sense and record temperature. Advancements in sensing technologies have led to a proliferation of “loggers” that span a range of prices and accuracy, but with the multitude of options that now exist, deciding which model to use can be challenging. Moreover, appropriate calibration and deployment of loggers – essential for generating reliable, accurate data – is often overlooked. Solar heating of instrument housings has previously been found to falsely elevate temperature readings, but awareness of this issue among coral reef scientists has never been assessed. Here, we perform a survey of recent literature to evaluate how often logger shading has been implemented in coral reef studies. We then preformed an in-situ evaluation of nine popular loggers to assess the degree to which solar heating biases temperature across different models. Of the 329 coral reef studies we reviewed, <14% reported shading or calibrating their temperature sensors, revealing a surprising lack of uptake of shading methods. In field tests, solar heating bias also varied significantly across loggers; many Onset® models, among the most popular loggers used, suffered the worst bias of up to 2.5ºC. In contrast, models like Sea-Bird® SBE-56, Odyssey® Xtreem PAR, and PME® MiniDOT were much less affected irradiance. In all cases, shading improved accuracy such that the effect of irradiance disappeared. As reef monitoring efforts expand globally, close attention to instrument capabilities and deployment best practices will improve the quality and cross-comparability of data collected.

ID: 405
Technological and Methodological Innovation in Underwater Surveys and Data Analysis

Keywords: image enhancement, DeepSeeColor, underwater photogrammetry, accuracy estimation

Assessment and accuracy estimation under controlled and real-world conditions of the recent DeepSeeColor method for underwater photogrammetric image enhancement

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The quality of underwater images plays a crucial role in various applications, including the ecological monitoring of coral reefs; however, it is affected by the physical and chemical characteristics of the underwater environment. Suspended particles can cause blur and haze due to the absorption and scattering of light. Additionally, the different attenuations of red, green, and blue result in a depth-dependent green or bluish colour.

The methods for image quality improvement are usually based on image quality degradation models that consider underwater imaging and light propagation principles; nevertheless, the computation of the optical parameters of these physical models is a complex task. In this framework, researchers from the Woods Hole Oceanographic Institution recently proposed the DeepSeeColor method which combines an underwater image formation model with a deep learning model to efficiently estimate the cited optical parameters. It exploits gradient-based optimization methods to learn the backscatter and attenuation parameters using two simple convolutional neural networks. The networks are trained under self-supervision using the captured image and range map.

In the proposed work, the DeepSeeColor method has been tested on datasets acquired both in the laboratory (aquarium tests) and open water conditions to assess the potentialities of the methodology. The authors focused on the assessment of the colour enhancement accuracy, exploiting, when possible, the colour checker and computing the total colour difference. The number of images and the geometries of acquisition are crucial to assess the performances of the tested methodology. Laboratory experiments were conducted under controlled conditions of illumination, turbidity, geometry, and number of acquisitions. While, when dealing with open water conditions, the acquisition trajectories and the redundancy will be discussed together with data augmentation approaches.

ID: 774

Technological and Methodological Innovation in Underwater Surveys and Data Analysis

Keywords: Reef structural complexity, underwater photogrammetry, fish community, temporal changes, underwater geodetic network

Relating temporal changes in reef structural complexity as measured using photogrammetry to changes in fish community structure.

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Many species of coral reef associated fishes are highly dependent on the structural complexity provided by intact reefs. Goods and services supplied by reefs include essential habitat for obligate coral dwelling species, provisioning for corallivores, structural shelter from predators, and hydrodynamic refugia. Natural and anthropogenic perturbations that reduce the amount of live coral present on reefs and/or alter the three-dimensional structure of reefs therefore have the potential to greatly alter the community composition and size structure of the associated fish communities. The coral reefs surrounding the island of Moorea, French Polynesia experienced a massive thermal event in 2019 that resulted in widespread coral bleaching and mass mortality of stoney corals.

We used underwater photogrammetry coupled with rigorous geodetic methods providing reliable 3D models of the reef structure and its changes over time with known metrical uncertainties to extract metrics related to reef structural complexity. We then used these metrics to explore how temporal changes in different aspects of reef structural complexity relate to observed changes in the associated fish community. Critical to this effort was the development of a methodology capable of showing annual changes of the reef structure at the sub-centimetre level. The procedure is built on 4 blocks: (i) the establishment of permanent, underwater geodetic networks, which provide a temporally stable and common reference datum and, also, an independent quality check for multi-temporal 3D models produced with photogrammetry; (ii) a metric evaluation of underwater camera systems for photogrammetric and multi-temporal monitoring purposes; (iii) the design of a reliable camera network geometry to minimize the errors of the photogrammetric 3D coral reef models; and (iv) an estimate of the propagation of measurement and modelling uncertainties throughout the photogrammetric workflow to identify statistically significant changes over time.

ID: 515

Technological and Methodological Innovation in Underwater Surveys and Data Analysis

Keywords: Coral reefs, Acoustics, Deep-learning, Acoustic indices

Linking deep-learning and acoustic indices approaches to analyse coral reef soundscapes

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Passive acoustic monitoring has emerged as a powerful tool for ecological enquiry, conservation, and monitoring on coral reefs. However, acoustic indices — the predominant automated approach to soundscape analysis — are limited by methodological and practical shortcomings, likely reflecting the extreme data loss engendered in summarising a detailed recording in a single metric. While their simplicity allows straighηorward interpretation in terms of acoustic properties, the ecological relevance of these properties is still unclear. In contrast, deep-learning approaches, which are datarich and show promise in detecting soundscape differences on coral reefs, overcome some limitations of acoustic indices. However, deep-learning approaches are often labelled as 'black-box' methods, as their internal mechanisms remain obscure to the user. In this study, we combine a deep-learning technique with acoustic indices to enhance interpretability while taking advantage of the power of artificial intelligence. Mapping acoustic indices onto AI-derived variables helps to reveal which acoustic properties are driving differences between reef soundscapes. When applying these methods to acoustic recordings from Kimbe Bay, Papua New Guinea, our results reveal that individual reefs and habitat types have distinct acoustic signatures that likely relate to the acoustic activity of fish and snapping shrimp. This study advances the methods used in the analysis of coral reef soundscapes, which can be applied in future studies to aid reef conservation efforts.

ID: 742
Technological and Methodological Innovation in Underwater Surveys and Data Analysis

Keywords: Carbonate budget, Calcification rate, 3D point clouds, skeletal linear extension, Southeast Asia

Utilizing photogrammetry to quantify 3D coral growth in turbid settings

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Coral growth and calcification are key drivers of carbonate production on coral reefs. These colony-scale metrics underpin reef carbonate budgets and framework construction, and are commonly used to quantify the health status and ecological trajectory of coral reefs. There are few regional datasets of coral growth and calcification currently available, especially within Southeast Asia. A bias in these data also exists toward remote clear-water reef systems, with coastal turbid reefs largely unstudied, despite their common occurrence and large spatial extent in the region. However, quantifying genera-specific growth rates within turbid settings is challenging due to the visual impediment caused by high turbidity. Traditional methods to measure coral growth, such as Alizarin-red staining or coral coring, are time-consuming and destructive to corals. Here we utilize a novel non-invasive method to quantify the growth rates of 20 coral genera on highly turbid reefs in southern Singapore. Underwater three-dimensional (3D) photogrammetry from subsequent years was acquired to generate high-resolution 3D point clouds of coral colonies, which were then compared to measure skeletal linear extension and volumetric change over time. Bulk skeletal density values were then applied to calculate calcification rates. Our findings provide data on how marginal coral reefs grow and calcify, and how growth can vary with coral morphology. We also highlight the potential application of 3D photogrammetry for coral research within turbid settings, due to its ability to filter sediment particles. The use of novel methods to collect fast, precise, and non-invasive coral growth rate metrics can further improve reef budget assessments and give insight into the impact of human-induced stressors on coastal reef ecosystems.

Session 10: Coral Reefs Under a Socio-Economic Perspective

Dive into the intricate world of coral reefs through the lens of socio-economic dynamics in our upcoming session, "Coral Reefs Under a Socio-Economic Perspective." Embark on a captivating journey exploring the multifaceted realm of coral reefs within the context of socio-economic dynamics in our session, "Coral Reefs Under a Socio-Economic Perspective." This session promises an illuminating discourse on the profound significance of coral reefs beyond their ecological value, focusing on their pivotal role in providing essential ecosystem goods and services crucial for human well-being.

We invite contributions that delve into the intersection of coral reef conservation and social sciences approaches. Share your insights on the intricate balance between human societies and these vibrant marine ecosystems. How can we craft effective conservation policies that safeguard these reefs while considering the socio-economic needs of local communities?

Moreover, the session will spotlight innovative ideas fostering a 'blue circular economy,' showcasing sustainable practices that not only preserve coral reefs but also promote economic growth and well-being. How can we create economic systems that not only benefit from but also actively contribute to the preservation of these vital natural resources?

Furthermore, the session will spotlight the imperative of evaluating the ecosystem services offered by coral reefs. Share your research, methodologies, and findings that elucidate the quantification and valuation of these invaluable services. How can a comprehensive understanding of the ecosystem services of coral reefs inform better conservation strategies and policy frameworks?

Join us in shaping a comprehensive understanding of coral reefs that transcends ecological boundaries, acknowledging their profound socio-economic significance. Share your research, perspectives, and innovative strategies to inspire a collective effort towards the sustainable preservation of these underwater wonders. Your contributions will fuel discussions that drive meaningful action, fostering a harmonious coexistence between humanity and the mesmerizing world of coral reefs. Submit your insights and be part of this transformative dialogue.

Keywords: ecosystem goods and services, social sciences approaches, conservation policies, blue circular economy, evaluation of the ecosystem services of coral reefs

Session chair

Nathalie Hilmi, Centre Scientifique de Monaco
(Monaco)

Take home message

- MPAs are tools to protect the ocean ecosystems and the coastal communities, which rely on nature for their livelihood and well-being
- Coral reefs conservation and restoration benefits to the biodiversity and to the people who depend on the services that nature renders to the humanity
- Unsustainable practices (i.e., overfishing) lead to environmental damage (i.e., coral reef destruction), loss of ecosystem services (i.e., habitat for species and fish stocks decline), endangerment of natural assets, and threaten the associated industry (i.e., fisheries), jeopardizing the entire economy

Speed talks

ID: 319 / **Parallel Session 10-1: 2**
Coral Reefs Under a Socio-Economic Perspective

Keywords: Marine science, Inclusion, Gender, Urbanization, STEM careers

The growing role of women in coral reef research in the Gulf Cooperation Council

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As the most biodiverse and productive ecosystem in the Gulf Cooperation Council (GCC), coral reefs have supported coastal communities for millennia. Demands for improved management and conservation following rapid development in the 1970s have led to a dramatic growth in science seeking to document and describe the status of regional reefs; however, the role of women in this field remains understudied. Using an explanatory semi-sequential mixed-methods design, in which a systematic review preceded semi-structured interviews, we address this gap by investigating the prevalence and perspectives of women conducting reef science in the GCC. Of the 852 reef-related publications included in the review, the majority (53 %) were exclusively authored by men, with no female authors occurring in the literature until 1985. The six-fold increase in female-inclusive publications that occurred in the subsequent three decades did not eliminate the substantial gender divide in publication output and the senior authorship position. Moreover, over half of published female scientists were researchers from the Global North, while Khaleeji researchers (citizens of GCC nations) were a minority - a trend with implications for knowledge leaks and ineffective conservation efforts. Six themes emerged from the interviews (n = 47): 1) history of female contributions to reef science in the GCC, 2) success factors for scientific productivity, 3) barriers affecting professional practice, 4) author collaboration and credit, 5) growing presence of Khaleeji researchers, 6) parachute and neocolonial science. Our results highlight the need to sustain diverse gender and local voices in research shaping conservation efforts. Considering that the region remains densely populated in coastal zones and dependent on the surrounding marine provinces, member states must propagate greater inclusive and indigenous representation in science to support advancement of reef research and conservation.

ID: 654 / **Parallel Session 10-1: 6**
Coral Reefs Under a Socio-Economic Perspective

Keywords: Nature Future Framework, Nature's Contributions to People, Marine Protected Areas, Ecosystem Services, Reef Life Survey

The global contribution of tropical reef fishes to nature and people

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Anthropogenic activities are eroding biodiversity and the associated contributions to nature and people, perhaps nowhere more than on tropical reefs. Yet, the dual imperative to protect nature and sustain human well-being is facing potential trade-offs and synergies that remain poorly quantified. In this symposium, I would like to present a global quantitative analysis of 29 fish-based potential contributions to nature and people, using 1,237 tropical reef surveys of 1,024 species. Based on the Nature Future Framework (NFF), we introduced a heuristic framework classifying tropical reefs according to the "Nature-for-Nature" (NN) and 'Nature-for-People' perspectives (NP), and investigated how these contributions are spatially segregated. We found that while many of the NN contributions are highly positively correlated to total fish biomass, such as nitrogen recycling (r=0,96), others are largely independent, such as the mean trophic level (r=0,10). We showed that trade-offs among contributions are not the rule, so tropical reefs can simultaneously provide high levels of different contributions. Covariations among contributions were consistent across regions, suggesting that fish-based contributions are more likely to be driven by local or regional processes rather than by geographical constraints, with the exception of endemism and evolutionary distinctiveness. This framework offers the opportunity to explore different options for managing tropical reefs towards more favourable ecological and social futures.

ID: 566 / Parallel Session 10-1: 5
Coral Reefs Under a Socio-Economic Perspective

Keywords: Coral reefs, Red Sea, ecosystem services

Sustaining Red Sea coral reefs: Guardians of ecosystem services in a changing World

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The Red Sea coral reefs serve as invaluable ecosystems, offering a myriad of services essential for human well-being and environmental stability. Through an examination of ecosystem goods and services, this paper underscores the critical importance of preserving these reefs amidst escalating threats. Despite covering less than 1% of the seafloor globally, Red Sea coral reefs harbor over 25% of marine life, playing pivotal roles as biodiversity havens, natural shields against hydrodynamic forces, and vital economic assets through tourism and fisheries. However, rapid coral decline imperils these services, impacting over half a billion people reliant on reefs for sustenance, income, and coastal protection. Economic valuations estimate global coral reef benefits at approximately US$30 billion annually, emphasizing the urgency of conservation efforts in the face of climate change and unsustainable practices. In the Red Sea region, burgeoning coastal development exacerbates threats, with overfishing and unregulated tourism amplifying local stressors. Such pressures, compounded by climate change impacts, endanger the resilience of Red Sea coral reefs, endangering the livelihoods of 28 million people across the basin. Thus, proactive conservation measures are imperative to safeguard the Red Sea's rich biodiversity and ensure the continued provision of essential ecosystem services for present and future generations.

ID: 724 / Parallel Session 10-1: 7
Coral Reefs Under a Socio-Economic Perspective

Keywords: Restoration, Cold-Water Corals, Economic Valuation, Ecosystem Services; Mediterranean Sea.

Restoration of cold-water corals is not as expensive as it was: a case study from the Mediterranean Sea based on ecosystem services evaluation

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Deep-sea habitats are heavily impacted worldwide due to different anthropogenic activities (e.g. trawling and littering). Inhabiting depths of > 50m, cold-water corals (CWC) are ecosystem engineers that act as hotspots of biodiversity and provide a plethora of ecosystem services (ES) needed for human wellbeing and for the correct functioning of natural processes. However, their life-history traits make them one of the most affected organisms by human activities. Restoration has successfully been used worldwide in shallow corals and other coastal ecosystems, but little attempts have been made on deep reefs, mainly due to technological difficulties and costs of restoration. In the current study, a cost-benefit analysis has been carried out considering the of Bari Canyon (Mediterranean Sea) as a case study, through an economic calculation of the ES and the cost of restoration per hectare. We demonstrated that restoration is not as expensive as previously documented, and that the value of ES provided by CWC surpass the costs of restoration at mid-term. Furthermore, previous attempts of valuating ES have not considered some essential aspects such as biodiversity and spillover effects. Here, we summarize current knowledge in restoration of CWC, identify gaps and propose future perspectives and initiatives to decrease costs of restoration.

