

REEF ENCOUNTER

The news magazine of the International Coral Reef Society



REEF PERSPECTIVES

Lyndon de Vantier:
What Future for
Coral Reefs?

Jorge Cortes: Back-
shifting the Baseline

REEF ACTIONS

International Coral
Reef Initiative (ICRI)

Global Coral Reef
Monitoring
Network (GCRMN)

Hawai'i Coral
Restoration Nursery

GRADUATE REPORTS

Corallicolids in Caribbean
Corals

Conservation Priorities in Fiji
Coral Rubble – just dead
coral?

Coral Recruitment in
Tanzania

Tridacna squamosa in
Malaysia

REEF DEPARTURES

Angel Alcala

Bob Kinzie

Richard Kenchington

APPENDIX

Enewetak Coral

Taxonomy Workshop
(1976)



www.coralreefs.org
ISSN 0225-27987

Volume 38, No. 1
June 2023
Number 53

REEF ENCOUNTER

VOL 38 | June 2023

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.

Coordinating Editor

Rupert Ormond (rupert.ormond.mci@gmail.com)

Deputy Editor

Caroline Rogers (caroline_rogers@usgs.gov)

Editorial Panel

Beatriz Casareto (becasar@shizuoka.ac.jp)

Douglas Fenner (douglasfennertassi@gmail.com)

Deborah Gochfeld (gochfeld@olemiss.edu)

Edwin Hernandez-Delgado (coral_giac@yahoo.com)

Dennis Hubbard (dennis.hubbard@oberlin.edu)

Nicolas Pascal (nppacific@gmail.com)

William Precht (william.precht@gmail.com)

Silas Principe (silasprincipe@yahoo.com.br)

Sue Wells (suewells1212@gmail.com)

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.

President: Christian Voolstra (Germany) (christian.voolstra@uni-konstanz.de)

Vice President: Tracy Ainsworth (USA) (tracy.ainsworth@unsw.edu.au)

Treasurer: Anderson Mayfield (USA) (abm64@miami.edu)

Recording Secretary: Anastazia Banaszak (Mexico) (banaszak@cmarl.unam.mx)

Communicating Secretary: Mark Eakin (USA) (corals.and.climate@gmail.com)

Council Members (2021-2024)

Nicole Browne (Australia)

Luis Eduardo Calderon (Mexico)

Sarah Davies (US) (co-opted)

Ilsa Kuffner (US)

Vikash Munbodhe (Mauritius)

Kennedy Osuka (Kenya)

Raquel Peixoto (Brazil)

Nikki Traylor-Knowles (US)

Council Members (2023-2026)

Deepeeka Kaulysing (Mauritius)

Tries Razak (Indonesia)

James Reimer (Japan)

Hector Reyes-Bonilla (Mexico)

Verena Schoepf (Netherlands)

Coral Restoration Consortium Chapter

Tom Moore (tom.moore@noaa.gov)

Scott Winters (Scott@coralrestoration.org)

Tali Vardi (tali.vardi@noaa.gov)

European Chapter (chair)

Get Woerheide (woerheide@lmu.de)

Mexican Chapter (chair)

Rafael Cabral Tena (rafacabraltena@gmail.com)

Mid-East Chapter (chair)

John Burt (john.burt@nyu.edu)

Student Chapter (co-chairs)

Jenny Mallon (jmallon967@gmail.com)

Morgan Short (ms4341@mynsu.nova.edu)

Conservation Committee (co-chairs)

Simon Harding (simon.harding@usp.ac.fj)

Raquel Peixoto (raquel.peixoto@kaust.edu.sa)

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](#).

Editor in Chief

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

OFFICERS' REPORTS

4 President's Message

5 Treasurer's Report

SOCIETY ANOUNCEMENTS

6 Society Awards & Honors

7 European Coral Reef Symposium



CHAPTER REPORTS

9 Conservation Committee

11 Student & Early Career Chapter

13 Middle-East Chapter

REEF PERSPECTIVES

14 What Future for Coral Reefs?

Lyndon de Vantier

28 Back-shifting the Baseline

Jorge Cortés



REEF RECRUITS

33 Corallicolids in Caribbean Corals

Akacia Halliday-Isaac

35 Conservation Priorities in Fiji

Katherine Newcomer-Lawson



38 Coral Rubble – just dead coral?

Michelle Taylor

41 Coral Recruitment on Pemba Island, Tanzania

Natalie Andersen

44 *Tridacna squamosa* in Malaysia

Lee Li Keat



REEF ACTIONS

49 Global Coral Reef Monitoring Network

(GCRMN) Britta Schaffelke et al.

54 International Coral Reef Initiative (ICRI)

Marie Touchon

57 The Hawai'i Coral Restoration Nursery

Megan Short et al.



REEF DEPARTURES

60 Angel Alcala

Alan White & Sue Wells

62 Bob Kinzie

Scott Santos



65 Enewetak Coral Taxonomy Workshop (1976)

Brain Rosen



66 Richard Kenchington

Pat Hutchins et al.

69 ICRS MEMBERSHIP

69 NOTES FOR CONTRIBUTORS

ABOUT THE COVER | Coral diversity and abundance on a reef near Gam Island in the Raja Ampat Marine Park, Indonesia. Photo by Caroline Rogers.

EDITORIAL & OFFICERS' REPORTS



PRESIDENT'S MESSAGE

Christian R Voolstra, ICRS President

Dear International Coral Reef Society (ICRS) friends and colleagues:

The International Coral Reef Society is a scientifically and culturally rich organization and I am proud and honored to serve as its President. Given the dire outlook for coral reefs it becomes ever more important to be an active voice for coral reefs and to effect scientific, political, and societal change.

I am incredibly grateful for the prior work of the Council led by President Andrea Grottoli and Vice President Joanie Kleypas. The finances of the society are very much in order, we have a publishing agreement with Springer for our Society's journal 'Coral Reefs' that lets us receive royalties, the ICRS has expanded to include multiple new chapters, and we have launched the 'Plan of Action' and 'Pledge for Reefs'. This incredible effort of 'cleaning up' and 'housekeeping' puts us now in a position where we can focus our efforts even more strongly on actively shaping our society and impacting the trajectory of coral reefs.

The ICRS, as the global organization representing coral reef science, can make a difference- and we all can be a part of it. Keep in mind that our society is shaped by its members and that any member can participate in any effort. I want all of us to help build an active network so that we can grow stronger together. To this end, we have announced the ICRS Mentoring Program, to foster partnerships across career stages and institutions, and to promote belonging. We are also actively working with ICRI, CODAP, and other organizations (via ICRS representatives that report to the Council) to consolidate our common efforts and become a louder voice that is heard, not only within the realm of research, but also in politics and society.

We are also preparing to transform the ICRS webpage into a more active hub for information and (scientific) exchange. We are re-visiting our ICRS award guidelines and may add further awards to recognize efforts in communication & outreach. We are discussing a conference sustainability award to honor outstanding efforts to lower carbon footprints, and we are strategizing how to increase our income from donations, so as to further fuel our efforts to ensure a future for coral reefs.

