

REEF ENCOUNTER

The news magazine of the International Coral Reef Society

Registration deadline for online attendance at Bremen ICRS extended to June 30th



REEF PERSPECTIVES

Roger Bradbury:
what are coral reefs?
A call for diversity
and inclusion

REEF CURRENTS

Ines Lange &
Chris Perry: ten
years of
ReefBudget

REEF ACTIONS

ICRI Plan of Action
Cnidarian cell
culture consortium
Hainan South China
Sea Institute
C30 survey method

REEF EDGE

Unusual coral
community in Sudan
Sponge - coral
competition in India



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REEF ENCOUNTER

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International Coral Reef Society



ICRS

International
Coral Reef Society

REEF ENCOUNTER

VOL 37 | June 2022

Reef Encounter is the Magazine Style Newsletter of the International Coral Reef Society. It was first published in 1983. Following a short break in production it was re-launched in electronic (pdf) form. Contributions are welcome, especially from members.

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INTERNATIONAL CORAL REEF SOCIETY

The International Coral Reef Society was founded (as the International Society for Reef Studies) in 1980, at a meeting in Cambridge, UK. Its mission is to promote the acquisition and dissemination of scientific knowledge to secure coral reefs for future generations.

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CORAL REEFS - THE JOURNAL

The International Coral Reef Society also publishes through Springer its premier scientific journal entitled "CORAL REEFS". The Journal publishes high quality scientific papers concerning the broad range of fields relevant to both modern and ancient reefs. For further details, including the list of editors [see here](#).

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Morgan Pratchett (email: morgan.pratchett@jcu.edu.au)

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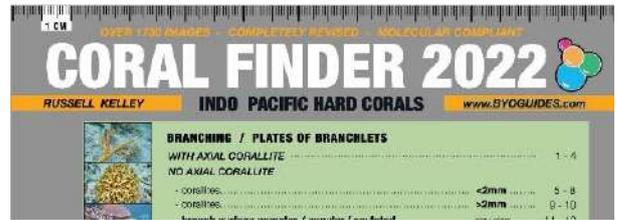
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ABOUT THE COVER | Coral reef monitoring at Cabo Pulmo, a marine protected area in the Gulf of California, Mexico. Part of educational activities directed by Luis Calderon-Aguilera (see page 7). Photo by Manuel Olán-González (PhD candidate, UNAM, Mexico).

EDITORIAL & OFFICERS' REPORTS



EDITORIAL

Rupert Ormond (editor-in-chief, *Reef Encounter*)

In the last issue of *Reef Encounter* we highlighted the experiences of ICRS members attending the COP26 climate change (UNFCCC) meeting in Glasgow. The team finished the COP greatly enthused by the experience of meeting so many like-minded participants, but concerned that despite the support of the great majority of national delegations for commitments that would enable us to keep global warming to within the key 1.5°C target, some large and powerful countries would end up dragging their feet to the point that, in the end, the sum of national commitments would be quite inadequate to achieve that goal. Since then, the only encouraging related news seems to have been the change of government in Australia to one that hopefully will take the causes of six mass bleaching episodes on the Great Barrier Reef, plus unprecedented wildfires and floods, more seriously. Otherwise, atmospheric CO₂ levels continue to rise as steeply as before, and are now 50% higher than pre-industrial levels¹, and the world is still on track to see a global temperature rise of at least 2.7°C². As yet, no country has delivered on their COP26 promise to revisit and further strengthen their climate plans³, while one respected environmental correspondent has wondered in print whether 30 years of major environmental conferences and conventions have achieved anything at all⁴.

Given the situation, it is critical that we empower reef scientists and managers from as many countries as possible, especially from coral reef countries, to voice their concerns at the effects of global warming on reef health and productivity, and to advise their national governments accordingly. This means enabling reef specialists from less wealthy countries to participate fully in relevant networking opportunities and, whenever practicable, attend key conferences and workshops. For this reason, I was glad when Reef Encounter received an opinion piece from Elisa Bayraktarov and colleagues calling for mechanisms to increase participant diversity and inclusion at scientific meetings. Many if not all members of the Society will have worked in close collaboration with friends and colleagues from other nations, and doubtless for such reasons, the Society seems well ahead in this regard in comparison with other international societies. We have mechanisms to ensure that members from coral reef regions can be represented on Council, regional chapters through which members from the global south can also participate, and greatly discounted membership dues for members from low and lower-middle income countries⁵. The idea that conference registration fees should be graded in a similar way seems eminently sensible, so it is laudable news that the organising committee of ICRS2022 in Bremen next month have been able to extend free online participation to both presenting and non-presenting ICRS members employed and residing in low, lower-middle, and upper-middle income economy countries. Congratulations are due to conference convener Christian Wild and his team for this initiative.

At last next month the Bremen ICRS will be taking place, with many of us there in person. The event will be an important test-bed for coordinating online with in-person participation. Most of us are anxious to cut our air miles and carbon emissions so that online attendance at global conferences will likely become the norm. At the same time many of us look forward to meeting up with old dive buddies, perhaps for just one more time!

¹ National Oceanic and Atmospheric Administration (NOAA), USA, 3rd June 2022 (<https://www.noaa.gov/news-release/carbon-dioxide-now-more-than-50-higher-than-pre-industrial-levels>)

² United Nations Environment Programme (UNEP) Emissions Gap Report 2021 (<https://www.unep.org/resources/emissions-gap-report-2021>)

³ Adam Vaughan, New Scientist, 16th May 2022 (<https://www.newscientist.com/article/2320379-cop26-no-countries-have-delivered-on-promise-to-improve-climate-plans/>)

⁴ Fiona Harvey, The Guardian, 11th June 2022 (<https://www.theguardian.com/environment/2022/jun/11/cop-climate-change-conference-30-years-highlights-lowlights>)

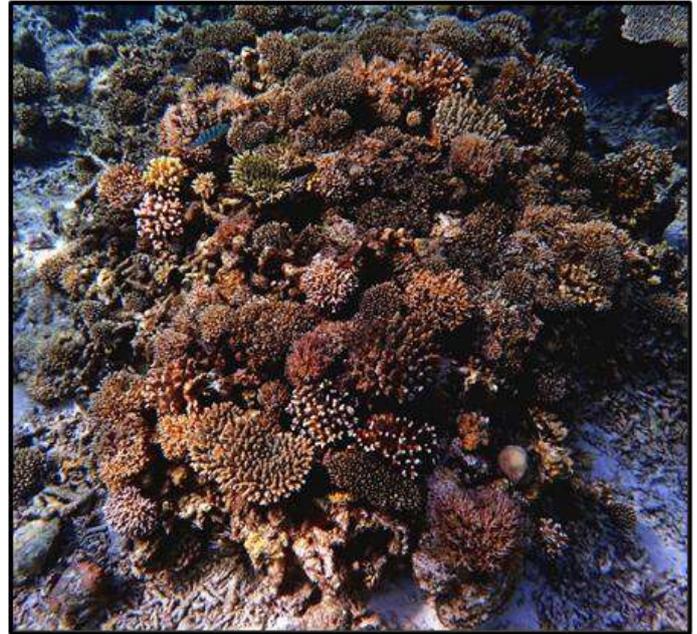
⁵ As defined by the World Bank



TREASURER'S REPORT (2021)

Anderson B. Mayfield, ICRS Treasurer

It is well known amongst my friends and family that, since at least 2007, I have saved every receipt (paper or electronic) for items I've purchased, pasted each and every such paper receipt into one of a series of notebooks, and entered the associated data into a spreadsheet. Yes, even the odd soda (\$1 US) gets logged. I'd like to think that this means that a) your membership dues are in able hands, and b) if anyone can appreciate getting the most out of a membership dollar, it would be me. As such, I am pleased to report that the ICRS treasury had an eventful and busy 2021 (and an even busier first quarter of 2022).



A healthy coral reef association!

From figure 1 below, you'll see that we spent around \$75,000 USD on things such as financial management and, more importantly, fellowships and awards. Specifically, we disbursed nearly \$35,000 in grants to our members (approximately half of our expenditures), and the plan for 2022 is to go far above this figure by doling out over \$50,000 in awards *and*, for the first time ever, tapping into our savings in order to be able to contribute an additional \$50,000 to the 2022 ICRS Bremen meeting so as to make virtual attendance free to all from low- and low-middle income countries. This explains why our projected expenses for 2022 are well above our mean annual amount of ~\$85,000. Otherwise, we have already given out ~\$50,000 in awards, fellowships, and conference registration fee waivers as follows:

- ▶ 2 new Ruth Gates awardees @ \$5,000/award = \$10,000
- ▶ 1 new ICRS communications fellow @ \$2,000/award = \$2,000
- ▶ 6 new ICRS graduate research fellows @ \$2,500/award = \$15,000
- ▶ 20 ICRS student registration fees @ ~\$550/student = \$11,000
- ▶ 10 ICRS student travel awards @ \$1,000/student = \$10,000
- ▶ 1 "World Reef" awardee @ \$2,500/award = \$2,500
- ▶ 1 Coral Reef Conservation awardee @ \$2,500/award = \$2,500

As Ruth's first PhD student, I am especially proud that we received enough donations in 2021 (>\$14,000) to support, for the first time, *two* Ruth Gates awards. Indeed, we were fortunate enough to have received nearly \$18,000 in donations in 2021, and, as of April 25th, we have already secured almost \$13,000 in donations during 2022. This may be related to our recently adding new donation options; not only can you donate to the 1) Ruth Gates Award and 2) ICRS

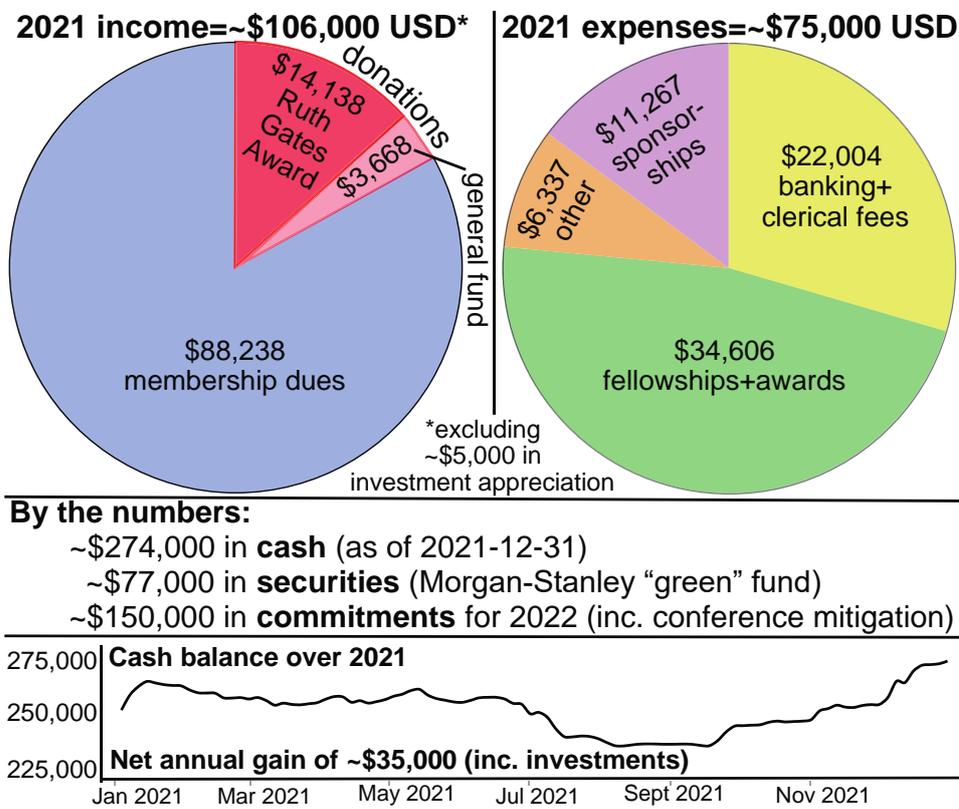


Figure 1. Summary of the Society's current financial status

general fund (as in years past), but you can also select to support 3) student and early career researcher travel, 4) conference cost mitigation, and 5) the Coral Reef Conservation and World Reef Awards. As routinely stated during council meetings, the long-term financial goal of ICRS is *not* to build up a hefty endowment (though that *would* be nice), but to continue working towards the goal of having increasingly more individuals from low- and middle-income countries able to take the opportunity to share coral reef-related findings through both in-person or virtual meetings.

In addition to seeking donations from our membership base, the new ICRS fundraising committee is exploring other means of diversifying our income streams, including being formally vetted by international charity evaluators (e.g., Charity Navigator) so that corporations and other prospective large donors can have the utmost confidence that their contributions to our funds will have maximum impact. I can also report that we are also in the final stages of formalizing the first-ever long-term ICRS strategic financial plan, whose overarching goal is to “ensure a secure a financial future for the society so that it can sustainably fulfill its mission and vision.” However, I cannot guarantee that we have thought of everything with respect to investments, donations, membership growth and the like. In consequence, I would welcome any and all feedback pertaining to how ICRS can grow as a society, and how we can work with our collective membership base, both to share all significant coral reef research findings and, whenever and wherever possible, to conserve the wonderful, yet imperiled ecosystems that have been the predominant focus of my life for the past 20 years.

Anderson B. Mayfield, Taiwan
andersonblairmayfield@gmail.com



EDUCATION COMMITTEE (March 2021 – March 2022)

Luis E. Calderon-Aguilera, chair

I took office in January 2021 and am very happy to have with me on the committee a terrific team of committed members working pro coral reef conservation and research through education (see table).

Among the most relevant activities conducted from March 2021 we have:

1. Recruited two new members
2. Held regular meetings
3. Depurated (removal of broken links and updating of contact information) the [webpage](#). We have kept the good material already present, and will continue to collect resources in different languages and share them via the website
4. Retrieved last year awards reports, and
5. Reviewed the Science Communication Fellowship award applications.

Members	Country
Adrienne Correa	USA
Catherine Naum	Australia
Frida Rodríguez-Escobar	Mexico
Heather Page	USA
Luis E Calderon-Aguilera	Mexico
Ranjeet Bhagooli	Mauritius
Sandra Gilchrist	USA
Zhihua Zhang	China

One of the objectives of this committee has been to promote the inclusion of under-represented groups. Therefore, we have adopted the following guidelines in assessing and selecting candidates for the Science Communication Fellowship award:

1. **Accessibility:** *Is the applicant physically or mentally challenged? How could we improve call launches for blind people, for instance? Are we sure color-blind people can access all the ICRS information? Are people in wheelchairs, or with Down's Syndrome invited to onsite ICRS events?*
2. **Communication:** *Does the applicant have limited communication methods (i.e. using only written, oral, sign language or braille)? Is their mother language different from English? Is their mother alphabet different from Roman (e.g. kanji, Arabic script, etc.)?*
3. **Cultural background:** *Does the applicant have a background associated with negative stereotypes (e.g. Mexican, Asian, Middle Eastern, non-white European)? Are we ensuring that ICRS activities are fully open to cultural diversity?*
4. **Economical background:** *Is the applicant limited by their financial possibilities? Are we unintentionally excluding single mothers, students, or orphans?*
5. **Identity:** *Does the applicant identify with a non-binary gender?*
6. **Attitude:** *Regardless of the above, is the applicant open to diversity and policies of respect and tolerance? Do they agree with a 100% non-discrimination policy, or do they rely on stereotypes that could jeopardize the society's intentions?*
7. **Relationship building:** *Is the applicant good at relationship building? Do they have any relevant partnerships?*

Luis E. Calderon-Aguilera, chair
leca@cicese.mx



MEXICAN CORAL REEF SOCIETY / CHAPTER

Guillermo Horta-Puga, chair

The MCRS may be one of the youngest of ICRS chapters, but it is also among the most active. We use social media (especially Facebook) and email for outreach to our members and to spread news of courses, events, conferences, etc., relevant to coral reefs in Mexico, and worldwide. Our community is enthusiastic and typically posts several announcements and invitations to events to our website (www.somac.org.mx/somac/) and our Facebook site (www.facebook.com/groups/216686455273) every week.

In addition, we have since 2020 been organizing, on a monthly basis, usually the second Wednesday (24.00 h, UTC), on-line webinars, in Spanish, on various topics related to coral reefs (see www.facebook.com/somacoral). Some of our members participate in ICRS Council, and more generally we encourage our students and colleagues to participate in the activities of both ICRS, as well as MCRS.



Our most significant upcoming event, from 26-30 September, in Veracruz, in the Gulf of Mexico, will be the 11th Mexican and 2nd Pan-American Coral Reef Congress (www.somac.org.mx/congreso/xi-cmac/). We hope to see you in Veracruz where you can experience the local coral reefs (see image left). Meanwhile we thank ICRS for its kind support, as a result of which we

are able to cover for several students the payment of registration fees to enable them to attend the Congress.

Guillermo Horta-Puga, chair
horta@unam.mx



ICRS-SECC

International Coral Reef Society
Student & Early Career Chapter

We are pleased to share the news that the Student Chapter has now officially re-launched as the “*Student and Early Career*” Chapter! (In recognition of the rule permitting participation of early career members.)

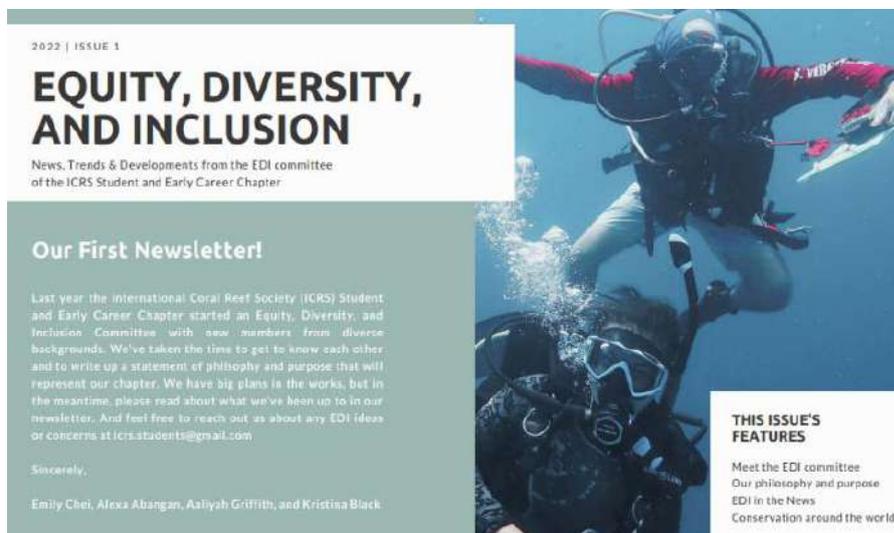
The ICRS Student and Early Career Chapter is a community dedicated to providing support and resources both for students and for recent graduates in transitional roles within the coral reef science community. To mark this transition, we launched a logo competition. We received 8 entries which were reviewed and voted upon by the chapter. The winning artist gave a description of the logo which included these key points.

‘The logo design was inspired by the ICRS logo, preserving the colour palette and the distinctive elements of the original composition: a brain coral and a school of fish. The woman in the forefront represents the native peoples of America, and the male figure represents the Afro-descendant community. The objective of these figures is to exalt the youth, diversity, and inclusion of the chapter. The logo includes a chain of DNA which transmutes into a school of fish, with the intention of showing the union of all living beings in one common genetic past. The hair of both figures is transfigured into two coral heads: one of the brain-type coral inspired by the original ICRS design, and a branching coral releasing gametes as a sign of health, youth, and continuity.’

- from the description by winning logo artist Rosa Carmen Sotelo Casas

We used our annual ICRS budget to support registration costs for a student and an early career researcher to attend ICRS-2022 in person. The competition received 49 applications from 14 ECRs and 35 students. All applications were anonymised and evaluated using a blinded model and strict criteria to reduce bias. We are working on plans for our in-person meet and greet at ICRS-2022 for students and early career researchers.

Since our last update, the SECC Equity Diversity and Inclusion committee has finalised our philosophy and purpose statements. We have also launched our first EDI newsletter, available at: www.coralreefstudents.org/edi.



Otherwise, don't forget to follow us on twitter [@ICRSstudent](https://twitter.com/ICRSstudent), and Instagram [@icrs.students](https://www.instagram.com/icrs.students), and to check out our latest blogs on www.reefbites.com and read about our work on our website www.coralreefstudents.org.

To get in touch with the ICRS SECC please email us at icrs.students@gmail.com.

SOCIETY ANNOUNCEMENTS

ICRS Awards and Honors 2022

The Society's Officers and Council have announced the winners of this year's Society's Awards. The awardees are:

Eminence in Research Award – **Virginia Weis**, USA
 Eminence in Research Award – **Nicholas Polunin**, UK
 Mid-Career Scientist Award – **Christian Voolstra**, Germany
 Early-Career Scientist Award – **Georgina Gurney**, Australia
 Coral Reef Conservation Award (\$2500) – **David Obura**, Kenya
 World Reef Award (\$2500) – **Safira Warili Hawari Djohani**, Indonesia

Those listed above automatically received ICRS Fellow status. The following nominees were also awarded ICRS Fellow status:

Caroline Rogers, USVI
Lisa Rodrigues, USA
Madeleine van Oppen, Australia
Michael Lesser, USA
Raquel Peixoto, Saudi Arabia
Sarah Davies, USA

The Society is also pleased to announce the following Fellowship winners. The Ruth Gates and Graduate Research Fellowships provide financial support for student research projects, while the Science Communications Fellowship supports a society member in the development of science communication skills. The awardees are:

Ruth Gates Fellowship (\$5000)

Natalia Uribe-Castaneda, Colombia
Liam Lachs, UK

Graduate Research Fellowship (\$2500)

Alexandra Pierre, Haiti
Bibiana Nassongole, Mozambique
Danielle Becker, USA
Li Lee, Malaysia
Michelle Taylor, UK
Shakeel Jogee, Mauritius

Science Communication Fellowship (\$2000)

Hannah Rempel, USA

We thank all nominees, nominators, and writers of letters of support. You all help make the ICRS a thriving Society. The ICRS supports diversity and inclusivity, and is happy to be able to recognise the most diverse cohort of awardees to date, representing scientists and students from across the globe.

Thank you for all that you do to investigate, protect, and conserve coral reef ecosystems.

Dr. Carly J Randall, ICRS Honors and Awards Committee Chair
Dr. Andréa Grottoli, ICRS President

ICRS Student Travel Grants 2022

The International Coral Reef Society Officers and Council have announced the 20 winners of this year's International Coral Reef Society's Student Travel Grants. These grants will facilitate the participation of Society student members in the upcoming 15th ICRS Symposium in Bremen, Germany. The awardees are:

Student Travel Grants (Registration cost + \$1000 travel expenses)

Eduardo Gabriel Islas-Dominguez, Mexico
Erin Dillon, USA
Frida Estela Rodriguez-Escobar, Mexico
Hui Jing Ong, Singapore
Igor Pessoa, Brazil
Jacqueline Rivera-Ortega, Mexico
Jessica Maria Orrante-Alcaraz, Mexico
Kristina Black, USA
Maria Isabel Martinez-Rugiero, USA
Tacey Hicks, USA

Student Travel Grants (Registration cost)

Brooke Benson, USA
Daisy Flores, USA
Gabrielle Martineau, USA
Gaby Carpenter, USA
Joseph Heard, Hong Kong
Julia Briand, Canada
Sarah Cryer, UK
Sophia Costa, USVI
Talisa Doering, Australia
Timothy King, Hong Kong

Congratulations to all awardees; we look forward to your participation in the 15th ICRS in 2022!
 Thank you to all applicants and writers of letters of support. You all help to make the ICRS a thriving Society.

Dr. Carly J Randall, ICRS Honors and Awards Committee Chair
Dr. Andréa Grottoli, ICRS President

European Chapter student grants

The **European Chapter** of the Society has announced the awarding to the following students of grants to enable them to register for ICRS2022 in Bremen.

Student Grants (approx \$500)

Robbert-Jan Geertsma, Wageningen University, Netherlands
Henrique Bravo, University of Groningen, Netherlands
Thea Moule, Bangor University, Wales, UK

Gert Wörheide, Chapter Chair, Ludwig-Maximilians-Universität (LMU) Munich, Germany

Ruth D. Gates Endowed Chair in Coral Reef Systems

The Society is pleased to advise members that the [Hawai'i Institute of Marine Biology](https://www.himb.hawaii.edu/) (HIMB) at the University of Hawai'i, Mānoa, has recently announced the establishment of the Ruth D. Gates Endowed Chair in Coral Reef Systems, honoring the research and outreach of the Society's immediate past president, the late and much missed Ruth Gates. The chair is open to applications from researchers in any discipline(s) of coral reef systems research with a vision for innovative, integrative, and transdisciplinary basic or applied research in coral reefs, including but not limited to socio-ecological systems, environmental engineering, solution-oriented technology including artificial intelligence, reef fisheries, oceans and human health, ridge-to-reef processes, and sustainability science, in addition to biology/ecology of coral reef ecosystems. The mission of HIMB is to be a global hub for cutting-edge science and technology aimed at understanding and conserving tropical marine and coastal ecosystems. Its principal facilities and operations are located on Moku o Lo'e (Coconut Island), a 29-acre island surrounded by a coral reef in Kāne'ohe Bay, on the windward side of the island of O'ahu, about 15 miles from the UH Mānoa campus. The Institute has just completed a \$40 million renovation of its facilities to accommodate growing research and education programs, and in support of approximately 150 employees, including 23 research faculty.



Applications from suitably qualified members are encouraged. The post is an 11-month, tenure-track faculty position, 75% research and 25% instruction, at the rank of Full Research Professor. Exceptional candidates may be considered at the level of Associate Research Professor. The Hawai'i Institute of Marine Biology is committed to supporting diversity, equity, and inclusion in science and to UH Mānoa's strategic priority and institutional goal of becoming a Native Hawaiian Place of Learning. For more information please see:

www.himb.hawaii.edu/2022/05/03/himb-recruits-ruth-d-gates-endowed-chair-position-in-coral-reef-systems/

Review of applications will begin on or about June 30th 2022, and will continue until the position is filled. To apply go to: www.schooljobs.com/careers/hawaii.edu/jobs/3527570/assoc-full-researcher-11-mo-ruth-d-gates-endowed-chair-pos-0086497?pagetype=jobOpportunitiesJobs

KEY INFORMATION

Post duration

11 months

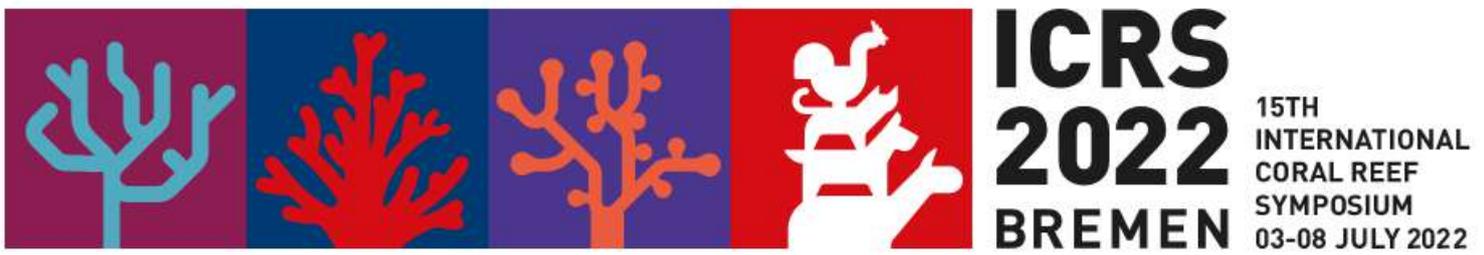
Location

Hawai'i Institute of Marine Biology

Review of applications

June 30th, 2022





Having successfully completed the 14th ICRS 2021 Virtual, **the University of Bremen and the Bremen Convention Bureau (WFB)** are pleased to confirm that, as eventually planned, we will be hosting the 15th ICRS as an in-person event from 3 - 8 July 2022 in Bremen, Germany. The meeting will include plenary talks, a science-to-policy dialogue, social events, workshops, and social/science tours, as well as both in-person and virtual oral and poster presentation opportunities (see the conference website at: icrs2022.de).

Bremen is a charming historic city, with impressive city-centre buildings dating back to the 15th century and pleasant riverside areas incorporating both museums and adjacent woodlands and parks.

As most readers will know, the Symposium is the primary international conference on coral reef science, conservation and management, bringing together leading scientists, early career researchers, conservationists, ocean experts, policy makers, managers, and the public. It will be the key event to develop science-based solutions addressing the present and future challenges of coral reefs, which are globally exposed to unprecedented anthropogenic pressures. It will present the latest scientific findings and ideas, provide a platform to build the essential bridges among coral reef science, conservation, politics, management and the public, and will promote public and political outreach.

The key dates are as shown below - **in particular note that the final registration deadline is not until June 15th**. In addition, members based in developing countries should note that, as a result of financial support from the Society and the Conference Organisers **there will now be free registration for on-line participation in ICRS 2022 for all presenting and non-presenting ICRS members currently employed and residing in low, lower-middle, and upper-middle income economy countries** (as defined by the World Bank). For details of how to apply for this concession see: www.icrs2022.de/registration/presenters-based-in-low-and-middle-income-countries.