ID: 454 / **Parallel Session 10-1: 4**
Coral Reefs Under a Socio-Economic Perspective

Keywords: heavy metals, lollyfish, trepang, sea cucumbers, golden sea squirt

Bioaccumulation of mercury and other potentially toxic elements in *Holothuria* (*Halodeima*) *atra* and *Polycarpa aurata* associated with gold mining in North Sulawesi, Indonesia

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Coral reef species are increasingly threatened by multiple stressors, including potentially toxic elements (PTEs) pollution. Depending on the extraction methods and mineralogy of local rocks, gold mines can release PTEs into the catchments and thus reach marine habitats. Although the use of mercury in industrial mines has been eliminated following the Minamata Convention, mercury amalgamation practices in artisanal and small-scale gold mines (ASGMs) persist in several Indo-Pacific regions.

The contamination of PTEs in marine sediments and suspended particulate matter and their bioaccumulation in the edible, deposit-feeder, holothurian *Holothuria* (*Halodeima*) *atra* and the suspension-feeder ascidian *Polycarpa aurata* were assessed, comparing samples collected downstream to four mine sites (two industrial and two ASGMs) and at four control sites in the North Sulawesi, Indonesia.

In sediments, mean concentrations of arsenic, gold, cobalt, chromium, copper, mercury, nickel, lead, antimony, and zinc were significantly higher at sites receiving mine discharges than at control sites. Particularly, mercury overcame the upper guideline value downstream of the oldest ASGM. High mercury concentrations were also found in suspended particulate matter downstream ASGMs. Significantly higher concentrations of As, Au, Co, Cr, Cu, Hg, Pb, Sb, Sn, and Zn were found in holothurians near mines, especially ASGMs. There, the ascidians also showed significantly higher concentrations of Hg and Cu.

Environment contamination and bioaccumulation varied according to mining processes, environmental matrix, and species; however, concentrations and bioaccumulation of PTEs, especially mercury, were very high, posing risks for both the environment and human health.

To reduce the impact and possible long-term consequences of gold mines on marine coastal habitats, it is necessary to phase out mercury amalgamation for gold extraction, regulate artisanal mining, and enforce environmental laws; moreover, regular PTEs monitoring, possibly including “biomonitors” like this holothurian and ascidian species, must be a priority objective for many countries in the Indo-Pacific regions.

ID: 381 / **Parallel Session 10-1: 3**
Coral Reefs Under a Socio-Economic Perspective

Keywords: trophic ecology, productivity, fisheries, connectivity

Quantifying energy and nutrient fluxes in coral reef food webs

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The movement of energy and nutrients through ecological communities represents the biological ‘pulse’ underpinning ecosystem functioning and services. However, energy and nutrient fluxes are inherently difficult to observe, particularly in high-diversity systems such as coral reefs. We review advances in the quantification of fluxes in coral reef fishes, focusing on four key frameworks: demographic modelling, bioenergetics, micronutrients, and compound-specific stable isotope analysis (CSIA). Each framework can be integrated with underwater surveys, enabling researchers to scale organismal processes to ecosystem properties. This has revealed how small fish support biomass turnover, pelagic subsidies sustain fisheries, and fisheries benefit human health. We now explore opportunities for combining frameworks, for example contrasting ecosystem models with productivity predicted from surveys, and overlaying pelagic isotope samples with large-scale oceanographic data.

ID: 196 / **Parallel Session 10-1: 1**
Coral Reefs Under a Socio-Economic Perspective

Keywords: Coral reefs, Ecosystem services, Community-based conservation, Restoration, Sustainability

Connecting communities to coral reefs: a socio-ecological perspective on coral restoration programs in a remote marine protected area

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There has been a discernible rise in coral restoration initiatives over the past few years, with Indonesia emerging as a global leader. Due to advancements in accessible methodologies, favourable public opinion, and government-backed initiatives, local communities now have more opportunities to participate in coral restoration projects. The purpose of this study is to provide a fundamental assessment of a community's level of knowledge concerning coral restoration activities in a remote marine protected area in Indonesia. The level of involvement in restoration activities, as well as the potential for future strategies based on community needs, were all examined in the primary data through quantitative and qualitative analysis. Knowledge gaps regarding ecological services and perceptions of coral reef quality were also identified, which highlight the growing need for effective communication strategies to raise awareness of climate change-related issues. Direct engagement can be improved through connecting communities with coral reefs and encouraging the next generation of conservationists to develop local stewardship. To engage more community members in local conservation programs it is crucial to address notable issues such as language barriers and identifying socio-cultural approaches. Securing future restoration funds and locating possible restoration sites can be tools to sustain existing and upcoming coral restoration programs. The result of this study highlighted the benefits of community-based coral restoration activities and how to improve overall engagement. To maximize the potential for social-ecological benefits, a long-term strategy supported by strong local stakeholder involvement and participation guided by NGOs and MPA management is essential.

Posters

ID: 113
Coral Reefs Under a Socio-Economic Perspective

Keywords: ecosystem services, functions, scientific value, natural experiment, baselines

How can we conceptualise the scientific value of coral reef systems?

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The valuable ecological functions and services provided by coral reef systems in nature is widely acknowledged: they do things which help other living things survive and flourish (Costanza et al., 2014; Moberg & Folke, 1999). Meanwhile, in the laboratory, many 'model' or 'experimental' organisms are acknowledged to perform valuable roles which help scientists better understand the world (Ankeny & Leonelli, 2020). Coral reef ecosystems perform similar valuable scientific roles, but these are yet to be systematically explored or factored into assessments of their value, despite occasional attempts to do so (Cesar & Beukering, 2004; Gravestock & Sheppard, 2015, p. 261)). Properly accounting for the various ways in which reefs are significant for humans and other organisms requires including scientific value alongside other better studied forms. Here I outline some of the key scientific functions provided by coral reefs, to help incorporate consideration of them into evaluations of reef systems. I focus on three sets of functions that reefs provide: 1. acting as ecological baselines; 2. acting as natural archives; 3. acting as natural laboratories and sites for natural experiments. Whilst simply recognising these functions might not appear novel in itself, here I define, explore and systematise them, connecting them with developments in other disciplines (including environmental economics, philosophy of science, and sustainability science) with a view to better articulating an underappreciated dimension of coral reef environmental valuation.

ID: 340
Coral Reefs Under a Socio-Economic Perspective
Keywords: small-scale fisheries, seafood, nutrition, environmental change

Disentangling key drivers of nutrient concentration in coral reef fish to achieve food and nutrition security

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Fish are a rich source of many micronutrients, including iron, zinc, vitamin A, vitamin B12, fatty acids. These nutrients are essential for humans and contribute to healthy growth and development when consumed as seafood, leading to a growing interest in understanding how reef fish contribute to human diets. Statistical models fitted to published nutrient content data show that nutrient concentrations in marine fish species muscle tissues vary both with phylogeny and with species-level traits such as trophic level, body size, and diet. However, nutritional composition of most coral reef fish species remains sparse and not distributed evenly across the tropics and little is known about how local environmental conditions can affect nutrient content among reef fish species. Here, we aim to investigate potential drivers of the nutritional composition of reef fish species. We specifically assess how (i) environmental conditions such as primary productivity, temperature, and reef habitat; (ii) ecological traits such as trophic position and feeding behaviour and (iii) morpho-anatomical traits such as body size and growth rate can affect nutrient composition of 18 common reef fish species. 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.

Session 11: Beyond Corals and Fishes - Evolution and Biodiversity of Neglected Reef Taxa

Coral reefs, as hyper diverse ecosystems, host thousands of species fulfilling crucial ecological roles and providing essential ecosystem services. This diverse array of organisms ranges from sub-microscopic entities shaping microbial communities to micro- and macroscopic lesser-known invertebrates and algae. This session aims to shed light on the evolutionary pathways and biodiversity of often-overlooked reef taxa, expanding our comprehension beyond the more extensively studied realms of corals and fishes.

Given the unprecedented challenges facing coral reefs due to global change, understanding the complete spectrum of biodiversity within these ecosystems becomes imperative. Focusing on neglected reef taxa, this session seeks to uncover insights capable of informing conservation strategies, influencing policy formulation, and guiding future research endeavours. Contributions exploring the evolution, biodiversity and ecology of these taxa are invited, promoting a more comprehensive perspective on, and understanding of, coral reef ecosystems.

Keywords: invertebrates, algae, plants, fungi, genomics, transcriptomics, systematics, phylogeny, phylogenomics, phylogeography, connectivity, non-indigenous species, cryptic species

Session chairs

Gert Wörheide, Ludwig-Maximilians-Universität München (Germany)

Marc Kochzius, Vrije Universiteit Brussel (Belgium)

Take home message

- Noncoral invertebrates are highly diverse but severally understudied, resulting in an incomplete understanding of a) their functional ecology and b) the services they provide to the coral reef ecosystem and society.
- Because of the large variety of important ecological functions and services they provide, conservation should also more thoroughly consider the vast diversity of non-coral invertebrates.
- Museum collections and especially the type material they house are important resources to anchor species surveys conducted by molecular methods, e.g. species identification, distinction, and phylogeny.

Regular oral presentations

ID: 290 / **Parallel Session 11-1: 3**
Beyond Corals and Fishes - Evolution and Biodiversity of Neglected Reef Taxa

Keywords: Symbiosis, Decapoda, Biodiversity, Community ecology, Habitat degradation

Drivers of temporal dynamics in coral-dwelling gall crab communities on central Red Sea reefs

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Cryptic marine invertebrates, many associated with scleractinian corals, form the hidden majority of coral reef biodiversity. Symbiotic decapods represent a highly abundant group of coral associates, yet their occurrence, distribution and temporal dynamics are understudied. This is particularly evident in coral-dwelling gall crabs (Cryptochiridae), obligate symbionts of scleractinians which inhabit skeletal modifications within their hosts. To address these knowledge gaps, we established 12 permanent belt transects (0.5 by 20 m) at 5 to 9 m depths on four Red Sea reefs. During a baseline survey in September 2022, all potential gall crab host colonies were measured, photographed and examined for dwellings. Results showed significant differences in host community composition between sites, and cryptochirid prevalence rates across all available hosts ranged from 25 %-56%. A total of 514 host colonies have since been resurveyed biannually to investigate temporal dynamics of the cryptochirid community. Considering the short time between sampling efforts, we observed unexpectedly high crab turnover rates, with significant differences among host genera. Finally, a widespread bleaching event in summer 2023 presented a unique opportunity to evaluate how a disturbance event influenced temporal community variations at reef and colony scale, compared to periods without significant disturbances. We found a substantial decline in gall crab abundance at two sites. Turnover increased for some cryptochirid-coral associations but decreased for others, revealing distinct responses to disturbances. Here, we unveil previously unknown rapid temporal dynamics in cryptochirid communities. While bleaching led to high reef-scale extinction rates, it also has the potential to shape colony-scale cryptochirid turnover. Our findings emphasise that cryptochirids are highly vulnerable to host mortality and thus severely threatened by habitat degradation. Moreover, their community dynamics may change significantly amid the rising frequency of bleaching events, underscoring the need to deepen the understanding of coral-associated communities and their ecological function in coral reefs.

ID: 182 / **Parallel Session 11-1: 2**
Beyond Corals and Fishes - Evolution and Biodiversity of Neglected Reef Taxa

Keywords: Marine Ecology, Molecular Biology, Reef Functioning, Cryptobiome, Reef Heterogeneity

Investigating the relationship between reef heterogeneity and the diversity and functioning of cryptobenthic communities over time

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Coral reefs are highly complex ecosystems with diverse habitats and exceptional biodiversity. The majority of reef diversity is comprised of small organisms, generally overlooked that dwell within cryptic spaces in the reef matrix (the reef “cryptobiome”). To study coral reef cryptic communities, Autonomous Reef Monitoring Structures (ARMS) - cubic-like structures of nine stacked PVC plates have been developed and applied globally. We deployed 32 ARMS units in four different habitats within a central Red Sea reef, retrieving 16 units after 7 months and 16 units after 2 years of colonization. The four habitats consisted of two hard-coral areas - one with higher biodiversity and another with lower biodiversity - along with a turf algae-dominated and a coral rubble-dominated site. We investigated the influence of the habitat and its associated benthic community composition features in the colonization patterns of the cryptobiome. We also assessed whether these patterns differ between short-term (pioneer) and long-term (established) colonization. Furthermore, in situ incubations of the ARMS were performed using personalized incubation chambers to investigate the key ecological functions of these communities, such as their role in the nitrogen and carbon cycles, and reef calcification. We found that turf-dominated habitats show a unique signature from a biological and chemical standpoint, that is already visible in pioneer stages and that the loss of hard-corals can shift the functioning of the reef cryptobiome. However, our study also suggests that habitat heterogeneity contributes to the high biodiversity of reef cryptobiome, with different habitats harbouring unique species, highlighting the need to preserve habitat heterogeneity in conservation and restoration efforts. This is the first time the biogeochemical functioning of the cryptobiome is assessed using ARMS, providing a framework to be applied within the ARMS Global Project to better understand the dynamics and roles of this critical biodiversity component of coral reefs.

ID: 375 / Parallel Session 11-1: 4
Beyond Corals and Fishes - Evolution and Biodiversity of Neglected Reef Taxa

Keywords: eutrophication, coral reefs, benthic communities, metabarcoding, Indonesia

Coastal eutrophication transforms shallow micro-benthic reef communities

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Coral reefs are impacted worldwide by coastal eutrophication, which is often translated by a decrease in coral cover and an increase in other organisms, including algal blooms. Additionally, to corals and other macro-benthos, benthic meio- and microfauna communities are affected tremendously; hence, they have been often used as water quality indicators. A question remains: which micro-benthic taxa are best suited as indicators of coastal eutrophication in reef ecosystems? To answer this question, we compared three groups that have been previously declared bioindicators of reef environmental conditions: foraminifera, diatoms and bacteria, from the reef flat and slope of 12 islands in the Spermonde Archipelago (Indonesia) following an in- to offshore turbidity gradient. Insights from sediment DNA metabarcoding (using exact sequence variants) and satellite images showed that the eutrophication variables (total suspended matter and chlorophyll a) and distance to mainland affected the large benthic foraminifera community composition the most (17.5 %), followed by diatoms (14.3 %) and prokaryotes (12.6 %) on the reef flat. Based on the canonical correspondence analysis, this effect dropped by approximately half with increasing water depth on the reef slope, down to a maximum of 30 m. Additionally, key foraminifera and diatom indicator taxa were associated with different levels of eutrophication. The foraminifera *Elphidium* and *Neorotalia* as well as 24 benthic diatom taxa were significantly coupled to highly turbid waters, based on the indicator species analysis. Further away from the coast, the foraminifera *Amphisorus*, *Peneroplis* and *Heterostegina* significantly characterised low turbidity regions together with some diatom species of the genera *Nitzschia*, *Halamphora* and *Triceratium*. In conclusion, large benthic foraminifera translated the local coastal eutrophication more strongly than benthic diatoms and prokaryotes. Our study highlighted the effect of water quality on the community compositions of the three groups, enhancing our understanding of their spatial ecological patterns in reefs.