In addition, arrangements for the next European Coral Reef Symposium (ECRS) meeting, to be held from July 2-5, 2024, in Naples, Italy, have been confirmed, and preparations for the 15th International Coral Reef Symposium, to be held from July 19-24, 2026 (provisional dates) in Auckland, New Zealand are well underway.

My thanks go to the Officers and Council members who voluntarily work tirelessly for the Society and to everyone else for their continuous support. Your dedication and commitment to reefs makes a difference. Let us work together to secure a better future for coral reef ecosystems and the research that supports this pursuit, by working together across nationalities, institutions, and responsibilities!

Sincerely,

Christian R Voolstra, President, ICRS



TREASURER'S REPORT

Anderson B. Mayfield, ICRS Treasurer

Like many of you, prior to my becoming the International Coral Reef Society's (ICRS) treasurer two years ago, I only ever renewed my membership to qualify for meeting discounts. This stemmed from my failure to realize just how much goes on behind the scenes. For instance, did you know that ICRS gave out over \$120,000 US in members benefits in 2022? Nearly half of this amount went to making the 2022 ICRS Bremen meeting free to virtually attend for those from low- and middle-income countries. The remainder went to a large number of awardees, including those who won the following annually granted awards: the World Reef Award (\$2,500), the Coral Conservation Award (\$2,500), six graduate student fellowships (\$2,500 each), the science communications fellowship (\$2,000), and, for the first time ever, two Ruth Gates fellowships (\$5,000 each). We also sent over \$20,000 to our adept Bremen meeting organizers, of which ~\$5,000 was to cover student registration costs and \$15,000 to cover student travel awards (to attend the meeting in-person). The remaining ~\$20,000 went towards 1) physical prizes / awards, 2) shipping of these awards, 3) student membership awards, and 4) additional funding to the in-person Bremen meeting to help reduce conference costs. Yes, I am now on a first-name basis with our bank's wire transfer clerks, and I fully expect to receive a Christmas card from them this year!

An exciting ICRS "first" is happening in 2023; thanks to the diligent efforts of past ICRS President Andrea Grottoli, we have a new contract with Springer (the publisher of our flagship journal *Coral Reefs*), as a result of which, instead of *paying* Springer several thousand dollars (USD) to cover publication costs, we will now *receive* royalties from Springer for their *Coral Reefs*. It is estimated that we should receive over \$30,000 sometime in the near future. This we will use towards reducing the costs of future conference attendance, as laid out in our first-ever ICRS financial plan (rolled out last year).

Although not a financial goal per se, ICRS officers and council acknowledge the fact that we need to do a better job of engaging those from the developing world; after all, this is where the vast majority of our beloved coral reefs are located (Figure 1). To date, we have adjusted our membership dues structure so that those from low-income countries pay lower rates, with student membership dues being lower than those for PhD-level researchers and professionals. We have also expanded the means by which payments can be made; it is no longer necessary to have an international credit card, as we can now accept payment via cash, checks, money orders, credit card, PayPal, and Western Union. (And, I would not be beyond exchanging membership with someone to help me with my myriad treasury duties!) Despite these modest gains, as well as the staggering success of our first formal (2022) fundraiser (in which >\$25,000 were raised from donations from our generous members), we still have a long way to go in ensuring that we truly represent the diverse cadre of coral reef researchers, conservationists, and hobbyists across the globe. As an all-volunteer-based organization, progress can oftentimes be slow. But, if you have any suggestions with respect to fundraising, increasing inclusivity, or other matters that could benefit the society and our diverse membership base, please do reach out to me at icrstreasurer@gmail.com.



Fig 1. A coral reef off Pulau Ai (Maluku, Indonesia), an area with few members.

Anderson B. Mayfield, Taiwan

SOCIETY ANNOUNCEMENTS

2023 ICRS Awards and Honors

The International Coral Reef Society (ICRS) is pleased to announce the recipients of this year's awards and honors. They are:

Eminence in Research Award – Monica Medina, USA
Mid-Career Scientist Award – Christian Wild, Germany
Early-Career Scientist Award – Nils Rådecker, Switzerland
Coral Reef Conservation Award (\$2,500) – Victor Bonito, Fiji
World Reef Award (\$2,500) – NohoraGalvis, Colombia

The winners listed above automatically receive ICRS Fellow status. The following nominees were also awarded ICRS Fellow status (subject to maintaining membership status):

Michel Pichon, Australia
Margaret Miller, USA
Simon Harding, UK
Carly Randall, Australia
Line Bay, Australia

We are also pleased to announce the following fellowship winners. These fellowships provide financial support for student research projects (Ruth Gates and Graduate Research Fellowships) and assist with the development of science communication skills for a society member (Science Communication Fellowship). The awardees are:

Ruth Gates Fellowship (\$5,000) - Igor Pessoa, USA
Graduate Research Fellowships (\$2,500)
Dominique Gallery, USA
Hannah Merges, USA
Lindsay Taylor, USA
Melissa Versteeg, UK
Helen Yan, Australia
Clara Lei Xin Yong, Singapore

Science Communication Fellowship (\$2,000) - Audrey Tan, Singapore

Due to the high standard of applications this year, the ICRS Awards Committee also wishes to provide an honorable mention for the following applicants:

Early-Career Scientist Award– Kate Quigley and Mary Donovan
Ruth Gates Fellowship– Danielle Becker and Claire Williams

Thanks to all nominees, nominators, and reference writers. You help make ICRS a thriving society.

Nicola Browne and Ilsa Kuffner, Co-Chairs, ICRS Honors and Awards Committee
Christian Woolstra, President, ICRS

SOCIETY ANNOUNCEMENTS

The European Coral Reef Symposium

Naples 2024

We are pleased to confirm that the **European Coral Reef Symposium - ECRS 2024**, organized under the auspices of the European Chapter of the International Coral Reef Society, will take place in Naples, Italy, from 2nd-5th July, 2024. It is intended that the meeting should focus on bridging knowledge gaps between tropical, temperate, and cold-water coral reefs.

Provisionally it is anticipated that activities on Tuesday 2nd will include a visit to the marine station and the aquarium, and a small number of workshops, with the opening ceremony being held that evening.

Conference sessions will begin on Wednesday 3rd based around a series of themes, each of which should be able to accommodate a variety of oral and poster presentations. The proposed themes are:

1. Lessons from the Past to Inform the Future

Keywords: geological drivers, palaeontology, paleoecology.

2. Coral Reef Structure and Functioning

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

3. Biology and Ecology of Holobionts in Coral Reefs

Keywords: chemical ecology, photobiology, symbioses.

4. Global Climate Change and Environmental Stressors

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

5. Coral Reef Anthropic Pressures, Conservation, and Restoration

Keywords: effects of tourism, overfishing, chemical pollution, plastics and other emerging contaminants, the nature-based solution to coral reef restoration, the super coral hypothesis, coral aquaculture.