16

March
2022

Abstract Submission Deadline

for re-submission of already evaluated abstracts

24

March
2022

Abstract Evaluation Result

for submitters of new abstracts

07

April
2022

Final Registration Deadline

for submitters of new abstracts

15

June
2022

Final Registration Deadline

for non-presenting participants

03

July
2022

ICRS 2022 Commences

The 15th International Coral Reef Symposium opens its doors

- › 01: Reef environments and climate of the past
- › 02: Species and their populations
- › 03: Ecosystem functions and services
- › 04: Microbial ecology, holobionts and model organisms
- › 05: Cold-water and temperate reefs
- › 06: Unexplored and unexpected reefs
- › 07: Scalable observations and technologies
- › 08: Human relations to reefs
- › 09: Global and local impacts
- › 10: Organismal physiology, adaptation and acclimation
- › 11: Resilience, phase shifts and novel ecosystems
- › 12: Conservation and management
- › 13: Interventions and restoration
- › 14: Outreach and education
- › 15: New theories and future projections



The Conference Sessions are grouped into 15 overarching themes (see above). Each theme will incorporate a series of specialised sessions as well as an open session, that will cover all aspects of the theme not addressed by its specialised sessions. Theme 14 is an exception, in that it will only include an open session.

If you are still looking for accommodation, then please note that the WFB Bremen Convention Bureau has reserved rooms for ICRS 2022 participants; these can be easily booked during the registration process. You can choose from among hotels of different categories with different rates. Most rates are very reasonable, with the costs for hotel rooms being significantly lower (on average approx. 30 - 40 %) than those for the previous ICRS 2016 in Honolulu. Many hotels are in walking distance to the conference venue or have easy access to public transportation (included in the conference ticket). Payment does not need to be made until arrival at the hotel. For further details see: www.icrs2022.de/services/accommodation

A series of exhibits and film shows have been arranged, linked to the conference (see images above and below). Note that some showings take place ahead of the conference, while others can be accessed on-line for a longer period. For details please see <https://www.icrs2022.de/program/event-program> and www.deepwave.org/icrs-filmfestival-2021.

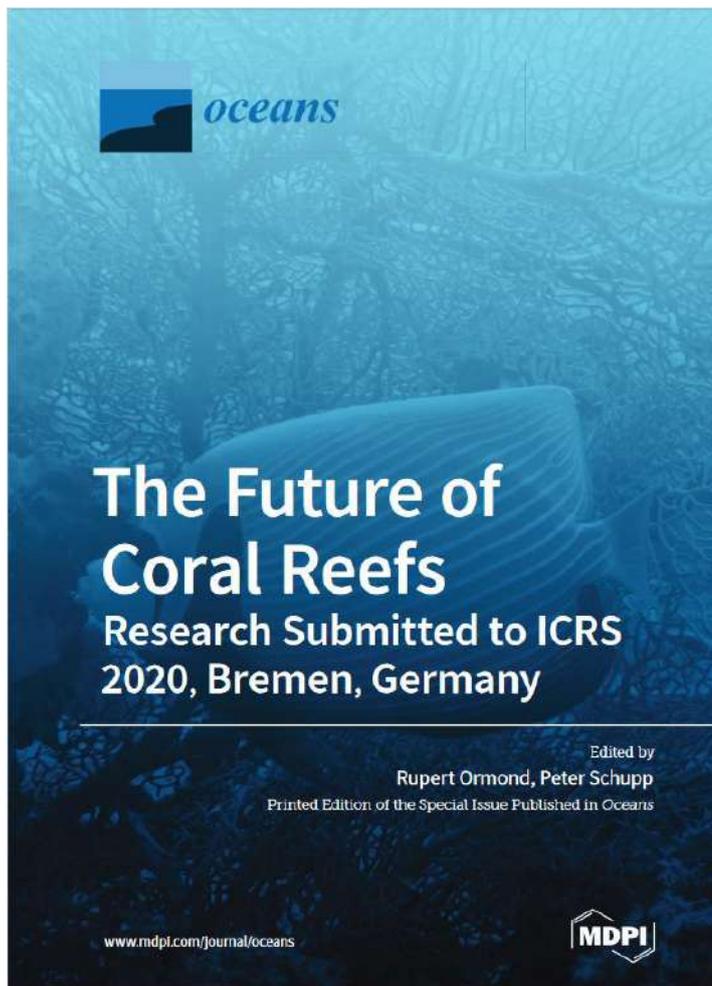


A Code of Conduct will be in operation affecting all participants (see: www.icrs2022.de/code-of-conduct) and child care (for children aged 1-12) with trained personnel will be available in an especially adapted area during the symposium week from 7:30 a.m. – 6:00 p.m. (for registered parents). For details on how to contact the secretariat please see: www.icrs2022.de/services/contacts.

We hope to see you in Bremen!

Christian Wild, Chair 15th ICRS (2022) Organizing Committeer

ICRS 2020/21 BREMEN SPECIAL ISSUE



The first Special Issue of papers submitted to the Bremen International Coral Reef Symposium in 2020 and 2021, and published in the open access journal *Oceans*, has now been published as a separate volume. The whole 282 page volume is now available as a [free download](https://www.mdpi.com/books/pdfview/book/5484) at: <https://www.mdpi.com/books/pdfview/book/5484>. A print version is also available for purchase.

The volume contains 16 refereed papers as listed in the boxes below.

A second Special Issue will be published in *Oceans* to include papers submitted to the upcoming in-person ICRS 2022 symposium in Bremen. Thanks to support from the publishers MDPI, all papers will be published free of charge, and made available on-line as open access publications immediately on final acceptance by the editors. The editorial team includes members of the organising committee led by Christian Wild.

For author's instructions and other information please see

www.mdpi.com/journal/oceans/special_issues/coralreefs2

The deadline for new submissions is 30th September 2022.

Erika Gress, Igor Eeckhaut, Mathilde Godefroid, Philippe Dubois, Jonathan Richir and Lucas Terrana Investigation into the Presence of <i>Symbiodiniaceae</i> in Antipatharians (<i>Black Corals</i>) Reprinted from: <i>Oceans</i> 2021, 2, 44, doi:10.3390/oceans2040044	1
Simona Ruffaldi Santori, Maria Carla Benedetti, Silvia Cocito, Andrea Peirano, Roberta Cupido, Fabrizio Erra and Giovanni Santangelo After the Fall: The Demographic Destiny of a Gorgonian Population Stricken by Catastrophic Mortality Reprinted from: <i>Oceans</i> 2021, 2, 20, doi:10.3390/oceans2020020	15
Stanton Belford Shallow-Water Species Diversity of Common Intertidal Zoantharians (Cnidaria: Hexacorallia: Zoantharia) along the Northeastern Coast of Trinidad, Southern Caribbean Reprinted from: <i>Oceans</i> 2021, 2, 27, doi:10.3390/oceans2030027	29
Hazel M. Canizales-Flores, Alma P. Rodríguez-Troncoso, Eric Bautista-Guerrero and Amílcar L. Cupul-Magaña Molecular Phylogenetics of <i>Trapezia</i> Crabs in the Central Mexican Pacific Reprinted from: <i>Oceans</i> 2020, 1, 11, doi:10.3390/oceans1030011	41
Ashani Arulananthan, Venura Herath, Sivashanthini Kuganathan, Anura Upasanta and Akila Harishchandra The Status of the Coral Reefs of the Jaffna Peninsula (Northern Sri Lanka), with 36 Coral Species New to Sri Lanka Confirmed by DNA Bar-Coding Reprinted from: <i>Oceans</i> 2021, 2, 29, doi:10.3390/oceans2030029	51
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Diana Castaño, Diana Morales-de-Anda, Julián Prato, Amílcar Levi Cupul-Magaña, Johanna Paola Echeverry and Adriana Santos-Martínez Reef Structural Complexity Influences Fish Community Metrics on a Remote Oceanic Island: Serranilla Island, Seaflower Biosphere Reserve, Colombia Reprinted from: <i>Oceans</i> 2021, 2, 34, doi:10.3390/oceans2030034	101
Kara Noonan, Thomas Fair, Kristiaan Matthee, Kelsey Sox, Kylie Smith and Michael Childress Reef Fish Associations with Natural and Artificial Structures in the Florida Keys Reprinted from: <i>Oceans</i> 2021, 2, 36, doi:10.3390/oceans2030036	115
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Mary O. Shodipo, Berilin Duong, Alexia Graba-Landry, Alexandra S. Grutter and Paul C. Sikkil Effect of Acute Seawater Temperature Increase on the Survival of a Fish Ectoparasite Reprinted from: <i>Oceans</i> 2020, 1, 16, doi:10.3390/oceans1040016	143
Pia Bessell-Browne, Hannah E. Epstein, Nora Hall, Patrick Buerger and Kathryn Berry Severe Heat Stress Resulted in High Coral Mortality on Maldivian Reefs following the 2015–2016 El Niño Event Reprinted from: <i>Oceans</i> 2021, 2, 14, doi:10.3390/oceans2010014	165
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When Art Meets Coral Research

the *TANDEM HUMANS-CORALS* competition exhibition

According to the Paris Climate Change Agreement of 2015, global warming should be limited to 2°C degrees and, if possible, 1.5°C, to prevent major impacts to the environment and life on Earth. Reaching this agreement was like taking a long walk on a tightrope. The latest climate talks in 2021 resulted in the Glasgow Climate Pact, which finally saw a call to reduce coal use and fossil fuel subsidies. However, recent projections suggest a temperature increase of 2°C will still likely occur, resulting in the loss of 90-99% of Earth's corals. On day one of his presidency, US President Joe Biden rejoined the Paris Agreement and promised net zero emissions by 2050. However, his predecessor, by opting out of the agreement and taking other economic actions, made it nearly impossible to reach these targets. Since "a picture is worth a thousand words" and it is important to combat the "out of sight, out of mind" attitude, we organized an artistic initiative to draw attention to the problem and advocate for concrete and effective international climate actions.

To this end, the synthetic corals project, an NSF-ideas lab funded research initiative at the interfaces of coral biology, computer science and materials science, studied the analogy between corals as a non-model organism and humans, a species which has benefitted from an immense amount of biomedical research. A comparison with humans may open new ways to understand and help corals. To bring this analogy to the general public and help focus attention on keeping global warming within the 1.5°C limit, we organized a mail-art competition "**Tandem Human-Corals**". 124 artists from 68 locations in 10 different countries on 3 continents participated, with 262 submissions being received. For this project we encouraged artists to develop their own ideas of the analogy between humans and corals. The resulting diversity of artworks involves the use of many different artistic media – oil, acrylic and watercolor painting, but also pencil drawings and collages integrating different materials and sources. More than 90% of the art was created specifically in response to the competition, and more than 50% are available only as a single original.



No183 - Dijana AGATIC: "Gaias Prognose - Alarmstufe Gelb - Bleiche Gefahr/ Gaia's Forecast - Alarm (Levelalarm Yellow) - Bleaching Danger", Mixed Media, digital graphic

Despite the covid pandemic related restrictions the exhibition has already traveled to 5 different locations, (1) Munich, (2) Dusseldorf, (3) Cologne, (4) Kiel and (5) Berlin (see www.tandem-human-coral.info/exhibits-2.htm). This exhibition has now arrived in (6) **Bremen**, in time for the “Olympics” of coral reef research, **the 15th International Coral Reef Symposium**.

We invite all coral researchers attending the conference to visit the traveling exhibition and participate in voting for the most popular art submission. The gallery **KUNST:HAUS:FINDORFF** (Plantage 3) showing the **Tandem Human-Corals** exhibition is only a 400 m (¼ mile) short walk from the convention center where the ICRS is taking place (see the map). The competition should be exciting given that the idea for it was born in conjunction with the NSF ideas lab research project. Thus, scientific creativity meets artistic creativity with the common goal of tackling the climate crisis of which corals have become the principal victims. Votes will be counted on July 8 and the winner will be announced at the end of exhibit Finissage on July 8 at 5 pm. Votes counted at each location of the wandering exhibit will be aggregated and will eventually be used to identify the overall winner who will receive an award of 500€.

All pictures are also on view online at www.tandem-human-coral.info/pictures.htm, but participation in the voting can only be done at the physical exhibition where the originals are on display. After the Bremen ICRS, the next stops for the exhibition will be (7) Bremerhaven, at the University of Bremerhaven, from July 14th – 16th, in conjunction with a climate conference and a presentation on corals. Subsequent venues will include (8) Vilshofen an der Donau and (9) Hamburg. If you are interested in sponsoring a future exhibition of the art collection, or have suggestions for suitable locations, please contact clemte@gmx.de.



Location of the Exhibition. It is only a short walk from the ICRS Conference Venue to Plantage 3, where the tandem human coral exhibition will be on display. The exhibition will be open from July 3rd – 7th from 12 noon until 8 pm, and on July 8th from noon until 6 p.m. Copies of this map will be available as printed flyers at the conference.



No67 - Anuar ABDULLAH: "Man and the Coral Reef", Acrylic on Canvas, 150cm x 92cm (Photography) ... Nets and fishing lines drape the reef. Human destruction is on the foreground. Yet the man takes no action.

Liza M. Roger¹, Judith Klein-Seetharaman²,
Clementine Klein³

¹Chemical and Life Science Engineering, Virginia Commonwealth University, Richmond, Virginia, USA;

²School of Molecular Sciences and College of Health Solutions, Arizona State University, Phoenix, Arizona, USA;

³Independent Artist

SEE MORE

For more information about the science project please see:

<https://corals.cs.tufts.edu/research/>

And for more information about the exhibition / competition:

<http://www.tandem-human-coral.info/indexxx.htm>



XI MEXICAN CORAL REEF CONGRESS II PAN-AMERICAN CORAL REEF CONGRESS

**September 26-30, 2022
Veracruz, México**

Dear Colleague

The Mexican Coral Reef Society and the Universidad Veracruzana (ICIMAP), are calling all researchers, academics and students interested in Coral Reefs to present their studies at the *XI Mexican and II Pan-American Coral Reef Congress*.

This is a unique opportunity to present your research advances to the scientific community in a high-level academic environment. In addition, the journal *Hidrobiológica* will publish a special issue, where you will be able to publish the studies you present at the Congress. The deadline for the reception of abstracts is May 31/2022. Contributions in English, Portuguese, and Spanish are welcome.

More information: <http://www.somac.org.mx/congreso/xi-cmac/>

¡Hope to see you at Veracruz!

Chair of the Organizing Committee
Dr. Horacio Pérez España
UV, ICIMAP
hperez@uv.mx

President of the MCRS
Dr. Guillermo Horta-Puga
UBIPRO, FESI, UNAM
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XI CONGRESO MEXICANO DE ARRECIFES CORALINOS II CONGRESO PANAMERICANO DE ARRECIFES CORALINOS

26-30 de Septiembre del 2022

Veracruz, México

Estimado Colega

La Sociedad Mexicana de Arrecifes Coralinos (SOMAC) y la Universidad Veracruzana (ICIMAP) estamos convocando a todos los investigadores, académicos y estudiantes, interesados en los arrecifes coralinos, a presentar sus estudios en el *XI Congreso Mexicano y II Panamericano de Arrecifes Coralinos*.

Esta es una oportunidad única para dar a conocer a la comunidad científica, los avances en sus investigaciones, en un ambiente académico de buen nivel. Además, la revista *Hidrobiológica* editará un número especial, dónde ustedes podrán publicar los trabajos que presenten en el Congreso. La fecha límite para la recepción de resúmenes es el 31/mayo/2022. Son bienvenidas las contribuciones en español, inglés y portugués.

Más información: <http://www.somac.org.mx/congreso/xi-cmac/>

¡Los esperamos en Veracruz!

Presidente del Comité Organizador
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2023
APCRS
5th Asia-Pacific Coral Reef Symposium

NUS, SINGAPORE | 19TH - 23RD JUNE 2023

The 5th Asia-Pacific Coral Reef Symposium (APCRS) will be held at the National University of Singapore over 19–23 June 2023. With the theme ‘*Coral reef science and management in a rapidly changing world*’, the 5th APCRS will be a forum for reef scientists and managers to present, discuss and integrate the science and conservation of Asia-Pacific coral reef ecosystems. We hope the Asia Pacific scientific community can come together to create new paradigms to meet the key challenges facing the region’s reefs.

As the host institution and supporting agency for the 5th APCRS, respectively, the National University of Singapore and National Parks Board are honoured to welcome you to Singapore in 2023!

The call for sessions and workshops is now open through 30 June 2022. We invite researchers, graduate students, resource managers, policymakers and educators to submit proposals for meeting session themes and workshop ideas at www.apcrs2023.org/Proposal.html. Sessions should address coral reef science and management in the Asia-Pacific region.

IMPORTANT DATES

- 30 June 2022:** Session Proposal Deadline
- 1 August 2022:** Call for Abstracts
- 30 November 2022:** Abstract Submission Deadline
- 1 January 2023:** Early Registration Opens
- 31 January 2023:** Presenters Notified of Abstract Evaluation
- 28 February 2023:** Early Registration Closes
- March 2023:** Conference Session Schedule Announced
- May 2023:** Full Conference Programme Announced
- 19–23 June 2023:** Asia-Pacific Coral Reef Symposium

Call for abstracts

The call for abstracts will open towards the end of 2022. For more information, please follow us on Facebook, Instagram and Twitter [@apcrs2023](https://www.instagram.com/apcrs2023) or visit our website at www.apcrs2023.org.



What are coral reefs?

Roger Bradbury

Australian National University
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Introduction

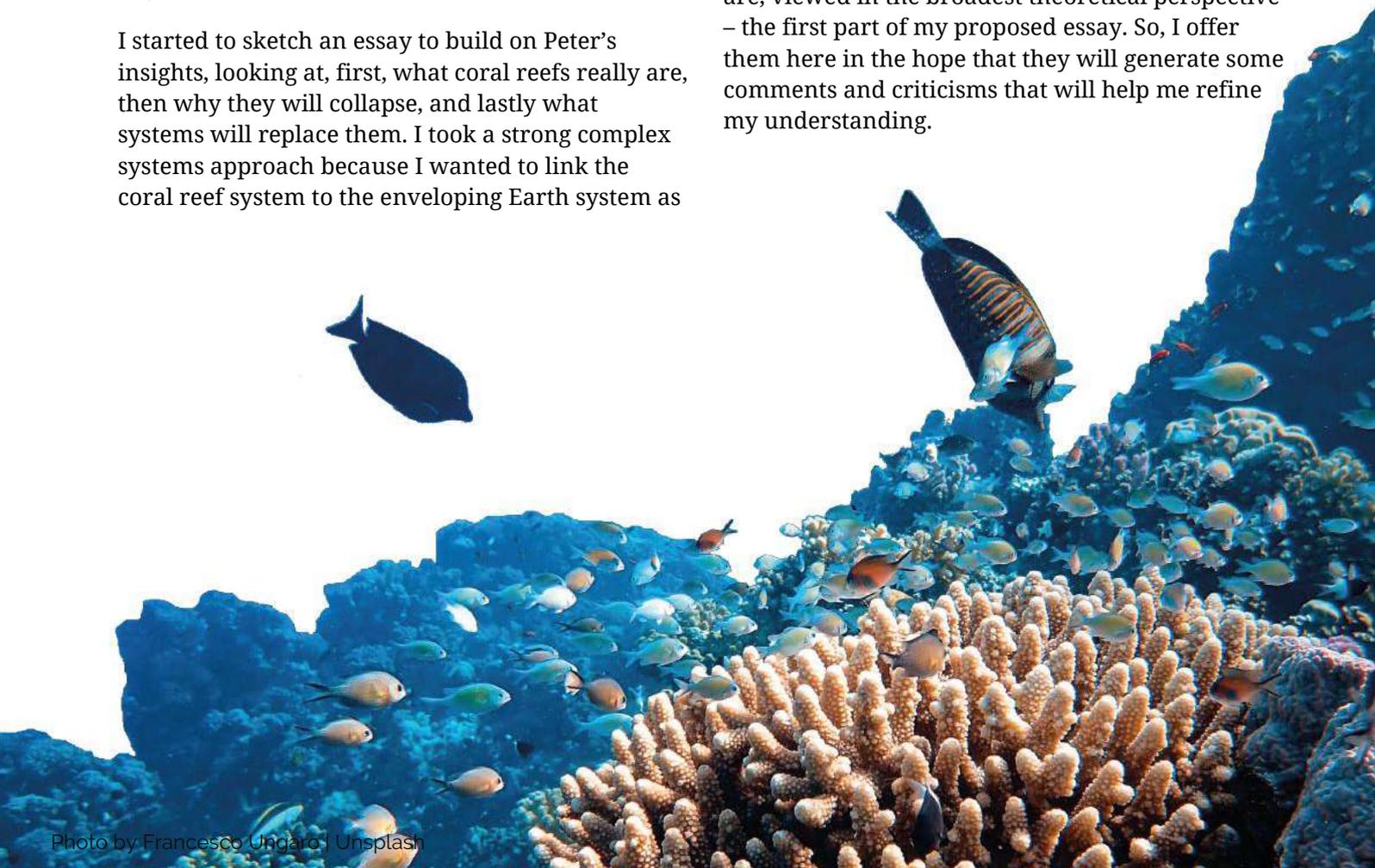
I was brooding over the fate of coral reefs in the Anthropocene when I read Peter Sale's (2021) magisterial piece, *Baselines still shift, reefs still degrade, most of us don't really care*, in *Reef Encounter*. It made me wonder, once again, about whether we understand what coral reefs really are, after so many shifts in baselines and so much degradation – and where this will all end.

I started to sketch an essay to build on Peter's insights, looking at, first, what coral reefs really are, then why they will collapse, and lastly what systems will replace them. I took a strong complex systems approach because I wanted to link the coral reef system to the enveloping Earth system as

it reorganises itself into the Anthropocene, as well as to its neighbouring complex systems including the human system.

In that linkage I was echoing the ideas Rob Seymour and I proposed, in 2009, that coral reefs are fated to be 'just road-kill on the highway to the emerging Anthropocene, collateral damage as the new Earth system takes shape' (Bradbury and Seymour 2009).

And I've come, tentatively, to what I believe are some new insights about what coral reefs actually are, viewed in the broadest theoretical perspective – the first part of my proposed essay. So, I offer them here in the hope that they will generate some comments and criticisms that will help me refine my understanding.



My jumping-off point is Fred Grassle's 1968 prediction of the future of the Great Barrier Reef:

“There are two kinds of human experience which enable man to partially understand his position in nature. One is looking up at the stars and I think the other is swimming out over the edge of the Reef. Too few people have been able to see the Reef, and none has adequately described the experience. In the future the reefs may be doomed but if we can increase our efforts now at least the memory of this experience may be preserved.”
(Grassle 1968)

This is a catastrophe for the world. And it is a sad outcome for those of us who love coral reefs. But we must face the awful reality foreseen by Fred. Here I want to build on Fred's insights of half a century ago. And perhaps even help preserve the memory.

I want to explain what it is that we will have lost – that is, what coral reefs really are. I will thread Fred's evolutionary arguments about the fundamental nature of coral reefs as ecosystems with more modern notions of the dynamics of complex systems, and, in particular, introduce the principle of Maximum Entropy Production (Dyke and Kleidon 2010). I need to do this to strip back our understanding of coral reefs to the idea of them as complex systems that process the sun's energy in a unique way. But in doing so, I must reluctantly strip away the very beauty of coral reefs that attracted and bewitched us as reef scientists in the first place.

What coral reefs really are

What are coral reefs really? This is not a simple question. Fifty years ago, Fred Grassle himself struggled with it (Grassle 1968,1973), and others like Ann Cameron (1974,1977) and Joe Connell (1978) have understood the difficulty of the question. They tried to strip away the epiphenomena of reefs – the beauty, the variety, the complexity – to find a kernel, an essence, that made ecological and evolutionary sense (Hutchinson 1965). But classic Darwinian evolution does not extend to ecosystems. At that time, we didn't have

the theory – we didn't even have the words – to describe such systems. Ludwig von Bertalanffy (1968) had only just published his book on general systems theory, and Dick Levins (1970) had just published his pathbreaking essay, *Complex systems*, bringing the idea of complex systems to biology. Both were largely unknown to coral reef scientists.

Those few scientists who thought about coral reefs as systems at all, thought about them firmly in Ray Lindeman's (1942) trophodynamic terms as they tried to measure the flow of energy and matter – or better, the energy embodied in matter – through food webs (Odum and Odum 1955). These 'productivity' studies painted a mechanistic picture of reefs that was essentially non-Darwinian, in the sense that the high-level entities in play – producers, consumers and the like – were not evolutionary entities. But by focussing on the stocks and flows of matter and energy in ecosystems they missed the bigger picture to do with the nature of the systems they were dealing with – that is, with what coral reefs really are. They lost the Darwinian frame of reference of ecology but did not find another.

The frame that reef scientists *didn't* find was emerging in these same years through a deeper understanding of the thermodynamics of open systems. Erwin Schrödinger (1944) in his astonishing essay, *What is life?*, noted that the fate of all closed dynamical systems is fixed by the laws of thermodynamics. That is, systems that are completely isolated from the rest of the universe, with their own fixed dollops of energy and matter, and some sort of energy transforming process, will all run down over time, as their entropy increases, to a final steady state where nothing happens except the disordered collisions among their molecules.

In contrast, Schrödinger argued, open dynamical systems, often called 'non-equilibrium systems', can cheat this fate, at least for a time, and use a flow of energy from outside their system to create inside their system a state of low entropy – a state of high order or organisation. Living systems are complex open systems that have leveraged evolution to

master this trick. The result is that the Earth now hosts a biosphere that is far from disorder. Its low entropy is maintained by the flow of energy from the sun cascading through ecosystems and creating subsystems that have become more ordered – more complex – through time.

From this perspective, the key to understanding how and why complex systems like ecosystems exist lies not in how they manage energy transformations – a first law matter – but how they wrangle entropy – a second law matter (Morowitz 1968; Smith and Morowitz 2016). And from this perspective, it seems clear that reef scientists (including, I must admit, myself (Johnson et al. 1995)) have spent too much time developing a *trophodynamic* view of coral reefs and not enough time thinking about their *thermodynamics*.

To understand that wrangling of entropy within a complex system, Schrödinger proposed the idea of negative entropy, later shortened to negentropy by the information theorist, Léon Brillouin (1953). Negentropy is reverse entropy (and is formally equivalent, in physics, to free energy or exergy). It increases as a system increases in orderliness.¹

As Adam Liska and Casey Heier (2013, 574) describe it:

“The ordered energy in a system that is available to do maximum work on its environment has been defined as free energy (often alternatively defined as exergy). From fluids to organisms to empires, local order arises in far-from-equilibrium open systems from inputs of free energy, thus countering the natural pull towards disorder described by the second law of thermodynamics.”

¹ This description of the roles of negentropy and the Principle of Maximum Entropy Production is adapted from my recent paper (Bradbury 2021) on cyberspace as a complex adaptive system.



Coral reefs: maximum negentropy machines in need of further inputs – courtesy International Coral Reef Initiative (ICRI) (see page xx); © Cinzia Osele Bismark / Ocean Image Bank

The principle of Maximum Entropy Production (MaxEP) (Dyke and Kleidon 2010) describes the way in which open systems actually manage the trick of increasing their negentropy in the face of the second law. It suggests that sufficiently complex open systems – such as living systems – will configure themselves, when driven hard enough by an external force, to produce entropy at the maximum rate allowed by existing constraints (Haff 2014, 399). That is, they take in usable energy from a low entropy source, such as sunlight or electricity, and pass it through one or more energy transformations until that energy is shunted out of the system to a high entropy sink of low temperature, and unusable heat. In doing so, they maximize the production of entropy through their system as they squeeze out as much utility as they can from the energy flow.

Thus, as external energy flows into a living system, the system will respond by altering its configuration through evolution, becoming more complex, more ordered, and with higher negentropy, to manage that flow in such a way that the outflowing energy has high entropy even as the entropy within the system is lowered. As living systems respond to MaxEP, they evolve to increase their negentropy.

Those laws! (A refresher)

In every high school physics class, there comes a time when the teacher introduces the *Laws of Thermodynamics*. They might seem arcane at first – what is this entropy thing that you can't see, touch or smell? And then they might seem obvious, as much of science does once it is explained. They might even seem satisfying as the teacher uses the laws to show that a perpetual motion machine is impossible.

But they are more than that – they are profound. And they shape the universe and determine the fate of things from the scale of galaxies and beyond to the scale of cells and below.

A refresher is in order.

The first law states that in all energy transformations in nature, the total amount of energy is conserved. Energy is neither created nor destroyed but rather converted from one form – say, electric energy – to another – say, the kinetic energy of a body in motion.

The second law concerns entropy, which measures the degree to which the energy in a system is distributed. It measures how much the system's energy is 'smeared out'. When there are energy gradients in the system – that is, the energy is not smeared out and entropy is low – energy transformations can occur and 'work' – that word that physicists love – can be done in the system. But after the transformation, the entropy of the system always increases as the energy gradients decrease, even as the total energy of the system remains constant. In simple terms, energy gradients drive fluxes that act to reduce the gradients that drive them.

This means that all closed systems – those that have no inputs or outputs of energy or matter – eventually run down as energy gradients disappear and entropy increases. Ultimately, all the energy in the system ends up as uniformly distributed heat energy. This state of 'thermodynamic equilibrium' is signalled by all the parts of the system reaching a uniform temperature.