ID: 704 / Parallel Session 11-2: 2
Beyond Corals and Fishes - Evolution and Biodiversity of Neglected Reef Taxa

Keywords: Crustacea, cryptic species, coral reefs, exosymbiont, conservation genomics

Museomics unveils cryptic diversity and biogeographic patterns in the coral-guard crab, *Trapezia bidentata*

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Found throughout the Indo-Pacific, *Trapezia* crabs are obligate exosymbionts of corals, living between the branches of their hosts where they improve their overall health by removing sediments off coral branches, deterring predators such as *Acanthaster* sea stars, and increasing survival rates of juvenile colonies. Due to their reliance on corals, they are susceptible to changing climates and threatened by habitat destruction. In an effort to clarify the phylogeny and systematics of this genus as well as characterize the genetic connectivity between endangered populations of a widespread *Trapezia* species throughout the Indo-Pacific, we applied a recently developed genome subsampling method and generated thousands of SNPs from degraded museum samples. While previous studies have provided insight into the topology of the *Trapezia* phylogeny, the use of different single-gene markers resulted in variable resolutions while still hinting at cryptic speciation. In contrast, our genome-wide approach was able to clarify the phylogenic relationship of 12 *Trapezia* species collected from museum specimens. Additionally, our in-depth analyses of the widespread species *T. bidentata* revealed that despite their long dispersal ability, some *T. bidentata* populations are genetically very divergent. We identified four genetic clusters within *T. bidentata* suggesting cryptic speciation in the Indian Ocean and Marquesas Islands. Populations of Central and West Pacific, on the other hand, showed clear signs of admixture across a heterogeneous seascape, attributing to a potentially long pelagic dispersal phase, expansive gene pools and high adaptive potential of the species. Overall, the greatest drivers of divergence within *T. bidentata* are currents and historic barriers to dispersal rather than geographic distance. The study presented here highlights how genomic approaches can improve our understanding of species evolution and ecology and provide critical guidance to mitigate future losses and conserve ecosystem functions.

ID: 720 / **Parallel Session 11-2: 3**
Beyond Corals and Fishes - Evolution and Biodiversity of Neglected Reef Taxa

Keywords: Cryptobenthic, Autonomous Reef Monitoring Structures, Anthropogenic, Metabarcoding, Diversity

FutureReef: A global partnership to understand the future of coral reef biodiversity

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Coral reefs harbour >25% of known marine species and provide a range of important ecosystem services which are being lost at an accelerating rate due to multiple local and global stressors. Studies of reef biodiversity have historically focused on large-bodied and conspicuous groups of organisms, such as fishes and corals, and this limited scope severely hinders our ability to predict what future reefs will look like and what ecosystem services they will provide. In a collaboration between 12 project partners, we have combined standardised genetic data from 370 Autonomous Reef Monitoring Structures (ARMS) across 14 countries and 141 reef sites. The aim of the project is to understand how anthropogenic change is altering the vastly understudied coral reef cryptobiome, or the ~90% of reef diversity that lives hidden within the reef matrix. We provide the first global analysis of cryptobenthic reef diversity and yield fundamental insights into how anthropogenic stressors affect cryptic reef communities. We also highlight the potential of using standardised biomonitoring tools and bacterial (16S rRNA) and eukaryotic (COI mtDNA) genetic data to provide simple yet informative metrics of reef health, that go beyond current, and often uninformative, alpha-diversity metrics.

ID: 179 / **Parallel Session 11-1: 1**
Beyond Corals and Fishes - Evolution and Biodiversity of Neglected Reef Taxa

Keywords: Coral-associated fauna, Coral reefs, Cryptic invertebrates, Host-parasite relationships, Host specificity index

Host specificity of coral-associated fauna and its relevance for coral reef biodiversity

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Coral-associated fauna predominantly consists of invertebrates and constitutes an important component of coral reef biodiversity. The symbionts depend on their hosts for food, shelter and substrate. They may act as parasites by feeding on their hosts, by overgrowing their polyps, or by excavating their skeletons. Some of these species partly reside inside their hosts, making them cryptic and easily overlooked in biodiversity surveys. Prior to this study, no quantitative overview was available on these inter-specific relationships. In this study, we address the variation in host ranges and specificity across four large coral-associated taxa and compare them between the Atlantic and Indo-Pacific oceans. These taxa are: coral barnacles (Pyrgomatidae) coral gall crabs (Cryptochiridae), tubeworms (Serpulidae), and date mussels (Lithophaginae). An index of host specificity (S_{TD}) was calculated per symbiont species, based on distinctness in taxonomic host range levels (species, genus, family, etc.). Mean indices were compared among the four associated taxa and the two oceanic coral reef regions. Barnacles were the most host-specific, tubeworms the least. Indo-Pacific associates were approximately 10 times richer in species and two times more host-specific than their Atlantic counterparts. Coral families varied in the number of associates, with some hosting none. This variation could be linked to host traits (coral growth form, maximum host size) and is most probably also a result of the evolutionary history of the interspecific relationships. Potential relations between morphological traits of coral species and hosting potential for coral-associated fauna and its relevance for coral reef biodiversity will be further evaluated.

ID: 463 / **Parallel Session 11-2: 1**
Beyond Corals and Fishes - Evolution and Biodiversity of Neglected Reef Taxa

Keywords: Porifera, Species delimitation, Genomics, Clade-Specific Elements, Target Capture

An alternative hypothesis for species distinction using a probabilistic-genomic approach: coral reef sponges make a case.

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Unambiguous identification of species is indispensable for biodiversity assessment and a better understanding of biological and ecological observations in hyperdiverse ecosystems such as coral reefs. However, methods for reliable species identification in many important coral reef taxa are still deficient. This is especially true for difficult-to-identify marine demosponges of the order Haplosclerida, a species-rich group of sponges widely abundant and ecologically important on tropical coral reefs. Traditional morphological species distinction of the Haplosclerida is challenging because of the general lack and ambiguity of diagnostic morphological traits. Molecular taxonomy is equally difficult due to the insufficient resolution of the single-gene markers at lower taxonomic levels. With the recent development of a clade-specific multilocus probe assay consisting of 20,000 enrichment elements, designed to target 2,956 loci across the Haplosclerida (Van der Sprong et al. 2023), we can access genome-wide information across the order. Using these resources, we now have broadened the applicability of multilocus data for species identification, delimitation, and discovery in coral reef sponges. Using target capture, we recovered between 175 and 1158 loci (mean: 635 ± 245 *SD*) from 134 haplosclerids from the Red Sea. We apply coalescent-based models on the clade-specific elements data to infer species trees of the haplosclerids and reveal potential hidden diversity within several taxa. By taking this probabilistic approach, we provide a quantitative method with a testable alternative species hypothesis. In this vein, genome-wide information can be further leveraged for biodiversity research as it has great potential for rapid species identification and revealing undiscovered diversity in a systematically complex but highly diverse and ecologically important coral reef taxon.

Speed talks

ID: 348 / **Parallel Session 11-2: 9**
Beyond Corals and Fishes - Evolution and Biodiversity of Neglected Reef Taxa

Keywords: Octocorallia, invasive species, systematics

Carijoa riisei: one vs a set of different species

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The octocoral species *Carijoa riisei* Duchassaing and Michelotti 1860 (family Carijoidae) was originally described from St. Thomas, Western Atlantic. After its designation, numerous specimens similar in gross morphology were observed from tropical, sub-tropical and temperate reefs across the Western Atlantic and Indo-Pacific regions. Consequently, the species was considered invasive and detrimental to numerous ecosystems, a hypothesis further exacerbated by more recent widespread overgrowths observed on both natural and artificial structures possibly due to increasing temperatures. Despite this, the possibility of having a set of different species has been poorly explored, and both mitochondrial and nuclear markers have shown limited resolution in species delimitation works. The aim of this study is to assess the existence of one versus multiple species using novel genome reduction methodologies, such as targeted capture of Ultraconserved Elements (UCEs) and other exonic loci. Since this technique has already been proven capable to solve familial- to species-level relationships amongst many taxa, including Anthozoans, we expect higher resolving power than with single-locus markers, which will either corroborate or dispute the invasive status of the species *C. riisei*. Since management actions have been taken against this species in some locations and without a comprehensive taxonomic evaluation of the group, this work is of great importance in order to guide conservation actions.

ID: 442 / **Parallel Session 11-2: 11**
Beyond Corals and Fishes - Evolution and Biodiversity of Neglected Reef Taxa

Keywords: citizen science, nudibranchs, diversity, tropical

Discovering nudibranch diversity in Terengganu, Malaysia through community collaboration approaches

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This research conducted in Malaysia focused on exploring the diversity of nudibranchs, employing utilizing a citizen science approach to further gather comprehensive data on their biology, ecology, and conservation status. Nudibranchs were underrepresented in Malaysia's IUCN Red List, necessitate documentation for effective conservation. Collaborating with virtual citizens, particularly divers using platforms like GoogleForm and media socials, yielded a rich dataset encompassing species details, photographs, and locations. Identifying and documenting 77 species across 13 islands in Terengganu waters, the study revealed a majority in the Cladobranchia suborder (62.5%) and the Doridina suborder (37.5%), with a few falling outside these suborders. Most species were categorized as "Not Evaluated" on the IUCN Red List. Based on the data contributed from the community, the study then further shifted to ground truthing surveyed on selected islands of Terengganu namely Pulau Bidong and Pulau Kapas. From this survey, the study aimed to verify the diversity, size range, and habitat preferences of aeolid and dorid nudibranchs. Pulau Bidong documented 25 species across 11 genera and 7 families, with Phyllidiidae as the dominant family and *Phyllidia elegans* as the most abundant species. Through photoquadrat analyses, unveiled 13 species from 6 genera and 5 families, with Phyllidiidae again dominating and *Phyllidiella pustulosa* as the most abundant species. The study highlighted diverse size ranges, habitat preferences leaning towards algae, coral, and dead coral with algae, and an absence of nudibranch specimens over 60 mm. Collaboration between researchers and citizen scientists played a pivotal role, contributing significantly to nudibranch conservation efforts and expanding scientific knowledge. This research underscores the importance of citizen science in establishing a robust scientific foundation, especially during movement restrictions, and suggests the potential for statistical and modeling analyses to identify marine priority areas and assess future conservation risks for nudibranchs.

ID: 723 / **Parallel Session 11-2: 15**
Beyond Corals and Fishes - Evolution and Biodiversity of Neglected Reef Taxa

Keywords: Co-extinction, cryptobiota, ecological network, invertebrates

Evaluating robustness of a Caribbean coral-symbiont network in a changing climate

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Coral reefs are facing an increasing number of threats, endangering not only coral species, but also the diversity they host and support. In the Caribbean, more than half of the coral species are listed as threatened on the IUCN Red List, but the consequences of the (local) disappearance of a coral species on its obligate symbionts (i.e. associated fauna in this study) have not been previously quantified. To address this gap, we built an ecological network of corals (3.163 colonies) and their symbionts (12.704 individuals) to evaluate its current stability, but also to test its future resilience in case of (local) extinctions. Patterns of associations amongst corals and symbionts were also investigated to identify keystone coral species and vulnerable symbiont species in Caribbean reef systems. We found that some of the network properties appear to confer resilience (i.e. connectance and nestedness), but others are indicative of an already susceptible network (i.e. modularity). We furthermore observed that the removal of threatened corals had as much impact on the symbiont fauna as the random removal of corals, highlighting that the conservation status of corals is not correlated to the symbiont biodiversity they support. This study provides a tool for future conservation actions to evaluate the contribution of individual coral species on the overall diversity of coral-dwelling fauna they support, and identify keystone species in the studied network.

ID: 126 / **Parallel Session 11-2: 4**
Beyond Corals and Fishes - Evolution and Biodiversity of Neglected Reef Taxa

Keywords: ARMS, cryptobiome, biodiversity, Red Sea

A decade of research on Red Sea coral reef associated invertebrates: Autonomous Reef Monitoring Structures unravelling the dynamics and roles of the hidden majority

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Autonomous Reef Monitoring Structures (ARMS) were developed to advance the knowledge on the biodiversity patterns of small organisms inhabiting the reef matrix that, due to their small size, nocturnal habits, and preferred ecological niches, are overlooked during traditional reef surveys. These organisms are part of the reef “cryptobiome” and are estimated to contribute to the majority of the whole reef biodiversity. They play fundamental roles in reef functioning including nitrogen and carbon cycling. However, very little is known about their diversity, community composition and trends in coral reef habitats. Over the last decade, we have assessed the metazoans (eukaryotic) and bacteria (prokaryotic) comprising the Red Sea cryptobiome using ARMS. We have investigated spatial and temporal trends throughout the Red Sea and encompassing the global bleaching event of 2015/2016. The Red Sea cryptobiome was analysed over different spatial scales, namely along the latitudinal gradient of the Red Sea, across the shelf, and even in different benthic habitats within a reef. Investigating changes in the community at different scales, especially smaller ones, is highly relevant considering the variability observed at reef sites. To advance our knowledge on the ecological functioning of the cryptobiome, we conducted in-situ incubations of ARMS (in association with metagenomic analysis) and measured ecosystem processes in both pioneer (seven months of colonization) and mature (two years of colonization) communities. Here, we will provide a summary of the main findings, challenges and future research avenues that span the fields of metabolomics, metaphylogeography, and connectivity, potential marine invasive species, and co-occurrence analyses of reef benthic communities.

ID: 345 / **Parallel Session 11-2: 8**
Beyond Corals and Fishes - Evolution and Biodiversity of Neglected Reef Taxa

Keywords: Sinularia spp., Sclerophytum spp., South China Sea, phylogeography, phylogenetics

Phylogeography of Finger Leather Corals *Sclerophytum* spp. and *Sinularia* spp. in the South China Sea

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The coral reefs in South China Sea (SCS) are crucial components that support its rich marine biodiversity. However, there is a severe lack of data on their population genetics in the Xisha Islands (also known as the Paracels Islands), which is important for effective implementation of conservation efforts to restore the declining reef cover reported in this area. In this study, we identified and examine the population genetics of finger leather corals (*Sclerophytum* spp. and *Sinularia* spp.) at 21 sites in three distinct regions in the SCS (the Xuande Archipelago and the Yongle Archipelago, and Sanya) with the aid of a multilocus DNA barcode (*COIX*, *28S* rDNA, and *mtMutS*). *Sclerophytum* spp. and *Sinularia* spp. in the South China Sea can be grouped into three clades, with two major clades predominantly found in different geological areas. The observed genetic diversification in the two genera is likely due to allopatric speciation and local/ecological adaptations, as gene flow between metapopulations appears to be largely unhindered. We also found limited connectivity between Yongle Archipelago and the other two regions, suggesting it has a relatively lower recovery ability. Overall, this study provides valuable insights into the conditions of coral reefs in the Xisha ecoregion and highlights the need for more phylogeography studies on other species in the area.

ID: 679 / **Parallel Session 11-2: 13**
Beyond Corals and Fishes - Evolution and Biodiversity of Neglected Reef Taxa

Keywords: Symbiotic relationships, sea anemones, crustacean, host, association.

Going further into the symbionts associated to the sea anemone *Telmatactis cricoides* (Duchassaing, 1850) in the Canary Islands.

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Symbiotic relationships are very common in marine ecosystems. Among cnidarians, anemones are considered the group that establishes a wider number of associations, with crustaceans being the most common partners. In the Canary Islands, the giant anemone *Telmatactis cricoides,* a benthic organism of template reefs, has been described in association with many species of crustaceans. The present study examines which species are found associated to the anemone and which factors could influence these associations in the archipelago. To this purpose, field surveys were displayed in different locations of the islands of Tenerife, La Palma, Lanzarote and Fuerteventura, by means of scuba diving in a depth range of 5-30 m, between the years 2021 and 2024. More than ten species were found associated with *T. cricoides*, being the most common the squat anemone shrimp *Thor amboinensis.* Other frequent symbiotic species were the arrow crab *Stenorhynchus lanceolatus* and the cleaner shrimp *Lysmata grabhami*. Additionally, a laboratory experiment with *T. amboinensis* was reproduced in order to test its preference for different potential hosts, and its behaviour when living associated to *T. cricoides*, as an approach to a better understanding of this relationship. The laboratory experiment consisted of host choices trials, where two different hosts were offered at the same moment to the shrimps to verify if there was a preference for any of the three anemones species offered *(Telmatactis cricoides, Anemonia sulcata and Anemonia melanaster).* The shrimps showed no clear preference for any of the anemones offered in the laboratory experiments. *T. amboinensis* appears to be immune to the toxins of the anemone after a long acclimatation period. In conclusion, this study highlights the complexity of symbiotic relationships and the importance of the anemone *T. cricoides* as a species that harbours a great diversity of symbionts.