7. Community-Based Monitoring and Ecosystem-Based Management

Keywords: marine spatial planning, stakeholder engagement, citizen science, people awareness.

8. Shallow Temperate Reefs

Keywords: biodiversity, connectivity, functioning and threats, biological invasions.



<https://ecrs2024.eu/>

9. Mesophotic and Cold-Water Coral Ecosystems

Keywords: biodiversity, connectivity, functioning, threats.

10. Technological and Methodological Innovation in Underwater Surveys and Data Analysis

Keywords: precise survey, unmanned and deep surveys, image semantic segmentation, data FAIR.

11. Coral reefs under a socio-economic perspective

Keywords: ecosystem goods and services, social sciences approaches, conservation policies, blue circular economy.

12. Global lockdown due to COVID-19: what have we learned?

Keywords: both positive and negative effects on reef conservation and management.

13. The Ocean Decade: The Science We Need for the Coral Reefs We Want

Keywords: mid- and long-term perspectives in science development.

Key dates are as follows:

Calls

- ▶ October 2nd, 2023 - Call for abstracts opens
- ▶ December 16th, 2024 (midnight CET) - Call for abstracts closes
- ▶ February 13th, 2024 - Notification of acceptance
- ▶ March 5th, 2024 - Authors registration deadline

Registration

- ▶ July 30th, 2023 - Early bird registration opens
- ▶ March 5th, 2024 (midnight CET) - Authors' registration deadline
- ▶ March 20th, 2024 (midnight CET) - Early bird registration closes
- ▶ March 21th, 2024 - Regular registration opens
- ▶ June 25th, 2024 (midnight CET) - Regular registration closes
- ▶ July 1st - 5th, 2024 - Onsite registration

To keep up-to-date with further details you can subscribe to our newsletter at <https://ecrs2024.eu/>

Massimo Ponti (massimo.ponti@unibo.it)
Carlo Cerrano (c.cerrano@staff.univpm.it)
Conference organisers

Gert Woerheide (woerheide@lmu.de)
Chair, ICERS European Chapter



CHAPTER & COMMITTEE REPORTS

Conservation Committee Activities

The ICRS Conservation Committee was established with the objectives of helping the society promote the conservation of reefs and providing scientific expertise in climate change discussions. The committee actively participates in events such as the Intergovernmental Panel on Climate Change Conferences, where it advocates for coral reef conservation in the context of climate change mitigation and adaptation strategies.

A significant achievement for the ICRS Conservation Committee was obtaining observer status at the Conference of the Parties (COP) in 2021. The COPs serve as the decision-making body responsible for monitoring and reviewing the implementation of the United Nations Framework Convention on Climate Change (UNFCCC). Attaining observer status granted the ICRS an opportunity to attend these critical climate change meetings and advocate for CO₂ emissions reduction as a crucial measure for coral reef conservation.

In 2021, the ICRS participated in COP26 in Glasgow, distributing a flier entitled "A Plan to Save the World's Coral Reefs," which was based on the science-to-policy paper developed by multiple members of the society. The paper, as previously described in Reef Encounter, focuses on three main pillars for restoring coral reefs and mitigating future loss: (A) reducing CO₂ emissions, (B) mitigating local stressors (e.g., managing fish stocks or improving water quality), and (C) active restoration/rehabilitation.

In November 2022 Raquel Peixoto, Mariana Rocha de Souza, and Yasser Geneid, members of the ICRS delegation, attended COP27 in Sharm El Sheikh, Egypt (see Reef Encounter 52, p.40-41). The committee actively engaged in workshops with the Global Fund for Coral Reefs (GFCR) and the Coral Research and Development Platform (CORDAP), and had the opportunity to meet with key policymakers, such as the Brazilian President, Luis Inacio Lula da Silva, the Minister of Environment of Egypt, Yasmine Salah El-Din Fouad Abdel Aziz, and the Minister of Environment of Brazil, Marina Silva. These interactions served to strengthen ties and underscore the significance of coral reef conservation for their respective countries.

ICRS delegates also engaged and participated in several discussions in different round tables and workshops. Raquel Peixoto presented talks in workshops and round tables in different pavilions in the blue, green and innovation zones, presenting recent data on the coral reefs crisis and on science-based solutions for minimizing the current coral decline (Knowlton et al. 2021; Voolstra, Suggett & Peixoto 2021; Peixoto et al. 2022). She discussed bottlenecks and opportunities for taking action focused on coral reef conservation, restoration and rehabilitation. Mariana Rocha de Souza and Raquel Peixoto, both Brazilians,



Mariana Rocha de Souza talking to Marina Silva, the Brazilian Minister of the Environment



Raquel Peixoto presenting at the Moana Pavilion event at COP27: What tools do we have to improve rapid adaptation and resilience of corals?

are now following up with the Brazilian Minister of Environment and have plans for a further meeting to discuss coral reef issues and propose policies.

Throughout the year, there are opportunities for organizations to submit documents that shape climate change discussions. The ICRS Conservation Committee submitted a document to contribute to the UNFCCC Ocean and Climate Dialogue, an annual conference in preparation for COP. The document focused on four key areas, all well aligned with ICRS's science to policy document: 1) Prioritizing nature-based solutions: highlighting

coral reef management as a nature-based solution that safeguards ecosystems while providing societal benefits through climate change and natural hazard mitigation; 2) Creating a map of existing and proposed ocean-based solutions: developing a resource that can be referenced in other UNFCCC meetings when discussing nature-based solutions; 3) Exploring partnerships with the Standing Committee on Finance: identifying links where existing program funds can be utilized for ocean activities outlined in the Nationally Determined Contributions (NDCs); 4) Emphasizing the importance of including the oceans in other UNFCCC forums: recognizing the oceans as crucial carbon sinks and a source of diverse nature-based solutions.

The ICRS Conservation Committee acknowledges the significance of collaboration and partnership in achieving its goals. As part of these efforts, the committee actively engages with the wider RINGO (Research and Independent non-Governmental Organizations) constituency, a global network of scientific organizations and NGOs focused on ocean and climate issues, CORDAP (Coral Research and Development Platform), ICRI (the International Coral Reef Initiative) and GFCR (Global Fund for Coral Reefs). We are currently jointly considering how we can advocate a strong and unified message at CoP28, to be held this November / December in Dubai, UAE.

Mariana Rocha de Souza

References

- Knowlton N, Corcoran E, Felis T, de Goeij J, Grottoli, A. 2021. Rebuilding Coral Reefs: A Decadal Grand Challenge." <http://cris.leibniz-zmt.de/id/eprint/4751/>.
- Peixoto Raquel RS, Voolstra CR, Sweet M, Duarte CM, Carvalho S, Villela H, Lunshof JE, et al. 2022. Harnessing the microbiome to prevent global biodiversity loss. *Nature Microbiology* 7: 1726–35.
- Voolstra CR, Suggett DJ, Peixoto RS. 2021. Extending the natural adaptive capacity of coral holobionts. *Nature Reviews Earth*. <https://www.nature.com/articles/s43017-021-00214-3>.