A physicist friend, John Finnigan (to whom I am indebted for this summary), quipped:

First law of thermodynamics: The best you can do is break even

Second law of thermodynamics: You can't break even

But this is not so for open systems that can accept inputs of energy and material to maintain energy gradients and counter the increase in entropy.

And we know that complex open systems, especially living systems, organise themselves – that is, create local order and structure – to maximise the flow of energy and thus entropy to maintain themselves. The principle of Maximum Entropy Production describes this process for complex open systems as they create local order – negentropy – and shunt entropy out of the system.

Thus, the diver's outboard motor transforms the chemical energy in the fuel to the kinetic energy of the motion of her boat as she travels to her dive site. There, a coral polyp transforms the chemical energy stored in molecules in its tentacles to the kinetic energy of muscle contraction to capture a zooplankter. And there, electrical energy in the diver's nervous system triggers the transformation of chemical energy to the kinetic energy of writing on a slate. The transformations are lossy in each case – ultimately to low temperature heat, and the entropy of these systems increases in each case.

But the two living systems – complex adaptive systems – manage the transformations through their evolved structures, increasing their negentropy as they shunt the entropy from their systems. It's the essence of being alive.

But learning to manage the flow takes immense periods of time. As living systems have evolved, they have become better at configuring themselves. They have complexified as evolution has discovered ever more subtle ways to maximize the flow of energy. At first, the external forces driving these systems were abiotic, to which living systems evolved to respond to temperature, salinity, and the like. Over geological time, biotic forces became more prominent as living things competed against each other for resources or preyed on one another as resources.

Peter Haff (2014) has argued that a strong interpretation of MaxEP would suggest that the biosphere was one solution to the Earth's energy flows and was selected by entropy maximization. There may be other solutions, and it may be possible for complex adaptive systems to find other, better solutions that are potentially available to them. But this may not always happen. There may be hidden constraints that prevent that discovery. And, in any case, the search for solutions takes time. Thus, the Earth system took nearly two billion years to evolve a biosphere based on free oxygen harnessed by mitochondria. This created the greatly increased stores of negentropy seen in the great diversification of life known as the Cambrian explosion.

It seems clear that coral reefs, as complex adaptive systems, found, over geological time, a novel solution to the MaxEP problem for their particular environment – warm, shallow, nutrient-poor tropical seas. It is also clear that this solution was unavailable to other living systems. In fact, this solution was so subtle that it was only found three, perhaps four, times in the last half a billion years of the evolution of the Earth system. The Tabulata and the Rugosa, cnidarians from the Palaeozoic era, and perhaps the poriferan *Stromatoporoidea* from the same era, first discovered the MaxEP solution used by the Scleractinia of today's coral reefs.

The key elements of the solution found by reefs are these: a tightly co-adapted capture of solar energy by short-lived microorganisms – the zooxanthellae – together with the encapsulation of those

organisms in long-lived megastructures – the hermatypic corals – that optimally position them for photosynthesis. This symbiosis was driven by MaxEP. And it's telling that the whole process operates just below its thermal threshold (Hoegh-Guldberg et al. 2007, Fig. 1, p 1738). The MaxEP principle would predict that, in a stable environment, corals would be driven – and tightly adapted – to operate near their biochemical maximum (at which metabolic processes run mostly quickly).

But that's only part of the story. The long-lived coral megastructures are themselves surrounded by and interact with a set of large, long-lived organisms – including fish, sharks, cetaceans, sirenians, turtles, pinnipeds and crocodiles – with which they interact to form the coral reef ecosystem. Many of these organisms live their lives around their home reef, a phenomenon Ann Cameron (1974) called 'stationariness', a phenomenon she thought a consequence of the stability of coral reef environments.

Of course, today some reef scientists may not recognise some of the penumbra of mega-vertebrates surrounding the corals themselves. Perhaps they see only the fish – and then not large decades-old ones. But the historical record is clear that these organisms were integral parts of the coral reef ecosystem (Bertram and Bertram 1973; Jackson 1997; Dillon et al. 2021) and thus integral components of the MaxEP solution that is that system.

This set of large, long-lived and 'stationary' organisms together dramatically slows down the flow of energy through the coral reef system from the sub-second time scales of microbial photosynthesis to time scales of decades or beyond for the energy stores in large long-lived organisms. This allows the system the time to drive towards MaxEP and allows further complexification of the system – seen as an increase in order, negentropy and diversity (Tainter 2006).

That further complexification is what we see when we dive on a decent reef – the stunning diversity of

organisms that have been able to evolve to make a living by exploiting bits and pieces of this large, long-lived store of negentropy.

And negentropy concepts have something useful to say about how this further complexification occurs, although the mathematical details are beyond our purposes here. Roddy Dewar and Annabel Porté (2008) offer a compelling analysis of the use of Maximum Relative Entropy (MaxREnt), a generalisation of the better-known principle of maximum Shannon entropy (MaxEnt), for explaining the origin of ecological patterns.

Their analysis goes to the heart of the matter of species diversity – ‘why there are so many kinds of animals’ as Evelyn Hutchinson (1959) put it in his famous essay, *Homage to Santa Rosalia*. This is a problem that has vexed ecologists at least since Charles Elton (1927) a century ago. And in the years

since, many ecologists, including Ronald Fisher (1943), Frank Preston (1948), Robert MacArthur and Dick Levins (1967) and Bob May (1973), built a consensus that the explanations of diversity lay in the ideas of ecological dynamics – especially processes of competition, predation and symbiosis – generating the observed patterns of community structure.

Dewar and Porté offer a refreshing counter to this primacy of dynamics. They argue that the explanation of community assembly patterns is ‘not unique to ecology but rather reflects the behaviour of complex systems with many degrees of freedom under very general types of environmental constraints’ (Dewar and Porté 2008, p 399). That is, ‘the statistical explanation of ecological patterns is not merely analogous to that of thermodynamic behaviour; mathematical similarities between the two explanations point to their common origin in the generic statistical behaviour of complex systems under very general types of environmental constraints’ (op. cit., p 390).



The Second Law of Thermodynamics:

Life on Earth can't get more complex because that would require energy, and the sun doesn't exist.

With thanks to Zach Weinersmith (Saturday Morning Breakfast Cereal) for permission to reproduce his cartoon.

In this view, community assembly patterns – and by extension what ecologists understand as species diversity – are best explained as a consequence of the statistical mechanics of the complex systems we call ecosystems, rather than as the deterministic dynamics of such systems. Species diversity patterns are expressions of community-level behaviour that can be realised in the greatest number of ways at the individual level. The observed community-level behaviour – the species diversity – ‘represents the most probable way in which a large number of internal degrees of freedom (individuals) could self-organise when subject to a relatively small number of environmental constraints (space and resources)’ (op. cit., p 397).

They conclude ‘MaxREnt provides a statistical perspective on community assembly which contrasts with previous dynamical models. MaxREnt explains community assemblages in terms of the most probable species abundance distribution that

could occur under given environmental constraints, without assuming anything about the internal population dynamics' (op. cit., p 397). For us, this means that the manifest diversity of coral reefs is but an epiphenomenon of the underlying phenomenon of this complex system's adherence to the principle of MaxREnt and its drive to MaxEP.

And the historical record is also clear that while the diversity of coral reefs has been created by the drive of these complex systems to MaxEP, reefs have been, and continue to be, degraded as neighbouring complex systems – human societies – intercept negentropy stores of coral reefs in their own drive to *their* MaxEP. The collapse of coral reef systems may be manifested as a decline in diversity, but the damage to system structure is deeper, especially in the loss of the long-lived mega-vertebrates. John Pandolfi (2003), leading our team, was able to show convincingly that many, perhaps most, of the coral reefs in the world today began degrading centuries ago. There was no *noble savage* period of sustainable use of coral reefs, no Rousseauian *state of nature*. There was, instead, a progressive increase in harvesting coral reef organisms – mainly fish – as human cultures intercepted the negentropy of coral reefs at the maximum level allowed by their technology, complexifying their systems and reaching for their MaxEP at the expense of coral reef systems.

This centuries-old degradation of coral reef systems by neighbouring systems is confounded by the decades-old broaching of Holocene planetary boundaries for the temperature and acidity of tropical seas (Hoegh-Guldberg et al. 2007) – the careless by-product of the human use of fossil-fuel free energy (Steffen et al. 2015). The emerging Earth system is antithetical to the MaxEP solution for coral reefs.

Coral reefs, then, are complex open systems. They are subsystems of the Earth system, itself a complex open system. From the Middle Triassic to the Holocene, coral reefs were able to reach a solution to MaxEP that had been found only a few times before in the Palaeozoic. They became the major ecosystems in shallow, tropical, nutrient-poor seas

worldwide. Their drive for MaxEP created a large, long-lived and 'stationary' store of negentropy. This allowed further complexification through MaxREnt. And created the stunning diversity and transcendent beauty that so transfixed Fred Grassle.

But as the Earth system undergoes reorganisation from the Holocene to the emerging Anthropocene, the MaxEP solution that coral reefs found, and exploited so successfully, may no longer be reachable (Hoegh-Guldberg et al. 2007). Moreover, the key driver of the emergence of the Anthropocene – the growing impact on all other systems within the Earth system of the human system's drive for its own MaxEP – means that more and more of the negentropy stores of coral reefs will be intercepted by adjacent human systems (Pandolfi et al. 2003).

Sadly, coral reefs are destined to suffer the same fate as their Palaeozoic forebears. ▶

This essay is the first part of a planned three-part piece on the future (or not) of coral reefs. The conclusions are tentative and are offered for comment and criticism. I will be pleased to respond. My email is roger.bradbury@anu.edu.au

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Joining global efforts to halt coral reef decline: a call for more diversity, equity, and inclusion at international scientific meetings

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Finding solutions to the global coral reef crisis will require active adaptive management, where scientific results on successes vs failures at local field sites are used to inform conservation interventions and natural resource management. Any scientific progress and solution-focused innovation starts with the exchange of knowledge. Scientific conferences can quickly disseminate major research findings and encourage public debates to push the boundaries of science. Traditionally, global biodiversity conservation meetings have required long-distance travel,

registration fees, and hotel expenses. These costs are a participation barrier for delegates from the Global South, including low, lower-middle, and upper-middle income economy countries (as defined by the World Bank, and hereafter together referred to as lower-income countries) in Latin America, Asia, Africa, and Oceania, where most biodiversity hotspots occur. With the outbreak of the COVID-19 pandemic, many conferences changed from ‘in-person’ (physical) to ‘online attendance’ (virtual), while some conferences tested the ‘hybrid’ model with one or multiple conference hubs for in-person attendance combined with a platform for virtual participation.

Aligned with the United Nations’ Sustainable Development Goal 10 to “Reduce inequality within and among countries”, to achieve positive conservation outcomes we need to focus all our efforts on a more **Diverse, Equal, and Inclusive (DEI)** approach and strive to enable delegates from lower-income countries to attend international meetings, so as to foster the exchange of knowledge and collaboration at a global level. The switch to virtual conferences offers a unique opportunity to expand access to more diverse societies.

However, examination of virtual and hybrid events in 2020 – 2022 reveal that high registration fees are still a barrier to DEI. Registration fees for 20 virtual conferences on marine science and/or biodiversity ranged from 0 to 500 USD (US dollars) (**Table 1**), with an average at 231 USD. However, four conferences had a completely free registration and three were ≤ 100 USD. We note that “free” conferences are provided based on significant inputs and funding from professional bodies or other groups, that is, someone else has covered the costs of setting up and running them. In contrast, the cost of attending in-person at a hybrid conference (6 in total) ranged from 320 to 949 USD (**Table 2**). This wide range of fees reflects a wide variety of arrangements for on-line participation. For instance, some conference organisers only permit instantaneous participation, while others host pre-recorded presentations and / or allow viewing for up to a year later - an arrangement incurring considerable costs but beneficial to

participants in meetings with multiple parallel sessions.

Nevertheless, there is a need to overcome the greatest barrier to sharing scientific results at the international level: the high cost of conference registration and of travel to the conference site. Here, we provide evidence from our own observations and discuss strategies for improving DEI and fostering international networking. We focus on conferences in marine biodiversity conservation, as this is the area of expertise of the authors. We demonstrate one example in coral reef research (Reef Futures, Florida, 2018) where participation of delegates from lower-income countries was encouraged at the inception of the conference. We also document the steps taken by the oldest international reef society (ICRS) to promote DEI for the 2022 15th International Coral Reef Symposium in Bremen, encouraged by a call from within the scientific community.

[...] there is a need to overcome the greatest barrier to sharing scientific results at the international level: the high cost of conference registration and of travel to the conference site.

The Reef Futures conference – an in-person event held in the Florida Keys during 2018 - was the first international conference held solely with the aim of finding inclusive and feasible solutions to coral reef restoration. This conference convened an international community of 550 reef restoration scientists, practitioners, businesses, and civil organisations from nearly 40 countries. Thanks to a significant effort by the conference organisers to secure in-kind and cash sponsorships, DEI were improved by providing ~ 55 scholarships to scientists and practitioners from lower-income countries to participate upon application. With a commitment to DEI, nearly 10% of all participants received attendance support financed by a multitude of sponsors (including Paul G. Allen Family Foundation, XPRIZE, The Ocean Foundation, Iberostar Hotels & Resorts and the International Coral Reef Society).

Table 1: Comparison of registration costs for virtual (i.e., on-line) national and international biodiversity and marine conferences between 2020 and 2022. All fees are displayed as 'non-member, non-student participation fees' for taking part in the virtual format of the conference (from most expensive to least expensive).

Conference name & year	Location of organisers	Source/Website	No of delegates (if known)	Format	Registration cost (USD 2022)
International Conference on Coral Reef Biology, Geology and Ecology, ICCRBGE001 2021	Sydney, AUS	https://waset.org/biology-and-geology-of-coral-reefs-conference-in-december-2021-in-sydney	Unknown	Virtual	500
International Conference on Coral Reef Biology, Geology and Ecology, ICCRBGE001 2022	London, GBR	https://waset.org/coral-reef-biology-geology-and-ecology-conference-in-november-2022-in-london	Pending	Hybrid	Virtual: 500
15 th International Coral Reef Symposium 2022	Bremen, DEU	https://www.icrs2022.de/	Pending	Hybrid	Virtual: ~452 Free to participants from low, lower-middle, and upper-middle income countries
11 th International Conference on Environment Science and Biotechnology 2022	San Francisco, USA	https://waset.org/environmental-science-and-biotechnology-conference-in-june-2022-in-san-francisco	Pending	Hybrid	Virtual: 450
14 th International Coral Reef Symposium 2021	Bremen, DEU	https://www.icrs2021.de/	1300	Virtual	413
10 th International Conference on Environment Science and Biotechnology 2021	Osaka, JPN	http://www.icesb.org/	Unknown	Hybrid	Virtual: 400
9 th World Conference on Ecological Restoration 2021	Global	http://www.ser2021.org/	1400	Virtual	Non-Member: 399 Equity Non-Members (students, retirees and others): 169
National Conference on Ecosystem Restoration 2021	Gainesville USA	https://conference.ifas.ufl.edu/ncer2021/index.html	Unknown	Virtual	295 To access conference session recordings: 95
ECSA 58 - EMECS 13: Estuaries and coastal seas in the Anthropocene – Structure, functions, services, and management 2021	San Sebastian, ESP	http://www.estuarinecoastalconference.com/	Unknown	Virtual	248
The 7th International Conference on Agricultural and Biological Science 2021	Jinzhou, CHN	http://iser.co/Conference2021/Kenya/1/ICABS/	200	Hybrid	Virtual: 220
8 th International Symposium on Marine Sciences 2022	Gran Canaria, ESP	https://isms-canarias.com/en-isms	Pending	Hybrid	Virtual: ~210
74 th Annual Gulf and Caribbean Fisheries Institute (GCFI) 2021	Marathon, USA	https://www.gcfi.org/gcfi74/	Unknown	Virtual	200 for US delegates; 100 for non-

					US delegates
XL Congreso Ciencias del Mar 2021	Concepción, CHL	https://congresocienciasdelmar.cl/	~300	Virtual	110
Society of Ecological Restoration Australasia 2020	Darwin, AUS	https://www.sera2020.org/	~130	Virtual	100
GEO BON Open Science Conference 2020	Leipzig, DEU	https://conf2020.geobon.org/	~120	Virtual	75
International Marine Conservation Congress (IMCC) 2020	Kiel, DEU	https://conbio.org/mini-sites/imcc6	700	Virtual	50
Reef Futures 2022	Key Largo, USA	https://reeffutures.com/coralrestorationconsortium/frontend/reg/thome.csp?pageID=44&eventID=1&traceRedir=2	Pending	Hybrid	Free
5 th ASSEMBLE Plus Conference 2021	Europe	https://www.assembleplus.eu/	571	Virtual	Free
International Conference on Marine Science 2020	COL	https://marinescience.co/	Unknown	Virtual	Free
6 th International EcoSummit Congress 2021	Gold Coast, AUS	http://www.ecosummitcongress.com/	Unknown	Virtual	Free

Table 2: Comparison of registration costs for physical (i.e., in-person) national and international biodiversity and marine conferences between 2020 and 2022. All fees are displayed as 'non-member, non-student participation fees' for attending in-person (from most expensive to least expensive).

Conference name & year	Location of organisers	Source/Website	No of delegates (if known)	Format	Registration cost (USD 2022)
15 th International Coral Reef Symposium 2022	Bremen, DEU	https://www.icrs2022.de/	Pending	Hybrid	Onsite: 949
ECSA 59 - EMECS 13: Estuaries and coastal seas in the Anthropocene – Structure, functions, services, and management 2022	San Sebastian, ESP	http://www.estuarinecoastalconference.com/conference-register.asp	Pending	Hybrid	Onsite: 849
Reef Futures 2022	Key Largo, USA	https://reeffutures.com/	Pending	Hybrid	Onsite: 575 for developed nation; 375 for developing nation
The 8 th International Conference on Agricultural and Biological Science 2022	Shenzhen, CHN	http://www.absconf.org	Pending	Physical	Onsite: 550
10 th International Conference on Environment Science and Biotechnology, ICESB 2021	Osaka, JPN	http://www.icesb.org/	Pending	Hybrid	Onsite: 430
1098 th International Conference on Agricultural and Biological Science, 2021	Unknown	http://iser.co/Conference2021/Kenya/1/ICABS/	Pending	Hybrid	Onsite: 320
8 th International Symposium on Marine Sciences 2022	Gran Canaria, ESP	https://isms-canarias.com/en-isms	Pending	Hybrid	Onsite: ~290
XL Congreso Ciencias del Mar 2022	Concepción, CHL	https://congresocienciasdelmar.cl/en/	Pending	Hybrid	Onsite: 284

At the Reef Futures conference, 23 scientists and practitioners from Spanish-speaking countries shared with scientists from as far away as Australia, their scientific and practical knowledge in implementing large-scale coral reef restoration projects. The meeting produced a multi-author review of coral reef efforts in Latin American countries and territories (Bayraktarov et al. 2020) and is an example of effective international collaboration made possible by supporting DEI at a global meeting. The same consortium of authors submitted a proposal for a session focused on the regional efforts in the Caribbean and Eastern Tropical Pacific to the International Coral Reef Symposium (ICRS20), when it was to be held in Bremen, Germany, in July 2020. This was the first time in its 50-year history that ICRS would have a session specifically inviting contributions from the Caribbean and Eastern Tropical Pacific and encourage work by local scientists from Spanish-speaking countries.

However, due to the COVID-19 pandemic, ICRS20 was initially postponed to 2021 (ICRS21) and then held as a virtual conference hosted from Bremen, Germany. Unfortunately, the virtual registration fees of 350 Euro (~413 USD) (a consequence of both the extra costs imposed on the organisers by the previous year's cancellation, and the need to broadcast and store so many parallel sessions) precluded most of the accepted delegates from lower-income countries from participating in the session on restoration in the Caribbean and Eastern Tropical Pacific. The registration fees for previous International Coral Reef Symposia were likewise high; further, they were held in what for most were relatively distant locations, such as Hawaii (ICRS16) and Australia (ICRS12), incurring high travel costs for many delegates¹. Nevertheless, the ICRS21 registration fee of 413 USD represented 70% of the average monthly wage of professional staff among the five main Latin American countries with coral

reefs (World Bank 2021). So, on this occasion, the opportunity to exchange scientific results between researchers from a diverse set of countries was largely lost.

For 2022, the ICRS Organising Committee concluded it was best finally to host a hybrid conference in Bremen, automatically accepting presentations approved for the virtual ICRS21, if the authors so wished. In early 2022, symposium chairs were asked to confirm whether their sessions, that were previously accepted for ICRS21, would reconvene in-person in July 2022. For this meeting, the International Coral Reef Society and ICRS22 Organisers made a commitment towards increasing DEI and agreed to contribute 50,000 USD in new sponsorship by offering free registration to all online presenters employed and residing in low, lower-middle, and upper-middle income economy countries. This clear commitment to DEI set a new precedent in the 50-year history of the International Coral Reef Symposia. The move was in part prompted by a group of session chairs and presenters who had written a letter outlining their concerns at the high online registration costs, which had now increased to 395 Euro (~452 USD). The letter was initially shared with the conference organisers, after which it was [made available via social media](#) (Twitter) and email lists (e.g., Coral-List). This is an example of a case where public discourse by the scientific community has assisted in promoting DEI.

At the same time, it needs to be acknowledged that the Organisers of the Bremen ICRS were placed in a near impossible situation when the COVID-19 pandemic irrupted in early 2020. It is appreciated that a significant drain in conference funding resulted both because costs could not necessarily be reclaimed when the original conference was postponed, and because some of the original sponsors had inevitably withdrawn their support. It should also be noted that the Society was already highly proactive in promoting diversity and equity. Over ten years ago, the Society introduced a system of scaled membership dues, with greatly reduced subscription rates available to members from low and lower-middle income countries. The Society

¹ But note that the Society only took over responsibility for the Symposia ~6 years ago, prior to the Hawaii meeting; previously they had been the responsibility of IABO – the International Association for Biological Oceanography – see Reef Encounter 49, p 29 (editor)

also introduced a system for election of council members that ensures that a proportion of them are from developing nations. For many years, the Society has been quietly promoting gender equality and generated a Diversity Statement and Code of Conduct, as a partial result of which, at least 50% of officers and council members have for some time been women.

Apart from the registration costs of conferences, there are also the additional costs of travelling, accommodation, and food, that need to be considered, if one wishes to attend a conference in-person. Given these huge costs, we would like to propose that the conference registration fees themselves for in-person participation should not exceed 20% of the average monthly wage of professional staff in the lower-income country of each respective delegate. In addition, we would argue that ideally on-line attendance for members from these countries should be free, upon application. International conferences should adopt a tiered cost structure for registration fees, where delegates from high-income and lower-income countries pay different registration fees that are affordable relative to the average monthly wage in each country. In addition, societies should promote more conferences in lower-income countries, with financial support from high-income countries. This would enable many more local delegates to participate in-person since they would not have to pay for such high travelling and accommodation costs. For example, travelling between Germany and south-east Asia costs ~1500-2500 USD, and in Germany accommodation costs ~70-150 USD per night and food ~30-80 USD per day. In comparison, costs for a conference in Bali would be around ~20-100 USD per night for accommodation and ~5-50 USD per day for food. Increasing the participation of lower-income countries attendees would promote an exchange of knowledge and greatly benefit resident scientists studying their local ecosystems. This is particularly important as poverty levels are higher in countries where biodiversity hotspots occur and where effective conservation is needed the most (Fisher and Christopher 2007). Better international knowledge

transfer would also reduce ‘reinventing the wheel’ and duplication of the effort which needs to be invested to conserve our precious ecosystems.

Here, we call for more action to increase lower-income country scientists’ access to scientific conferences and improve DEI outcomes. We strongly believe that the change to a virtual model, with an inclusive approach to providing financial support for participants facing socio-economic disadvantage, would significantly increase participation and dissemination of scientific results in a more global and inclusive manner (Wu et al. 2022).

Thus, in particular, we recommend the following strategies for improving DEI:

Make science exchange at conferences more accessible by adjusting registration fees and offering scholarships and travel grants to attendees from lower income countries.

A major component promoting a knowledge transfer is the exchange of visiting academics and students from lower-income countries to attend international conferences (Ramírez-Castañeda 2020). Providing travel grants to make attendance of scientists from lower-income countries possible, is therefore instrumental.

Strive towards new collaborations that will push the boundaries of science innovation and reveal new solutions to our biodiversity crisis.

Worldwide, nature is declining at unprecedented rates, with species extinctions accelerating and impacting people’s health and livelihoods (IPBES 2019). Avoiding ‘group-think’ and fostering an inclusion of a wide range of perspectives as well as local and/or traditional knowledge is paramount for finding innovative solutions to the global coral reef crisis. This was also the essence from the 6th International Panel on Climate Change report exploring climate change impacts, adaptation, and vulnerability (IPCC 2022). The global scientific community highlighted that if we want to halt biodiversity decline, we need new and more effective collaborations between academics, local communities, practitioners, businesses, and

governments to tackle the ‘wicked problem’ (i.e., Gann et al. 2019).

Conclusion, and where to next

If the goal is to halt global biodiversity decline, now more than ever, leading scientists and scientific societies must continue breaking the barriers to collaboration with lower-income countries and must foster effective DEI strategies, so as to promote wider participation in environmental problem-solving. Most recently, the COVID-19 pandemic has prevented high-income country scientists from traveling to overseas field sites, a situation that has encouraged scientists from lower-income countries to take a more active role in leading local field-based research. At the same time, the economic stress created by the need to keep field-based research projects alive has frequently forced local scientists to choose between investing in their research or attending expensive overseas conferences. It is therefore time to bring down, so far as possible, the barriers that in the past have often prevented scientists and practitioners from developing countries from sharing their work at international scientific conferences.

Given the increase in CO₂ emissions, the COVID-19 pandemic, the ever-evolving information technology, future conferencing may move towards virtual or at least hybrid with local nodes - a strategy that would allow for open, accessible, safe, and effective environments for people to interact. Conference organisers could apply a 4-step approach:

1) *Conference organising bodies (e.g. scientific, professional, government, industry associations/ societies/ unions/ institutes) need to change their business models by adding an Equality Clause that is aligned with the UN’s Sustainable Development Goal (SDG) 10 - to “Reduce inequality within and among countries” – and designed in particular (Target 10.6) to “Ensure enhanced representation and voice for developing countries in decision-making in global international economic and financial institutions in order to deliver more effective, credible,*

accountable and legitimate institutions” and (10a) to “Implement the principle of special and differential treatment for developing countries, in particular least developed countries, in accordance with World Trade Organization agreements”. The Equality Clause would consider ‘waiving registration fees for on-line participation’ and ‘providing equity discount for physical meetings’ to delegates from lower income countries.

2) *Conferences could somewhat reduce cost by looking for free or low-cost platforms or apps for conferencing, which are generalised rather than custom-made. For instance, although not free of charge, Zoom or Microsoft Teams are available through most organisations in charge of conference organising and can be used for webinars and workshops. Generic, out of the box, low-cost conference apps such as Whova can keep the costs down, e.g., as used at the International Marine Conservation Congress in 2021.*

3) *Conferences able to waive online registration fees and/or provide discounts for participants who cannot afford full registration fees have usually sought several corporate sponsors who have often also provided travel grants and reduced registration cost for on-site delegates.*

4) *Conferences should also investigate the introduction of a tiered approach where participants able to afford their registration and conference attendance pay somewhat higher registration fees than those less able to pay. The option to “Sponsor a colleague who has challenges attending” presented as a tick-box next to the carbon offset tick-box, could also appeal to some delegates.*

We acknowledge that the changes suggested above may seem challenging, but it is vital that we seek to maximise the accessibility of international fora, so that more of our global communities are able to engage and provide additional voices for biodiversity. ▶

Acknowledgments

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Response from the Society's President and the ICRS Organizing Committee Chair

The International Coral Reef Society is happy to report that it has already implemented most of the suggestions listed in this letter for the 15th International Coral Reef Symposium including free registration for all ICRS members from low-, lower-middle, and upper-middle income countries, tiered registration fees based on career stage, and the ability to participate virtually at a highly reduced cost. In addition, the Society's new financial plan includes three strategies for reducing conference registration costs for future symposia: 1) free registration for low, low-middle, and middle-income country members, 2) applying all of the newly acquired royalties from Springer for the Society journal *Coral Reefs* to reduce conference registration costs, and 3) the creation of a conference mitigation cost fund that donors can contribute to. In addition, all future Society symposia will be accessible both in-person and virtually. The ICRS is committed to continuing to increase equity, diversity, and inclusion at all future symposia.

Andrea Grottoli, ICRS President
Christian Wild, 14th and 15th ICRS Symposia organizing committee chair

REEF CURRENTS

Ten Years of ReefBudget: development, applications and recent methodology updates

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The cycling of calcium carbonate (CaCO_3) is one of four core process loops driving the functioning of a coral reef (Brandl et al. 2019). Measures of the rates of carbonate production and erosion (typically reported in the units $\text{kg CaCO}_3 \text{ m}^{-2} \text{ yr}^{-1}$) are therefore useful indicators of important reef ecosystem functions, including habitat provision, vertical reef accretion and sediment production (Perry and Alvarez-Filip 2019). Different approaches to measuring these carbonate budgets exist. Census-based methodologies have been

employed in many cases, because they provide information on the taxa-specific contributions to carbonate production and erosion, and because they can be readily integrated into other ecological monitoring studies.