ID: 673 / **Parallel Session 11-2: 12**
Beyond Corals and Fishes - Evolution and Biodiversity of Neglected Reef Taxa

Keywords: Sessile cryptobiome, Alpha-diversity, Beta-diversity, indicators, artificial reefs

Sessile cryptobenthic communities on Autonomous Reef Monitoring Structures (ARMS): multi-scale spatial patterns and environmental forcing on the outer slopes of Reunion Island's coral reefs.

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While coral reefs occupy less than 1% of the ocean's expanse, they harbour approximately 25% of known marine species. Nevertheless, our understanding of their diversity remains incomplete, in particular that of their cryptobiome. Reef cryptobiome encompasses a myriad of motile and sessile species that live concealed within the crevices of the coral reef matrix. This study focuses on the sessile component of reef cryptobiome. We addressed the following questions: What are the distribution patterns of the diversity of the sessile cryptobenthic communities at different spatial scales? What environmental factors influence their distribution? We deployed 27 passive sampling devices - called Autonomous Reef Monitoring Structures (ARMS) - at 9 sites located on the outer slopes of the coral reefs on the West and South-West coasts of Reunion Island (Indian Ocean). Submerged at 11 meters depth for two years, the retrieved ARMS plates were documented photographically, and the coverage of sessile cryptobenthos was estimated using the point-counting method CPCe. We studied the composition of its sessile communities, comprising taxa such as sponges, ascidians, bryozoans, foraminifers, annelids, or calcareous coralline algae. Pronounced community structuring exists at the intra-ARMS scale, highlighting a strong effect of water flow, light exposure, and sedimentation. Along the island's reef coast, geographic distance positively correlated with community dissimilarity (expressed as beta diversity). Notably, site orientation along the coast significantly affected community composition, potentially due to contrasted hydrodynamic conditions. Several morpho-species, representing taxa such as ascidians, bryozoans, and cirripeds, emerged as ecological indicators of different hydrodynamic settings. These findings confirm the efficiency of ARMS plates photo-analysis to assess variations within sessile cryptobenthic communities. These outcomes contribute to a better understanding of coral reef biodiversity, providing valuable insights for the effective management and conservation of these essential ecosystems.

ID: 685 / **Parallel Session 11-2: 14**
Beyond Corals and Fishes - Evolution and Biodiversity of Neglected Reef Taxa

Keywords: connectivity, coral reef, Indonesia, Western Indian Ocean

Zooxanthellate genetic diversity within the sea anemone *Heteractis magnifica* in the Indo-West Pacific

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The symbiotic association between hosting organisms and Symbiodiniaceae (zooxanthellae) is crucial for the overall health and survival of these hosts. This relationship is increasingly compromised by rising sea surface temperatures, resulting in bleaching events. The specific Symbiodiniaceae symbiont is often considered a measure of environmental stress tolerance. However, species and genetic variation within symbiont species are often ignored. Understanding the diversity, associations, and population genetics of Symbiodiniaceae within their hosts is essential for assessing the hosts' capacity to cope with climate change.

In this study, the diversity of Symbiodiniaceae species was investigated within the clownfish-hosting sea anemone *Heteractis magnifica* throughout the Indo-West Pacific. The nuclear marker 28S rDNA was used to identify Symbiodiniaceae species in 316 host anemones from 37 locations. All were identified as *Cladocopium*, with *C. thermophilum* and *C. goreaui* occurring the most. A third species, *C. infistulum*, was found for the first time in the host species *H. magnifica*. *Cladocopium* species exhibit high ecological diversity and wide distribution patterns.

Population genetic analysis revealed a strong population structure ($\Phi = 0.42$; $p < 0.001$) and overall differentiation between subpopulations of *C. thermophilum* in East Africa and the Indo-Malay Archipelago ($\Phi = 0.39$; $p = 0.03$). Limited gene flow and high levels of differentiation suggest the existence of a genetic break between East Africa and the Indo-Malay Archipelago. Likewise, *C. goreaui* exhibited a strong population structure ($\Phi = 0.22$; $p < 0.001$), but a clear genetic break between East Africa and the Indo-Malay Archipelago was not statistically supported. Further research is needed to fully comprehend their evolutionary and population dynamics in the Indo-Pacific.

ID: 146 / **Parallel Session 11-2: 18**
Beyond Corals and Fishes - Evolution and Biodiversity of Neglected Reef Taxa

Keywords: benthic communities, reef resilience, taxonomic diversity, urbanized reefs

Covariations of coral, macroalgal, macroinvertebrate and fish communities in an urbanised tropical reef environment.

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Coral reefs, known for their rich marine biodiversity and crucial ecosystem services, are increasingly threatened by human activities and climate-related challenges globally. This study explores the variations in species and communities within coral reef ecosystems, providing valuable insights into the health and dynamics of these marine environments. We conducted an in-depth analysis of coral reefs in urban coastal waters, focusing on hard corals, macroalgae, macroinvertebrates, and fish across multiple sites over a four-year period. Notably, despite their close proximity, the sites exhibited significant differences in species composition and benthic cover. However, hard coral cover and community structure demonstrated remarkable stability over time, indicating local factors may be key to coral resilience. The site with the greatest distance from urban influence showed the highest abundance and diversity of hard corals, macroinvertebrates, and fish. In contrast, the site most affected by land reclamation and landfill activities displayed the lowest diversity. Fish populations were closely linked to the health of hard corals and macroalgae, emphasizing their critical role in maintaining reef ecosystems. However, macroinvertebrates showed limited associations with other reef communities. The study also found that species diversity is significantly impacted by the interaction between species type and the physical complexity of the reef, measured by a rugosity index. While hard coral diversity increases with structural complexity, the diversity of other species like macroalgae, macroinvertebrates, and fish decreases, which may mask the impacts on reef communities. Our results underscore the importance of comprehensive, multi-species monitoring for the effective understanding and conservation of coral reefs in urban coastal areas, which are increasingly pivotal concerns in our era.

ID: 235 / **Parallel Session 11-2: 5**
Beyond Corals and Fishes - Evolution and Biodiversity of Neglected Reef Taxa

Keywords: ARMS, DNA barcoding, anthropogenic pressure

Unravelling the distribution patterns of red sea cryptobenthic decapods in response to environmental variabilities

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High biodiversity level is fundamental to guarantee a healthy ecosystem. Cryptobenthic fauna has a crucial role in maintaining ecosystem functioning and its comprehensive understanding is fundamental to effective conservation strategies and reef preservation. However, information about it remains limited worldwide. To address this gap, we deployed Autonomous Reef Monitoring Structure (ARMS) in three locations in the central coast of Saudi Arabian Red Sea, during two consecutive periods of two years: from 2019 to 2021, and from 2021 to 2023. These sites were strategically selected to investigate variations in cryptobenthic fauna in response to diverse human activities and development pressure. The large mobile organisms (>2mm) retrieved with the ARMS, with a focus on decapods (infraorder Brachyura and families Galatheidae and Porcellanidae from infraorder Anomura), were analysed using a combination of morphological and DNA barcoding approaches. Preliminary findings based on morphological identification of organisms revealed lower but stable alpha diversity in the region with the lowest anthropogenic pressure between the two periods, when compared to the other two regions. While, between 2021 and 2023, we observed a significant decrease in the number of species in the region under the highest pressure and, increase was observed in the region experiencing intermediate disturbance levels. It is expected that DNA barcoding will provide higher resolution on diversity patterns by discriminating between closely related (and often cryptic) species. Whilst different diversity patterns may be indicative of potential correlations with different levels of urbanization along the coast, drawing more precise conclusions requires the consideration of additional detailed ecological parameters and additional time periods to confirm this trend. This study provides valuable insights into the poorly understood cryptobenthic fauna of the Red Sea, emphasizing the importance of monitoring and assessing marine environments for effective conservation and sustainable management.

ID: 354 / **Parallel Session 11-2: 10**
Beyond Corals and Fishes - Evolution and Biodiversity of Neglected Reef Taxa

Keywords: Stenothoidae, Key to species, Antipathella wollastoni, epifauna, Marine animal forests.

"Hidden" biodiversity: a new amphipod genus dominates epifauna in association with a mesophotic black coral forest

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Black corals are important components of mesophotic and deep-water marine habitats. Their presence at great depths (e.g., 50 to 200 m) makes accessibility difficult, limiting our understanding of the associated biodiversity. Amphipods dominate vagile epifauna in marine habitats around the world, fulfilling important ecosystem functions. However, there are no studies on amphipods exclusively associated with black corals, including relationships between their ecological patterns (e.g., abundances) and the size of coral colonies. We investigated the epifaunal composition and abundance associated with black coral colonies of *Antipathella wollastoni* in the subtropical eastern Atlantic Ocean. In total, 1,736 epifaunal individuals were identified, of which 1,706 (98.27 %) were amphipods, belonging to 6 taxa. We identified and described a new amphipod genus and species within the Stenothoidae family, *Wollastenothoe minuta* gen. nov., sp. nov., which outnumbered the amphipod assemblage (86.15 %) and provided a complete taxonomic key of Stenothoidae family including this new finding. For the first time, the association between an amphipod species and a black coral was described, including a strong correlation between coral colony size and amphipod abundances. This study demonstrates that epifauna associated with mesophotic black corals remains largely undescribed.

ID: 276 / **Parallel Session 11-2: 7**
Beyond Corals and Fishes - Evolution and Biodiversity of Neglected Reef Taxa

Keywords: biodiversity, ARMS, non-indigenous species, community structure

Autonomous Reef Monitoring Structures (ARMS) reveal contrasting benthic community structure and prevalence of non-indigenous species in port areas relative to natural sites in the Cape Verde islands

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Biodiversity is vital for the processes that support all life on Earth, including humans. However, there are still parts of the oceans where biodiversity is poorly quantified. Coral-associated communities of the Tropical Eastern Atlantic are particularly understudied, but are nevertheless recognized as a marine biodiversity hotspot. While recent work has led to the discovery of numerous new species in Cape Verde, many benthic invertebrate phyla continue to be poorly studied, especially among cryptic taxa (e.g. ascidians, bryozoans, sponges). A first objective of this study was to examine cryptic biodiversity associated with coral communities in Cape Verde.

A second objective of the study is to examine how human activities affect benthic biodiversity. Ports are subject to intense human activity leading to highly altered environments. Cape Verde receives a high influx of international maritime traffic, including commercial and leisure vessels, which can transport non-indigenous species (NIS). Once established, NIS can spread from ports to natural sites, potentially displacing native fauna. Cryptic biodiversity was examined in both ports and natural sites using ARMS (Autonomous Reef Monitoring Structures) to determine whether the richness, diversity and prevalence of native species and NIS differed in these two marine habitats.

Benthic biodiversity was assessed in two ports, one marina and two natural sites on the islands of Santo Antão and São Vicente. At each site, three replicate structures were deployed for 9 months. Upon retrieval, mobile and sessile fauna were collected for taxonomic identification, metabarcoding and photo quadrat analysis (% cover). Temperature loggers were deployed on all structures, and sediment was collected adjacent to each ARMS in order to measure heavy metal concentrations. Ports and natural communities were compared in order to evaluate the environmental factors (including pollutants) and species interactions that best explained the differences among communities, with a particular focus on NIS.

ID: 777 / **Parallel Session 11-2: 17**
Beyond Corals and Fishes - Evolution and Biodiversity of Neglected Reef Taxa

Keywords: microbial sharing, connectivity, reciprocal transplant, microbiomes

Exploring *in situ* microbial sharing dynamics in urchin-coral symbiosis

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Coral microbial communities are essential for coral health and survival. However, the factors that determine microbial community structure, including dispersal and transmission among coral colonies, are poorly understood. Corals host a highly diverse community of marine fauna that may play an important role in determining coral microbiome structuring and dispersal. Since over half of coral-associated invertebrates are obligate coral dwellers, microbial sharing among corals by their macrosymbionts may be achieved through multiple microbial transmissions and persistent interaction with the coral host. To gain more insights into the complex microbial relationship among macrosymbionts and corals, we conducted a reciprocal transplant experiment using urchins *Enchinometra viridis* and *Agaricia tenuifolia* corals to explore their microbial dynamics *in situ*. Specifically, we utilized 16S amplicon sequencing to examine the similarities and alterations of bacterial composition and diversity for the urchin gut and coral surface tissue before and after 42 days of isolation in exclusion cages in the field. We hypothesize that *E.viridis* and *A. tenuifolia* microbiomes will be significantly different in composition and diversity across geographic locations that historically differed in environmental conditions. We also anticipate that bacterial diversity and composition among urchins and corals from separate habitats will show signs of bottom-up (coral to urchin) or top-down (urchin to coral) influence in bacterial transmission. Unravelling the intricate pathways of microbial transmission among corals and mobile macrosymbionts is significant, as it further unveils the intricate dynamics shaping coral microbiomes. This study not only sheds light on how macrosymbionts from differing environments can potentially change coral microbial communities, but underscores the potential for beneficial microbial exchange, impacting coral health and resilience in a changing environment.

ID: 740 / **Parallel Session 11-2: 16**
Beyond Corals and Fishes - Evolution and Biodiversity of Neglected Reef Taxa

Keywords: phylogenetics, evolution, symbiosis, functional anatomy, cytological morphology

Integrating divergent character sets in Zoanthidea systematics

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Zoanthidean cnidarians are soft-bodied polyps occurring in all benthic habitats from intertidal to deep sea and tropics to poles and are symbiotic with at least six invertebrate phyla including Porifera, Cnidaria, Arthropoda, Annelida, Echinodermata, and Mollusca. In the Caribbean they dominate coral reef crests and shallow bays and form symbioses with ~100 species of reef sponges, some with nearly 100% prevalence. Although they are the third most speciose order of hexacorallians behind Actinaria and Scleractinia, they are relatively neglected by any measure. Systematics research on zoanthideans was resuscitated by the application of molecular phylogenetics during the previous two decades and its examination of the evolution of symbiosis, functional anatomy, cytological morphology, and bathymetric and geographic distributions. Resulting revisions and analyses demonstrate that the conceptualization of character traits and their states for more than a century were largely uninformative of evolution. Emerging patterns indicate phylogenetically structured interacting functional characters responsive to their ecological and symbiotic circumstances. Integration of these divergent character sets into systematics improves our ability to correctly identify specimens (even in the absence of some characters) and expands our understanding of ecosystem functional roles of zoanthidean taxa. As climate change continues to degrade scleractinian prevalence and diversity, zoanthideans (along with sponges and gorgonians) will play increasingly important roles in reef ecosystems.

ID: 274 / **Parallel Session 11-2: 6**
Beyond Corals and Fishes - Evolution and Biodiversity of Neglected Reef Taxa

Keywords: community structure, next-generation sequencing, biomonitoring

Spatiotemporal monitoring of Singapore's urban coastal biodiversity using environmental DNA metabarcoding

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Environmental DNA (eDNA) comprises genetic material collected from the environment, including fragments shed from macroorganisms. Increasingly, eDNA is used as an indirect marker for biodiversity monitoring, with each sample providing a snapshot of targeted groups of organisms at a single time point. Furthermore, eDNA can help characterise species presence and community composition at taxonomic resolution and spatial coverage that often exceed those achievable from visual observations. To characterise an ecological community, it is critical to understand shifts in species composition through time to potentially differentiate resident from transient species in the studied habitats. In this study, we employed eDNA approaches to assess α- and β-diversity patterns spatially and temporally over a year across different habitat types in Singapore. Primarily, we used a metabarcoding approach, amplifying cytochrome oxidase subunit I (COI) for invertebrates and 16S rRNA for vertebrates, finding that regardless of marker used, α- and β-diversity measures varied between sites and sampling times. COI α-diversity decreased over time, while 16S α-diversity increased over time at most sites. Β-diversity was distinct between sites for both the COI and 16S assays, and were mostly distinct across time. These results provide insights into the changes in diversity and community composition, revealing the different diversity temporal patterns detected by distinct markers. Importantly, we suggest more mid- to long-term surveys to elucidate the community of resident species. Recognising the strengths and limitations of eDNA metabarcoding will help ensure that biodiversity monitoring based on temporal sampling at multiple sites will be useful for ecosystem conservation and management.