ICRS-SECC

International Coral Reef Society
Student & Early Career Chapter

The International Coral Reef Society Student & Early Career Chapter (ICRS-SECC) is a community dedicated to providing support and resources for students and recent graduates in transitional roles within coral reef science. This year we have implemented two new initiatives to increase our ability to support members in this particular career stage.

The first is the creation of an Early Career Researcher (ECR) Committee, which was established in 2022 to support and advocate for ICRS members who are navigating the highly transitional, and often challenging, early career phase. The committee's goal is to establish a platform for ECRs within the International Coral Reef Society. They aim to promote the work of recent graduates and to provide the ECR community with unique opportunities for enhancing their collaborative and support networks whilst developing the skills necessary for a successful career.



Morgan Short, Chair of ICRS-SECC



ICRS-SECC's sub-committee structure

careers in coral reef science. Several of our committees will collaborate to organize workshops around technical skill development, story-telling panels, and peer-peer networking.

Want to get involved?

See the opportunities below:

1. Apply for a position in the ICRS-SECC. Applications for positions that would start in late-August are open from June 1st - June 30th. Check our social media pages, website, or watch for an ICRS email for the application link.

The second initiative is a chapter-wide effort to create workshops and webinars to support networking and career development for students and early career researchers. This initiative was developed as a result of our workshop at the 15th International Coral Reef Symposium, during which we sought out feedback from student and ECR attendees to understand their needs as they navigate their



ICRS-SECC members at the in-person 15th International Coral Reef Symposium ▶

2. Share your knowledge or skills by leading a webinar or workshop hosted by the ICRS-SECC. If interested, send us an email.
3. Tag us in your Twitter posts about your papers, accomplishments, or offerings of advice (@ICRSreefstudent).
4. Be featured on our Instagram page by doing "A day in the life", an Instagram Takeover, or an Instagram Live (More info: message us on IG @icrs.students).
5. Complete a written interview to be a "Feature Friday" on our Reefbites Blog (More info: reefbites.com/student-corner).
6. Share about your organization's contribution to our reefs as a part of our "Science Saturday" series on Reefbites (More Info: reefbites.com/reef-community).

ICRS-SECC Steering Committee

Morgan Short (Chair), Jenny Mallon (Vice-Chair), Jenna Dilworth (Secretary), Nicola Kriefall (Webmaster), and Violeta Martinez Castillo (Treasurer)

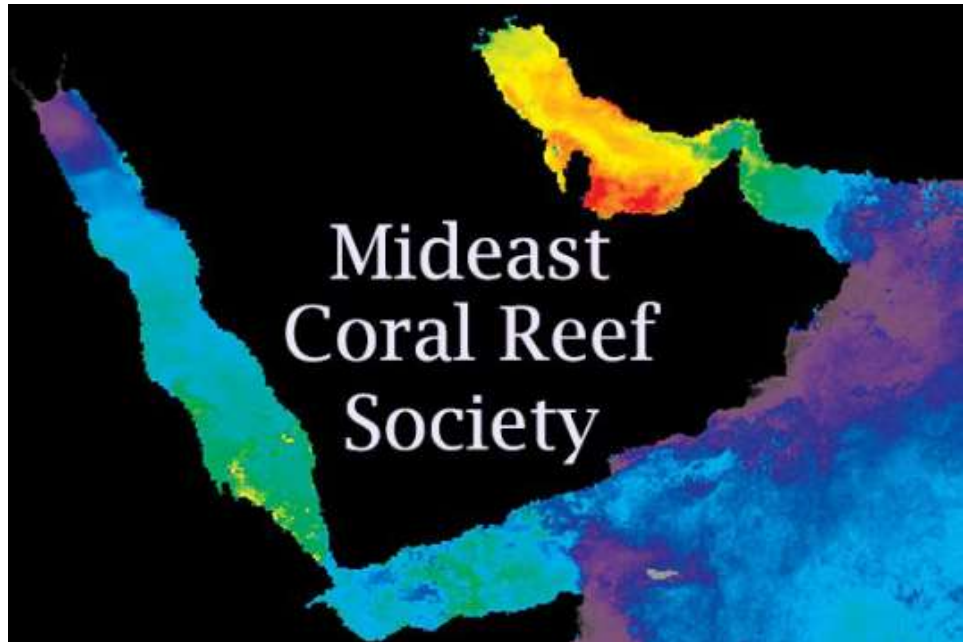
Connect with us!

Email: icrs.students@gmail.com
Website: www.coralreefsecc.org
Twitter: [@ICRSreefstudent](https://twitter.com/ICRSreefstudent)
Instagram: [@icrs.students](https://www.instagram.com/icrs.students)
Reefbites: www.reefbites.com

CHAPTER & COMMITTEE REPORTS

The Middle East Chapter / Mideast Coral Reef Society

The Northeastern Arabia Coral Reef Monitoring Network held a Workshop at New York University Abu Dhabi, May 9th – 11th, with the aim of consolidating regional efforts to monitor the important but declining coral reefs in the Arabian/Persian Gulf and the Sea of Oman (the ROPME Sea Area¹). Despite this ecosystem ecological and socio-economic value, regional monitoring efforts have been scarce, not standardized when undertaken, and unconsolidated, limiting effective management.



The workshop brought together regional reef experts to standardize coral reef monitoring practices and share survey data. Using the UAE's national program as a case study, the workshop demonstrated field methods, metadata standards, and data archival techniques and provided hands-on training in survey methods and data analyses and archival platforms ReefCloud and MERMAID.

A primary outcome of the workshop was an agreement to establish a cohesive and comprehensive regional assessment of reef conditions by May 2024, so that the data can feed into the GCRMN's 2025 status report. The workshop was organized by John Burt, the ROPME regional node to GCRMN and Jeneen Hadj-Hammou, the coordinator of the UAE national reef monitoring program. We are currently submitting proposals for funding to support a second capacity building and data exchange workshop in 2024.

John A. Burt, Chair, Mideast Coral Reef Society
Associate Professor of Biology, New York University, Abu Dhabi, UAE
(John.Burt@nyu.edu)

¹ Referring to the Regional Organisation for the Protection of the Marine Environment (ROPME), based in Kuwait and recognized by the United Nations Environment Programme (UNEP) as the regional seas programme (see <https://ropme.org>)

What FUTURE ? for CORAL REEFS

Lyndon DeVantier

Coral Reef Research, PO Box 129, Millaa Millaa, QLD, Australia
Ldevantier@aol.com

Earth's biodiversity, including **coral reefs**, is under increasing pressure. If a significant part of nature, be it a species, habitat or ecosystem, is lost or destroyed through wanton or unlawful human actions, should perpetrators face serious criminal charges? This question lies at the heart of a recent international legal initiative, the criminalization of ecocide (Stop Ecocide International 2023). Here in a two-part Perspective, I firstly review current thinking on the future of corals and the reefs they build, a topic of overarching relevance to our Society. In a forthcoming Perspective, I will outline the potential role of criminalizing ecocide, its rationale and process, in improving reef **futures**.