In this context, the *ReefBudget* methodology has now been widely used as a standardised protocol for the monitoring of carbonate budget states across sites in the Indo-Pacific and the Western Atlantic Oceans (Fig. 1). A dedicated homepage (<https://geography.exeter.ac.uk/reefbudget/>) provides openly accessible guidance on the methodology in the form of handbooks, survey sheets, data entry and calculation sheets, and collections of underlying rate data for use in calculations. In this article we want to give a short background on the development of the method and alert those interested in using it to recent updates on the methodology and databases.

How it started

Initial ideas around the development of a

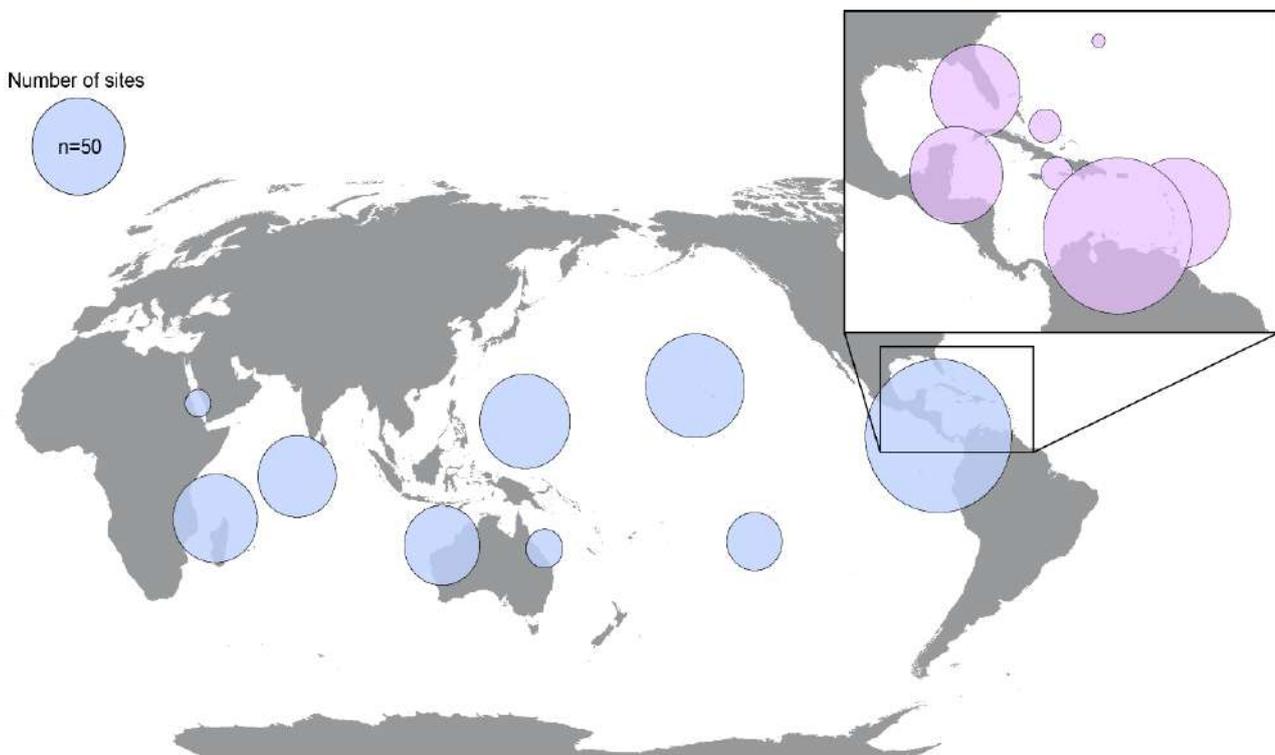


Figure 1: Geographic range of published reef carbonate budgets using the *ReefBudget* methodology. Bubble size indicates the number of sites surveyed (known to us) in biogeographical provinces across the Indo-Pacific (world map) and ecoregions within the Western Atlantic (inset). Most of the studies ($n=19$) and respective budget ranges are listed in Table S1 in Lange et al. (2020a) but the list has been updated with studies published 2019–2021. Some sites have been visited multiple times, which is not indicated in this figure.

standardised methodology for quantifying reef carbonate budgets arose from a review paper written in 2008. This review sought to present a conceptual framework for linking ecological changes on reefs to the processes driving the production and accumulation of reef structure (Perry et al. 2008). The ideas within this paper then led to a series of workshops which: 1) initially reviewed the merits of methodologies applied both in earlier carbonate budget studies (e.g., Stearn and Scoffin 1977; Hubbard et al. 1990; Harney and Fletcher 2003) and in other census-based ecological studies; and 2) then utilised and adapted these approaches to develop what was hoped would be a widely applicable survey method for quantifying biologically driven carbonate production and erosion rates. This early version of *ReefBudget* used planar coral cover and overall substrate rugosity metrics and combined resultant cover estimates with species-specific calcification rates to calculate reef-scale coral carbonate production (Perry et al. 2012). After initial field testing, the approach was applied across several Western Atlantic locations and the data was used to examine the effects of long-term regional ecological declines on carbonate production and reef accretion across the Caribbean (Perry et al. 2013; Perry et al. 2015b).

Having reflected on the uses, limitations, and potential refinements of *ReefBudget*, the methodology was then further developed with the aim of parametrising it for use in the Indo-Pacific. In the updated approach, coral cover is surveyed at a colony-level along the three-dimensional reef contour. This technique takes into account substrate rugosity and inter-species variations in skeletal growth morphologies, and thus better constrains calcification rates of individual coral colonies. In contrast to the Caribbean method, the Indo-Pacific *ReefBudget* employs genus- and



Figure 2. Conducting *ReefBudget* surveys in a coral reef in the Chagos Archipelago, where reefs are recovering from the bleaching event in 2015/2016 (photo: Ines Lange).

morphotype-level taxonomic categories, due to the high species richness and challenging in-situ coral identification issues encountered in this region. Details of survey methods and calculations are described in the [Indo-Pacific *ReefBudget* handbook](#).

How it's going

The updated *ReefBudget* methodology was first applied to sites in the Indian Ocean, including locations in East Africa, the Chagos Archipelago, and the Maldives. Most central Indian Ocean locations had very high positive carbonate budget states in 2015 or early 2016 (Perry et al. 2015a; Perry and Morgan 2017), but repeated surveys documented collapses in carbonate production and reef accretion potential following severe bleaching events in 2015/2016 (Perry and Morgan 2017; Lange and Perry 2019). This is worrying, as reefs with net negative budget states are unlikely to sustain important geo-ecological functions. Modelling approaches, as well as a global analysis of reef growth capacity, suggest that in the face of increasing sea levels, critical increases of water depth above reefs are likely (Januchowski-Hartley et al. 2017; Perry et al. 2018). On a more positive note, very recent research has shown that carbonate budgets in the remote and protected Chagos Archipelago presently appear to be

recovering relatively quickly from bleaching impacts through the fast return of key coral species (Fig. 2; Lange et al. 2022).

Following the Indo-Pacific approach, the Caribbean methodology was also then revised to include colony-level calculations, and the [Caribbean ReefBudget handbook](#) and calculation sheets were updated accordingly in 2019. In combination with historical survey data, recent monitoring showed that net carbonate budgets across the Mexican Caribbean have actually increased slightly over the last 15 years due to low but stable carbonate production rates, and to a decreasing abundance of bioeroding parrotfish (Molina-Hernández et al. 2020).

What's new?

Because the calculation of reef-scale carbonate production and erosion rates from in-situ survey data requires underlying information on coral growth and density, parrotfish bite rates and scar sizes, sea urchin erosion rates and rates of endolithic erosion, extensive tables of published data have been made available on the [ReefBudget](#) homepage alongside the method. An important point to note is that the calculation sheets are pre-set with species/genera-specific averages from all (known to us) available data from either the Indo-Pacific or the Caribbean. However, these underpinning rates are changeable, and users are encouraged to select the rates they feel are most appropriate – ideally to include locally obtained metrics. For instance, annual carbonate budgets in the Florida Keys were evaluated through a succession of bleaching events using temporally variable growth rates of the dominant coral (Manzello et al. 2018). A comparable example is the Chagos Archipelago, where we have collected a large set of locally obtained coral calcification and parrotfish erosion rate data for use in budget calculations (Lange and Perry 2020; Lange et al. 2020b).

Keeping an up-to-date record of calcification and erosion data that is emerging in the literature is not

an easy task and readers are invited to submit appropriate measurements and datasets to be included in regular updates on the [ReefBudget](#) homepage. The latest updates provide the most recent data collections, have removed minor glitches in the calculation sheets, improved the accuracy of calculations and tried to make the approach even more user-friendly:

- ▶ The Caribbean methodology, calculation sheets and databases were updated in June 2019 (version 2.1), with an additional fix to carbonate production sheets in September 2021. A translation of the handbook to Spanish is now also available.
- ▶ Indo-Pacific parrotfish and urchin erosion calculation sheets and databases were updated in June 2020 (version 1.3 and 1.2, respectively).
- ▶ The Indo-Pacific coral calcification database and carbonate production calculation sheets were updated in October 2021 (version 1.3). This update includes recently (since 2018) published data on coral growth rates and skeletal densities, and updated coral taxonomy in line with the 2021 version of the Coral Finder guide (Kelley 2020).

Other exciting developments include the use of our coral calcification data collections for a novel tool that has been developed for [CoralNet](#), allowing users to estimate benthic carbonate production rates from image annotations (Chen et al. 2021; Courtney et al. 2021). The utilisation of photographs and other planar data for use in carbonate production estimates is facilitated by applying recently defined colony scale conversion factors (González-Barrios and Alvarez-Filip 2018; Husband et al. 2022). Whilst there are inherent limits associated with using planar imagery, especially in highly complex terrains, the conversion approach offers interesting options for assessing historical image datasets, and for large-scale monitoring where in-water time is limited.



Figure 3 Explaining the *ReefBudget* methodology using a creative reef model during a training workshop run by BARCO LAB at Reef Systems Unit, Puerto Morelos, Mexico (photo: Ines Lange)

What's next?

We believe that the *ReefBudget* methodology provides a useful complementary tool to augment existing reef monitoring programs as it supports the assessment of reef functions alongside reef status. Two workshops in the Mexican Caribbean, hosted by the group of Lorenzo Alvarez-Filip at the Reef Systems Unit in Puerto Morelos in 2019 and 2022, facilitated training of local researchers, marine park managers and NGO staff in the use of the methodology (Fig. 3). The NOAA Coral Reef Conservation Program has also started to include *ReefBudget* surveys within their long-term monitoring programs, both in the Caribbean and in the Indo-Pacific.

Following from the discussions in Mexico and led by Rafael Cabral-Tena at CICESE in Baja California, we are currently in the process of developing a specific *ReefBudget* methodology and protocol for the Eastern Tropical Pacific region, given its distinct coral assemblages and bioeroding communities.

As we are constantly looking to develop, improve and expand the *ReefBudget* approach, we encourage interested readers to get in touch to discuss other applications, further modifications, or training opportunities.

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The Enrichment Enigma: Understanding Nutrient Thresholds in Reef Systems

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Background

The effects of enrichment by inorganic nutrients (such as nitrates and phosphates) on coral reef environments are long-debated and controversial.

While some scientists argue that nutrients may be contributing to increased coral resiliency, others counter that excess nutrient loading is linked to increased coral disease and subsequent mortality, or that it promotes the growth of algal turfs and macroalgae that can outcompete the corals. It is difficult, if not impossible, to reach a single conclusion regarding nutrient loading of coral reef environments as numerous questions must be addressed: Are the type of nutrients present in the system “good” or “bad”? Has a nutrient threshold been reached? What are the species-specific responses to varying nutrient concentrations? These questions may seem confounding, but following the nutrient yellow brick road is crucial if

we are to better understand the role that nutrients play in determining the health of coral reef environments.

Despite the wealth of ecosystem goods and services that coral reefs provide, local and global anthropogenic stressors are significantly impacting coral reefs worldwide. The frequency and severity of warm water coral bleaching events are increasing at a disturbing rate. It is therefore important to understand what other impacts may be exacerbating the effects of ocean warming.

Stressors can be generally categorized as natural or anthropogenic, biotic or abiotic, chronic or acute, and global or local. At any given time, there are often multiple categories of stressors acting on a natural coral reef environment. It may even be difficult to be certain into which category they fall. For example, ocean warming might be considered both anthropogenic, because of increasing carbon emissions, and natural, because there are also natural climate oscillations. Further, ocean warming can affect a reef at the same time as nutrient loading or sedimentation, both of which would be categorized as local, anthropogenic, abiotic, and either acute or chronic. For the purposes of this review, I shall concentrate on the interaction of ocean warming and nutrient loading.

Nutrients are not detrimental in every concentration. Just as the human body needs certain nutrients for survival, coral reef ecosystems need nutrients to maintain normal functioning, so that much of coral and reef physiology and ecology is adapted to securing adequate nutrients in an oligotrophic (low-nutrient) environment. One key reason that hermatypic corals can thrive in oligotrophic waters is because of their symbiotic relationship with their algal partners, the zooxanthellae. The coral animal acts as a host and, in generating normal metabolic waste products, provides the zooxanthellae with nutrients; in turn the zooxanthellae provide much of the fixed carbon that the coral animal uses for respiratory purposes (Jokiel & Dubinsky 1994). Corals, while absorbing the small quantities of nutrients available in the

water column, may also obtain inorganic nitrogen and phosphorus from their zooplankton prey. Zooxanthellae, like other forms of algae, require inorganic nitrogen and phosphorus, so that both they and their coral host are susceptible to any changes in surrounding nutrient concentrations (D'Angelo & Wiedenmann 2014). Recent evidence suggests that the coral microbiome may facilitate coral adjustment to changing environmental conditions (Reshef et al. 2006). More specifically, corals have been found to harbor diverse communities of diazotrophs, or nitrogen-fixing bacteria and archaea, that may contribute to nitrogen fixation and to overall holobiont functioning, especially in oligotrophic waters (Rädecker et al. 2015). The intricacies and complexities of coral-diazotroph interactions play an important part in understanding how corals may respond to increasing stressors.

While there is consensus within the scientific community that corals require base-level nutrients for growth, there has been intense debate regarding the direct and indirect effects of higher concentrations of these nutrients. This controversy developed largely because coral reefs can adapt and thrive across a nutrient gradient and are not necessarily restricted to low-nutrient environments (Szmant 2002), and because the balance of stressors (high nutrient input, overfishing of grazers) has varied considerably between different areas, even within the same geographical region. For example, fishing in the Florida Keys is managed to reduce the decline in grazers, but the reef system has experienced decline and breakout of disease in response to runoff from the Everglades (Lapointe et al. 2019). In contrast, islands in the Caribbean are not in the trajectory of runoff from nearby continental land-masses, but have experienced decades of overfishing that has led to an increase in macroalgal dominance and a decrease in coral cover, among other things (McClenachan et al. 2010). With all these interacting factors, it becomes hard to determine “good” vs. “bad” nutrient levels.

Classifying Nutrients

To fully understand a coral's nutrient needs, we

need to determine where these nutrients are coming from. An example of nutrients derived from natural sources is nitrogen and phosphorus concentrated in seabird and fish guano. These inputs, in healthy concentrations, can be important in oligotrophic ecosystems, since they can increase zooxanthellae density, which in turn can enhance photosynthesis and coral growth (Savage 2019). Provided these nutrient concentrations are kept in check, they can support a more stable, productive, and diverse ecosystem (Savage 2019). For example, a study by Becker et al. (2019) found that chronic low-level nutrient enrichment benefited coral thermal tolerance by increasing zooxanthellae density, leading to a net increase in photosynthesis and a greater total tissue biomass. Other studies have reported similar effects.

Issues start to arise when a particular nutrient threshold is passed, and with our anthropogenic input of nutrients to coastal systems on the rise, this is increasingly the case. The decline of coral reef ecosystems near heavily urbanized or industrialized areas and or agricultural regions has been especially linked to anthropogenic nutrient enrichment (D'Angelo & Wiedenmann 2014). As nutrients levels increase, rates of coral photosynthesis and respiration can be altered, resulting in a decrease in pH of the surrounding seawater. This can lead in turn to an increase in dissolution of the carbonate skeleton and a decrease in overall calcification, disrupting the corals' normal functioning and potentially causing whole-coral mortality (Silbiger et al. 2018) (see Figs. 1 & 2).

Furthermore, increased nutrient concentrations can lead to an overabundance of zooxanthellae; this can shift the relationship between the host and the algae from symbiotic to parasitic. This is because a marked increase in zooxanthellae

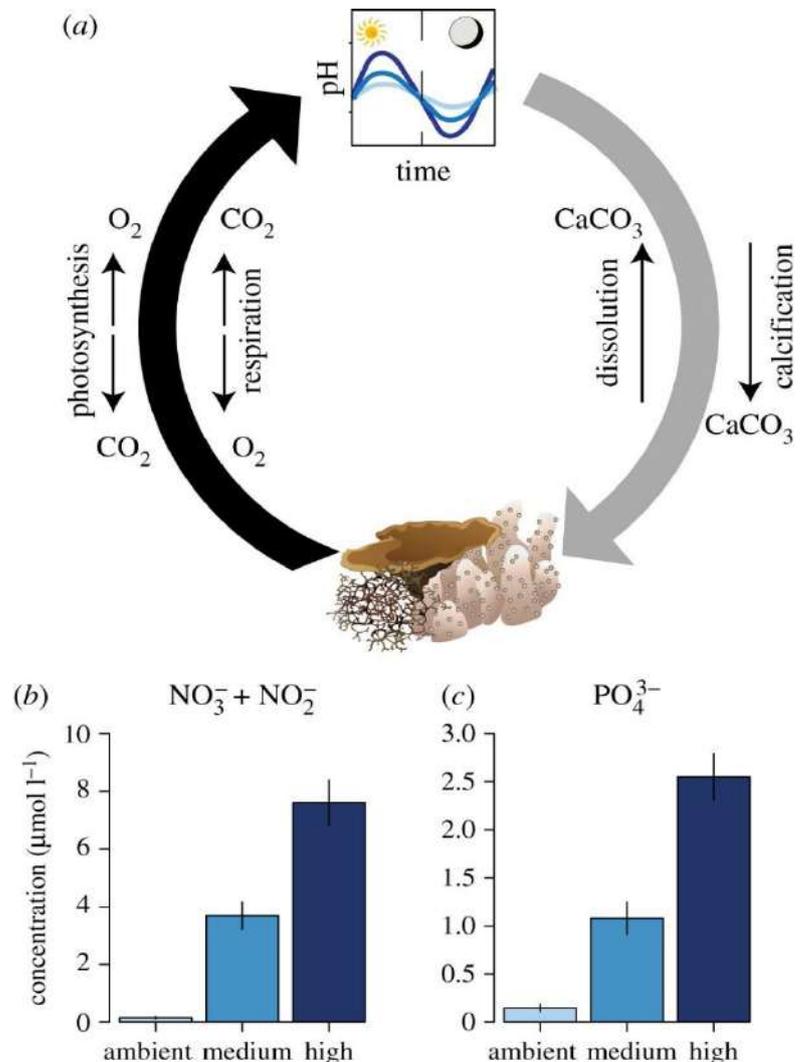


Figure 1. The effects of nitrate + nitrite and phosphate levels on coral calcification over time. Silbiger et al. 2018.

abundance can result in proportionally more energy being consumed in respiration, leaving less energy available as holobiont net primary productivity (Baker et al. 2018).

The effects of nutrient levels are known to differ by species. What might be a detrimental nutrient concentration for one coral species may be desirable for maintaining normal functioning in another. Effects also differ by situation. Two reefs containing coral species with similar nutrient thresholds and receiving similar anthropogenic nutrient input could react differently because of factors such as the natural nutrient concentrations already present, the presence or absence of herbivorous fish that control macroalgal growth, or



Figure 2. The rainbow we don't want: a coral fragment subjected to nutrient stress shows signs of bleaching and disease. Image Credit: Zoe Ruben 2021.

differences in water circulation and residency times.

So how can scientists determine how nutrients might be affecting a coral reef ecosystem when all these factors might come into play?

Molecular Approaches: The New Frontier?

Techologies, both old and new, have come together to create our current scientific appreciation of the effects of nutrient loading. To obtain a holistic picture, scientists must consider the issue in more than one context. Effects of stressors are generally observed as they pertain to overall coral health, rather than the health of individual components of the coral symbiosis. Generally, when we think of a coral animal, we think of the coral host and its zooxanthellae. However, the coral symbiosis is much more complex than this. Several other types of microorganism also call the coral home, including bacteria, archaea, fungi, and viruses, together constituting the coral microbiome. Corals,

it seems, can benefit from their microbial partnerships by recruiting different microorganisms that are more resilient to a range of environmental stressors, including nutrient loading (Morrow, Muller, & Lesser 2018; Figure 3).

Studies have found that bacterial communities within the microbiome may aid in nitrogen and sulfur cycling, both of which are crucial in nutrient loaded environments (Lesser et al. 2007 & Lema et al. 2012). A more recent study has demonstrated that it was the structure of bacterial profiles in the microbiome that drove coral tolerance of ocean warming in *Porites lutea*, while the structure of the corals' zooxanthellae community did not affect its tolerance (Pootakham et al. 2018).

Molecular techniques established only in recent years have allowed researchers to begin investigating some of these overarching questions by diving deeper into the world of microbial community composition. "Omics" approaches, such as genomics, metabolomics, and transcriptomics, can be used, in combination with biological and physiological response data, to gain a more holistic picture of how the coral animal is responding to stress at both phenotypic and genotypic levels. For example, biological response data may show that corals subjected to chronic high levels of nutrient stress may have lower zooxanthellae abundances than their non-stressed counterparts. These data could be further investigated by incorporating a genomics approach, such as gene sequencing, that may show whether the same stressed corals had higher prevalence of disease-associated bacteria and fungi. Instead of having just a sketch of the coral's response, we can paint an entire picture.

It is also important to re-acknowledge that typically no single stressor is acting alone on a coral at any given time; there are often multiple interacting stressors that contribute to coral damage and mortality. Research has shown that when corals are subjected to numerous stressors, the microbiome may shift towards a dysbiotic state, potentially leading to disease and even mortality (Zaneveld et al. 2016). We can see from such work just how

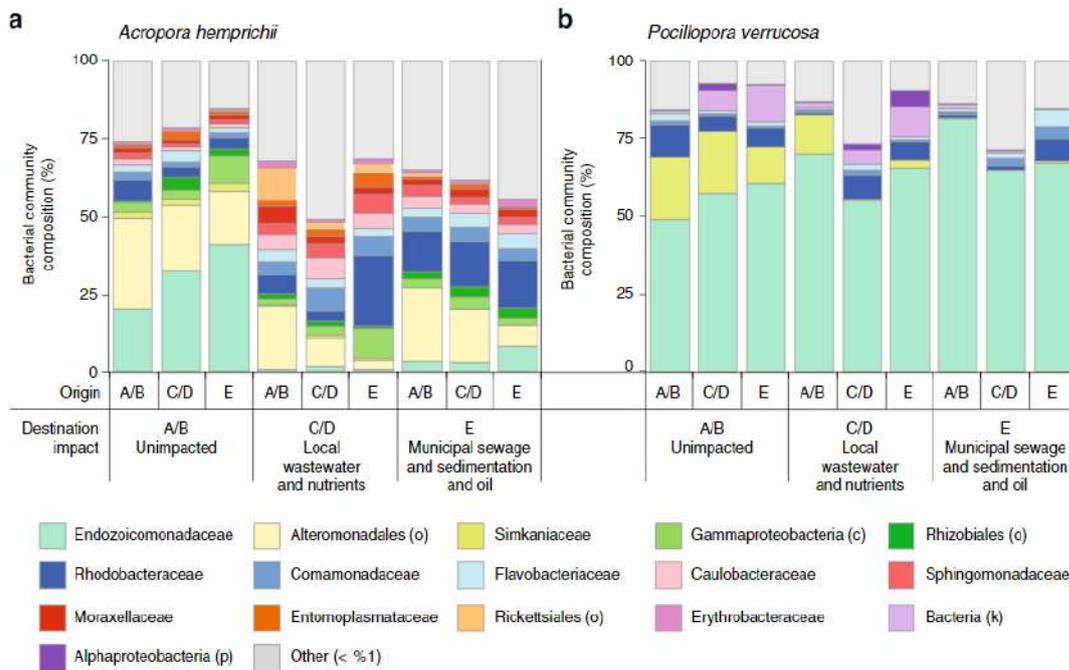


Figure 3. Observed shifts in bacterial community composition of two coral species based on presence / absence of potential stressors. Ziegler et al. 2019.

helpful it can be to combine both established and cutting-edge techniques in work to answer questions about the mechanisms of stressors on coral reefs. But enough about the science, what about action?

Science-Based Solutions

Just as many different techniques are being used to understand and explain science, so multiple approaches are also used to tackle climate issues. No one set of solutions will be applicable to different regions since each may have its own local stressors.

Clearly global impacts such as ocean warming, ocean acidification, and sea-level rise must be mitigated on a much broader scale, since they independently affect 11% of reefs worldwide (Guan et al. 2020). Local impacts, such as sedimentation, overfishing, and nutrient loading affect another 22% of reefs worldwide and have the potential to influence coral reef response to and recovery from global climate issues (Guan et al. 2020). However, global and local stressors combined are now affecting a as much as 61% of reefs worldwide (Guan et al. 2020). Therefore, it is now urgent to document the interacting effects of local and global

stressors so that we can implement location-based management strategies.

It can be a difficult, even overwhelming, challenge to determine actionable and economically feasible science-based solutions to local and global stressors such as nutrient loading and ocean warming. Good & Bahr (2021) suggest a combination of risk assessments, assisted evolution, and focused management strategies to address the multiple interacting stressors that are driving current coral reef decline (Fig. 4).

Accepting this analysis, it is vital that we implement all three areas of science-based solutions when seeking to create management and recovery plans for our reefs. We can circle back to the dual issue of nutrient loading and ocean warming to examine this further. Scientists can manipulate the coral microbiome to breed corals that host more resilient bacteria or zooxanthellae, but this action will be more successful if partnered with work to restrict nutrient loading to coastal areas and limit global CO₂ emissions.

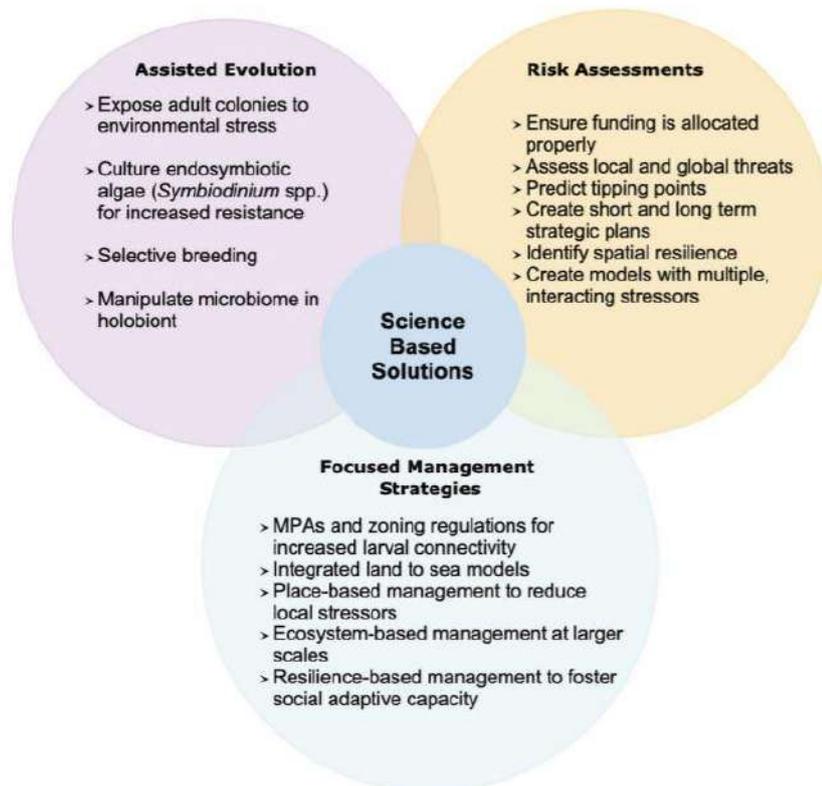


Figure 4. A synthesis of science-based solutions that can be used by managers and policymakers to address stressors related to coral reef decline. Good & Bahr 2021

Conclusion

Nutrient loading is becoming an ever-prominent issue in areas of high urbanization, intense industrial activity, and intensive agriculture. Consistently high ocean temperatures can exacerbate the effects of nutrient loading and lead to coral bleaching, disease, and frequent coral mortality. Global and local stressors must be mitigated in tandem with work using advancing molecular techniques paired with location-based and ecosystem-based management strategies if we are to maximize success. There can still be a future for coral reefs if we embrace a more integrative and inclusive way of thinking.