Posters

ID: 275
Beyond Corals and Fishes - Evolution and Biodiversity of Neglected Reef Taxa

Keywords: Coral rubble, community ecology, degraded habitats, benthic invertebrates

Drivers of benthic invertebrate community structure in degraded habitats on tropical coral reefs

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Coral rubble is a naturally occurring habitat on tropical coral reefs, formed by the physical destruction of hard corals through hydrodynamic action or bioerosion. Despite its seemingly barren and featureless appearance, coral rubble forms complex microhabitats that can host a great density and diversity of life including microbes and biofilms, sessile and encrusting taxa, and motile cryptobenthic fauna and fishes. Motile cryptic fauna, including crustaceans, annelids, and molluscs, comprise the highest density and diversity of animals directly associated with coral reef substrates. Their diversity and abundance enable them to perform a wide range of functional roles including scavenging, predation, bioturbation, and parasitism. However, one of their more influential roles is arguably as a significant basal energetic resource to higher level consumers.

Ongoing coral reef degradation caused by local and climatic factors have resulted in coral rubble becoming an increasingly prevalent bottom habitat on reefs globally. As such, there is critical need to determine whether increasing degraded habitats, like coral rubble, may support reef trophodynamics through enhanced biodiversity and resource availability from the bottom-up. In this study, we aim to understand what factors influence cryptic fauna bioavailability in coral rubble habitats. We examine naturally derived coral rubble habitats across Palmyra Atoll, an uninhabited remote atoll in the Central Pacific, and use distance-based linear modelling to determine the effects of micro-scale habitat factors on cryptic fauna community composition, density, and biomass.

ID: 501
Beyond Corals and Fishes - Evolution and Biodiversity of Neglected Reef Taxa

Keywords: crinoidea, symbiotic community, commensalism

On diversity of myzostomids (annelids associated with feather stars) from South China sea

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Myzostomida – small symbiotic polychaetes residing on feather stars from South China sea have been studied. We discovered a new species and several other species recorded for the first time in Chinese coastal waters. Low value of overlap with the seven previously known Myzostomida species from Chinese waters highlights vast potential points of interest and significant gaps in understanding fauna in South China Sea. Some specimens were sampled for the first time from shallow waters of Hainan Island, situated at the ecological confluence of the China-Japan subtropical subregion and the Indo-Malaysian tropical subregion within the Indo-West Pacific Warm-water Biotic Region. Present study clarifies current geographic range of some myzostomids, which might be helpful in the context of recent spreading of some warm-water marine species northward.

ID: 475
Beyond Corals and Fishes - Evolution and Biodiversity of Neglected Reef Taxa

Keywords: soft coral, gorgonian, Indian Ocean, DNA barcoding, ultraconserved elements

Unique octocoral communities of Oman

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The waters of the Arabian Peninsula are variable, understudied, and provide a glimpse into what future marine environments might look like as climates change. A diversity of habitat types exist: from warm waters in the Gulf of Oman to areas in the southwest that receive seasonal upwelling. Oman's Dhofar region presents a particularly unique environment, with an unexpectedly low pH and a mix of kelp beds and coral communities. Moreover, the Arabian peninsula's coral reefs have been isolated from the surrounding areas of the Indian Ocean, leading to high levels of endemism of marine organisms. Octocorals, which include soft corals and sea fans, are resilient and ecologically important organisms that dominate Indo-Pacific reefs and are among the taxa that have not been previously studied and analysed in depth. The aim of this study is to assess the biodiversity and biogeography of octocorals around Oman. We surveyed five geographical regions that spanned from the Gulf of Oman to the southernmost Dhofar area. Octocoral diversity was assessed with DNA barcoding of the mutS and 28S genes and target-enrichment of ultraconserved elements and exons (UCEs). We found 97 unique operational taxonomic units, used as proxies for species, that belonged to 42 genera and 24 families, of which at least two genera and more than 12 species are new to science. Overall, strong differences in biodiversity between the studied regions were noted, with the highest levels of biodiversity and endemicity in the Dhofar region. This is in alignment with previously published studies highlighting the role of environmental factors in shaping biodiversity along the coast of Oman.

ID: 687
Beyond Corals and Fishes - Evolution and Biodiversity of Neglected Reef Taxa

Keywords: sea turtles, climate change, sex ratio

Will hawksbill sea turtles, *Eretmochelys imbricata*, exist in the next century: A worldwide meta-analysis of temperature-dependent sex determination

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The hawksbill sea turtle, *Eretmochelys imbricata*, plays an important role in coral reef ecosystems, controlling the growth of sponges on reef surfaces but following centuries of exploitation, global stocks have been drastically depleted. Moreover, their nesting distribution is tightly confined to tropical latitudes and their shallow nest depth makes their nests vulnerable to ambient temperature fluctuation. This is particularly detrimental to sea turtles, which require a narrow thermal range for successful incubation and exhibit temperature-dependent sex determination where fluctuations in nest temperature can affect the sexual demographics of the clutch. Climatic warming could further decrease global stocks by producing a demographic imbalance in the population or incubation temperatures exceeding lethal maximums. This study combined data from in situ hawksbill nests and constant lab incubations for a global comparison of nest temperature effects to determine the susceptibility of this species to climate change. We estimated the thermal reaction norm of embryo growth for five rookeries, from three different regional management units (RMUs). For four of the five rookeries analysed, we observe an acceleration in embryo growth at higher temperatures, even those exceeding 34°C implying this species may be resilient to temporarily elevated temperatures. We observed a clustering of thermal reaction norm of embryo growth by geographic region, with sites within the Atlantic RMU clustering together, we attributed this to similarities from close genetic proximity. We validate the first model to predict the sex ratio, taking into account temperature fluctuations during incubation, reflecting in situ conditions. Our results show the first assessment of regional adaptation in the face of anthropogenic climate change.

Session 12: The Ocean Decade: The Science We Need for the Coral Reefs We Want

This session invites new and innovative ideas of coral reef science, from individual projects to national and multinational initiatives, that address the aims of the United Nations Decade of Ocean Science for Sustainable Development (2021-2030, www.oceandecade.org).

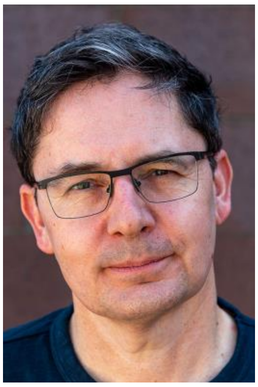
To enable the "coral reefs we want" (clean, healthy and resilient, productive, predicted, safe, accessible, inspiring and engaging) under ongoing and future climate change, next to reducing fossil fuel emissions immediately, we must complement existing approaches with transformative research, pushing new boundaries to achieve step-changes in our understanding of challenges and solutions, and increasing predictive capacity for complex systems. According to the Ocean Decade Network, it is critical to deliver on the following ten challenges: (1) understand and beat marine pollution; (2) protect and restore ecosystems and biodiversity; (3) sustainably feed the global population; (4) develop a sustainable and equitable ocean economy; (5) unlock ocean based solutions to climate change; (6) increase community resilience to ocean hazards; (7) expand the global ocean observing system; (8) create a digital representation of the ocean; (9) skills, knowledge and technology for all; (10) change humanity's relationship with the ocean.

In this session, we are looking for new conceptual and methodological approaches and solutions at various scales in time and space that transcend disciplinary boundaries to deliver on one or more of these challenges, with a focus on coral reef science. The session aims to explore mid to long-term scientific advances, so preliminary ideas and results are encouraged.

Keywords: Mid- and long-term perspectives in science development

Session chairs

Sally Keith, Lancaster University (United Kingdom)



Thomas Felis, MARUM/University of Bremen (Germany)

Take home message

- …is cross-scale
- …breaks down disciplinary silos
- …is inclusive
- invites diversity of thought and approach
- not "owned" by any one group or person

Regular oral presentations

ID: 613 / **Parallel Session 12-1: 4**
The Ocean Decade: The Science We Need for the Coral Reefs We Want
Keywords: interventions, climate change, bleaching, assisted migration, assisted gene flow

Beyond borders: The urgent need to share genetic resources across national boundaries and over species biogeographic ranges to maximize reef coral survival in an era of climate change

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The persistence of coral reefs in shallow tropical seas is under threat from climate change, whose effects are most obvious during sporadic periods of prolonged high temperature stress, resulting in catastrophic episodes of bleaching and mortality. In the Caribbean, the summer heatwave of 2023 exemplified the sudden nature of these events and highlighted the need for a comprehensive long-term strategic plan to explicitly manage for warming temperatures and progressively worse heatwaves. Such plans must include the development, testing, and implementation of novel approaches that are outside of historical practice and current regulatory frameworks. One such approach involves sourcing corals (and/or holobiont partners) from warmer sites that span species biogeographic ranges and cross-national management jurisdictions, and introducing this genetic diversity to cooler sites via translocation and/or breeding. Such assisted gene flow approaches have the dual value of allowing heat-tolerant corals to be used to build climate resilience in cooler areas, while also rescuing them from their current warm locations where they remain under threat from even more stressful conditions. The potential benefits of this approach, and the broader challenges, are perhaps no better exemplified than in Florida and the wider Caribbean, where both the need and the opportunity exist to begin these efforts, but are challenged by regulatory frameworks, diverse national stakeholder interests, and funding constraints. Overcoming these obstacles and pooling genetic resources will require extensive intergovernmental cooperation, novel policy developments (e.g., a restoration CITES exemption), and compensatory mechanisms to encourage the participation of nation states in the warmest areas. Such policy frameworks will not only facilitate the (relatively conservative) objective of sharing genetic resources internationally to help buy time, but will also build the needed constituency for the additional next-generation interventions that may be needed in the coming years if further mitigation is required.

ID: 695 / **Parallel Session 12-1: 5**
The Ocean Decade: The Science We Need for the Coral Reefs We Want
Keywords: coral reefs, adaptation, climate change

Adaptive reefs, adaptive pathways for fishing communities, and gender: towards equitable and (bio)diverse climate change mitigation

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Arguably, adaptation is key to surviving climate change – for people and species alike. Coral reef ecosystems and the people depending on their ecosystem services must adapt to achieve long-term sustainable balance between human development and ecosystem persistence. However, questions about conceptualising the wicked problem of adaptation remain, particularly where we need to consider the adaptation of multiple building blocks across ecosystems and societies. We will first define adaptation of coral reefs across scales, exploring concepts and metrics that upscale from genes to the broader ecosystem. With data ranging from genomic diversity of two coral species to ecosystem-wide complexity measures identified from space in Indonesia, we show the predictive capacity of remotely sensed metrics for identifying adaptive reefs. We will then apply a similar lens to Indonesian and Philippines coastal villages to explore the climate change vulnerabilities and potential for adaptation for different genders and identities within these fishing communities. We will show how adaptation potential varies with gendered roles in the fishery, identify key drivers of both climate change vulnerability and adaptation to declining reef integrity, and how these relationships differ between locations. Finally, do fishing communities interact with adaptive reefs, and if so, how? Climate change vulnerability of reef biota and reef fishers intersect where heavy dependence on reef resources and reef degradation reinforce a deadly spiral of decline. We will consider how we can combine evolutionary, ecological, social, and gender-specific information to understand how this socio-ecological system works, or perhaps, to be even more perplexed. Predicting adaptative capacity at large scales and low cost and co-developing pathways to overcome the vulnerability that comes from declining reefs are clear first steps that have wide policy implications. We will conclude with a summary of approaches to integrate such new knowledge into policy and decision making for future sustainable fisheries.

ID: 835 / **Parallel Session 12-1: 7**
The Ocean Decade: The Science We Need for the Coral Reefs We Want

Keywords: Passive acoustic monitoring, Machine learning, coral restoration, Seychelles

Listening to the reef: assessing coral restoration efficacy using soundscape data and machine learning in the Cousin Island Special Reserve, Seychelles.

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Present threats to coral reefs require interventions such as coral restoration; measuring restoration effectiveness with Passive Acoustic Monitoring (PAM) may provide a comprehensive ecological assessment. Coral restoration via asexual fragmentation and propagation has been reported to improve the likelihood of survival of reef organisms in places where coral losses have already been observed. Monitoring of restoration efforts is imperative but relies on extensive manpower and expertise, and measurements of success of restoration are often limited to metrics that neglect to provide comprehensive assessment of reef health. In this study, we assess the potential for passive acoustic monitoring to complement traditional visual survey methods in measuring restoration success within the reef surrounding the Cousin Island Special Reserve in the Seychelles. Here, detrimental bleaching events in 1998 and 2016 severely degraded the area, and in consequence since 2010, active restoration has taken place. Soundscapes were recorded at four sites with a range of coral cover, namely the restoration donor and out-planting sites, and healthy and degraded control sites. Soundscape data were collected in November-December 2023 using HydroMoths. Each sampling period lasted twenty-four hours to include diurnal variation, and each site was sampled four times to balance recordings over one full lunar cycle. Data are analysed both manually for phonic richness, allowing the identification of individual biotic sounds, and with machine learning to differentiate between soundscapes in their entirety, together providing insight into the behavioural differences of reef organisms. For the machine learning component, we extracted features from recordings using a pretrained neural network and then used unsupervised clusters to assign recordings into similar groups. These results provide an indication of the ability of passive acoustic monitoring to detect more subtle differences between sites with low coral cover, complementing current ecological assessments.

ID: 344 / **Parallel Session 12-1: 2**
The Ocean Decade: The Science We Need for the Coral Reefs We Want

Keywords: climate change, larval competency, larval survival, meta-analysis, trait-based ecology

Predicting demography from species traits: larval development time and its sensitivity to warming depend on egg size in corals

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In the absence of demographic data, readily measurable life history traits, like egg size, can be used to predict how vital rates vary across species, facilitating modeling and analysis of high-diversity assemblages. We assessed the larval survival and competency dynamics of four previously unstudied coral species at current and warmed temperatures, and combined it with data for three other species to assess how well egg size predicts mortality and the minimum time to competency, both determinants of larval dispersal. Minimum time to competency increased with egg size; moreover, warming-induced reductions in time to competency were greater for species with larger eggs. In contrast, morality rate and its response to warming were both independent of egg size. These findings show how assemblage-level responses to environmental change can be projected in diverse communities, and indicate how warming-induced changes in larval biology may reshape reef coral metacommunities.

ID: 100 / **Parallel Session 12-1: 1**
The Ocean Decade: The Science We Need for the Coral Reefs We Want

Keywords: Sea Surface Temperature, Coral Bleaching, Remote Sensing

Inconsistent coral bleaching risk indicators between temperature data sources

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Coral reefs are facing severe threats and are at risk of accelerated decline due to climate change-induced changes in their environment. Ongoing efforts to understand the mechanisms of coral response to warming rely on multiple sources of temperature data. Yet, it remains uncertain whether the Sea Surface Temperature (SST) data used for coral reef studies are consistent among different data products, despite potential implications for conservation. A better understanding of the consistency among the different SST data applied to coral reefs may facilitate the fusion of data into a standard product. This will improve monitoring and understanding of the impact of global warming on coral reefs. Four types of SST data across North-Western and South-Western Australia are compared to assess their differences and ability to observe high thermal stress during historical coral bleaching events. The four SST data sources included those derived from Global Circulation Models, NOAA CoralTemp SST product, ESA CCI SST product, and coral core derived SST. Coral bleaching risk indicators, Degree Heating Week (DHW), and Degree Heating Month (DHM) were calculated using these sources and compared for consistency. DHW and DHM were inconsistent among data sets and did not accurately reflect high thermal stress metrics during moderate and severe bleaching events. Some reefs did not experience bleaching in spite of high DHWs and DHMs, suggesting a mismatch in data scales, or perhaps other oceanographic factors and coral adaptation. By exploring the differences and similarities among these four data sources, this study highlights the need to compare existing indicators of thermal stress from different data sets.