With few exceptions, there is strong evidence that key indicators of reef 'health', notably coral cover and fish biomass, have declined in recent decades (Wilkinson 1993, 2004, Ginsburg 1994, Gardner et al. 2003, Alling et al. 2007, Bruno and Selig 2007, Pante et al. 2008, Veron et al. 2008a,b, Paddock et al. 2009, De'ath et al. 2012, Jackson et al. 2014, Sherman et al. 2023), as indeed over longer time-scales (Jackson 1997, Aronson and Precht 1997). Proximate causes of decline are well documented (Wilkinson 2004, Fenner 2022). The 'usual suspects' include, in no particular order, diseases, predator irruptions, marine heat waves, destructive and overfishing, land reclamation and dredging, sediment and nutrient runoff, and introduced species. Acidification and deoxygenation pose increasing threat, as do evolving synergies with natural disturbance regimes. Ultimate causes –human population growth and consumption –are also well understood (Wilkinson 2004, Riegl and Glynn 2020, Fenner 2022), dating from the early warning by Malthus (1798) on population, and more recently from Meadows et al. (1972) in *The Limits to Growth*.



A voracious 'appetite'

Brit Ben Elton (1993) made dark, satirical comedy of this in his novel 'This Other Eden', in a section titled 'Dying of consumption': "...The one single and abiding criterion by which the success of countries is judged is in terms of their 'growth'. Each year the great nations agonize over how much they have 'grown'. How much more they have made, how much more they have consumed. Consumer confidence is actually considered a measure of a country's relative economic strength. ...

Consumption is synonymous with 'growth' and growth is good. It is always good, whenever and wherever. Hence, clearly consumption is good, all consumption, anywhere, anytime. Judged by the logic of world economics, the death of the planet will be the zenith of human achievement, because if consumption is always good, then to consume a whole planet must be the best thing of all."

Various indicators, from the Planetary Boundaries framework (Rockström et al. 2009) to the Earth Overshoot and Ecological Footprint approaches (Wackernagel and Beyers 2019), show that, collectively, many in the 'developed world' are living well beyond our means (Ripple et al. 2019). We are borrowing (perhaps stealing is a more appropriate word) from current and future generations; with insufficient effort, to date, to stabilize or reduce consumption, or even pay fairly for the privilege. Projected loss and damage estimates to 2050 are of the order of US\$ 1 – 1.8 trillion (Markandya and González-Eguino 2019). The last is an ongoing topic of discussion at the United Nations Conference of Parties on Climate Change (UN Framework Convention on Climate Change COP27 2022). Of course, not all of us consume at the same level. Indeed, the top 10 percent of income earners, a tiny fraction of our global population, but likely including some reef scientists, consume far more than the rest, with greenhouse gas emissions (47 percent of human total) to match (Bruckner et al. 2022). The impacts on our biosphere are increasingly obvious, although they have been for generations of ecologists, illustrated in a classic quote by Aldo Leopold (1949):

"One of the penalties of an ecological education is that one lives alone in a world of wounds. Much of the damage inflicted on land [and sea] is quite invisible to laymen. An ecologist must either harden his shell and make believe that the consequences of science are none of his business, or he must be the doctor who sees the marks of death in a community that believes itself well and does not want to be told otherwise."



Figure 1. Studio portrait of Aldo while a professor at the University of Wisconsin. (2023, Board of Regents of the University of Wisconsin System). From Wikimedia Creative Commons

Leopold's thinking highlighted an underlying dichotomy. Simply put, whether humans are part of, or separate from, nature. The answer is obvious to those with a rational understanding, but unfortunately not to some decision makers, still operating under dogma that nature was created to serve humans, justifying ecologically damaging exploitation. There is a huge literature on this subject, much of it from First Nations peoples, the best-known quote attributed to Alanis Obomsawin (1972) (Figure 2): "... the most affluent of countries,

operates on a depletion economy which leaves destruction in its wake. Your people are driven by a terrible sense of deficiency. When the last tree is cut, the last fish is caught, and the last river is polluted; when to breathe the air is sickening, you will realize, too late, that wealth is not in bank accounts and that you can't eat money."



Figure 2. Alanis Obomsawin 2010. Photo by Kat Baulu.

Ecologists, along with some economists and others (Costanza et al. 1997, Daly and Farley 2004, Raworth 2017, Laybourn et al. 2018, Hickel et al. 2022, The Club of Rome 2023), have thought deeply on this existential dilemma, expressing a broad range of opinions, warnings and possible solutions. For coral reefs, these have resounded ever more clearly since the early 1990s, with many more recent analyses and commentaries (Hoegh-Guldberg 1999, Kleypas et al. 2001, Hughes et al. 2003, Aronson et al. 2003, Pandolfi et al. 2003, Wilkinson 2004, Loya 2007, Hoegh-Guldberg et al. 2008, Veron 2008a,b, Bradbury and Seymour 2009, Veron et al. 2009, Sale 2011, Hughes et al. 2017a,b), continuing to the present (Kleypas et al. 2021, Obura et al. 2022, Bowden-Kerby 2023).

Differing views

Yet despite broad general agreement on the proximate and ultimate causes of reef condition, and major future threats, recent commentary on reef futures in Reef Encounter and elsewhere has highlighted what appears to be diametrically opposing views from senior members of our Society on the future of coral reefs. Put simply, these range from optimism through pessimism to fatalism, views explored at length in 'Coral Whisperers' (Braverman 2018). As a Society whose Plan of Action, and recent publication (Knowlton et al. 2021), include the proactive promotion of science-based decision making and coral reef protection, members grapple with these issues daily.

Roger Bradbury (2022a) in his Reef Encounter review of "Coral Reefs of Australia": Perspectives from beyond the water's edge' noted that the dominant public narrative of governments, NGOs and most scientists, remains positive: "The good news is that it is not too late to reverse much of the harm and turn from decline to recovery."

Bradbury considered this "... a cyclically reinforcing Panglossian story –each stakeholder reinforcing the other ... But this is scientifically wrong. The Anthropocene forcings that are bringing an end to the world's coral reefs are locked in and are beyond the power of any government to alter. ... coral reefs are just roadkill on the Anthropocene highway". Bradbury concluded: "Scientists – especially in the Australian Coral Reef Society – need to say for coral reefs: There. Is. No. Hope."

Clearly a fatalistic view, formed over a lifetime of thoughtful research (Bradbury 2022b). I think it fair to say that Roger Bradbury is not alone. This view is widely held among ocean elders. Charlie Veron and colleagues made the point clearly in their 2009 warning: "If CO₂ levels are allowed to reach 450 ppm (due to occur by 2030–2040 at the current rates), reefs will be in rapid and terminal decline world-wide from multiple synergies arising from mass bleaching, ocean acidification, and other environmental impacts. Damage to shallow reef communities will become extensive with

consequent reduction of biodiversity followed by extinctions.”