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REEF EDGE

A vulnerable shallow water sand-dominated coral reef environment within a Sudanese Red Sea UNESCO world heritage site

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Introduction

The Red Sea is one of the most biologically diverse tropical seas outside the Indo-Pacific center of marine biodiversity in the Indo-Malay region (Spalding et al., 2001). Historically, the Red Sea has been reported as a hotspot of coral reef endemism, with a pool of unique genetic lineages that are exported to other regions. More recently, DiBattista et al. (2016) reported 346 species of scleractinian corals, 635 polychaetes, 211 echinoderms, 79 ascidians, 231 crustaceans, 137 molluscs, and 1071 shallow-water fishes. In total, 2710 species have been identified on Red Sea coral reefs with levels of endemism ranging from <10% (for scleractinian corals, molluscs, and echinoderms) through 10%–12.9% (for polychaetes, crustaceans and fish) to 16.5% for ascidians. The Red Sea has perhaps been less studied than other extensive reef systems (Berumen et al., 2013), but has seen increased scientific attention in recent years, with active research institutions in Saudi Arabia, as well as Israel and Egypt. The global threat to coral reefs due to the effects of accelerating anthropogenic global warming have made the heat tolerant corals found in the central Red Sea the focus of high-impact studies (e.g., Savary et al., 2021). In this context we have been pursuing a project, “Building institutional capacities for an ecosystem approach to management of the marine fishery in the Red Sea State”, in order to investigate the magnitude and



Figure 1. Map showing the location (inset) and extent of the Dungonab Bay and Mukkawar Island National Park (DMNP), designated as a UNESCO world heritage site since 2016 (delineated in black). The red pointer marks the location of the survey site on the sheltered south-western side of Mukkawar Island.

impact of Sudan’s artisanal coral reef fishery on Red Sea reefs (see Olsen et al. 2021).

The Sudanese coast, on the western shores of the Red Sea, is about 750 km long, including bays and inlets, and extends from 18°N to 22°N. Three distinct depth zones are recognized: shallow reefs-studded shelves less than 50 m in depth, deep shelves from 500 to 1000 m, and a central trench reaching a maximum of 3000 m off the city of Port Sudan. Most of the coast is bordered by fringing reefs 1-3 km wide, separated by deep channels from an offshore barrier complex 1-14 km wide. The outer barrier complex drops steeply to several hundred meters in depth.

Here, we report data from 2016 and 2017 on the occurrence of an unusual shallow water coral reef environment, dominated by *Acropora pharaonis* (IUCN status: vulnerable), that we have found on the sheltered SW side of Mukkawar Island in northern Sudan (Fig. 1). The site is situated within the Dungonab Bay and Mukkawar Island National Park (DMNP), inscribed as a UNESCO world

heritage site since 2016 (UNESCO 2016). This status was granted the area to promote protection and due to its function as a biodiversity hotspot (e.g. Kessel et al. 2017). However, the DNMP is not a strictly protected MPA, and local fishers were allowed to continue the artisanal coral reef fishery after its designation.

Materials and methods

The data presented here were collected in 2015-17, during the first coastwide coral reef surveys conducted by Sudanese agencies which covered sites along the entire coast in order to assess coral reef fish assemblages and determine the health status of the reefs. Fish and corals were surveyed by underwater visual census (UVC) by means of diver-operated video (DOV) using a stereo camera rig. Data on coral cover was obtained by analyzing the benthic video transects for habitat cover using an adaptation of the Reef Check protocol for benthic UVC, and colony heights for *A. pharaonis* formations (Fig. 5) at the site described here were obtained by analyzing the stereo videos recorded during three horizontal fish transects using the SeaGis software EventMeasure.

Results and Discussion

Coral species from nine genera were found at the site on the SW side of Mukawwar Island, but the site was dominated by a forest consisting of numerous large and apparently old stands of *Acropora pharaonis*. While the large size of the colonies indicate stability, our analysis of the benthic video transects indicated a small decline in benthic cover between 2016 and 2017 (Fig. 2), with live coral cover reduced from 9.25% to 6.5%.

Although transects were started from the same Global Positioning System (GPS) location in both years, and following the same compass direction, we note that the difference in live coral cover could be due to slight differences in transect path between the two years.

However, the reduction in live cover did not correspond to an increase in dead cover, with dead coral cover also being reduced - from 40.75% in 2016 to

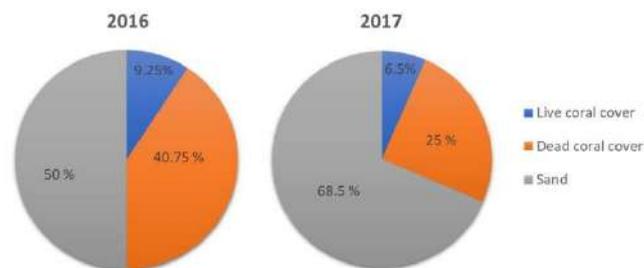


Figure 2. Substrate cover at the study site on the SW side of Mukkawar Island, as estimated from benthic video transects recorded during November 2016 and 2017.

25% in 2017 (Fig. 2). We suspect that these changes were related to the movement of sand, so that sand covered more dead coral in November 2017 than in November 2016. This notion is supported by the increase in sand cover from 50% to 68.5% between 2016 and 2017. We speculate that the site is highly dynamic in terms of substrate and that the dominant growth form of *A. pharaonis* (Fig. 3) at the site is an adaptation to frequent movement of sand brought about by the currents and wave surge around this part of the island; possibly there may also be sand loading from dunes on the nearby Mukkawar Island, and even the mainland. The tall fragile colonies (Fig. 4), several measuring >1 m in height in 2017, are clearly vulnerable to breakage (Fig. 5) and their existence and long-term persistence at the site (judging by colony size) is likely testament to there having been very little disturbance from anchoring and fishing operations (e.g., handline, traps, gillnets).

We recommend that the site is included in plans for special measures to conserve vulnerable ecosystem features within the DMNP. We also recommend regular monitoring of the site to assess its resilience to cumulative stressors in the Red Sea ecosystem.



Figure 3. The UVC survey site on the SW side of Mukkawar Island (see Fig. 1): a) and b) example images from benthic video transects (left camera), c) and d) *Acropora pharaonis* colonies viewed from the level of the colony at approximately 6 m depth.

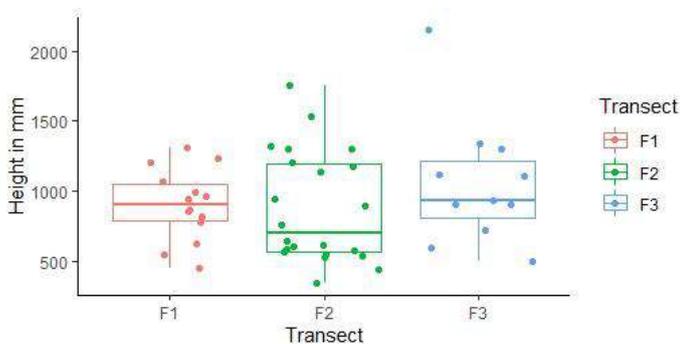


Figure 4. *A. pharaonis* colony heights on three 50 m UVC fish transects in SW Mukkawar as obtained from the stereo diver operated video (DOV). Boxplots show median values, upper and lower quartiles, whiskers the full range of values, and jittered points the individual measurements



Figure 5. *A. pharaonis* was a dominant feature of the site, with some colonies being partially topped (a, b) and/or topped and smothered (c). Among other live hard corals found at the site were *Millepora dichotoma* (a, c), and low growth forms of *Porites* sp. (a, b); also present was *Tubipora musica*, with emergent polyps evident (a, c).

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2017 Northern leg dive team (left to right): Abdualdrada Mirghani Elhag, Maurizio Chiarenza, Even Moland, Abdelmohsin Mohamed Suliman.

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Space competition under thermal stress: clonoid sponge versus favid coral, Gulf of Mannar, India

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Introduction

Persistent and prevalent decline of coral reefs due to global temperature anomalies has, over the past couple of decades, developed into the most significant issue now affecting the marine environment (e.g. Eddy et al. 2021). Within each

local reef community, space competition among the sessile reef dwellers during and after a mass bleaching event plays a large part in driving benthic community shifts or in permitting recovery. Notably some nuisance sponges have been portrayed as powerful space competitors, which can kill corals either during rapid population outbreaks of the sponge, or under changing environmental conditions (Rützler & Muzik 1993, Turicchia et al. 2018). This property of sponges has been explained in part by their greater ability to withstand temperature fluctuations and also by their capacity of benefitting from poor water quality conditions (e.g. Kelmo et al. 2008). In particular, excavating clionaid sponges have been described as faring better than corals under tough climatic conditions, such as elevated sea water temperatures (Schönberg et al. 2017a, 2017b). However, certain species of clionaid sponges have also been reported as being negatively affected by high sea water temperature (Achlati et al. 2017, Marlow et al. 2018). Thus, the ecology of sponge-coral interactions may vary not only from region to region, and from species to species, but depending on prevalent environmental conditions.

Corals in the Gulf of Mannar (GoM), southeast India, have been in decline over recent decades due to a range of natural and anthropogenic threats (Edward et al. 2012). Pattinamaruthoor patch reef (N 8° 54' 06.71"; E 78° 12' 53.66"; World Geodetic System 1984) in the GoM is a not legally protected reef where water depth ranges between 1 and 3 m, and the coral assemblage is dominated by acroporid corals (Raj per. obs.). On this reef we investigated a number of ecological issues, including the significance of interactions between corals and sponges. Our interest focused on factors affecting the spread of the sponge into the live coral, a phenomenon not previously studied in this region. In a pilot study described here we monitored the interactions between a single colony of the favid coral *Favites abdita* and a *Cliona viridis*-like sponge and investigated how the interaction was affected by seasonal changes in temperature.

Materials and Methods

In order to monitor sponge-coral interactions, a single brown, photosymbiotic bioeroding sponge in contact with a colony of *F. abdita* was marked, and their joint appearance recorded over a period of one year. The sponge was identified, using morphological characteristics, as belonging to the *C. viridis* species complex (see Ashok et al. 2018). At the start of monitoring a steel nail holding a colored plastic tag was driven into the coral colony on the line of the front between sponge and coral. Subsequently the distance from the tag to the invasion front, as the sponge invaded the coral, was measured every fifteen days, so as to determine the sponge's rate of progression or regression with respect to the coral. The study was conducted from March 2019 to March 2020. Sea water temperature was measured every month using a digital thermometer.

Results and Discussion

There is a general perception that *C. viridis*-like sponges are strong space competitors of living corals and that they can gradually take over substrates previously covered by live corals (reviewed in Schönberg et al. 2017a). In the present study, under the relatively benign ambient conditions that existed from Mar-May 2019, the sponge advanced over the live coral at a rate of several mm per month (Fig. 1), equating to a rate of 3.6 cm yr⁻¹, in accord with data reported for other brown clionoids from other regions (e.g. Acker and Ris González-Rivero et al. 2013). However, the rate

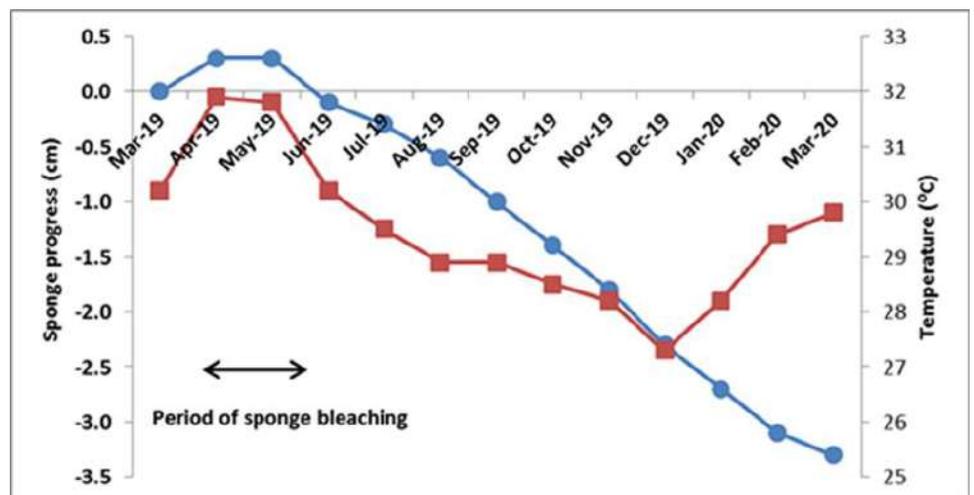


Figure 1. Tissue gain or loss of the sponge *Cliona viridis* in competition against the coral *Favites abdita*, expressed as the positive or negative advance of the boundary of the sponge with the coral with respect to the original position of the front (blue round symbols, left y-axis), compared to local sea water temperature (red square symbols, right y-axis).

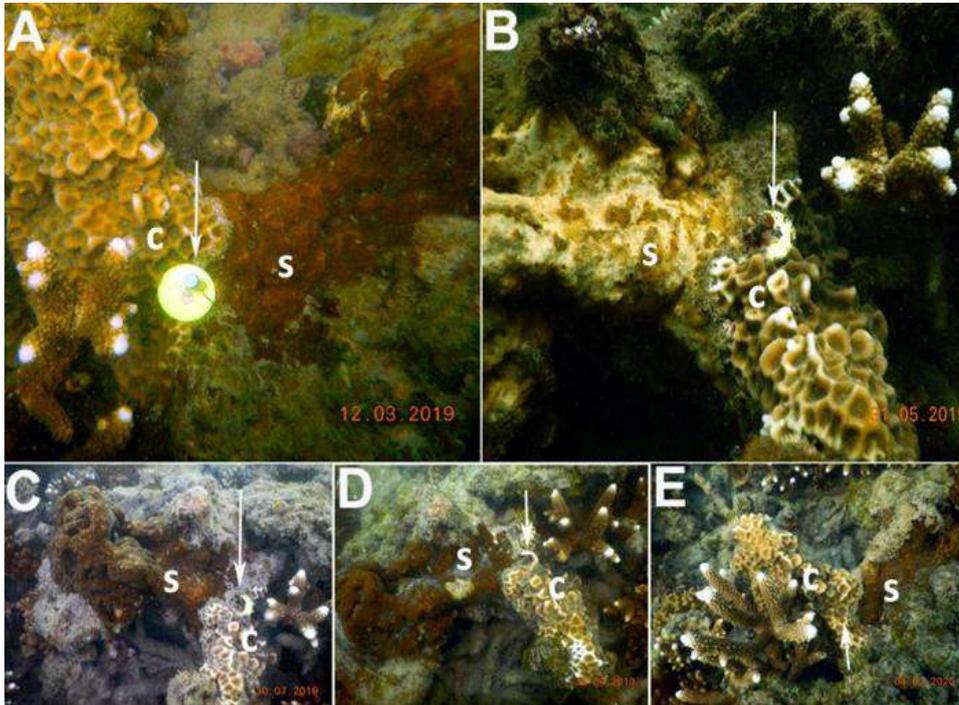


Figure 2. Progress of a *Cliona viridis*-like sponge (S) into a live hard coral, *Favites abdita* (C), in the Gulf of Mannar over one year, with the zone of interaction indicated by an arrow: A) March 2019, initial marking of the zone of interaction with a yellow tag, B) May 2019, apparent bleaching of the sponge, while the coral looks healthy and is overgrowing the tag, C) July 2019, apparent recovery of the sponge, while now the coral looks slightly paler, D) November 2019, progress of the coral into the sponge, both organisms now optically healthy, E) March 2020 the tag is now entirely overgrown by the coral, and the area of the sponge reduced in comparison with the situation in March 2019. Note the photographs were taken from different angles.

of progress of clionaid sponges into live corals can be seasonally variable and likely also depends on each competitor's health status. In April 2019 sea water temperatures on the Pattinamaruthoor patch reef rose as high as 31.9 °C, causing widespread coral bleaching through the entire GoM. At this time the sponge was observed to gradually pale, even though the study colony of *F. abdita* remained optically unbleached (Fig. 2).

This is one of very few observations of clionaid bleaching that have been observed in the field in the absence of experimental manipulation (Hill et al. 2016; Marlow et al. 2018). It indicates that at least some photosymbiotic *Cliona* spp. may be impacted by thermal events, despite earlier evidence of their hardiness (Vicente 1990). When the present sponge became pale, its progress into the *F. abdita* colony slowed and then became negative, with the coral regaining space from the sponge (Fig. 1, 2). By May 2019, the sponge appeared optically to be completely bleached, while the coral still looked healthy. Some studies have presumed that sponges, in particular clionaid sponges, do not suffer much from changing climatic conditions (e.g. Chaves-Fonnegra et al. 2018).

However, there have also been other recent reports indicating that clionaid sponges can be negatively affected by temperature anomalies (Hill et al. 2016, Achlatis et al. 2017, Fang et al. 2018, Marlow et al. 2018).

In July 2019 the clionaid sponge being monitored was observed to recover completely from bleaching, when sea water temperatures had decreased to 29.5°C (Fig. 1, 2). This observation supports the belief that photosymbiotic clionaid sponges can recover quickly after experiencing bleaching (Marlow et al. 2018). Between June 2019 and March 2020, the progress of the coral (*F. abdita*) over the sponge was about 0.36 cm mo⁻¹ (equivalent to 4.3 cm a⁻¹), comparable with the rate of advance of the sponge prior to the heat event. The coral's

maximum progress was recorded between November and December 2019, when the local winter water temperature was 27.3 °C (Fig. 1). The processes of bleaching and recovery of corals and sponges vary from species to species and depend on various factors (e.g., Hill et al. 2016). Further, the symbiont species and clades associated with corals or sponges have a key influence on their susceptibility or resistance to temperature anomalies (Schönberg et al. 2008, Fang et al. 2018).

The observations described here provide a preliminary insight into how temperature variation can influence space competition between coral species and bioeroding sponges. More detailed studies of coral-sponge interaction are warranted to identify underlying factors and possible outcomes. Given that *C. viridis*-like clionaid sponges are more often perceived as stress-resistant and as strong, fast growing space competitors, able to kill corals (e.g., López-Victoria et al. 2006), the resilience of this colony of *F. abdita* during the summer months was an unexpected result.

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First record of fluorescent bleaching of *Acropora cervicornis* in the Morrocoy National Park, Venezuela

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The health and survival of coral reefs are threatened globally by a series of factors (natural and anthropogenic), with the ongoing increase in seawater temperatures now being the greatest threat. During the last two decades the increase in sea water temperatures (SWT) has been more intense, frequent and long-lasting, producing mass coral bleaching (breaking of coral-algae symbiosis) events with increasing frequency (Eakin et al. 2019). Bleaching involves the disruption of the relationship between coral and their endosymbiotic zooxanthellae, which is of great importance since hermatypic corals obtain the greater part of their energy (up to 90%) through the carbon fixed photosynthetically by these algae (Muscatine 1990). If raised SSTs continue bleached corals typically die, but it is known that corals can recover after a bleaching event, a process that can take from months to over a year (Fitt et al. 1993).

Coral bleaching is normally manifested by the loss of all color in the corals, turning them completely white. However, sometimes bleaching can result in

corals that are quite colorful, with the corals, despite the loss of zooxanthellae, developing brilliant blue, purple, or pink tones (McGraw 2016, Fagerstrom et al. 1994). In this note we report the first record in Venezuela of a coral (a colony of *Acropora cervicornis*) displaying colorful bleaching of this type (Fig.1). This colony was observed on the reef of Pescadores Key in Morrocoy National Park (MNP), a marine protected area (MPA) on the central western coast of Venezuela. It was found at 10°52.9'32"N and 68°12.50'13" W, at a depth close to 1 meter, growing on a solid substrate of old coral (probably *A. palmata*) colonized by some turf algae. The colony had a maximum diameter of 23.5 cm and an average height of 12 cm. According to the NOAA Coral Reef Watch, the SWT on the photo date corresponded to the "No Stress" category; therefore, it may be that high solar irradiance may have contributed to bleaching, as is frequent in shallow reef areas.

Most of the colony's branches retained their original color at their base, but presented a pink-fuchsia coloration on their top half, while a minority of branches were bleached totally white. According to Bollati et al. (2020), this pink color results from upregulation of photo-protective host pigments, green fluorescent protein (GFP) like pigments, driven by increased internal light fluxes following symbiont loss. This mechanism is considered an advantage to the coral because it provides photoprotection for the gastrodermal zooxanthellae by screening them from excess sunlight.

This observation is not of course new, but has been observed in many reef-building corals in different coral reef regions (Salih et al. 2006; Ramesh et al. 2019; Bollati et al. 2020). Colonies expressing GFP-like pigments are found in 17 out of 18 coral families identified by Veron (Smith, 2012). More particularly fluorescence has been recorded in numerous genera in the Caribbean region including *Orbicella*, *Montastraea*, *Madracis* and *Agaricia* (Vermeij et al. 2002, Mazel et al. 2003). Photoprotection and photosynthesis enhancement have been reported from Curacao, and one function of fluorescent proteins (FPs) as supplemental antioxidants that prevent oxidative stress in coral tissue noted from Florida (Vermeij et al. 2002, Palmer et al. 2009), supporting the view that FPs have multiple functions (Smith, 2012). The photoprotective role of GFP is still under discussion (Zawada et al. 2003, Mazel et al. 2003, Lyndby et al.

2016). Nevertheless, it seems that during bleaching zooxanthellae overproduce harmful reactive oxygen species as a result of damage to photosystem II (Lesser, 1997), so that eventually the coral-algae symbiosis breaks down, and the coral become bleached (Baird et al 2009). In addition to a response involving GFP-like proteins, there are other postulated mechanisms that may reduce the damage caused by light flux and UV. These include the acquisition of mycosporine like amino acids and the presence of several antioxidant systems and stress enzymes that deal with oxidative stress in the coral (Baird et al. 2009).

A further refinement is that different sub-types of zooxanthellae can provide differing degrees of protection from bleaching. Zooxanthellae of clade "A", the predominant clade in *A. cervicornis* (Thornhill et al 2005) seem more resistant to bleaching (McCabe Reynolds et al 2008), because they are more resistant to combinations of high light intensities and high temperatures (Fitt et al. 2000). In contrast zooxanthellae of clade D have been observed to be mainly tolerant to high-temperatures (Rowan 2004).



Figure 1. Colorful bleaching in a colony of *Acropora cervicornis*, Morrocoy National Park, Venezuela. Photographs by B. Rujano, March 13, 2019.

Populations of *Acropora cervicornis* have suffered a dramatic decline in the Caribbean region since the late 1970s (Gladfelter 1982, Aronson and Precht 2001), the species being classified as Critically Endangered by the IUCN (Aronson et al. 2008). Currently, the population status of *A. cervicornis* in Venezuela is only partially known, nevertheless the

species is scarce within the MPA and has been classed as Vulnerable by the Red Book of the Venezuelan Fauna (Zubillaga and Pauls, 2015). It is considered to be moderately or highly susceptible to both bleaching and to white-band disease (Aronson et al. 2008). Bleaching events were recorded in the MNP in 1987, 1995, 2005, and 2010. However, the area was also severely affected by a mass mortality of both corals and other invertebrates in 1996 (Villamizar 2000, Laboy-Nieves et al. 2001) and historically has been subject to impacts due to oil and cement industries, sediments, sewage, chemical contaminants, tourist development, unregulated boat traffic, and overfishing (Bone et al. 2005). All of these factors may have affected the health and size of *A.cervicornis* populations in this locality. Thus, it remains possible that the unusual appearance of the colony described here may also involve other impacts.

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REEF RECRUITS

Spatial variation in marine sponge diversity on southern Gulf of Mexico and Mexican Caribbean coral reefs

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Introduction

In recent decades, coupled with the high mortality of scleractinian corals (due to elevated water temperatures, pollution, and ocean acidification), reefs in the Tropical North-western Atlantic have become increasingly dominated by sponges (Pawlik et al. 2013). In addition, there is evidence that on different reefs in the Caribbean, the erosion rates are higher than the rates of accretion, leading to the reefs becoming flattened. In this context, it has been shown that sponges have mitigated the loss of structural complexity, replacing in part the role of corals (Bell et al. 2018). In the light of this information, describing the spatial patterns of sponge diversity and abundance must be a fundamental objective for any reef biodiversity monitoring program.

Spatio-temporal patterns of diversity reflect how species respond to the biological, environmental, and historical properties of its habitat. For example, variations in diversity between regions could result from macroenvironmental processes such as oceanographic conditions, dispersal limitation, or a combination of both. Simultaneously, variations in species diversity within ecoregions may reflect

how species use and compete for resources at a local scale, or tolerate particular environmental conditions, or reflect variations in the supply of recruits, or a combination of all these factors (Legendre et al. 2005). Each of these processes acts at different spatial and temporal scales, with lesser or greater effects on the distribution and abundance of each species (Levin 1992). In this sense, quantifying the spatial scales of variation in the diversity of reef sponges will allow us to identify the relevance of the potential processes sustaining the current diversity patterns. The project described here aimed to quantify for the first time spatial scales of variation in the diversity of sponges on Mexican reefs in the Western Caribbean (WC) and Southern Gulf of Mexico (SGM) ecoregions. It also aimed to identify the relative importance of macroecological and local processes in maintaining the current patterns of diversity on sponge reefs in these regions.

Study area

The project compared two Mexican reefs in the Western Caribbean (WCar) and Southern Gulf of Mexico (SGoM) ecoregions (sensu Spalding, 2007). These two ecoregions represent variation in large scale or gamma diversity. Within these ecoregions we selected three subregions sensu Wilkinson (2009): the Veracruz platform (sampled coral reefs: La Blanquilla, Isla de Enmedio, Cabezo, Hornos, and Isla Verde); the Campeche Bank (sampled coral reefs: Arrecife Alacranes, Cayo Arcas and Bajos de Sisal, and Bajos del Norte), and the Caribbean

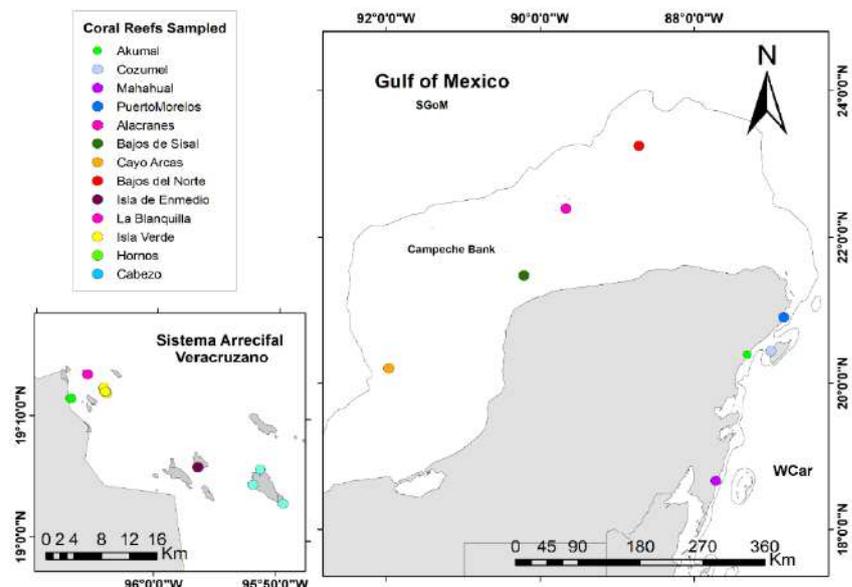


Figure 1. Coral reefs sampled in south-east Mexico as part of the present project in the biogeographic regions of the Southern Gulf of Mexico (SGoM) and Western Caribbean (WCar) (right), and within the Gulf of Mexico around Veracruz (left).



Figure 2. The field work consisted of a) sampling quadrats of 1x1 m within which sponges were identified and counted b) photographing species, in this case *Verongula rigida* and *Niphates* sp.

platform (sampled coral reefs: Puerto Morelos Mahahual, Akumal and Cozumel) (Fig. 1).

The Graduate Fellowship provided by the International Coral Reef Society (ICRS) allowed me to undertake the fieldwork on the coral reefs on the Mesoamerican Barrier Reef System at Puerto Morelos, Mahahual, Cozumel, and Akumal.

Methods and Materials

Fieldwork: quadrats (1 m²) placed along transects (20 m length) were used to estimate the diversity and abundance of sponges. Since the reef systems sampled have very different geomorphologies (i.e. fringing reef, bank reef, patch reefs), all transects were oriented perpendicular to the coast, randomly located over a depth range starting at 6 m. Simulated resampling methodology was used to calculate the multivariate standard error associated with the sampling effort and to estimate the number of sites per reef and the number of quadrats per site required to complete sampling (using the SSP R package).

A total of 624 quadrats were sampled in 63 localities on thirteen coral reefs (Fig. 1). Samples of sponge tissue were collected to confirm the identity

of species following the standard procedures, using tissue cuts and dissociation of spicules followed by observation under the microscope (Hajdu et al. 2011; Ugalde et al. 2015).