ID: 767 / **Parallel Session 12-1: 6**
The Ocean Decade: The Science We Need for the Coral Reefs We Want

Keywords: Shifting baseline syndrome, historic changes, Caribbean, type I error

A process-based version of Shifting Baselines Syndrome in reef ecological studies: What happens when ecosystem state decouples from historically important drivers of abundance?

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Coral reef ecology relies on ecological theory to test existing and new ideas about the factors underlying reef functioning. Such theories are often derived from past studies whose findings might no longer hold true due to new ecological settings that have arisen in the wake of powerful and diverse anthropogenically-driven changes. Recent changes on Caribbean reefs have occurred rom so many varied stressors, that the ecological processes once understood to be the most important structuring mechanisms (such as herbivory and point-source pollution) are no longer predictive of the organismal abundance and composition of shallow reef communities. Using long-term (~40 years) and high-resolution spatial data (130 sites) from Curacaoan reef communities, we show that the ability to identify the most powerful structuring processes on Caribbean reefs (e.g., coastal development, pollution, coral recruitment, fishing) often depends on the decade in which such studies were conducted. For example, in Curacao, 40-years ago, the degree of coastal development was a strong predictor of coral cover on adjacent reefs. In contrast, spatial patterns of coastal development no longer predict present day coral cover. Thus, using present day surveys to test the relative importance of historic drivers of reef composition can lead to the false conclusion that they are not, or were never, ecologically important. This will result in their lessened consideration in management or conservation frameworks, often in favour of “trendier” candidates. We posit that a process-based version of the Shifting Baselines Syndrome therefore exists, in which historically important factors are neglected or forgotten. Failure to recognize the recent decoupling of ecological drivers and resulting patterns will result in a lessened ability to understand present-day patterns in reef community composition and a failure to recognize the importance of the ecological processes that actually served as the most important historic drivers of reef growth or decline.

ID: 447 / **Parallel Session 12-1: 3**
The Ocean Decade: The Science We Need for the Coral Reefs We Want

Keywords: coral reef, climate change, capacity building, restoration, conservation

Doing good better: adapting research-based coral conservation and restoration to local community stake holding

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Reef survival requires a global dedicated effort. Although science-informed approaches are shown to improve coral restoration outcomes, R&D-guided reef restoration fails to be implemented at scale. This is due to technological hurdles, cost, and missing local capacity-building. Likewise, already available measures, such as fisheries management, significantly improve conservation outcomes, but fail to be implemented due to lack of control and alternative livelihoods for fishermen. Here we propose to adapt current R&D-guided conservation and restoration measures to local stake holding by streamlining overly technical procedures, capacity-building at the community level, and the creation of alternative sources of income that support reef recovery. Gili Asahan is a small island in the strait of Lombok. Like many reefs in this area, corals have experienced recurrent bleaching, and reefs are harvested by illegal fishing practices. Several years ago, the local people started to take active ownership and implement coral conservation and restoration practices. We describe our efforts to assist this endeavour and the process to build a reference framework to implement a long-term sustainable conservation and restoration agenda into socio-economic livelihood. Our aim is to establish a scalable local community-owned and -driven reef conservation and restoration framework that can readily be implemented by other local stakeholders. The path to global reef survival relies on parallelizing local efforts at scale, not the top-down driven focus efforts of large-scale organizations that operate in few reefs and even fewer countries. Doing this requires empowerment of local communities to apply the science we know works by adapting overly complex and costly procedures to methods executable by reef practitioners and government agencies alike and the provision of alternate livelihoods embedded in reef conservation.

Speed talks

ID: 109 / **Parallel Session 12-1: 8**
The Ocean Decade: The Science We Need for the Coral Reefs We Want

Keywords: genomes, taxonomy, conservation, coral reefs

Are currently available coral genomes correctly identified? A case study from the genus *Acropora*

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Genomes are a useful resource for research in many areas of science. However, a genome's utility depends in large part on the organism they represent having been correctly identified. Recent and ongoing changes in the taxonomy and systematics of many groups suggest that at least some genomes are likely to have been misidentified. Here, we assess the accuracy of species names of 22 genomes of the staghorn coral genus *Acropora* (Family Acroporidae) using multiple lines of evidence, including a phylogeny based on targeted capture of ultraconserved elements and exonic loci and comparisons with the type material. Of the 22 genomes examined 18 are almost certainly incorrectly identified, 2 are possibly correct and only 2 are almost certainly correct. Our assessment of the taxonomic status of these genomes is that 9 represent undescribed species, 8 are junior synonyms and only 5 represent currently accepted species. We argue that these incorrect identifications are not the fault of the researchers that produced these genomes, rather they are a damning indictment on the current taxonomy of genus *Acropora*. Nonetheless, we argue that competent taxonomists, familiar with modern integrated approaches, need to be included when choosing organisms for sequencing to ensure maximum benefits from these projects. In addition, the full potential of sequencing projects will not be fully realized without a commensurate investment in taxonomy.

ID: 341 / **Parallel Session 12-1: 10**
The Ocean Decade: The Science We Need for the Coral Reefs We Want

Keywords: Imaging, Microscopy, Biomineralisation, Micro-plastic, Corals

Multi-photon imaging of coral skeletons for the detection of organics within centres of calcification and microplastic contamination

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Corals are constantly exposed to environmental dangers that can lead to devastating effects on the ecosystem they provide. Corals face multiple threats, such as rising temperatures, changing weather patterns, decreasing pH, and contamination from micro-plastic pollutants. To protect reef environments, we must understand how these threats affect the physiological function of corals, which requires investigation at the interface of chemistry and biology. Currently, multi-photon label-free techniques are being widely implemented within life sciences due to their non-destructive nature, straightforward sample preparation requirements and the depth of information they provide.

Here, Coherent Anti-Stokes Raman Scattering (CARS) Microscopy is used to study the localisation of organic material in coral skeletons to address two topical issues: (1) the contribution of skeletal organics to coral biomineralisation and skeletal construction (2) the incorporation of microplastics within coral skeletons. The developed methodology uses a multi-modal imaging setup, in which a non-linear tuneable excitation source is coupled to a laser scanning microscope to produce spatially high-resolution, 3-dimensional CARS and Two-Photon Excitation Fluorescence (TPEF) Microscopy images. The laser's tunability allows us to target multiple vibrational modes within the C-H stretch region, revealing multiple layers of chemical information. Further to toolset development, we will also show how to isolate micron-scale features within coral skeletons using image segmentation, supporting new analysis and sample comparison techniques. CARS and TPEF may also be used to separate organic and inorganic particles, giving potential functionality in detecting inorganic microplastics. This ability to chemically identify micro-scale plastic materials is an ideal tool for studying the incorporation of inorganic objects into coral skeletons. Initial results showing the identification of microplastic material in coral samples will be displayed, alongside examples of how the further development of this toolset can be used better to understand the impact of microplastic pollution on reef environments.

ID: 335 / Parallel Session 12-1: 9
The Ocean Decade: The Science We Need for the Coral Reefs We Want

Keywords: Symbiont shuffling, adaptation, foraminifera, holobiont, assisted evolution

Inducing menthol-bleached symbiont switching in *Amphistegina lobifera*: A novel approach for reef calcifier resilience

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The Ocean Decade addresses pressing challenges in coral reef preservation, focusing on ecosystem and biodiversity protection and restoration. While some coral holobionts exhibit symbiont switching under stress, the ability of lesser-known taxa, like benthic foraminifera crucial for biodiversity and carbonate production, remains uncertain. This study investigates the potential of generating thermally tolerant reef calcifiers through menthol/DCMU-induced bleaching under controlled conditions, using the diatom-bearing foraminifera *Amphistegina lobifera*, common in global coral reefs. Following a successful 4-week bleaching protocol rendering foraminifera aposymbiotic, re-inoculation with different diatom strains was conducted for 10 days to test symbiosis re-establishment. Mortality during menthol bleaching was low (<20%). In the re-inoculation phase, aposymbiotic individuals of *A. lobifera* were exposed to diatom strains representing common symbionts (*Nitzschia* spp. and *Fragilaria* spp.) and a potentially more thermally tolerant strain (*Minutocellus* spp.). Photosynthetic efficiency recovered in all individuals re-inoculated with diatom strains. For symbiont cover, treatment-specific responses were evident. Common diatoms, *Fragilaria spp.* (87.39% ± 13.42) and *Nitzschia* spp. (61.03% ± 38.64), showed significant relative increases. The newly introduced *Minutocellus spp*., previously unidentified in *A. lobifera*, exhibited a lesser but noteworthy increase in symbiont cover (49.00% ± 42.94). These findings underscore the adaptive symbiont flexibility in the foraminifera holobiont, suggesting their potential to cope with future ocean warming by acquiring new symbionts post-bleaching. This novel approach holds promise for contributing thermally resistant holobionts to coral reef restoration, fostering resilience in future reefs.

ID: 548 / Parallel Session 12-1: 11
The Ocean Decade: The Science We Need for the Coral Reefs We Want

Keywords: Correlative 3D imaging, coral skeleton construction, biomineralisation

Correlative imaging approaches for the characterisation of coral skeletal construction.

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Stony corals form the structural framework of coral reefs, underpinning many of the ecological services they provide. Understanding how coral skeletons are constructed and how changes to the environment may affect this construction, are paramount for the preservation of these environments(1).

At the micron-scale, skeletal extension is accomplished through the deposition of centres of calcification (CoC), with the skeleton then thickened by the deposition of acicular fibres(2). Despite the importance of these micro-structures, the precise influence of environmental factors on the growth and relative abundance of CoCs and fibres in the skeleton remains unknown. This study aims to address this knowledge gap and thereby contribute insights to the preservation of coral reef ecosystems.

The main challenge to quantifying the relative abundance of CoC and fibres in coral skeletons is their small size; tropical corals possess CoCs which are typically < 10 µm wide, while forming complex 3D structures winding through the skeleton(3). Here, we use 3D photogrammetry and micro-computed tomography (µCT) to characterise macro-scale skeletal morphology, while highly specialised Synchrotron Radiation Computed Tomography (SR CT) is used to visualise the microstructural details – including CoCs and fibres within the coral skeletons. Together, we hope to understand how micron-scale alterations to these key sites of biomineralisation may drive skeleton-wide alterations, driven by variable nutrient availability. In addition to the mechanistic insight offered by this study, techniques used for image processing, image segmentation, dataset alignment and correlative quantification will be discussed.

This cross-scale study will shed light on how environmental conditions influence skeletal macro- and micro-structure. Additionally, emphasis will be placed on the value of computed tomography to act as a non-destructive 3D imaging tool to study coral skeleton construction.

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Posters

ID: 181
The Ocean Decade: The Science We Need for the Coral Reefs We Want

Keywords: Coral Disease, Mucus, Pathogens, Vibrio spp., Penetration

Understanding coral disease pathogenesis: the role of bacterial mucus penetration

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Outbreaks of infectious disease on coral reefs can lead to rapid reef degradation, which is a global concern. However, the pathogenesis of the diseases affecting corals remains poorly understood. In order to develop new strategies to combat infection in corals, it is critical to understand the mechanisms by which implicated pathogens cause disease. One way in which corals resist infection is by secreting a surface mucus layer (SML). The SML is a multi-functional hydrogel interface between the underlying epithelium and the external environment. It acts as a chemical and physical barrier and is considered a first line defence mechanism against colonisation by potential pathogens. Nevertheless, marine pathogens have evolved sophisticated virulence traits which allow them to disrupt and degrade the SML, potentially leading to infection. In this study, the virulence mechanisms of coral pathogens including 7 *Vibrio* spp. and a single species of *Photobacterium* were evaluated, using a range of physicochemical methods. A novel *in vitro* mucus permeation assay was developed, using porcine small intestinal mucus (PSIM) as a model system. The assay was used to quantitatively assess the ability of the pathogens to penetrate through and degrade the mucus layer. Motility was also investigated to understand whether this was a factor influencing mucus penetration. Results obtained indicated that coral pathogens appeared to be able to penetrate the PSIM layer. Additionally, rheological and biochemical examination of mucus exposed to *Vibrio coralliilyticus* (CC007) has been demonstrated and showed that coral pathogen is able to considerably alter the rheology of mucus through production of potent mucolytic enzymes. These results provide important preliminary insights into the possible mechanism of disease pathogenesis of the species studied, which could be used to inform and develop innovative strategies to tackle infection in corals and potentially higher mammals.

ID: 641
The Ocean Decade: The Science We Need for the Coral Reefs We Want

Keywords: restoration, communication, coral reefs, education, society

From coral reefs to schools in a landlocked country: Meet “Jeanne”, the marine restoration e-bike

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With the increasing threats coral reefs and other marine forests (e.g., seagrass meadows and seaweed banks) are facing around the world, social awareness and action are needed now more than ever. However, most people are unaware of the vital roles these ecosystems play, especially people living in landlocked countries, like Austria. Moreover, many have never considered that they can be part of the solutions to preserve these ecosystems. To shine light on these issues, the project RESTORESEAS, together with the Natural History Museum Vienna, has developed “Jeanne”, the marine restoration e-bike. “Jeanne” is an interactive workshop on wheels, directed at school classes in the ages of 10-14 years old, and is intended to be used in outdoor locations such as parks. The 2-hour workshop is separated in three parts. First, there is a storytelling session in which an expert uses hand-animated illustrations to tell the story of coral reefs and marine forests, from their origin until their relationship with humanity over the centuries and their current state. The second part is a self-guided sensory experience in the park, allowing children to establish a connection between their own surroundings and the underwater environment of marine forests. In the third and final session, participants create a stop-motion video, telling their own stories about the marine world, combining their own imagination with all they learned during the workshop. The goal of “Jeanne” is to, not only showcase the research on marine forest conservation and restoration done by RESTORESEAS, but also to convey a sense of responsibility towards marine ecosystems, and to increase the participant’s feeling of connectedness with the marine environment. As much as we need to restore coral reefs and marine coastal ecosystems, we also need to restore regenerative aspects of human cultures, which are integral to the sustainable use of resources.

Session 13: Insights into further fields of coral reef research around the world

Although the chosen different sessions are general and wide-ranging, the fields of research around coral reefs are difficult to summarize in a limited number of topics. Therefore, this session wants to open the doors to the most innovative, diverse and/or cross-cutting studies, which cannot be fully identified with the previous sessions.

Session chairs and committee members: This session was moderated by the ECRS24 Scientific Committee

Massimo Ponti

Carlo Cerrano

Gert Wörheide

Michael Sweet

Benjamin Müller

Laura Núñez Pons

Caterina Longo

Monica Montefalcone

Riccardo Rodolfo-Metalpa

Christine Ferrier-Pages

Take home message

- Studies on corals and their habitats know no disciplinary frontiers
- Observational and interdisciplinary approaches are necessary to have a holistic view of ecological processes and their change over time
- New technologies offer tools to rapidly expand our knowledge at all levels of biological organization; however, only an effective networking among researchers can bring to solutions to face global crises

Speed talks

ID: 526 / Parallel Session 13-1: 6
Insights into further fields of coral reef research around the world

Keywords: Coral Health, Sunscreen, Coral Growth

Can sunscreen be a positive for corals?