Another recent example (Bowden-Kerby 2023): “The widespread demise of coral reefs due to climate change is now a certainty ...” Other commentary (Pontes 2022), however, has highlighted the evolving viewpoint of the latest ICRS Darwin Award winner, Nancy Knowlton, noting her transition from being one-half of ‘Drs. Doom and Gloom’ (with Jeremy Jackson) to focus on ocean optimism and solution-oriented communication. Knowlton argues that negativity gets in the way of action, especially when communicating with policymakers who prefer to hear about problems that have solutions. Obviously, these worthwhile considerations rely on politicians being ethical, genuine in their desire for better ecological and human outcomes, seeking that elusive social, environmental and economic ‘triple bottom-line’.

Others take positions somewhere along the spectrum between the poles of doom versus hope. For example, Hughes et al. (2017a) concluded: “... reefs are degrading rapidly in response to numerous anthropogenic drivers. In the coming centuries, reefs will run the gauntlet of climate change, and rising temperatures will transform them into new configurations, unlike anything observed previously by humans. Returning reefs to past configurations is no longer an option. Instead, the global challenge is to steer reefs through the Anthropocene era in a way that maintains their biological functions.”

This view may be considered a form of defensive pessimism (Norem and Cantor 1986), of setting low expectations and considering bad or worst-case scenarios, a position justified when negative future outcomes are serious (catastrophic in this case) but, potentially, can be prevented. Peter Sale (2021) was perhaps having ‘a bob each way’ as the old English saying goes, albeit with the odds also stacked towards a bad outcome for reefs: “I also look forward to a possible future which includes viable, high-diversity, productive, actively calcifying reefs, and to a much more likely future where reefs as we

knew them in the 1960s have disappeared entirely. Reaching that desirable, but less likely, future will require substantial innovation in our understanding of the dynamics of complex ecological systems ...”.

A range in views is understandable, given that our scholarly journals are filled with findings that can inform and support various perspectives, occasionally with apparently conflicting results, at least as captured in media ‘sound bites’. One’s thinking, and mood, can swing on an almost daily basis, in response to the latest articles and mainstream news reports. Indeed, it is a basic tenet of the scientific method that one should keep an open, albeit sceptical, mind, responsive to new discoveries that may change understanding – paradigm shifts – of which there have been several reef-related in recent decades.

What future for corals and reefs?

There is little argument that valued reef attributes have declined, albeit with a few surprises, nor that they will continue to change (Done 1999, Hughes et al. 2017a), ‘rolling with the increasingly heavy punches’ our species throws at them. But how badly they may fare remains contentious among our peers, one example being disagreement on risks of extinction for corals during our Anthropocene biodiversity bottleneck (Carpenter et al. 2008, Dietzel et al. 2021). This is a crucial aspect of good science. Yet such disagreement can confuse the media and public. It can also be used maliciously by those wishing to exploit, a point made by former colleague turned science communications guru Randy Olson. He argues for a clear, coherent, concise and consistent message as the best way to engage the media, public and politicians (Douglas et al. 2022). So is there cause for ocean optimism, or are reefs already too far down that ‘slippery slope to slime’ (Pandolfi et al. 2003, 2005)?

A few questions can help inform perspectives on reef futures, short- and long-term. If species are lost, locally, regionally or globally, can functional redundancy play a role in reef continuity, with different species fulfilling the same or similar

functions (putting aside ethical considerations on causes of loss)? Can reefs recover from ‘phase-shifts’, as from accretional to non-accretional states (Done 1999, Rogers and Miller 2006, Done et al. 2007)? Do alternate states exist and are they stable (Dudgeon et al. 2010)? At what point does reduction or loss of species, coral cover or diversity, along with other valued attributes, equate with reef loss or collapse per se? Ultimately, when is a reef, or reef tract, declared ‘dead’?

Ancient history

On the longest of geological timescales, biogenic reefs have existed in various configurations for half a billion years (Wood 2011, Penny et al. 2014), albeit punctuated by long hiatuses, reef gaps of the fossil record (Veron 1995, 2008a,b, Stanley 2003). On such timescales, corals and the reefs they build are dependent on interactions of geo-tectonics with large-scale oceanic patterns and climate, exemplified by closures of the Tethys Ocean and, much more recently, the Isthmus of Panama (Coates et al. 1992, Veron 2011, Wallace et al. 2020).

Over their long evolutionary history, reefs have been constructed by different constituents, of which the Scleractinia are the latest, extant for some 240 million years since the end-Permian (Stolarski et al. 2011). Presently comprised of some 1680 shallow and deep-water species (Hoeksema and Cairns 2023), the order has survived every subsequent mass extinction (Buddemeier and Smith 1999, Baron-Szabo 2006), albeit with losses in diversity at times of environmental upheaval, several of which have been linked to major changes in the carbon cycle (Veron 2008a,b). During such times, corals may have reverted to soft-bodied,

anemone-like forms (Stanley 2003), as some species can do today (Fine and Tchernov 2007, see Coral ‘magicians’ section).

With one important caveat, it seems unlikely that future human activities will drive the Scleractinia totally extinct. Perhaps the less-studied deep water species may carry the Order forward, although those have their own challenges (Hennige et al. 2020), not discussed further here. The caveat: that our present civilization will collapse catastrophically before, or with, coral reefs, taking them down with us (Diamond 2004, United Nations Office for Disaster Risk Reduction 2022, Bulletin of the Atomic Scientists 2023). Whatever the result of humanity’s exceedance of planetary boundaries, reefs of some form, built by distant descendants of our present biota, or novel lineages, will likely flourish in the geological future, as for example