Statistical analysis: Identification of the relevant spatial scales of variation in the distribution of species was carried out through the partition of multivariate variation using a full hierarchical nested model with four sources of variation: (1) Ecoregions (Western Caribbean [WCar], South Gulf of Mexico [SGoM]), (2) subregions (Veracruz, Campeche Bank, and Mexican Caribbean), (3) localities within each reef, and (4) transects and quadrats within each site. Statistical analyses were carried out using PRIMER v7 & PERMANOVA + (Clarke et al. 2014). Species richness per reef was estimated with rarefaction curves based on species incidence and sample coverage (Chao & Jost 2012; Colwell et al. 2012), using the R package iNEXT (Hsieh et al. 2016)

Preliminary Results and Discussion

We have recorded 145 species (Fig. 5) of sponge belonging to 16 Orders, 46 Families, and 66 Genera of the Classes Demospongia, Homoscleromorpha, and Calcareia. The Puerto Morelos reefs in the Caribbean subregion had the greatest species richness with 61 species; in contrast, Hornos Reef in the Veracruz Reef system in the Veracruz subregion had the fewest species with only 26 recorded. It was found that the observed species richness was very close to the estimated richness. This can be seen in the rarefaction and extrapolation curves of species, where on most reefs the observed curves almost reached the asymptote (Fig. 3A). In concordance, the estimator of sampling coverage indicated that

Table 1. PERMANOVA partitioning and analysis of the sponge assemblage. The analysis was based on Bray–Curtis dissimilarities of fourth root transformed values. The last column shows the percentage of components of variation

SOURCE	gl	SS	MS	Pseudo-F	P(perm)	CV (%)
EC	1	87615	87615	0.83668	0.668	-7.77
SU(EC)	1	95230	95230	3.4218	0.002	18.49
AR(SU(EC))	10	3.35E+05	33472	3.3972	0.001	20.31
SI(AR(SU(EC)))	47	5.03E+05	10692	3.8064	0.001	23.64
RES	564	1.58E+06	2809.1			45.33
TOTAL	623	2.65E+06				100.00

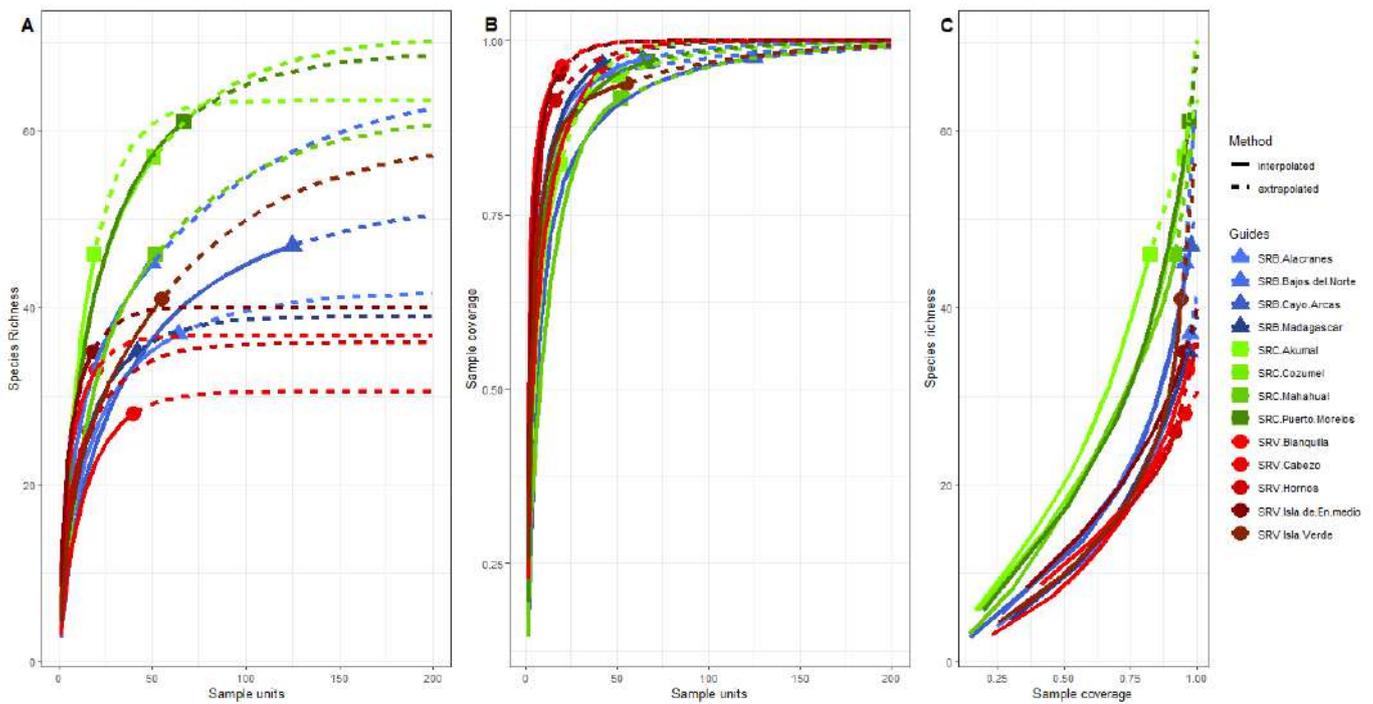


Figure 3. Sample coverage analyses and interpolation and extrapolation of richness values based on the incidence of species for each locality; different colors indicate the subregion concerned. (A) Species accumulation curves (B) Sample-coverage accumulation curves (C) Sample coverage curves based on rarefaction (solid line) and extrapolation (dotted line) for species richness.

all displayed between 91 and 98% of the expected richness (Figs. 3B, C).

The exploratory data analysis nMDS (Fig. 4) showed grouping of the data by subregions. In addition, the coral reefs in the SGoM showed a greater dispersion compared to SAV and Caribbean reefs. However, no gradient was observed between the subregions. Significant statistical differences were detected in the spatial scales of subregions, reefs, and localities (Table 1, p-values <0.05), but the components of variation across ecoregions were not significant. 45% of the variation could be

explained for the scales of sites and reefs, highlighting the potential effects of local environmental and habitat heterogeneity due to such factors as rugosity, wave exposure, and local interspecific competition. These processes could also explain both the high local diversity of marine sponges and the high variability in sponge assemblages on coral reefs within the same subregions. The component of variation associated with Subregion explains only 18% of the total of variation, indicating the importance of the macroecological processes that allow connectivity between corals within the ecoregions. These findings imply that conservation strategies should not only consider the use of protected areas, but also recognise the importance of internal processes within each subregion and locality in sustaining diversity at large spatial scales.

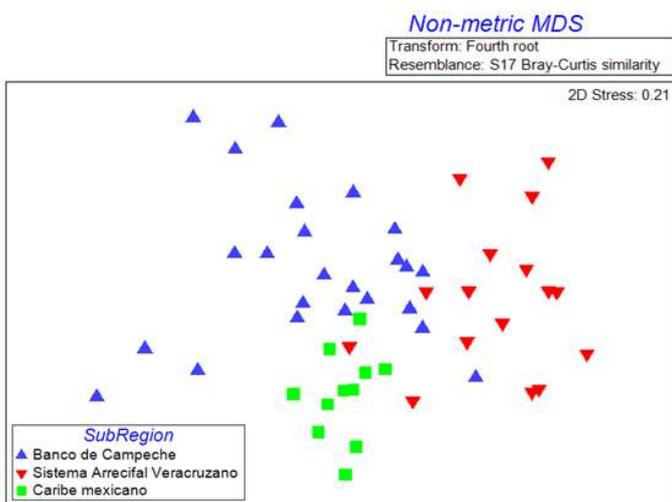


Figure 4. Non-metric Multi-Dimensional Scaling analysis (nMDS) based on the centroids of each coral reef in each subregion. It is observed the greatest dispersion is found among the Banco de Campeche reefs, but no gradient is observed.

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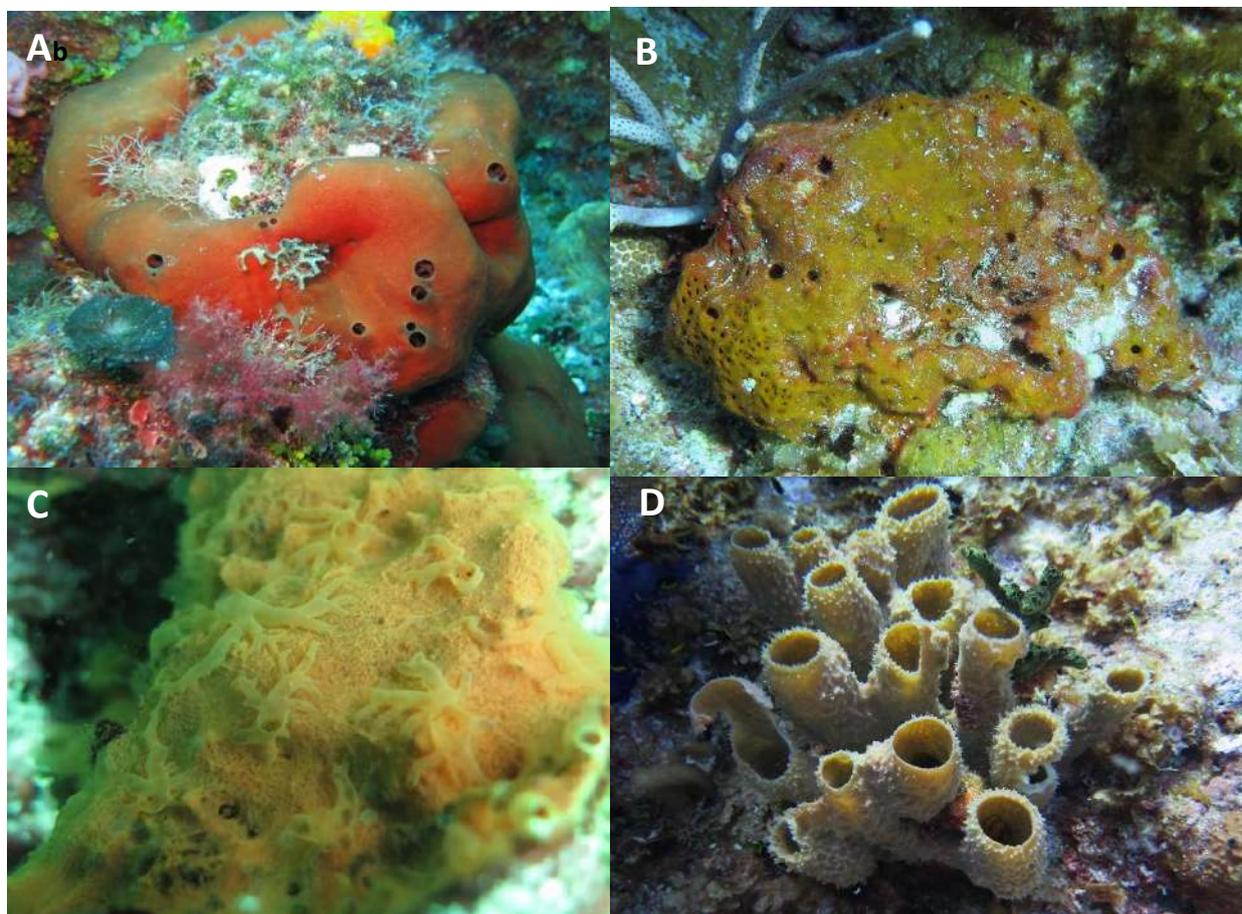


Figure 5. Some of the sponges recorded during the field trips. A. *Plakortis halichondrioides* (Wilson, 1902), B. *Svenzea flava* (Lehnert & van Soest, 1999), C. *Vansoestia caribensis* Díaz, Thacker, Redmond, Pérez & Collins, 2015, D. *Callyspongia vaginalis* (Lamarck, 1814)

About Diana Ugalde

I am a Marine biologist interested in the study of marine sponges, their taxonomy, and ecology. Currently, I am doing my Ph.D. trying to understand the diversity patterns of sponges at the coral reefs of the Gulf of Mexico and the Mexican Caribbean.



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Recovery under thermal stress: the effect of copper enrichment on the branching coral *Stylophora pistillata*

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Introduction

Coral reefs are declining worldwide at high pace, mostly as a result of climate change-induced seawater temperature warming and ocean acidification (Hughes et al. 2017a, 2017b). In such a context, the identification of local coral refugia, where corals display beyond expected thermal resistance, is crucial (Cacciopaglia and van Woesik 2015). The Gulf of Aqaba (GoA), located in the northern Red Sea, has been defined as a coral refuge and hosts such resistant coral species (Fine et al. 2013; Bellworthy and Fine 2017; Osman et al. 2018). However, coral reefs of the GoA are mostly fringing reefs, located very close to the shore, and

exposed to land-based pollution. Land - and sea - based anthropogenic pollution has already been extensively studied for coral reefs, and has been proven to alter the coral bleaching threshold (Fabricius 2005; Wooldridge 2009). With a growing coastal population, mass-tourism, intense urbanization, and increasing numbers of on-shore industrial activities (namely oil and mineral terminals, commercial harbor) the corals of the GoA are increasingly threatened by pollution (Fine et al. 2019).

Heavy metals such as copper, iron, and zinc are key elements of the coral's metabolism since they are assimilated and used as micronutrients (Gajić et al. 2018). When in excess these micronutrients were reported to cause severe damage to corals including inhibition of enzyme activity, ion deficiencies, and increased oxidative stress (Yruela 2009). In the most severe cases, disruption of coral reproduction and coral larvae mortality have been reported (Bielmyer et al. 2010; Reichelt-Brushett and Hudspeth 2016; Zhou et al. 2018). Copper (Cu) is a well-studied marine pollutant, linked in corals to reduced fertilization and fecundity, reduced photosynthesis, and mortality (Gissi et al. 2017). In the GoA, the concentration of Cu in the reef seawater ranges from 2 to 15 $\mu\text{g L}^{-1}$ (Ali et al. 2011), which is considered toxic for most marine organisms. A previous study at this site demonstrated that exposure of the common branching coral *Stylophora pistillata* to Cu in combination with elevated temperature ultimately reduced the thermal tolerance of this otherwise

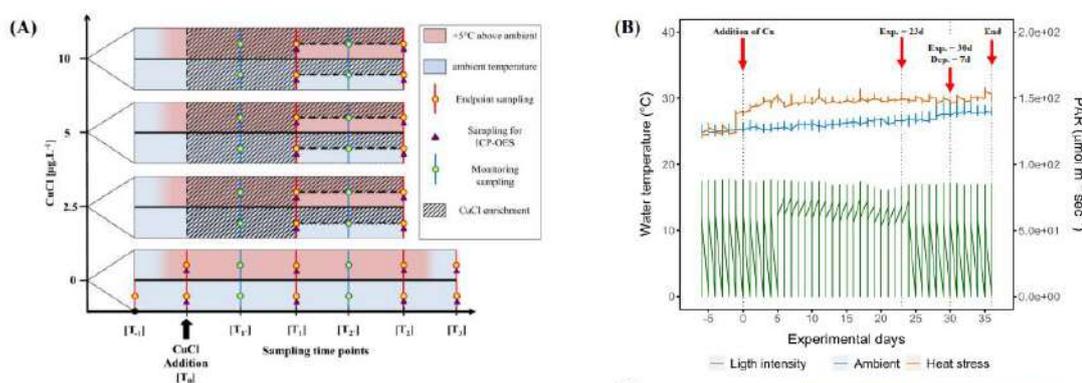
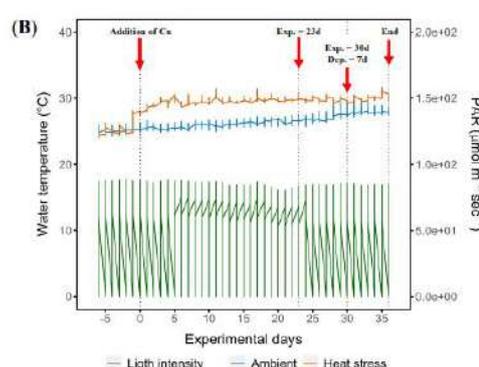


Figure 1. Experimental design and conditions. (A) *Stylophora pistillata* coral fragments from the Gulf of Aqaba (GoA) were exposed in combination to elevated temperatures (27°C (ambient) and +5°C (32°C)) and several copper (Cu) concentrations (0 – 2.5 – 5 – 10 $\mu\text{g L}^{-1}$) for 23 days (T₁), and then placed in depuration (0 $\mu\text{g L}^{-1}$ Cu) for one week (T₂) at their respective temperature. (B) shows the experimental conditions recorded during the experiment. 'Exp.' stands for 'exposure to Cu', 'dep.' for 'depuration'. 'Exp. = 23d' means corals were exposed to Cu for 23 days. (C) The Red Sea Simulator in Eilat, Israel, with the corals exposed to Cu in their respective incubation chambers, placed in the aquaria at different temperatures.



(locally) extremely resistant species (Banc-Prandi and Fine 2019). Moreover, physiological host and symbiont recovery from a 14-day exposure to Cu at environmentally relevant concentrations (1 $\mu\text{g L}^{-1}$) and ambient seawater temperature can be achieved

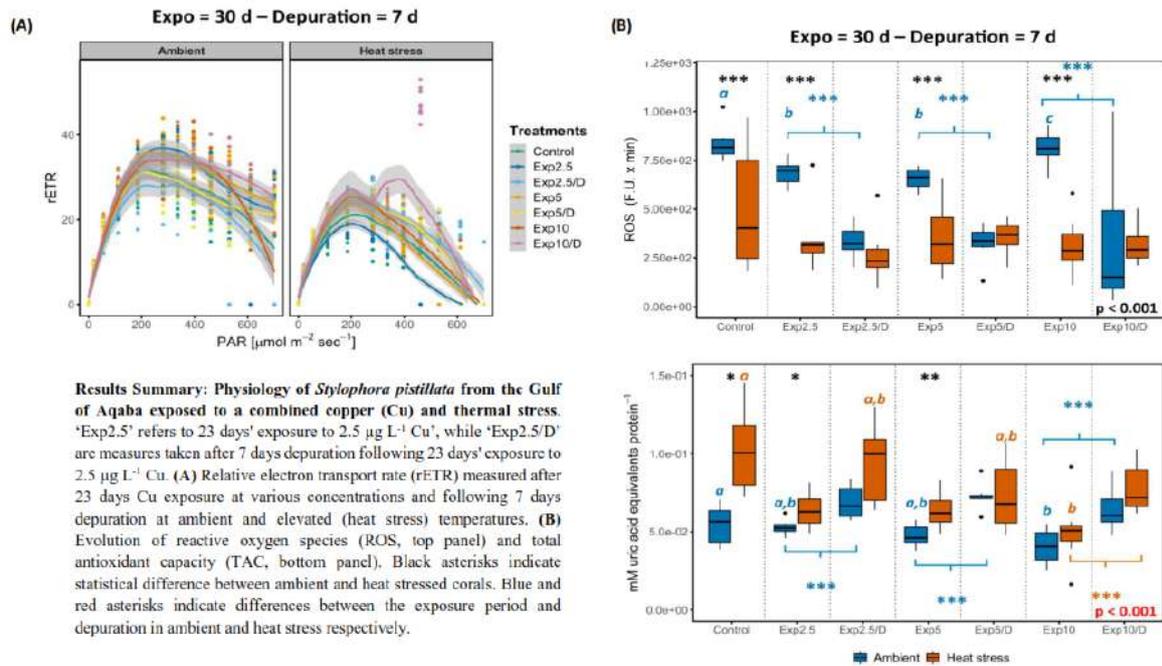


Figure 2 Physiology of *Stylophora pistillata* from the Gulf of Aqaba exposed to a combined copper (Cu) and thermal stress.

over a period of 28 days' depuration (Banc-Prandi et al. 2020).

The present study aimed to test how recovery from Cu contamination during depuration is affected by elevated seawater temperatures. We tested the hypothesis that the recovery of *S. pistillata* from acute exposure of several different concentrations of Cu will be limited under a global warming scenario. The research questions were (1) how does

copper enrichment affect *S. pistillata*'s physiology (photochemistry and oxidative stress) under thermal stress? (2) Can *S. pistillata* recover from environmentally relevant concentrations of dissolved Cu? (3) Is the corals' recovery ability impacted when Cu is combined with thermal stress? (4) Which biological marker(s) allow us to best observe the response of this coral species to environmental stressors?

Methods

To enable backwards comparability to previous experiments in this region (Banc-Prandi and Fine 2019; Banc-Prandi et al. 2020), the physiological response of *S. pistillata* (host and symbiont) to Cu contamination was characterized during both the exposure (2 weeks) and depuration (1 week). Corals were exposed to a gradient of Cu concentrations (0 – 2.5 – 5 – 10 $\mu\text{g L}^{-1}$) and two experimental temperatures (27°C ambient – 32°C heat stress) using the Red Sea Simulator (Fig. 1) experimental system in Eilat, Israel (Bellworthy and Fine 2018). We also measured the level of oxidative stress in the coral tissue (ratio of reactive oxygen species

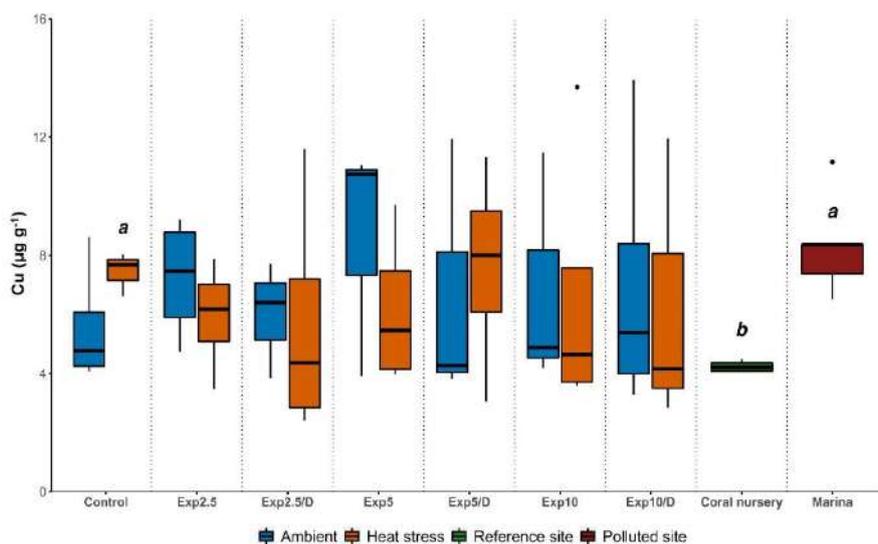


Figure 3 Copper (Cu) concentrations measured in coral tissue at each sampling time point. 'Exp2.5' refers to '23days' with 2.5 $\mu\text{g L}^{-1}$ Cu, while 'Exp2.5/D' are measures taken after 7 days depuration following 23 days' exposure to 2.5 $\mu\text{g L}^{-1}$ Cu. The reference site indicates where experimental corals were collected and the Marina is a local site with concentrated anthropogenic pressures. Different lower case letters indicate statistically significant differences between groups.

(ROS) to total antioxidant response (TAC)), as these processes have previously been shown to react to heavy metal enrichment (Banc-Prandi and Fine 2019; Marangoni et al. 2019). Additionally, the graduate fellowship grant to JB enabled us to determine the concentration of Cu within coral tissue resulting from each treatment condition. Mass-spectrometry (ICP-OES) was used in order to measure whether Cu was accumulated in the coral tissue or if the contaminant had been either used or expelled at each sampling time-point.

Results

The results of this study suggest that there is an additive effect of elevated temperature and Cu enrichment on the physiology of *S. pistillata*. Such conditions may alter the recovery process of corals during depuration following an acute contamination event. We detected a significant change in both photochemical parameters and in the oxidative stress response (Fig. 2). The corals' response was dose, time, and temperature dependant, and involved (1) an increase in the efficiency of the symbiont's photosynthetic pigments to harvest light at their reaction centres (as indicated by an increase in both maximum quantum yield and maximal relative electron transport rate) and (2) an increase in the quantity of ROS together with activation of TAC, which may place a high energetic demand on the coral host. Gross photosynthesis increased with higher doses of Cu and only returned to baseline levels after 2.5 and 5 µg L⁻¹ (not higher), and under ambient temperatures, similar to the concentration of Cu accumulated in coral tissues (Fig 3). Recovery during depuration was dose and temperature dependant, in that corals recover better from a lower dose of Cu and at ambient compared to elevated temperatures. This recovery seemed to be mediated by a boost in the antioxidant defence pathway. Accordingly, we noted that maximum quantum yield, maximum relative electron transport rate, ROS, and TAC were the biological markers that showed the strongest response. Therefore, we propose that these parameters are good candidates to characterise stress response of *S. pistillata* in similar future experiments.

Combination of Cu and elevated temperature resulted in a slight reduction of *S. pistillata* thermal tolerance, in some parameters only. We suggest this coral's resistance to elevated temperatures may be mediated by a boost of the antioxidant defence mechanisms, leading to an overall reduction of

oxidative stress, known to trigger apoptotic cascades leading to bleaching and mortality. Overall, this study advocates a better management of land and sea-based pollution, especially in this context of global warming, if the GoA is to remain a coral refuge.

About Jessica Bellworthy

I am a Postdoctoral researcher assessing how the parental environment influences the fitness of the offspring produced in reef building corals.



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<https://sites.google.com/marsci.haifa.ac.il/masslab/team/jessica-bellworthy>

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Cryptic Diversity Matters for Coral Conservation

Matías Gómez-Corrales

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Background

Coral reefs are deteriorating as a result of local and global threats such as overfishing, diseases, and climate change (Smale et al. 2019). How reef ecosystems will respond to warmer oceans will be a function of genetic variation and how it is segregated among populations and communities. While plasticity is rampant among reef species, undetected cryptic variation makes many species more diverse and specialized than previously recognized (Knowlton and Jackson 1994). The balance between plasticity and specialization is key to the resilience of the coral reef ecosystems (Prada et al. 2008). However, the potential for cryptic species, morphologically similar yet genetically distinct groups, remains an overlooked aspect of coral reef biology, even within common reef dwellers. Highly plastic species should have an advantage in dealing with environmental change. In turn, species with specialized populations may have some populations able to survive in altered environments. The presence of such populations may reflect the likelihood that a species can adapt to changing conditions, although those probabilities may decrease by the current rapid change of environments.

Coral species within the genus *Orbicella* are major Caribbean reef builders, yet all are now listed as threatened under the Endangered Species Act (NOAA 2014). These species were once part of the *Montastraea* (now *Orbicella*) *annularis* species complex (Budd et al. 2012). While originally deemed a single cosmopolitan species with specialized ecotypes (Graus and Macintyre 1982), members of this complex were later described as three separate species (*O. annularis*, *O. faveolata* (Fig. 1), and *O. franksi*) (Weil and Knowlton 1994) with differences in ecology, morphology, spawning behavior and gamete compatibility. Leveraging genomic resources available for the common mountainous star coral, *O. faveolata* (Prada et al. 2016; Dzedzic et al. 2019), I recently uncovered cryptic lineages within this species on the reefs of Bocas del Toro, Panama (Gómez-Corrales and Prada 2020). Interestingly, these lineages differ in their susceptibility to bleaching. Additionally, I evaluated genomic variation among *O. faveolata* populations in Puerto Rico and found that some of the cryptic lineages I uncovered in Panama are also present there, segregated across a depth gradient. This raises the questions of whether this genetic segregation correlates with physiological and morphological disparity, and what traits are being selected for across light and depth environments. It also remains to be tested if the cryptic lineages differ in their ability to handle heat stress.

Research Undertaken

To understand the physiological and morphological bases of ecological specialization among the cryptic lineages of *O. faveolata*, as well as its adaptive potential across environments, we conducted



Figure 1. Mountainous star coral (*Orbicella faveolata*) at Media Luna Reef in Puerto Rico.

reciprocal transplants of 40 colonies from each lineage, that normally occur at different depths at Media Luna Reef, Puerto Rico. These experiments consisted in collecting 40 colonies from each depth and fragmenting them into 20 micro fragments per colony. Half of the fragments were placed in shallow (5 m) habitats, and the other half in deep (15 m). The survival rate was monitored every four months for a year (Fig. 2).

To test for physiological variation in response to thermal stress across cryptic lineages along depths, we collected fragments from each colony from all reciprocal transplants and exposed them to acute thermal stress challenges. We had a control tank (28.5 oC), and an experimental one (34.5 oC) each with two replicates. The experimental tank's temperature was ramped up by 6 oC over 3h, and then maintained at that temperature for another 3h. Temperature was then lowered to the initial 28.5 oC over a 2h period. To assess the physiological response in terms of bleaching before and after the experiment, we measured reflectance and pulse-amplitude modulation (PAM) fluorometry, and

stored samples to estimate chlorophyll a content and symbiont cell density between control and experimental fragments. Subsequently, to fully understand the association between mortality and physiological, morphological and genomic variation, I will be examining genome-wide variation among all transplanted colonies using a low-pass whole genome sequencing approach (LP-WGS).

Summary Results

Reciprocal transplants of shallow and deep colonies of *O. faveolata* at Media Luna Reef presented differential survivorships (Fig. 3). With over 75 % survivorship, deep colonies performed similarly well in shallow and deep habitats. In contrast, shallow colonies transplanted to the deep habitat had a survivorship below 40 %, whereas those placed back to their natal habitat had a survivorship of 66 %. Currently, I am in the process of analyzing all physiological data collected from acute thermal stress challenges and preparing genomic libraries for genomic analysis.