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Coral reefs harbour 30% of marine life, yet by 2030 90% will be displaying reduced ecological function, with many phase-shifting to algal dominated habitats. The major threat to tropical corals is bleaching, caused by our increasing carbon footprint and rising sea surface temperatures. This is closely followed by the devastating impacts of disease outbreaks. However, other stressors need to be accounted for as they could be locally important or increase the impacts of the main stressors through interaction effects. Recently, UV filters used in sunscreen have come under scrutiny, with studies highlighting negative effects of oxybenzone and octinoxate on corals. Following public debates, bans on certain sunscreen products (in locations such as Hawaii, US Virgin Island and Palau) were implemented. However, the studies which led to these bans have also come under scrutiny, primarily due to the lack of a standardized testing scheme. Despite the scientific uncertainty, "reef safe" sunscreen products have become available on the market, and associated terms such as "reef friendly" have begun to appear. But is it possible to go one step further, making a product offering the same level of protection to humans as common brands of sunscreen, but also resulting in positive effects on the corals themselves? We tested a new sunscreen product (as well as a current commercially available product) under controlled laboratory conditions over an 18-week period. We examined impacts on growth rates and photosynthetic activity of four Scleractinian coral species as well as their algal symbionts, microbiome and eco-physiology (total lipid concentration). As part of this work, we also developed a proposed standard testing protocol and a "protection factor" rating scheme, similar to UVA ratings. Here, we present the results, discuss development of the testing protocol and rating schemes, and make recommendations for future tests.

ID: 822 / Parallel Session 13-1: 14
Insights into further fields of coral reef research around the world

Keywords: coral reproduction, genetic diversity, temporal isolation, restoration, thermal tolerance

Reproductive timing and barriers among cryptic lineages of massive *Porites* coral in Palau: considerations for reef restoration

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There is a push for restoration efforts employing sexual reproduction and larval propagation to expand the diversity of species included; however, essential information on spawning events and reproductive biology remains sparse for most coral species. Massive reef-building *Porites* corals have been found to show high resilience to thermal anomalies and represent promising candidates for inclusion in restoration efforts, yet their reproduction is understudied and they are rarely included in larval propagation programs despite their broad distribution. Selecting parent colonies that are most likely to yield high reproductive success and offspring with greater thermal tolerance is critical for improving reef restoration. However, these efforts are complicated by the presence of cryptic lineages within the *Porites* complex, which have been identified in Palau. Most importantly, these lineages exhibit functional variation with respect to thermal tolerance. This cryptic diversity highlights the need to expand our knowledge of this key species in the pursuit of producing coral generations that can survive under changing ocean conditions. We have detailed the environmental cues that can be used to predict spawning events for *Porites* in Palau and provide insight into the temporal and zygotic reproductive barriers posed by the presence of these cryptic lineages in this species.

ID: 621 / **Parallel Session 13-1: 8**
Insights into further fields of coral reef research around the world

Keywords: Extinction, Functional ecology, Population ecology, Resilience, Trait-based

Integrating modelling tools to understand and predict the resilience of coral populations and communities to climate change.

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The effects of climate change are now more pervasive than ever. Marine ecosystems have been particularly impacted by climate change, with many being on the brink of collapse. Even in the most optimistic CO2 emission scenarios, the planet will continue to warm and experience the effects of climate change over the coming decades. In particular, climatic extreme events, such as marine heat waves (MHWs), are expected to increase in frequency, intensity, and duration. For this reason, understanding the resilience of key ecosystems, such as temperate or tropical coral reefs, to warmer temperatures is crucial to predicting their viability under future climatic conditions. However, understanding and predicting coral resilience requires a multidimensional approach that combines methods that can be applied at multiple levels of biological organisation. Here, we will present our work combining different approaches to study the resilience of coral populations and communities to MHWs. In particular, we use long-term monitoring datasets of Mediterranean coralligenous populations and communities as compelling case studies. At the population level, we unravel key mechanisms driving resilience to MHWs using demographic modelling tools. To extend this knowledge to the community-level, we combine functional community analyses with network analyses. With these two approaches, we show that the strong dependence of these communities on structural organisms, such as the octocoral *Paramuricea clavata*, renders them particularly vulnerable to any disturbance affecting this species. Overall, we show that the combination of demographic resilience, functional, and network analyses provides a comprehensive and complementary understanding of how coralligenous assemblages achieve resilience. We believe that these approaches have the potential to be applied to different octocoral and coral species, offering a valuable framework for improving the development of effective conservation strategies.

ID: 784 / **Parallel Session 13-1: 11**
Insights into further fields of coral reef research around the world

Keywords: Red Sea, regionalisation, clustering analysis, multivariate analysis, remote sensing

Regionalisation of Red Sea coral reefs: a new multivariate-driven clustering map

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Regionalisation aims to identify ecologically meaningful geographical units which are relatively homogeneous in their biotic and abiotic attributes, and are distinct from other such ecoregions. As such, regionalisation can, for example, aid conservation planning and the selection and prioritisation of reference sites. To date, several attempts have been made to regionalise the Red Sea, but these have been mostly arbitrary or ecologically-restricted and resulted in delineations that differ in terms of both the number and spatial extent of the regions; in part due to differences in discipline-specific research interests. Such inconsistencies stand to hinder interdisciplinary approaches to conservation, as well as to prevent the identification of the relevant spatial scales for efficient management. Presented hereby is a data-driven regionalisation of the Red Sea, which is revisable upon the emergence of new data. Long-term remote-sensing data regarding factors and variables that impinge on the health and survival of coral-reefs (e.g. sea surface temperature, salinity, nutrient concentrations) were used to statistically identify and map the Red Sea regions. Multivariate clustering analysis revealed the existence of two regions: the Northern-Central Red Sea and the Southern Red Sea, which are separated at latitude 18-20°N. Abiotic conditions that delineate this partitioning are dictated primarily by the large-scale processes of Arabian monsoon phases, thermohaline circulation, and an added effect of local anthropogenic stressors. Overall, this study presents the first quantitative and comprehensive regionalisation of the reefs of the Red Sea, and offers a robust basis for site prioritisation along its coastline. Furthermore, it highlights the transborder aspect of processes affecting the Red Sea, and hence the necessity to move away from politically constrained conservation and management policies toward regional collaboration and networking.

ID: 702 / **Parallel Session 13-1: 10**
Insights into further fields of coral reef research around the world

Keywords: environmental DNA, seabird, metabarcoding, nitrogen

Using tree-of-life eDNA metabarcoding to investigate trophic changes due to the presence of seabird-derived nutrients on coral reefs

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Environmental DNA (eDNA) metabarcoding has quickly become a common tool for documenting biodiversity and informing the conservation and management of coral reefs. The Chagos Archipelago is a remote no-take marine protected area, situated in the Central Indian Ocean, that provides an opportunity to study coral reefs facing few anthropogenic pressures. This study aims to use tree-of-life metabarcoding of eDNA to assess divergent trophic structuring across sites in the archipelago, and over time. Benthic seawater samples were collected from 13 sites across the archipelago in 2018, 2019, 2021 and 2022, and were analysed using four metabarcoding assays, targeting bacteria, metazoans, fish, and elasmobranchs (16S, COI, 18S and 12S). The samples were collected above coral reefs next to islands that host healthy seabird populations and those next to rat-infested islands. The reduction of bird derived nutrients due to the presence of invasive rats has been shown to alter fish behaviour, reduce coral growth, resilience to heat stress and fish biomass on these neighbouring reefs. However, studies have yet to explore these impacts on the diversity and structuring of whole reef communities. By investigating biodiversity patterns across major taxonomic groups, using co-occurrence networks, and investigating functional roles of key taxa, we aim to test ecological hypotheses regarding the trophic structure found at sites where beneficial ornithogenic nutrients have been lost.

ID: 803 / **Parallel Session 13-1: 13**
Insights into further fields of coral reef research around the world

Keywords: behaviour, morphology, taxonomy, whole genome sequencing, introgressive hybridization

Exploring new phenotypic traits for coral evolutionary biology and integrative systematics

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The fields of coral evolutionary biology and systematics are often hindered by a lack of robust phenotypic traits, particularly those that go beyond the traditional use of comparative morphology using skeletal attributes. However, corals do behave in ways that have been somewhat overlooked but that are now well within our reach, mostly due to the application of new technologies. Here, we compile a series of observations from our collaborative work, with implications to those in search for alternative coral phenotypic traits. For example, 1) the recent description of the dynamics and complexity in coral surface flows (using fluorescence beads and modelling approaches) is currently being extended and shows a wide diversity of quantifiable flow patterns with species-specific and other taxon-level responses. In addition, 2) to better understand colonial coral landscapes and surface currents, we are using techniques (e.g., micro CT) to describe topographic variation subjacent to formation of surface currents. Also, 3) we increase our understanding of the contribution of evolutionary jumps such as recent introgressive hybridization to the phenotypic variation of corals (using whole genome sequencing) in a closely related group of coral species. Yet another axis of our research 4) combines surface fluorescence and reflectance patterns allowing for quick *in situ* diagnosis of closely divergent lineages and cryptic species so far solely identified based on reduced representation genome sequencing techniques. Finally, 5) a historical microbial ecology approach based on (ITS2 rDNA sequencing of) 19th century museum coral specimens demonstrates the temporal flexibility of coral symbiont communities leading to the debate on the use of symbiont traits in coral systematics. In conclusion, by combining the power of past historical collections, present experiments performed on living coral, and innovative visualization methods, we aim to present new avenues to study coral evolution and species relationships, as well as to classify corals.

ID: 651 / **Parallel Session 13-1: 9**
Insights into further fields of coral reef research around the world

Keywords: Sit-and-wait predation, Bentho-pelagic coupling, Size ratio, Protocooperation

The role of macro-predation in the trophic ecology of benthic Cnidaria: describing the features of a neglected feeding modality

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Sessile Cnidaria dominate marine benthic habitat at several latitudes from tropical reefs to the deep ocean floor, contributing to the trophism of the benthic community. From 15 to 100% of their daily energy demand is covered by heterotrophic feeding, mainly through the rapid ingestion of small prey (i.e., mesozooplankton) by the action of a single tentacle per prey. Moreover, sessile cnidarians can ingest preys much larger than the individual polyp's mouth, showing a wide trophic plasticity. The feeding upon large animals has been described across many ecosystems and depths, although its dynamics lack a complete investigation. Through several approaches including literature review, underwater surveys, and laboratory experiments, we determined the common features of the large-prey feeding by polyps and the prey consumption rate. We witnessed an increase in the fitness and behavioural differences in polyps involved in large-prey consumption. The predation modality required to capture large animals is characterized by peculiar movements such as stretching of column and mouth, grabbing, contracting, and bending of the tentacles to bring the prey towards the gastric cavity. The handling time and the ingestion last up to 4 and 16 hours, respectively. Digestion requires up to 56 hours and can end with the ejection of indigestible prey pieces. We suggest that the predatory feeding activity of cnidarian polyps should be described by two distinct terms: micro-predation and macro-predation, determined according to the size ratio between the prey and the single polyp, the individual feeding behaviour, and the duration of the predatory action. Macro-predation should also include the protocooperative interaction among neighbouring polyps. When the prey size is too large to be handled individually, polyps can engage in collective predation by coordinating the same predatory behaviour, adding possible significance to the evolution of coloniality and the formation of aggregates.

ID: 787 / **Parallel Session 13-1: 12**
Insights into further fields of coral reef research around the world

Keywords: population genomics, hybridization, evolution, depth gradient, Curaçao

The landscape of hybridization and adaptation across reef depth in a coral community

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The identification of underlying adaptive mechanisms is a crucial first step towards understanding the capacity of species to adapt in a rapidly changing world. Hybridization and introgression (hybridization followed by back-crossing) may be particularly important for rapid evolution to changing environmental conditions, but investigations into their roles in adaptation to new environments has only begun. Hybridization, especially at range boundaries where species overlap, may be a rapid means of increasing standing genetic variation or introducing pre-adapted alleles into a population, with likely consequences for phenotypes, speciation, and community composition. Here, we use a 'reefscape genomics' approach that combines 3D photogrammetry and genomics to investigate cryptic speciation and hybridization in a genus of closely-related corals (*Madracis* spp.) in the Caribbean. To do this, we used low-coverage whole-genome sequencing for ~650 spatially-mapped coral colonies sampled from 5-90 meters in depth at sites that spanned the leeward side of the island of Curaçao. We find evidence for cryptic lineages that partition by depth in some currently recognized morphospecies but not in others. We also identify several putative hybrids in the dataset. Next, we examined population structure across sites and depths for each lineage and identified potentially adaptive loci to understand connectivity and environmental selection across the reef slope. The spatially-explicit nature of the sampling and yearly imaging of the reef also allow hybrid and non-hybrid colonies to be monitored over time, assessed as environmental conditions change, and for further identification of links between existing genomic information and phenotypic responses. A baseline understanding of genomic diversity within the reef and the evolutionary processes that drive these patterns can aid in the development of targeted management strategies for coral reef conservation.

ID: 252 / **Parallel Session 13-1: 1**
Insights into further fields of coral reef research around the world

Keywords: cryptobenthic, seabirds, isotope analysis, nutrient enrichment, community ecology

Seabird nutrient enrichment effects on cryptobenthic fishes in the Indian ocean

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The world's shortest-lived vertebrates, cryptobenthic reef fishes, play a critical role in coral-reef ecosystem functioning. Their high abundance, rapid growth, and extreme mortality underpins reef productivity, by converting hard-to-access food sources to readily accessible nutrients for larger consumers. These fishes' traits make them highly vulnerable to environmental disturbances: their limited dispersal and rapid turnover can expose them to risks of genetic isolation and local extinction. Here, we study how variation in nearshore nutrient subsidies affect these fish communities' role for trophodynamics in the Indian Ocean. Two sites were selected: Fregate Island, Seychelles, where varying densities of seabirds around the island result in different levels of nutrient input to the reef, and the Chagos archipelago, where 6 rat-invaded, seabird-poor islands were compared to 6 rat-free, seabird-rich islands. We used stable isotope analyses on end-members (algae, sponge, detritus, invertebrates) and select species of cryptobenthic fishes to explore how nutrient loads affect these communities. We show higher $\delta^{15}N$ near seabird colonies, suggesting that cryptobenthic fish rely directly on seabird-derived nutrients close to shore. Mixing models also highlight that benthic nutrients can reach farther into reefs when coupled with seabird inputs, with the transition from a primarily benthic to a primarily pelagic energy source occurring deeper adjacent to seabird colonies. Overall, fish communities exhibit higher reliance on benthic nutrient sources as opposed to pelagic sources when located close to seabird colonies, with contrasting effects of nutrient enrichment on cryptobenthic fish size. This study underlines the important role of seabirds for oligotrophic reef ecosystems, and evidences how cryptobenthic fish can transfer these nutrient subsidies to larger predators. With increasing anthropogenic pressure on reefs, including the threat of invasive species, evaluating the response of cryptobenthic fish to localized environmental variations is a critical step in elucidating how these chronically understudied fish may influence coral reefs' future.

ID: 337 / **Parallel Session 13-1: 4**
Insights into further fields of coral reef research around the world

Keywords: biomineralisation, transcriptomics, geochemical response, elemental composition

Gene expression and geochemical responses of *Stylophora pistillata* to nutrient availability

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The availability and stoichiometry of dissolved inorganic nutrients in coral reef ecosystems can be altered by natural processes and anthropogenic activities. Although these disturbances are known to affect growth and skeletal structure of symbiotic reef corals, we still lack a mechanistic understanding of these processes. Here, we examined the effects of nutrient availability and stoichiometry on the biomineralisation in *Stylophora pistillata* through analyses of gene expression, skeletal structure, and geochemical composition. Using controlled experimental conditions, we studied the responses of corals to different nutrient environments over 70 days. Corals were exposed to the following four nutrient pulse treatments: 1) a replete balanced nutrient treatment; 2) a deplete balanced nutrient treatment; 3) an imbalanced high nitrate, low phosphate treatment; and 4) an imbalanced low nitrate, high phosphate treatment. Exposure to low nutrients or phosphate starvation resulted in a restructuring of the coral transcriptome, a process that affected key functions such as cell adhesion, calcification, stress response, and ion transport. Total area and linear extension of the coral skeleton were similar across all treatments, but calcification rate was lower in low phosphate conditions. Skeletal elemental compositions, distribution of organics, and µCT analyses show that the relative availability of nitrogen and phosphorus in seawater influences the skeletal composition, porosity, and density in *S. pistillata*. These findings highlight the potential of these water parameters to affect the ability of corals to maintain and produce the three-dimensional structure of coral reefs.