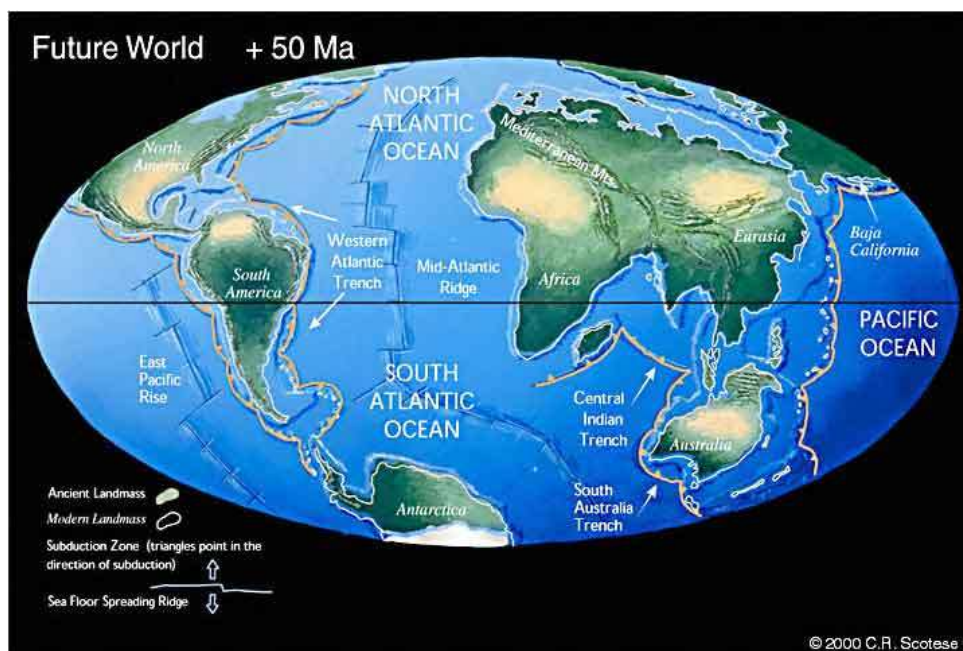


Figure 3. ‘Future world + 50 ma’ Map courtesy Christopher Scotese (<http://www.scotese.com/future.htm>), from “Plate tectonic maps and Continental drift animations” by C. R. Scotese, PALEOMAP Project (www.scotese.com)

fringing island arcs off central-South America, the central Indian Ocean and West Pacific some 50 million years hence (Figure 3, Scotese 2022). Mark Twain’s famous (mis)quote comes to mind “The reports of my death are greatly exaggerated”. Obviously, this is an esoteric, some may say fatuous, argument. Our serious, legitimate concern is for the immediate future, of which a post-

Anthropocene reef gap would be a terrible outcome.

Recent history: Inter-regional and inter-ocean differences

Reefs flourished as Earth warmed and seas rose following the last glaciation, although rates of accretion varied. Some reefs ‘kept up’, others ‘caught up’, a few ‘gave up’ (reviewed in Camoin and Webster 2014); for the former two modes, growth was in a sense analogous with Darwin’s (1842) model. The ensuing Holocene has in some regions been a ‘goldilocks’ epoch, albeit not everywhere. In parts of the tropical eastern Pacific, reef growth collapsed for 2500 years, from about 4000 years ago (Toth et al. 2012), attributed to increased variability of the El Niño–Southern Oscillation (ENSO) and its coupling with the Intertropical Convergence Zone. Such climatology is similar to predictions for the next century, which could drive eastern Pacific reefs toward another regional collapse (Toth et al. 2012). Within this reef province, however, as elsewhere, there are marked differences in accretion. Some reefs may yet again keep up with the rising sea, particularly if assisted via restoration of key reef-builders. For example, in the adjacent Caribbean Sea, a restored *Acropora palmata* zone could play a key role in mitigating the most extreme impacts of coastal flooding (Toth et al. 2023). Successful future interventions notwithstanding, many reefs may not keep up, with the rate of sea level rise itself dependent on future emissions scenarios (Rodriguez-Ruano et al. 2023).

A very rough analogue may be the high stand of sea level correlated with marine isotope stage 5e, from 130-115,000 years ago (Blanchon 2011). Sea levels were some six metres or more higher than today, with fossil reefs (Figure 4) present at locations as far afield as Arabia and Mexico. The major episode of reef building was apparently restricted to 128 and 121 thousand years ago (Stirling et al. 1998), a period when global ocean surface temperatures were warm and/or sea-levels were stable enough to allow prolific reef growth. At that time, there were no human forcings on climate, or other impacts.



Figure 4. *Platygyra acuta* colony in fossil coral reef some six metres above present sea level. Socotra Island, Arabian Sea. Photo Catherine Cheung

Today, some regions appear less resilient than others. Caribbean reefs have been a bellwether, from the combined effects of heat waves, diseases, overfishing, tropical storms, pollutants, and invasive species (Hughes and Tanner 2000, Aronson et al. 2003, Gardner et al. 2003, Miller et al. 2006, Rogers 2009, Rogers and Miller 2013, Jackson et al. 2014, Randall et al. 2014, Precht et al. 2016, Alvarez-Filip et al. 2022). These have caused massive reductions in coral populations, most recently with continuing regional losses from Stony Coral Tissue Loss Disease, affecting more than 20 species (Estrada-Saldívar et al. 2021), almost one-third of Caribbean coral species richness. These include the now critically endangered pillar coral *Dendrogyra cylindrus* (Cavada-Blanco et al. 2022), lost initially from the South-east Florida reef tract (Jones et al. 2021). It is not just Caribbean reefs, however, that have shown major changes. In the central Indian Ocean, the endemic, endangered *Ctenella chagius* (Sheppard et al. 2008) has suffered major population decline, mainly in heat waves beginning in 1998. It is now considered ecologically and functionally extinct on Chagos (Sheppard et al. 2020).

Rapid population losses are also reflected in the global decline in coral cover (Gardner et al. 2003, Bruno and Selig 2007, De’ath et al. 2012), recently estimated as dropping from 36 to 19 percent from 1997 to 2018 (Tebbett et al. 2023), with decreases

most severe in the Western Atlantic and Central Pacific. High macroalgal cover, widely regarded as characterizing the major degraded state on coral reefs, was considered a phenomenon largely restricted to the Western Atlantic. However, this discounts intra- and inter-regional effects in the Indo-Pacific; the misnamed ‘turf wars’ that occur between macro-algae and corals on hundreds of reefs along the inner Great Barrier Reef (GBR, see eg. Done 1982, DeVantier et al. 1998, 2006, Done et al. 2007), on sub-tropical reefs (Veron 2000) and on sediment and nutrient-enriched reefs elsewhere, from the Arabian Sea to Thailand and Vietnam.

Inter-ocean and inter-regional differences are also apparent in the extent of bleaching. Among regions, SE Asia, Australia and the Caribbean have the greatest extent over time; however, as a proportion of reefs in each region, extent of bleaching was greater in the East Pacific, West and central Indian Ocean, and Caribbean Sea. Over the four decades from 1980 to 2020, bleaching increased with depth in the western Atlantic, decreased with depth in the Indian Ocean, with no clear trend in the Pacific (Shlesinger and van Woesik 2023). There are always exceptions, as along with depth, local oceanography, shading and species identity have significant effects on susceptibility (Muir et al. 2017, Roach et al. 2021), as does past history. Indeed, the time series suggested a possible increase in coral thermal tolerance (Virgen-Urcelay and Donner 2023, Shlesinger and van Woesik 2023).