Concluding Remarks

My results show that corals from shallow areas are specialized to the environment where they are found, while deeper corals can be more resilient. This is remarkable given that these populations are found within 200 m of each other and have the potential to disperse tens of kilometers. This is key for coral outplanting-restoration efforts, as matching donor and transplanted sites reduces transplant mortality, promoting transplanted fragments' long-term survival. Minimizing transplant mortality is critical for managers investing in coral outplanting, as it is an expensive and laborious activity. Our research will advance coral reef biology by addressing how corals' vulnerability to warmer oceans is influenced by their cryptic diversity, and how this in turn

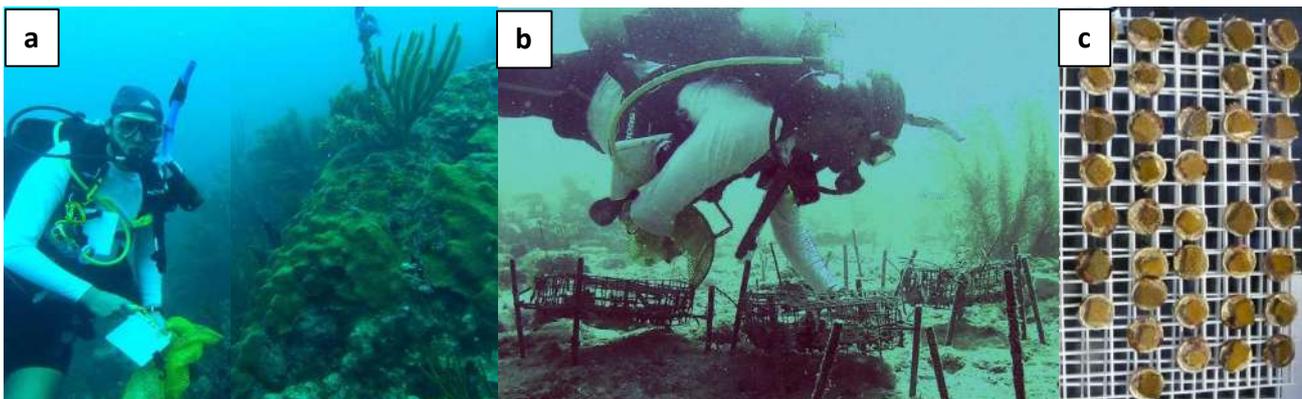


Figure 2. a) Field work at Media Luna Reef in Puerto Rico, b) Wire cages used for reciprocal transplants, c) *Orbicella faveolata* micro fragments as used in all experiments.

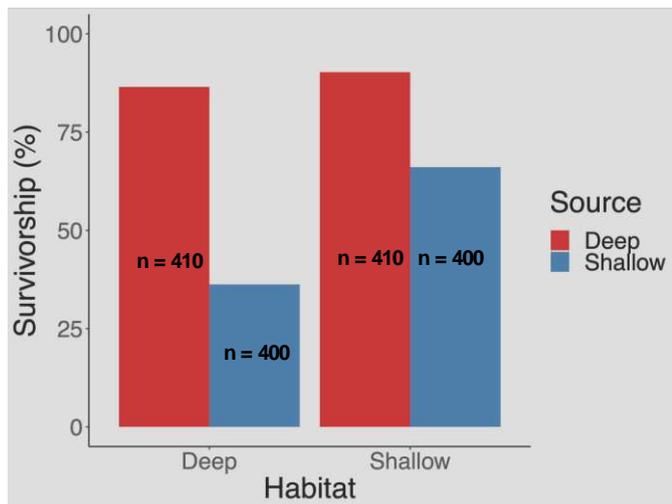


Figure 3. Survivorship percentage of *O. faveolata* reciprocal transplants after four months.

underlies physiological thermal tolerance, habitat preferences, and potential adaptation to climate change. Therefore, my work will also directly inform reef conservation strategies from a genomic and ecological perspective, by suggesting which coral morphotypes and populations would do better in different environments. Given the rapid decline of coral reefs worldwide and the projected increases in environmental variability, identifying evolutionary units of biological diversity with their singular physiological thresholds is critical to inform coral conservation efforts.

Acknowledgements

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About Matias Gómez-Corrales

My Ph.D. research centers around coral conservation genomics in the Caribbean. I aim to integrate coral genetics and phylogenetics to understand current trends of distribution and potential of adaptation to climate change of a key reef-forming group of hard corals (*Orbicella* complex) across the Caribbean Basin.



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 **ResearchGate:** / Matias-Gomez-Corrales

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REEF SHELF

Coral Finder 2022

Russell Kelley

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Available at: www.BYOGUIDES.com

US\$ 57.14

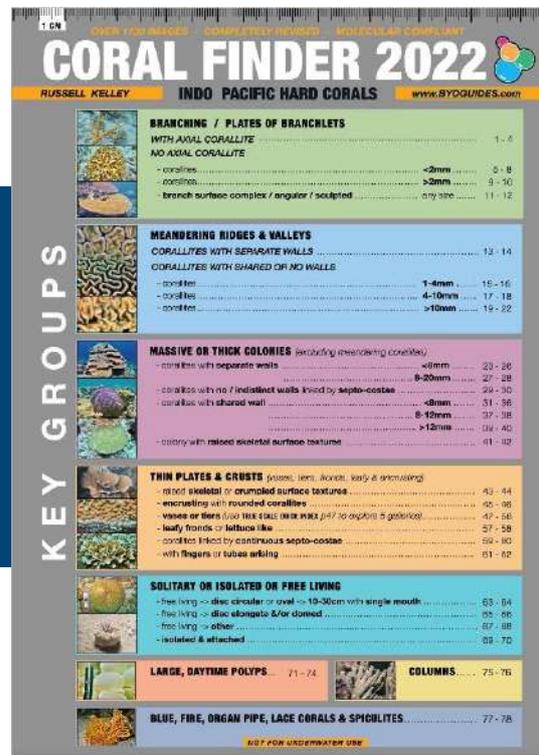
(not for underwater use)

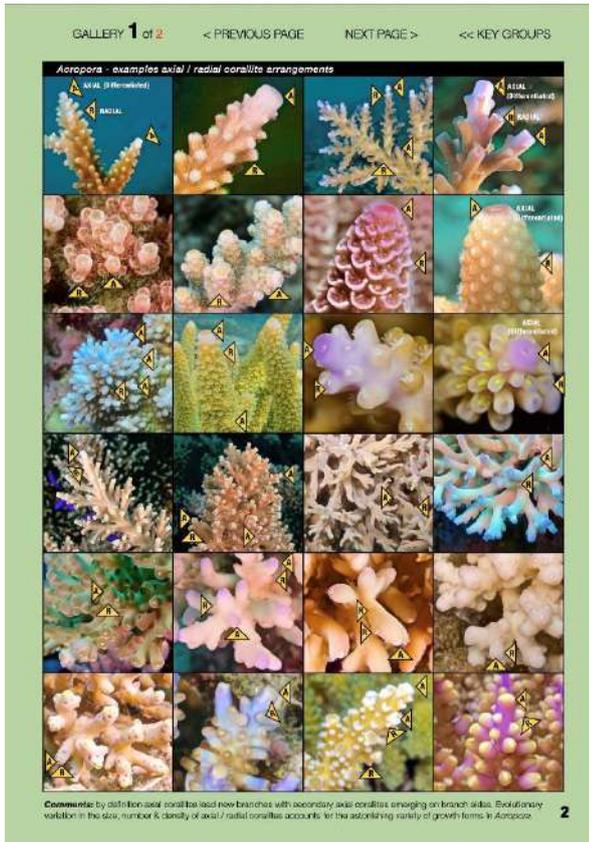
Coral Finder 2022 (CF2022) is the updated 5th edition of the popular CoralFinder guide book, which teaches users how to identify Scleractinian corals to genus level using a range of clearly-defined characters. Identification of corals is notoriously difficult due to a range of factors including their morphological plasticity, and more recently because molecular phylogenetics is changing our understanding of systematic relationships. What makes CF2022 such an excellent resource is that it teaches a process that allows the user to make informed and consistent decisions when identifying corals, with reference to the latest scientific research, but which remains robust to inevitable future changes to coral taxonomy.

Over the last 25 years, the ‘molecular revolution’ has fundamentally altered our understanding of the systematic relationships and evolutionary history of corals and many other branches of the tree of life. While these powerful new tools have provided fascinating insights into coral evolution, they have also shown that many of the characters traditionally used to delineate species, genera and families are not informative. Moreover, most coral families described in *Corals of the World* in 2000 have now been shown to be polyphyletic; for example, the 15 species of *Montastraea* split among 6 genera in three families. While these sorts of results excite coral taxonomists, they have a tendency to illicit a very different reaction in those trying to identify corals in the field. CF2022 does an admirable job of bridging this deep and

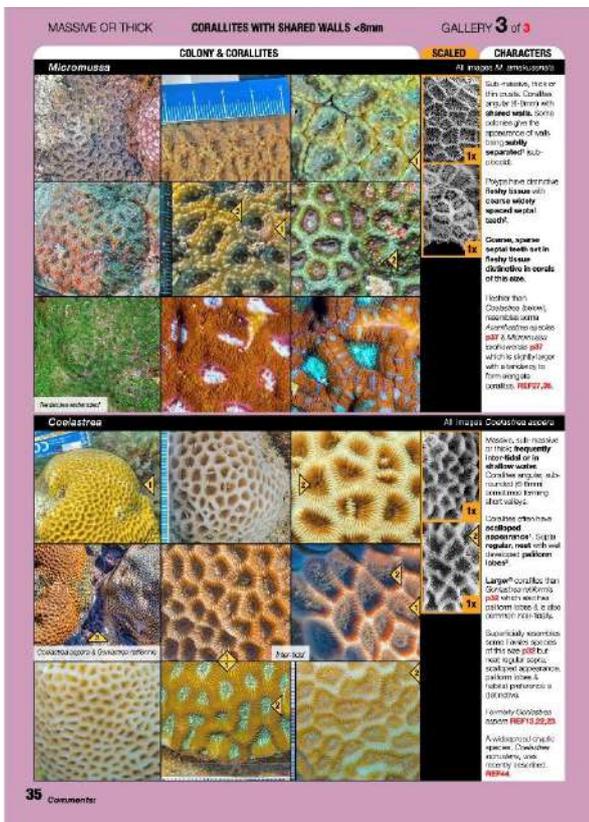
treacherous divide by using clearly-defined, quantitative characters for field identification of corals to genus level, while also providing information needed for the user to go further if they so desire. Consequently, it is both an excellent tool for the field scientist and the perfect introduction for those beginning their journey in the fascinating but sometimes daunting world of coral identification.

The real advantage of the CoralFinder series, including CF2022, is that it teaches a process rather than spreading a gospel. The start of the book defines and illustrates all of the characters used to delineate coral genera: what shape are the colonies and the corallites? How do you measure the corallites consistently when they often vary in size within a colony? These characters are then clearly illustrated using over 1700 images of corals in the field which, like previous CF editions, are arranged by genera with similar characters to clearly illustrate their differences. Learning these characters is critical for two reasons: firstly, it allows the user to make robust, repeatable decisions about the names they are applying to corals. While species and potentially even generic and family names will continue to change as new information comes to light, applying a consistent framework provides the best chance that data





An example page illustrating the key characters of the genus Acropora.



Coral Finder 'look-alike' collages allow the user to compare and contrast genera matching the description at the top of the page. The 'SCALED' column (reproduced at true scale in print) is a crucial reality check for the user.

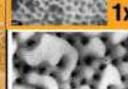
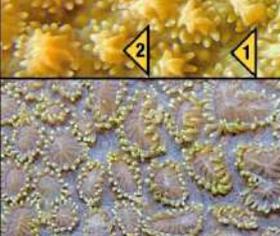
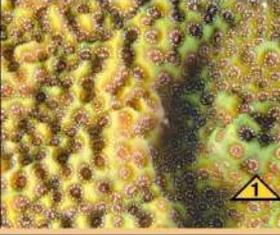
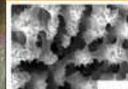
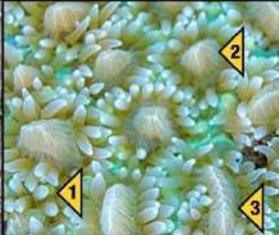
collected will be robust to future changes. In science we are always obtaining new information which can alter understanding of a subject. We can't always be right, but we can make our science repeatable, and CF2022 applies this axiom to the sometimes dark art of coral identification. The other key point is that even if the taxonomy does change, understanding the characters presented in CF2022 will allow users to rapidly update their knowledge to capture this new understanding. For those wishing to take this next step, CF2022 contains an excellent bibliography showing the research papers that describe all the gory details of how and why these taxonomic changes were made. In short, it provides all the basic tools, while also illuminating a path forward for those with masochistic tendencies.

Finally, one of Russell's great insights is to draw on 'the powerful human-eye brain supercomputer'. We are capable of processing multidimensional information in a way that is impossible to capture in a matrix of morphological characters. When we observe corals in the field, our brains are taking in much more information than we may realise, providing us with a capacity to differentiate things even when it is difficult for us to describe exactly how they differ. We can easily recognize different people by their facial features, even if we struggle to explain exactly what features we recognize. The same logic can be applied to corals – our human eye-brain supercomputer will often be able to differentiate corals by their 'giss' or 'jizz' (to use a birding term), and in many cases these empirical observations are subsequently confirmed by quantitative molecular analyses. Consequently, I strongly endorse Russell's call to engage that supercomputer when observing corals in the field. When it comes to identifying corals, there is no substitute for time spent in the field. So, grab a camera, a copy of CoralFinder 2022, and get out in the water!

Tom Bridge (Senior Scientist and Curator, Coral Ecology and Evolution Program, Queensland Museum Network, and James Cook University, Townsville)

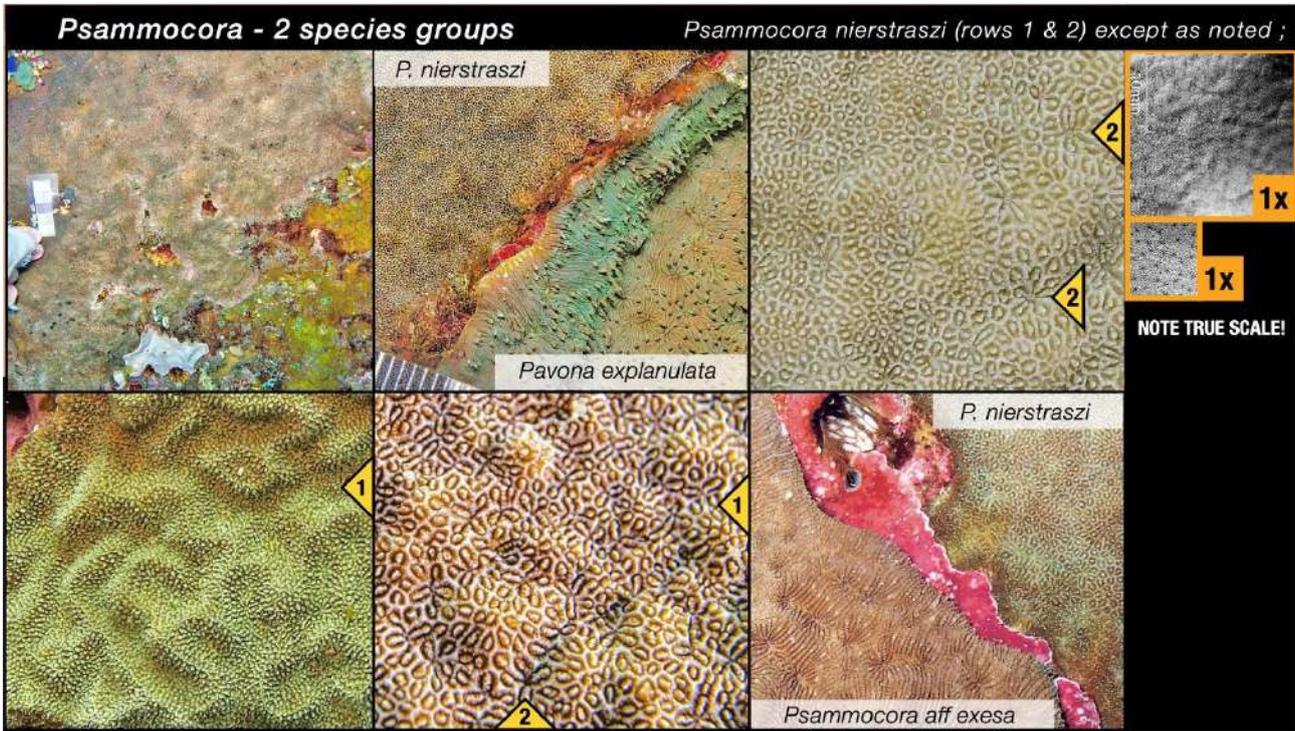
THIN PLATES

ENCrustING WITH RAISED SKELETAL or CRUMPLED SURFACE TEXTURES

COLONY & CORALLITES			SCALED	CHARACTERS
Montipora All images <i>Montipora</i> sp.				
				<p>Thin crusts, sheets, occasionally thicker. Corallites very small (0.5-1mm), poorly defined, often immersed¹ among complex skeletal structures on colony surface.</p> <p>Underwater the distinctive skeletal surface textures make thin plate <i>Montipora</i> generally easy to recognise. But a small number of plate forming <i>Porites</i> species (below) may cause confusion. In general <i>Montipora</i> corallites are slightly smaller & less well defined especially at the edges² of the colony.</p> <p>Note: <i>Porites rus</i> & <i>P. monticulosa</i> may cause confusion with platy <i>Montipora</i> species but collecting & bleaching a small skeletal sample will reveal the unique septal character of each genus, i.e. simple septal spines³ for <i>Montipora</i> & a complex arrangement of pillars for <i>Porites</i> (below).</p>
				
				
				
				
				
Porites All images <i>Porites</i> sp.				
				<p>Crusts or sheets which may flank central upgrowths. Corallites (0.8-1.5mm) set among surface ridges are slightly larger, better defined¹ than <i>Montipora</i> (above) - especially at colony edge². See discussion above.</p>
				
Hydnophora <i>H. bonsai</i> (row 1); <i>H. exesa</i> (row 2)				
				<p>Crusts, sheets, sometimes with upgrowths. Corallites obscure (2-3mm)¹ lying immersed between raised segments of skeleton called monticules².</p> <p>Monticules (a.k.a. hydnoophores - see glossary) may be conical bumps or fuse to form short ridges³.</p> <p>Monticules & corallite centres may be completely obscured by daytime extended tentacles.</p>
				

43 Comments: see also *Gardineroseris* p33, *Psammocora* p15,60, *Stylocoeniella* p31.

Coral Finder 'look-alike' pages are composed to illustrate the range of textures to be found within a coral genus, so ultimately helping the user understand species boundaries.



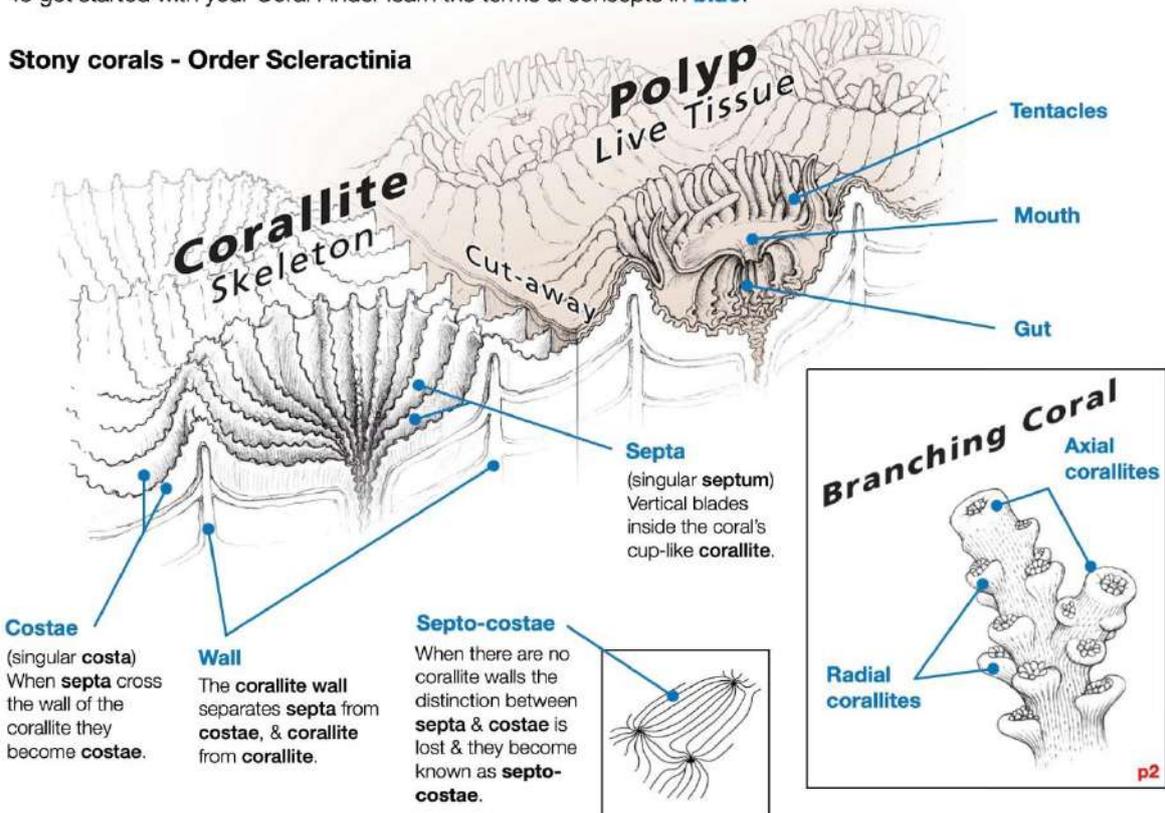
Detail from another 'look-alike' page. The 'two-shot' comparisons can be helpful in illustrating detail.

GLOSSARY

Watch the INTRO videos: www.byoguides.com

To get started with your Coral Finder learn the terms & concepts in **blue**.

Stony corals - Order Scleractinia



The 'Visual Glossary' illustrates a simplified subset of taxonomic terms, assisting the user to progress fairly quickly using the Coral Finder's visual search system.

Turning the Tide for Coral Reefs: the International Coral Reef Initiative Plan of Action 2021-2024

Marie Touchon (International Coral Reef Initiative Secretariat),
Francis Staub (Global Coordinator of the International Coral Reef Initiative),
Thomas Dallison (International Coral Reef Initiative Secretariat),
Caroline Donovan (National Oceanic and Atmospheric Administration),
Case Prager (U.S. Department of State)



The science on the state of coral reefs is clear: threatened by climate change and biodiversity loss, they are amongst the most vulnerable ecosystems on the planet, and future projections on their survival are bleak. The twin crises of climate change and biodiversity loss have brought into stark relief the need for greater collaboration and action, at the international level, to conserve, manage, and restore coral reefs.

Coral reefs and associated ecosystems provide many gifts to humans, but the climate crisis and other local anthropogenic stressors, such as land-based pollution, sedimentation, overharvesting, and illegal activities, pose direct threats to these ecosystems. Under current trends, we risk losing irreplaceable sources of food, medicine, coastal protection, and cultural and spiritual benefits, as well as the foundation for numerous livelihoods. Global and concerted action to conserve and manage coral reefs is urgently needed; actions taken in the next few years will be key to turning the tide for coral reefs.

It is in this context that the International Coral Reef Initiative (ICRI) Secretariat, under its newest Chair, the United States of America, is launching its Plan of Action for 2021-2024, **Turning the Tide for Coral Reefs**.

About ICRI

The International Coral Reef Initiative (ICRI) is a global partnership between Nations and organisations that strives to preserve coral reefs and related ecosystems around the world.

The Initiative was founded in 1994 by Australia, France, Japan, Jamaica, the Philippines, Sweden, the United Kingdom, and the United States of America. To date, ICRI has grown to a network of over 90 members, including 45 countries that are custodians of over 75% of the world's coral reefs, composed of a mix of governments, non-governmental organisations, and international organisations.

Since its founding, ICRI has played a vital role in bringing together those dedicated to the conservation, management, and restoration of coral reefs worldwide: informing international efforts to conserve reefs and associated ecosystems, providing both a forum for global advocacy on coral reefs and assisting managers of coral reefs at the national and local levels.

Over the course of the next three years, the ICRI Secretariat proposes to maintain progress towards Sustainable Development Goal 13 (take urgent action to combat climate change and its impacts)

and Goal 14 (conserve and sustainably use the oceans, seas, and marine resources).

This Plan of Action will guide and encourage actions taken by the Secretariat and its members.

Theme 1: Preparing for the Future: Promoting Resilient Coral Reefs

The first theme, **Preparing for the Future: Promoting Resilient Coral Reefs**, seeks to push for effective action to understand and promote the resilience of coral reefs and related ecosystems, through policies and conservation practices that encourage resilience-based management and recovery of coral reefs worldwide.

The desired outcome of Theme 1 will be achieved through three focus areas: 1) Strengthening policies to support conservation and recovery of coral reefs and associated ecosystems through resilience-based management frameworks; 2) Promoting capacity building for applying resilience-based management approaches; and 3) promoting and building capacity for the restoration of resilient coral reefs. Each action will be supported by ICRI's *Ad Hoc Committees* on Resilience-based Management and Reef Restoration.

Theme 2: Coral Reef Science and Oceanography: Advancing and Utilising the Latest Science and Technology

The second theme aims to utilise, promote, and convene new technologies and rigorous scientific data to report on the status of coral reefs worldwide, guiding science-based management and policies. To achieve this, under Theme 2, **Coral Reef Science and Oceanography: Advancing and Utilising the Latest Science and Technology**, ICRI will build capabilities for the monitoring of coral reefs, using 3D imaging technologies and other coral monitoring technologies, paired with Artificial Intelligence platforms, to build more consistency into data acquisition from coral reefs.

Moreover, the Global Coral Reef Monitoring Network (GCRMN), an operational network of ICRI will, alongside regular mechanisms for annual and

biennial reporting, develop data solutions, guidelines, and protocols for the collection, analysis, management, and sharing of reef monitoring data.

Theme 3: Local Threat Reduction: Integrating Response Planning Frameworks

For more than a decade, a common strategy for coral managers has been to develop response plans for the various threats plaguing corals. With the increase in bleaching events, coupled with unsustainable fishing practices, land-based pollution, diseases and vessel groundings, many managers have developed response plans to tackle such threats. In 2020, a need for integrated response-planning efforts was recognised. Theme 3, **Local Threat Reduction: Integrating Response Planning Frameworks**, therefore proposes to review and consolidate coral reef response plans and integrate them into a common response framework to simplify and facilitate response for local coral managers.



David Burdick | NOAA



© Julien Wickel | Marex

In conclusion, the ICRI Plan of Action for 2021-2024 gives context to the challenges associated with coral reef conservation; suggests concrete actions to overcome these challenges, and gives guidance to the coral reef community to help them turn the tide for coral reefs. ICRI will take every opportunity to raise the plight of coral reefs within the broader international community, and to promote the actions that can be taken at local, regional, and global levels to secure their protection and recovery.

Theme 4: Diversity and Inclusion: Expanding the Coral Reef Community

The fourth and final theme, **Diversity and Inclusion: Expanding the Coral Reef Community**, seeks to broaden the coral reef community to include under-represented voices, including those of indigenous, local, and youth communities. This will be implemented through connecting with youth audiences to inform, motivate, and empower the collective protection of coral reefs, associated ecosystems, and nature. ICRI will also seek to incorporate indigenous and local knowledge into policies and management plans by collaborating with indigenous people.

Read the Plan of Action 2021-2024 [here](#).

Learn more about ICRI: <https://www.icriforum.org>

 [@ICRI_Coral_Reef](#) (#ForCoral)



The Cnidarian Cell Culture Consortium

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In vitro research & cnidarian biology

In vitro studies are crucial research tools for understanding cell biology, cellular interactions, tissue development and immune response. Such studies complement *in vivo* experiments and have enabled great progress in the field of vertebrate research drug testing and discovery, disease and host-microbe interactions, gene editing, high-throughput toxicology screening and more. Methodological and technological advances have been such that *in vitro* vertebrate research has now moved to 3D cultures and organoids (“organ-on-a-chip” systems). In contrast, despite the fact that aquatic invertebrates represent the majority of freshwater and marine living organisms, attempts to maintain cell lines from marine invertebrates have been unsuccessful, mostly due to decreasing *in vitro* viability, and microbial contamination. Primary cnidarian cell cultures have nevertheless been generated from sea anemone tentacles and ectodermis (Barnay-Verdier et al. 2013; Rabinowitz et al. 2016), scleractinian coral polyp tissue (Domart-Coulon et al. 2004; Vizel et al. 2011; Lecoite et al. 2013; Nowotny et al. 2021; Roger et al. 2021), octocorals (Huete-Stauffer et al. 2015), and scyphozoan mesoglea (Frank and Rinkevich 1999), but none of these cultures

have generated axenic, immortal cell lines.

A major challenge of cnidarian cell culture lies in the tight endosymbiotic relationship they maintain with a variety of microorganisms. When cnidarians cells are put into a culture environment, this relationship can break down and cause “contamination” of the culture because the structural integrity of the tissue is no longer maintained. Despite this challenge, hopeful findings



Figure 1. Photos of Cnidarians. *Aurelia aurita* (top left), *Pocillopora damicornis* (top right) and *Exaiptasia pallida* (bottom right), and photo of biosafety cabinet with *in vitro* work underway (bottom left). (Photos: © Liza Roger)

continue to be published. A recent study by Kawamura et al. (Kawamura et al. 2021) appears to have successfully generated an immortal cell line; however, more work is needed to confirm such promising reports since contamination with unicellular marine photosynthetic eukaryotes has been reported in coral cell cultures of a similar species (Reyes-Bermudez and Miller 2009). Overall, many challenges remain in the cnidarian cell culture field, with inconsistent results regarding survival, proliferation, and viability likely reflecting the lack of standardized protocols.