ID: 527 / **Parallel Session 13-1: 7**
Insights into further fields of coral reef research around the world

Keywords: atoll hydrodynamics, numerical wave current modelling, hydrodynamic trajectory

Control factors and Future Trajectories of Atoll Hydrodynamics in Simplified Systems.

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Atolls are generally low-lying islands displaying a roughly circular combination of barrier reefs and channels around a central lagoon. Atolls are ocean-dominated environments whose evolution and exposition to global changes and their effect in terms of, for example, sediment transport, coral reef growth or lagoon turbidity, etc., mostly rely on hydrodynamics. In this work, an idealized atoll reef-lagoon is conceptualized as a system defined by N scalar quantities which are chosen among meteo-marine conditions (offshore wind, waves and mean sea level), morphological features (shape of the reef and of the lagoon), roughness properties (bottom complexity related to reef health), and hydrodynamic quantities (wave characteristics, levels, and currents inside the system). The latter hydrodynamic properties are calculated from the former components with dedicated wave-circulation numerical models. While wave transformations from the reef to the lagoon have already been quite well described in the literature, the combined exploration of wave transformation, water level and current patterns has been limited to 1D or to 2D systems representing simple linear barrier or fringing reefs. This study aims to generalize this approach to any small, low lying, and almost circular atoll, and to identify the morphological, frictional and meteo-marine quantities controlling its complete hydrodynamics.

With a representation based on 15 components, the relationships between morphology, coral reef health, meteorological forcings and hydrodynamic responses are explored numerically. From the statistical mining of an extensive simulation set, it is demonstrated that hydrodynamics (mean waves, current, setup) are controlled by 6 parameters which are offshore significant wave height, reef/ lagoon depth and roughness, and channel width. Finally, applying global change scenarios to this reduced list permits to gain insights in the trajectory (expected long term changes in time) of atoll hydrodynamics.

ID: 256 / **Parallel Session 13-1: 2**
Insights into further fields of coral reef research around the world

Keywords: sediment runoff, fish herbivory, benthic composition, mechanistic model

A mechanistic framework to predict reef ecosystem outcomes based on sediment concentration and herbivorous fish community composition

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Coral reefs contribute nearly $400 million/year to the local Hawaiian economy and possess great value in Indigenous Hawaiian identity and genealogy. Mitigating local stressors, notably sediment runoff, can improve the resilience of these economically and culturally relevant reefs in the near term. Despite sediment runoff's status as a primary contributor to coral decline and algal dominance, there is no clear mechanistic understanding of how to avert this sediment-mediated ecosystem decline. This study constructs a mechanistic framework to predict reef ecosystem outcomes based on sedimentation levels and herbivore community composition. Namely, we track the direct and indirect impacts of sediment runoff, the reduction of which is an effectual management target, on the fractional cover of coral, macroalgae, and epilithic algal matrix (EAM), as well as the biomass of herbivorous fish, a trophic guild responsible for preventing shifts from coral to algal dominance via algal foraging. Expanding upon a previous coral-algal competition model, this framework inputs data-driven rates (e.g., bite rates) and environmental metrics (e.g., sediment concentrations), making it a tractable tool to forecast the outcomes of vulnerable reef ecosystems globally. This investigation utilizes multiple runoff sites in O‘ahu, Hawai‘i as a case study, leveraging preliminary field and lab data to parameterize the foraging responses of three herbivorous fish functional groups (grazers, scrapers, and browsers) to sediment runoff. Results suggest that ecosystem outcomes—including critical sedimentation thresholds that lead to rapid declines in coral cover and herbivorous fish biomass—are highly dependent on the herbivore functional groups present in the system.

ID: 258 / **Parallel Session 13-1: 3**
Insights into further fields of coral reef research around the world

Keywords: Coral reef, Sedimentation, Herbivorous fishes

The spatio-temporal responses of herbivorous fishes to gradients of sedimentation.

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Sedimentation in near-shore coral reef ecosystems is increasing worldwide due to human activities including dredging, farming, deforestation, and urbanization. The direct impacts of sedimentation on corals and other benthic organisms are known to cause declining coral cover and health along with increased algal coverage and reduced diversity and abundance of reef fish. It is often assumed that observed changes in fish assemblages in sedimented habitats are due to declining coral health (i.e., bottom-up effects). However, recent evidence suggests that observed changes to fish assemblages may, in fact, be caused by direct impacts of sediments on the fishes themselves, and particularly herbivorous reef fish are affected at a larger proportion than other functional groups. Herbivorous fishes are often the last bastion against uncontrolled algal growth and serve as a vital trophic link for the persistence and resilience of coral-dominated reefs. To examine the direct impacts of sedimentation on Hawaiian herbivorous reef fish abundance and biomass, we are using a combination of fish and benthic field surveys at sites with a natural spatial gradient of sediment-exposed reefs over one year to capture temporal variation and in lab behavioural observations to examine their avoidance behaviour to suspended sediment. The findings aim to unravel the capacity of herbivorous fishes to maintain top-down control in algae management on sediment-afflicted reefs. This research not only contributes to the discourse on coral-algal dynamics under environmental stressors but also offers insights into the broader implications of sedimentation in the era of climate change. The outcomes are expected to inform conservation strategies and policy frameworks, reinforcing the resilience of coral ecosystems in a changing world.

ID: 467 / **Parallel Session 13-1: 5**
Insights into further fields of coral reef research around the world

Keywords: Symbiodiniaceae, endolithic niche, photobiology, UV radiation

Autoendolithic stage protects free-living coral symbionts from UV radiation

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Dinoflagellates in the family Symbiodiniaceae frequently engage in symbiosis with corals and various other marine hosts, while many have also preserved the ability to exist as free-living microalgae in planktonic and benthic habitats. In culture, free-living symbiodiniaceans can form calcium carbonate deposits, so-called symbiolites, that encase the microalgae as viable endolithic cells. This autoendolithic process also appears to occur naturally, as endolithic populations of Symbiodiniaceae were found in reef sands around the globe. Both symbiolites and reef sand grains absorb UV radiation, potentially providing the endolithic microalgae with a UV-protective environment.

Here we report on the photobiology of symbiolites and natural reef sand grains. UV-protective properties of symbiolites were tested using a modified microscopy imaging-PAM fluorometer that allowed the exposure of endolithic and non-endolithic cells to UV-A radiation, while recording their photosynthetic parameters F_s, F_m'. The internal light microenvironment of sand grains was characterised using Optical Coherence Tomography (OCT) and scalar irradiance microsensors, inserted into the grains through acid-etched holes in the mineral. This enabled us to characterise mineral fluorescence, reflectance and scattering properties when exposed to different UV and PAR irradiances.

The variable chlorophyll fluorescence measurements suggest that symbiolites reduce the impact of UV radiation on endolithic microalgae, as UV-exposure decreased F_s more markedly in non-endolithic cells, and quantum yield recovery dynamics indicated lower levels of photodamage in endolithic cells. Light microsensor measurements and OCT data indicate that sand grains have high scattering properties, and that UV radiation can be partially converted into photosynthetically active radiation (PAR) through mineral fluorescence. We argue that an autoendolithic lifestyle within reef sands could play an important role in the ecology of free-living Symbiodiniaceae, with possible ramifications for the availability of environmental symbionts for recruitment into coral hosts.

Posters

ID: 736
Insights into further fields of coral reef research around the world

Keywords: biodiversity, coral taxonomy, monitoring programs

How taxonomy changes ecology

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We, the people, use a common language to make sure that what we want to convey has a unique meaning - which is what makes the creation of information and the transfer of knowledge possible. This is especially true for scientists: we constantly need to agree on definitions to categorize and collect the data we use to produce information and knowledge, usually in the form of statistical results that answer our very varied questions. In ecology, we commonly use 'species' as a given when we estimate individuals in a population or diversity of an ecosystem assemblage in the field. But what happens when species boundaries change due to taxonomic revisions? Our analysis aims at turning the tedious exercise of taxonomical update of ecosystem monitoring projects into a mean to look at how ecological descriptors change when our definition of species gets more precise and informed thanks to further taxonomic research. We use spatially explicit coral assemblage time series from Jiigurru (Lizard Island, Australia) and their respective 3D reef reconstructions to see what happens when species boundaries get redefined and individual coral colonies get relabelled according to the newest taxonomy available for that site. Some old species populations were split into multiple new species populations, some species were lumped into a very plastic one, and some only changed names to reflect the original deposited types for the species. We show if the diversity ranking across sites persists, how new species partition their niches and how species matter, with particular focus on *Acropora spp.* assemblages. Taxonomy is always changing and updating, hence the importance of knowing how robust ecological results are to this. We hope to show how ecology and taxonomy need to inform each other and how important it is that we keep speaking the same language.

ID: 699
Insights into further fields of coral reef research around the world

Keywords: Chemical ecology, Porifera, Lendenfeldia, reef aquarium, sesterterpenes

Secondary metabolites of a captive coral reef sponge and their ecological roles

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Lendenfeldia Bergquist, 1980 is a marine sponge genus commonly found in flat reefs across the Indo-Pacific region. Despite their natural habitat, these sponges, known as the "Blue Photo Sponges", are also encountered in aquarium reef tanks and aquaculture facilities posing challenges as pests [1]. Previous chemical investigations into *Lendenfeldia* sponges, which are well known for their complex associated microbiome [2,3], have revealed a variety of bioactive secondary metabolites mainly belonging to the group of homoscalarane sesterterpenoids [4–7]. In this communication, we report the isolation and structural characterization of new bis-homoscalaranes from a sample of *Lendenfeldia* grown in aquarium, as well as the results of chemoecological studies aimed at assessing the defensive role of these metabolites against fish and crustaceans. In addition, the hypothesis that isolated compounds could prevent the sponge surface from being encrusted by biofoulers, as previously shown for other *Lendenfeldia* metabolites [8], is also discussed.

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ID: 717
Insights into further fields of coral reef research around the world

Keywords: octocorals, tropical reefs, physiology

It's tickle time! Reactions of Maldivian gorgonians' polyps to mechanical stimuli

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Cnidarians are characterized by the oldest and rudimental nervous system, showing a network of diffused nerve cells, localized in both ectoderm and endoderm. In colonial species, this network connects all polyps making them able to coordinate a reaction to external stimuli. Little is known about how the information is transmitted through the colony, from polyp to polyp. Here we present the first *in-situ* attempt to describe how the mechanical stimulation of a single polyp can affect the colony's reaction in Maldivian gorgonians. Eight genera from six families were investigated and stimulated using a dissection needle equipped with a polypropylene micropipette tip. The stimulation was applied to single polyps located in the apical and central portions of the colonies and repeated on the same colony at least 3 times per portion, always considering a different polyp, waiting for 90 seconds from one stimulus to another. The reaction to stimuli was videorecorded. While the families Anthogorgiidae, Paramuriceidae, Siphonogorgiidae and Subergorgiidae reacted just closing the stimulated polyp or a few surrounding the stimulation spot, in three cases we observed different behaviors when stimulation occurred in the central portion: (i) all individuals belonging to Melithaeidae family, if stimulated in the internodes, the polyps' retraction spreads bidirectionally stopping at the first nodes; (ii) one *Siphonogorgia* sp. retracted all polyps after repetitive stimulations; (iii) one *Ellisella* sp. retracted firstly the stimulated polyp along with the ones in close proximity, and secondly the polyps located in neighbouring branches. Considering the increasing frequency of necrotic episodes of gorgonians due to thermal anomalies and the frequent damages due to fishing lines it is worth interest to include the nervous system functioning in the vulnerability assessment of the species. Therefore, this study provides a first baseline for future research in the physiology of cnidarians.

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Insights into further fields of coral reef research around the world

Keywords: antibiotic resistance genes (ARGs), coral resistome, microbiome, Pocillopora verrucosa, heat stress

Exploring the coral resistome: abundance and diversity of antibiotic-resistant genes (ARGs) in the *Pocillopora verrucosa* microbiome

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The collection of antibiotic resistance genes (ARGs) in an environment is known as the resistome and has been extensively studied in soil, wastewater, animals, and humans. Many clinically relevant ARGs originate from such environments, and an increasing prevalence of multi-resistant strains in aquatic and marine environments has been recently reported. However, little is known about the resistome of some key marine biodiversity hotspots and their foundational species. Coral-associated microbial communities, for example, are complex and display adaptive abilities to their surrounding environments. As sessile animals, corals are highly exposed to co-occurring anthropogenic stressors, which can cause dysbiosis and lead to an increase in ARGs. In this study, I conducted metagenomics analyses on the coral *Pocillopora verrucosa* to present the first survey on the coral resistome. Corals were exposed to the coral probiotic *Cobetia* sp. and/ or the opportunistic pathogen *Vibrio coralliilyticus* BAA450 in a month-long heat stress mesocosm experiment. 12 ARGs were identified in the coral resistome: blaTEM-116, blaSHD-1, blaZOG-1, blaA, blaNDM-16b, blaCARD-16, blaRATA-2, ermX, fosX, and qnrS2, conferring resistance to β-lactams, macrolide, fosfomycin, and quinolones, respectively. Heat-stressed corals inoculated with *V. coralliilyticus* showed the highest diversity of detected ARGs. More specifically, blaTEM-116 was significantly enriched in heat-stressed corals ($p = 0.0123$), in *Vibrio* ($p = 0.0140$), in *Cobetia* ($p = 0.030$), and co-inoculation treatments ($p = 0.0104$). The identified ARGs, their diversity, and the specific conditions under which they are enriched contribute to our understanding of antibiotic resistance within coral-associated microbial communities. While further studies are necessary to further elucidate the coral resistome and immunity response, this first data on ARG abundance and diversity in corals can catalyse investigations that contribute to reef management and disease mitigation strategies.

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Insights into further fields of coral reef research around the world

Keywords: coral reef islands, Pacific, sea-level rise, shoreline change, machine learning

Exploring the drivers of coral reef island shoreline change using machine learning models

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Built from reef derived biogenic sediments, low-lying coral reef islands are considered one of the most vulnerable landforms to the impacts of anthropogenic climate change, particularly sea-level rise. While observational records of shoreline change provide evidence of high dynamism and predominant stability over recent periods of sea-level rise, efforts to statistically link morphological changes to processes and explore the attribution of processes as drivers of island change remain limited. In this study, we analyse a high-resolution multidecadal shoreline change record of islands from 42 atolls in the Pacific Ocean spanning an expansive region of diverse oceanographic and climatic conditions. We use this record to develop a set of machine learning (ML) models (using random forests and classification and regression trees [CART]) incorporating potential drivers of island change as candidate predictors. These predictors include regional-scale climatic and oceanographic variables (e.g., sea-level rise, wave energy, tidal range), and local-scale morphometric characteristics of islands and their underlying reef platforms. The models identify a set of 'important' predictors of island change, which notably are a combination of regional and local-scale properties. Additionally, results from the random forest models provide the opportunity to examine the interactions between the identified important predictors. Our study highlights the complex relationships between a range of controls on island change and the ability of ML models to explore such interactions. The results have important implications for future efforts in understanding attribution and lay the groundwork for projections of reef island change as the effects of climate change intensify.

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