However, as our knowledge of cnidarians and their partners grows, important questions arise, especially regarding the physiological basis of host-partner interactions (Connelly et al. 2022). Stable, long-term cell lines will help address these fundamental questions without the problems associated with manipulating and maintaining whole organisms in the laboratory. Despite cnidarians being the most intensively used taxa in ecotoxicology, they have mostly been studied at the individual (jellyfish, anemones, solitary corals) or colony level (reef-building corals); which has arguably limited progress not only in understanding their fundamental biology but also in understanding the impacts of environmental change and developing effective mitigation strategies.

In vitro research has the added advantages of reducing the need for whole organism harvesting and testing, of being more time- and cost-effective, and more ethically sound overall. The high-throughput capabilities and controlled conditions of *in vitro* research provide clear advantages, even if low translation to *in vivo* systems can sometimes indicate oversimplification of *in vitro* experimentation.

The Cnidarian Cell Culture Consortium initiative

The Cnidarian Cell Culture Consortium initiative brings together scientists from around the world (currently 26 scientists from 8 different countries), working on cnidarian cell culture, with the aim of harmonizing and consolidating cnidarian cell culture methods. To date these different groups have been working independently but finding similar challenges that, through collaboration, could be more easily

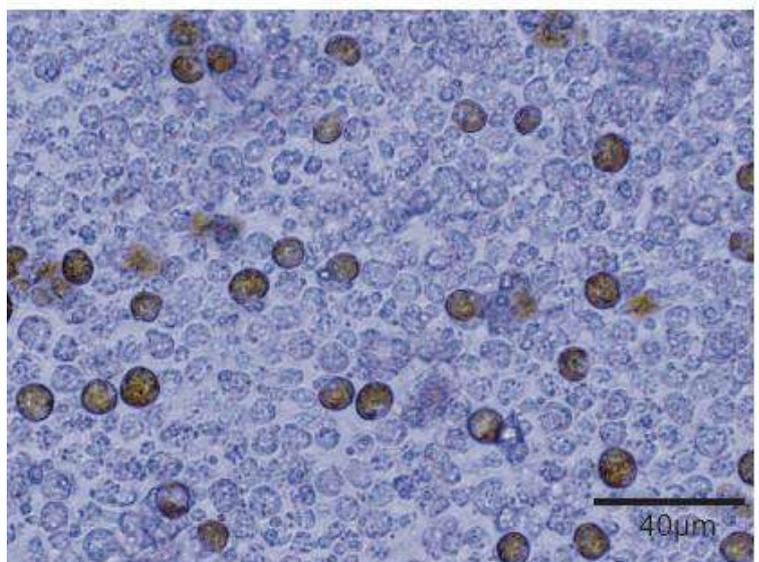
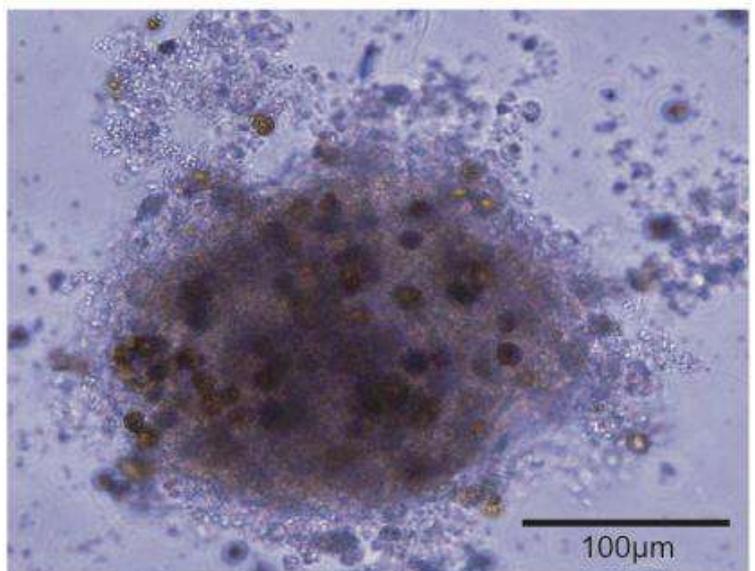


Figure 2. *Acropora digitifera* cell cultures. Cultures were initiated from *A. digitifera* adult colonies (top), using a calcium free water dissociation method (middle). After 4 weeks cultures consisted of individual *Symbiodinium* spp. cells and cellular aggregates displaying a unique, non-specific small round morphology (bottom). (© Alejandro Reyes)

resolved. The particular objective is to generate stable long-term cell lines that can be used to better investigate the cell biology and molecular processes critical to coral health.

Open invitation to join

We invite scientists who are involved in this area or interested in developing this approach in their laboratory to join the consortium. The more diverse perspectives we have, the better we will be able to address the challenges in novel ways. Please contact us at: cnidarialife@gmail.com.

What's next for the consortium?

We are planning a formal workshop, provided funding can be secured. The workshop will be geared toward early career scientists, with an emphasis on sharing new information, disseminating current protocols and results, and providing networking opportunities.

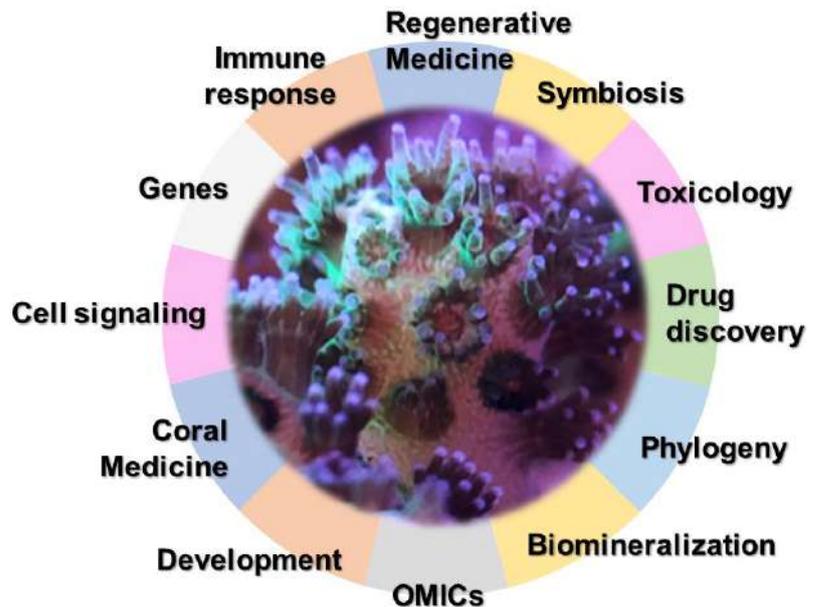


Figure 3. Unlocking *in vitro* Cnidarian research will increase our understanding of their biology and help us find solutions to mitigate the impacts of Climate Change (©Liza Roger)

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The Hainan South China Sea Institute of Tropical Oceanography

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South China Sea Institute of Tropical Oceanography, Innovation Road, Yazhou Bay Science and Technology City, Yazhou District, Sanya City, Hainan Province, China

The Hainan South China Sea Institute of Tropical Oceanography is a non-profit provincial scientific research institution, established in 2003 by its Founder Director, Hong Chen. The purpose of this organisation is to build a tropical oceanography institute with international influence. The main scope of its work is as follows:

1. *Marine scientific research, ecological restoration, environmental monitoring and protection of coral islands and reefs;*
2. *Research and technological development of intelligent equipment and engineering;*
3. *Technology development and utilization of biological and environmental resources;*
4. *Popular science and education, etc. Our future priorities include the combination of molecular technology and coral industry, the combination of marine intelligent equipment and coral farming, and the combination of ecological restoration and homeland protection.*

More information can be found on our website at: <http://tmbcn.cn>

The permanent facilities of the institute include a 1,200-square-meter coral laboratory, an environmental laboratory, a coral science museum, a coral experiment site on Quanfu Island in Yagong Island, Xisha, an offshore experimental platform in Li'an Lagoon in Lingshui New Village, and a coral garden on Phoenix Island in Sanya. There is also a "Sanya Coral Reef Restoration Research Laboratory". In addition, a new shark antibody bank, a coral Biobank, and an international forum on coral reefs have been created.



The Institute's Founder Director Hong Chen



The buildings where the South China Sea Institute of Tropical Oceanography is located.

Currently the institute is culturing millions of juvenile corals as part of its cultivation activities, establishing and maintaining coral gardens on Phoenix Island and Xisha Quanfu Island, establishing China's first coral Biobank, and researching and developing marine life armor and reef maintenance technology. The pristine coral hydroxyapatite developed by us has unique

characteristics that can be used in promoting the growth of bone cells and preventing their infection. In addition, we have achieved a series of innovative results during research on coral reproduction and disease, coral transplant robots, coral survey robots, seaweeds and red tides.

We welcome cooperation and exchanges with scientists from all walks of life!



Professor Ruth Gates visited our institution on October 21, 2016



Specimen collecting off local reefs

JOIN US FOR OUR 2022 3rd INTERNATIONAL CORAL REEF FORUM

September 23rd-24th, 2022

either ON-LINE or IN-PERSON

Location: Yazhou Bay Technology City, Yazhou District, Sanya, Hainan Province, CHINA

Registration required before 1st September 2022
Registration requests by email to: chenhong68@vip.163.com

On-line participation will be via ZOOM.
Log-in details will be provided following registration.

Empowering Communities to Monitor Coral Reefs in the Philippines

Denise Alcantara (denise_alcantara@dlsu.edu.ph)
Las Pinas City, Philippines

Two volunteers put on their wooden fins. One piece for each of them. They wear their masks and jump off the boat. One with a blue PVC monopod in hand, and the other with a navigational marker and a laminated guide with a set of random numbers. They swim toward the middle of the sampling station and begin their “C30” survey.

In a recent [study](#) published in the *Regional Studies in Marine Science*, Dr. Wilfredo Licuanan and his team described C30 as a “simple, rapid, scientifically valid, and low-cost method for citizen scientists to monitor coral reefs.” C30 is an image-based method requiring at least 30 reef images to be taken within a 1,875-m² sampling station¹. It has been proven to yield hard coral cover estimates that have a statistical ability to detect coral cover change comparable to five 50-meter photo-transects.

The Philippine archipelago is composed of over 7,000 islands and has the third largest area of coral reefs in the world. It is part of the Coral Triangle biodiversity hotspot, where over 500 coral species can be found. Its reefs are culturally and economically linked to the Filipino people, since the coasts of the islands are lined with reefs and support fisheries that in turn support the most vulnerable and marginalized sector of the population.

There are not enough Filipino scientists to study and monitor the reefs. “We need citizen science to make up for the relatively small number of reef scientists and large reef areas in the Philippines,” explained Dr. Licuanan, Professor and Founding Director of De La Salle University’s Br. Alfred Shields FSC Ocean Research (DLSU SHORE) Center, who led the Philippines’ second and most recent [nationwide assessment](#) of coral reefs from 2014 to

2017. It was a massive project implemented by a team of researchers flying around the country and diving on randomly-selected reefs. It took three years to visit around 400 reefs. But it had taken some 40 years for this nationwide assessment to take place following the first one. The data have proved that the Philippines cannot wait another 40 years before this happens. The island nation has lost around [one-third of its coral cover](#) in a decade.

Reef management in the Philippines

“It should be noted that conservation and management efforts for coral reefs differ between developed and developing countries,” noted the late Filipino national scientist, Dr. Edgardo Gomez, in a *Coral Reefs* [article](#) in 1996. “When coral reef management schemes are considered for implementation at a national level, there are at least two approaches. Often, because of limited awareness of local communities, there is a top-down approach from the central government. These sorts are almost always doomed to failure although some management actions, such as zoning and development planning, have to be done at both national and local levels,” he added.

The national scientist’s sentiments still ring true applying still to today’s circumstances. In reality, “the management of reefs is in the hands of local



Figure 1. An aquarium fisher taking a photo of the reef using a folding monopod and GoPro camera.

¹ Licuanan WY, Mordeno PZ, Go MV (2021) C30 - A simple, rapid, scientifically valid, and low-cost method for citizen-scientists to monitor coral reefs. *Reg Stud Mar Sci* 47:101961

government. So, the only way for those local governments to afford [reef] monitoring is through a citizen science model,” as Dr. Licuanan has confirmed. Citizen science is not a new movement. ReefCheck, for example, has been very successful in mobilizing volunteers to gather reef data which have proved invaluable in monitoring reef changes around the globe. However, recreational diving remains a skill that very few people have access to in the Philippines. So, this begs another question, how do we get more people involved in citizen science efforts to monitor coral reefs?

Role of citizen science

Last July 2020, the DLSU SHORE team received reports of coral bleaching from their local community partners, some of whom were trained to use the C30 method in Lian, Batangas. As reported in a [research note](#), the bleaching event prompted a collaborative, community-initiated reef monitoring effort. The multi-stakeholder group was composed of representatives of local government in the municipality of Lian, Batangas, of regional officers from the Department of Environment and Natural Resources - Community Environment and Natural Resources Office (DENR - CENRO) Calaca, and of volunteers from a people’s organization called Lian Fisherfolks Association, as well as of researchers from the DLSU SHORE Center. Each stakeholder’s role was distinct. The local government provided allowances and meals to the volunteers of the Lian Fisherfolks Association; while DENR-CENRO and DLSU SHORE provided technical support and equipment, respectively. In three days, the group surveyed six sampling stations in Talim Bay, two of which are marine protected areas.

Beyond being a data-gathering tool, the C30 method is also a communication and education tool enabling locals to identify and understand indicators of reef health. Volunteers are taught seven benthic categories to aid in processing the images in conjunction with the Coral Point Count with Excel extensions (CPCE) software. It also teaches the participants to identify live hard corals. Ideally, the images are processed in a public setting before the end of the survey day. In this case, the CENRO representative helped operate the laptop with the CPCE software and facilitated the image processing. All volunteers are encouraged to participate. Ten random points per image are scored. Then, the results are immediately shown to the participants so as to provide immediate feedback. Typically, this triggers valuable

conversation in which all stakeholders can participate.

“[C30] hits many key areas. One is you are improving awareness. You are improving education. You are generating information that is otherwise expensive to generate. And at the same time, you are making it locally relevant,” Dr. Licuanan shared.

Interoperability

According to the European Citizen Science Association, there are [10 principles of citizen science](#) that can aid in the development and assessment of any citizen science effort. The third principle emphasises the importance of both professional scientists and citizen scientists to the joint effort. The development of an image-based method was intentional, to ensure that scientists are able to verify the data and further process and analyze them for other scientific pursuits. On the other hand, the government also needed a low-cost monitoring method that could provide basic information on the state of the reef. “Due to the lack of knowledge and skills on coral reef assessment, the government needed an easy-to-execute, less expensive, and readily-available tool to help in preserving the marine ecosystem,” said Jason Boongaling, Forest Technician II of the DENR CENRO Calaca office. His role under the Conservation and Development Section transcends both forest and marine-related management efforts.

In the Philippines, many different reef monitoring methods have been in use. This has led to confusion between different government offices and institutions, making comparison between sites and regions virtually impossible due to inconsistent data collection and sampling protocols. “Local limitations concerning reef assessment and monitoring were constrained more by the limited appreciation of the importance of proper sampling considerations, site selection criteria, and cross-calibration among teams,” Dr. Licuanan has explained. He has assured stakeholders that by applying the same sampling and site selection protocols used in the nationwide assessment, hard coral cover data collected using the C30 method would be comparable. It seems that it is time for scientists to step down from their ivory towers and make science accessible and relatable to the people. As Dr. Gomez stated in the *Coral Reefs* article: “If, with all the scientific knowledge we have generated, we are unable to succeed, we must look elsewhere for a solution.”

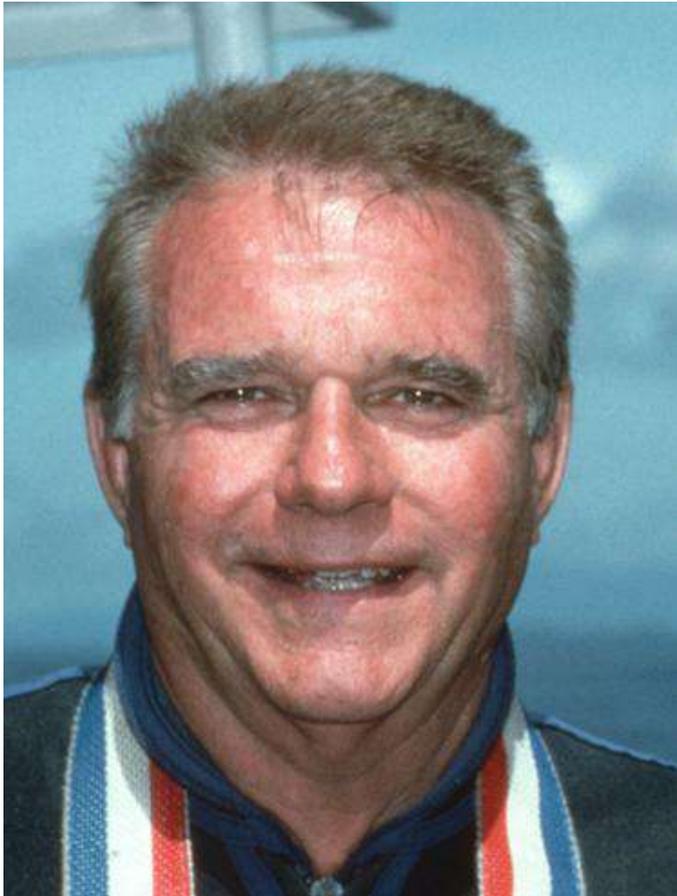
REEF DEPARTURES

Tributes to recently departed members and reef scientists

Ernst S. ("Ernie") Reese (1931-2022)

Deborah J. Gochfeld (gochfeld@olemiss.edu); Greta S. Aeby (greta@hawaii.edu)

On behalf of his former students and colleagues



The coral reef scientific community has lost one of the great ethologists, Dr. Ernst S. Reese, who passed away on February 21st 2022, a few weeks after his 91st birthday. Ernie, as he was widely known, was a faculty member in the Department of Zoology at the University of Hawai'i at Manoa from 1963 until his retirement in 2002. His research on butterflyfish behavioral ecology opened up a wide-reaching field of study including the use of Chaetodontidae as indicators of coral reef health. Beyond his scientific contributions, he was an ardent supporter of marine conservation, and an enthusiastic and supportive mentor.

Ernie obtained his undergraduate degree at Princeton University in 1953, followed by service in the U.S. armed forces as First Lieutenant and Executive Officer of a field artillery battalion in Austria. After his service, he enrolled in the graduate program in zoology at the University of California Los Angeles in 1956. Ernie became interested in innate animal behavior patterns, although animal behavior was still a fledgling discipline of zoology. He received his doctorate in 1960 under the mentorship of Professors George A. Bartholomew and Richard A. Boolootian, with a thesis on the shell selection behavior of hermit crabs. He published a paper in *Science* furthering this topic of study.

While attending dinner at an international oceanography conference, Ernie happened to sit next to Robert W. Hiatt, Director of the Eniwetok¹ Marine Biological Laboratory (EMBL) in the Marshall Islands. The laboratory was managed by the University of Hawai'i with the Division of Biology and Medicine of the U.S. Atomic Energy Commission, which was interested in attracting marine biologists to use the laboratory. Ernie was invited to visit the atoll with a fellowship from the U.S. Atomic Energy Commission to study coconut crabs. This



Ernie Reese in the early 1960s.

¹ then spelled Eniwetok, but now Enewetak



Ernie (second from left) with Dr. Konrad Lorenz (second from right) and colleagues at HIMB ca. 1966

chance encounter not only provided Ernie with his first opportunity to study the fauna of a tropical coral reef, but during his visit he met Al Tester, who was the chairman of the Department of Zoology at the University of Hawai'i. Dr. Tester invited Ernie to teach an introductory zoology course at UH.

Meanwhile, Ernie continued his postdoctoral studies with a fellowship from the National Science Foundation at the University of Groningen in the Netherlands and in Germany with Nobel Laureate Konrad Lorenz.

Following his postdoctoral research, Ernie became a fellow of the Hawai'i Institute of Marine Biology (HIMB), and was eventually offered a split faculty position between the Department of Zoology and HIMB on Coconut Island in Kaneohe Bay, Oahu.

While making a home for his family on Kaneohe Bay, his interests turned to the protection of coral reef environments. On Oahu, prior to 1967, Hanauma Bay was a popular fishing ground and camp for people from Honolulu, where most types of fishing were allowed. By the 1960's, fish stocks began to decline from the heavy fishing pressure. Dr. Reese and his graduate students documented the

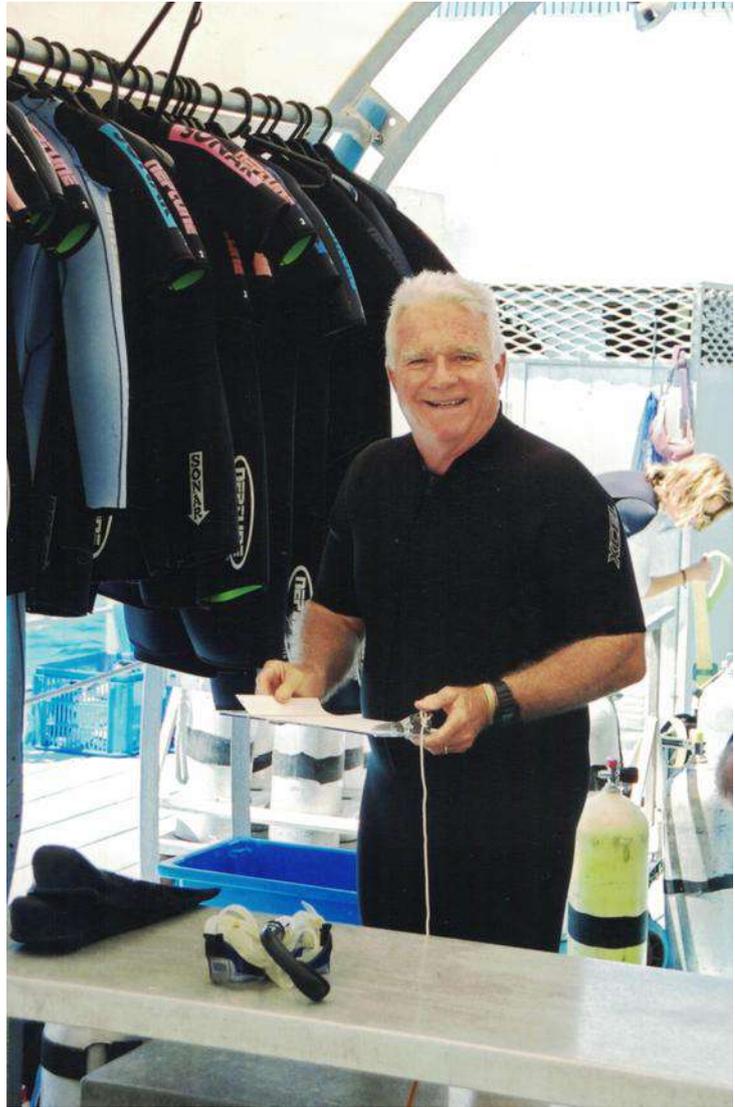


Keoki Stender

One of Ernie's favorite butterflyfish species – the redfin butterfly, *Chaetodon lunulatus*

environmental resources in the Bay and proposed that Hanauma Bay be set aside as a protected area and living museum. Many fishermen protested this idea for fear of setting a precedent to close other local fishing grounds. However, the data generated by an underwater survey convinced the Hawai'i State Legislature to designate Hanauma Bay as its first Marine Life Conservation District.

While a faculty member at the University of Hawai'i, Ernie's research focused on the social behavior of reef fishes. He became particularly interested in the relationship of food and feeding behavior to behavioral ecology and life history characteristics, the coevolution of corals and reef fishes, and orientation behavior of butterflyfishes. His research spawned new interest in studying butterflyfish behavior, and culminated in the development of the Butterflyfish Indicator Hypothesis. This novel idea that butterflyfish feeding and territorial behavior could be used as bio-indicators of conditions on coral reefs led to new and productive fields of study on coral reefs worldwide.



Ernie in Enewetak

Dr. Reese was awarded several professional honors and filled several leadership positions in the scientific community. He was President of the Animal Behavior Society in 1975 and the Hawai'i Academy of Science 1985-1986. He was director of the Mid-Pacific Research Laboratory at Eniwetok from 1977 to 1980. Throughout his career, his research was funded by the National Science Foundation, National Oceanic and Atmospheric Administration, Smithsonian Institution, and Special Legislative grants from the State of Hawai'i. The University of Hawai'i bestowed upon him a Faculty Performance Award in 2000 and elected him Emeritus Professor in 2002.

Throughout his professional life at the University of Hawai'i, Dr. Reese was concerned about the quality of education and helping students find their paths in life. He was an exceptional mentor, providing

kind support and thoughtful encouragement to students of all ages. He was always upbeat and enthusiastic, and shared his love of the oceans with his students. He will be missed by all who had the privilege of knowing him.

Ernst Reese is survived by his wife Ilze, their children Theresa McFarland (husband Bill) and Hans Reese (wife Michele), and seven grandchildren. He imparted to each his love of nature and the importance of family.



ICRS Membership

ICRS membership is open to anyone interested in any aspect of the science of coral reefs. While the society's membership consists principally of researchers, managers and students with involved with coral reefs and associated ecosystems, other people with genuine interests in or concern for reefs, of any type, are welcome. The benefits of membership include:

- ❖ Receipt of the Society's scientific journal *Coral Reefs* (on-line)
- ❖ Free (on-line) access to all past issues of *Coral Reefs*
- ❖ Receipt of the Society's newsletter/magazine *Reef Encounter* (by email or on-line)
- ❖ Eligibility for the graduate fellowships, students travel grants and communications fellowships offered by the Society
- ❖ Eligibility for the multiple honors and awards given by the Society, including mid- and early-career and conservation awards
- ❖ Access to the Society's on-line membership services, including the on-line Membership Directory
- ❖ Reduced registration fees for the International Coral Reef Symposium and other meetings sponsored by the Society.

Full / Individual Member

Membership includes all the benefits listed above, but rates vary depending on the mean income level of the member's country.

Student Membership

The benefits are the same as for a Full / Individual Member, and include on-line access to *Coral Reefs* at a much reduced rate.

Family Membership

Family memberships are available for partners who live at the same address. Each receives the same benefits as Full Individual Members, but only one copy of any material is supplied.

Sustaining Membership

Sustaining Membership is for those Members who would like to contribute extra to support the work of the Society. They receive additional minor benefits and their support is acknowledged in Society publications.

Honorary Membership

Honorary Membership has been conferred on a small number of members who have rendered special service to the society or otherwise distinguished themselves in the field of reef science.

Membership services are now operated by Schneider Group which provides such services to academic societies. They may be contacted at:

ICRS Member Services

**5400 Bosque Blvd, Suite 680
Waco, Texas 76710-4446 USA**
Phone: 254-399-9636
Fax: 254-776-3767
email: icrs@sgmeet.com

The membership subscription varies considerably depending on the type of membership selected and the primary country of residence of the member. Very generous membership rates are available for students and residents of developing countries.

For low to low-middle income countries, full membership costs only \$40 (US) per year, and student membership only \$20 (US) per year.

For details of current rates and to complete the on-line membership form or download a hard copy please go to the society's membership portal at:
<https://icrs.memberclicks.net/>

NOTES FOR REEF ENCOUNTER CONTRIBUTORS

Reef Encounter welcomes items for publications, especially:

- General overview articles (3-5 pages long) on a particular reef science topic in which the author(s) has a special interest (for the **REEF CURRENTS** section)
- Short communications / scientific letters (1-2 pages) reporting recent observations (for the **REEF EDGE** section)
- General interest articles (3-6 pages) describing personal views and experiences (for the **REEF PERSPECTIVES** section)

Reef Encounter also welcomes

- Announcements** about future meetings, workshops and activities
- Conference Reports** about recent meetings, workshops
- Book and Product Reviews for the **REEF SHELF** section
- Descriptions and news of projects for the **REEF ACTIONS** section
- Information to be included in the **REEF DEPARTURES** section (Obituaries)

Authors are encouraged to include colour pictures or other illustrations (normally 2-4 per article).

There are no specifications regarding the formatting of articles for submission to the editors – please submit them as WORD files (preferably with single spacing between lines).

However, we do require that references should be cited and listed using the style of the ICRS academic journal CORAL REEFS, see: <http://www.springer.com/life+sciences/ecology/journal/338>.

Articles from non-ICRS members are welcome, but the latter are generally given priority.

Items should be submitted by email to the senior editor (rupert.ormond.mci@gmail.com) or a relevant member of the editorial panel (see page 2).



Coral reef community in the South China Sea, Hainan Island, China. See Reef Actions (image: Hong Chen)



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Coral Reef Society