Shifting baselines

For corals, and despite significant innovation (eg. Aronson and Precht 1997, van der Meij et al. 2010), our collective ecological memory, as captured in reliable field data, is short. Early studies from the GBR (Yonge 1931) and Caribbean led the way (Goreau 1959), the former documenting key physiological processes, the latter classical patterns of zonation, long gone in most places today (Aronson and Precht 1997). In most of the Indo-Pacific, however, detailed ecological studies lagged by a decade or two (Loya 1972, Done 1982, Sheppard 1982, Connell et al. 1997). Of the various monitoring programs (Houk and van Woesik 2013),

the oldest have been accumulating data for some five decades (eg. Sheppard et al. 2020). Results and predictions are compiled in national, regional and Global Coral Reef Monitoring Network and Reef Check reports (eg. Wilkinson 1998, 2004, Castro 2001, Jackson et al. 2014, Souter et al. 2020, Sully et al. 2022, Towle et al. 2022). From modest, diver-driven beginnings, technological advances (Apprill et al. 2023), notably remote-sensed data, continue to be implemented (eg. Allen Coral Atlas 2023, NOAA Coral Reef Watch 2023). Modelling also continues to provide insight (Hughes 1984, Done 1987, Zhao et al. 2016), requiring reliable data on taxonomy, population and community structure, distribution and niche breadth, and life histories, along with environmental parameters. Despite the advances, acquiring such data remains a challenge, underscoring the critical importance of baselines, even if already shifted (Pauly 1995, Sheppard 1995, Jackson 1997, Olson 2002).

The Australian Institute of Marine Science Long Term Monitoring Program (AIMS LTMP) for the GBR and the Atlantic and Gulf Rapid Reef Assessment (AGRRA), initiated in 1986 and 1997 respectively, are cases in point. By the times of their initiation, both regions had already experienced significant anthropogenic change. The long prior history of human impacts to the Caribbean is well documented (Jackson 1997). The GBR had similar long-standing issues: river runoff had affected nearshore water quality (Lewis et al. 2021); fisheries had reduced harvested stocks (Ormond et al. 1990); increasingly-intense tropical storms episodically hammered sections of the reef tract; and at least two major population irruptions of crown-of-thorns starfish had eaten their way along much of the Reef (Walbran et al. 1989, Keesing et al. 1992, DeVantier and Done 2007). The last issue divided the reef science community of the day, creating an at times unruly debate on whether such cyclicity was natural (Sapp 1999). Overshadowed by more recent concerns, science, policy, management and communications lessons for our community from the crown-of-thorns controversy, as indeed monitoring results more generally, continue to resonate.

Sources and sinks

The GBR is among the most oceanographically connected of all reef systems, many of its ca 3000 reefs lying in the flow of surface currents that disperse larvae of corals, fish, and predatory starfish, among many other species, from source to sink with relative ease. On the GBR at least, management, often considered useless in the face of global impacts, does have a role to play in minimizing local impacts (Knowlton et al. 2021, Bowden-Kerby 2023). Many other reef systems, however, are far more isolated (Cowen et al. 2007), under more local – regional pressures (Wilkinson 1993, 2004, Burke et al. 2011), or further along a disturbance trajectory leading to recruitment failure (Hughes and Tanner 2000). Bowden-Kerby (2023): “Coral reefs without up-current sources of heat-adapted larvae are more vulnerable, and in theory, can be expected to undergo phase shifts away from broadcasting species and *Acropora* dominance and towards brooding species dominance over time, which is what we have seen in the field.”

Larval dispersal, connecting and restoring populations, remains a major goal of MPA network design (Salm et al. 2000, Wells et al. 2016, Lewis et al. 2017, Towle et al. 2022, van Woesik et al. 2022). Dispersal was key to the recent recovery in coral cover on the northern and central GBR (AIMS LTMP 2022). This has followed successive mass bleaching events, crown-of-thorns starfish irruptions, cyclones, floods, and other disturbances that collectively killed many millions, perhaps billions, of corals, placing strong selection pressure on survivors. Even among survivors, time was required, post-disturbance, to restore metabolic processes (Schoepf et al. 2015), including gametogenesis (Howells et al. 2016). This depends on the degree of physiological stress and injury sustained (Levitan et al. 2014), colony age (Rapuano et al. 2023), and is inter- and intraspecific (Roach et al. 2021). Indeed, the AIMS LTMP report cautioned: “The prognosis for the future disturbance regime suggests increasing and longer-lasting marine heatwaves, as well as the ongoing risk of outbreaks of crown-of-thorns starfish and tropical cyclones.

Therefore, while the observed recovery offers good news for the overall state of the GBR, there is increasing concern for its ability to maintain this state.”

Timing is everything

On the GBR and Indo-Pacific more generally, most coral species reproduce by broadcast spawning, typically timed to coincide with Springtime full moons (Harrison and Wallace 1990, Baird et al. 2009). For corals with the other main reproductive mode, larval brooding, survivors have a more regular seasonal pattern that may also include the cooler months. After a pre-settlement period as short as a couple of hours for some brooders to a week, month or longer adrift for both brooders and spawners, corals settle on a reef, typically in partly shaded nooks and crannies (Wallace 1985). This usually happens before the summer heat and calm that cause mass bleaching. Many of these nascent juveniles may be both adapted and ‘preadapted’ (exapted) to surviving the impacts of bleaching, and of predation and storms; adapted in that they are the progeny of corals that survived prior impacts, preadapted in that their micro-habitat choices, their small size, and correspondingly low numbers of endo-symbionts, provide them with a set of traits to avoid or minimize impacts of disturbance. These form ‘ready to go’ sets of populations to replenish reefs in the interim between disturbances (but also see Humanes et al. 2016). A similar phenomenon, albeit apparently by a single species, appears to have occurred on Vostok reef in the central Pacific, following severe coral bleaching in 2016: “...the *Montipora* colonies were all about the same size. That suggests ... corals elsewhere around Vostok had been reproducing sexually and releasing millions of eggs, which soon hatched and formed a massive cloud of larvae above the reef platform. A rain of *Montipora* larvae may have fallen and settled on the pink crust within a day — a single event that changed the seascape for years to come.” (Enric Sala, quoted in Alberts 2022).

Given a few years, growth of the new recruits can contribute to recovery of cover, but not necessarily diversity. Because growth rate, and time to first reproduction, varies among species, the disturbance interval, its frequency and intensity, are critical (Veron et al. 2009). In some regions, post-disturbance coral settlement and

recruitment have been poor, with early warning again from the Caribbean (Hughes and Tanner 2000), more recently from the Arabian Peninsula (Bento et al. 2017, Burt and Bauman 2020). In some Caribbean coral settlement hotspots, cover did not increase over more than a decade, revealing a ‘demographic bottleneck’ (Edmunds 2021).

As encouraging as it is, recent recovery of coral cover on the northern and central GBR, and elsewhere, does not inform the potential for major changes in diversity and community structure of recovering assemblages, nor the size and age-structures of populations therein (Cameron et al. 1991, Done and Potts 1992, Connell et al. 1997, Riegl et al. 2012, Álvarez-Noriega et al. 2018, Richards et al. 2021).

Coral community assembly, functional redundancy and invasive species

Recovering assemblages exhibit varied community configurations. Some show fidelity to pre-disturbance community structure; others less so, dominated by fast-growing ‘weedy’ taxa, with loss of coral species with different life histories. On the GBR’s mid- and outer-shelf reefs, the most recent recovery has again been dominated by rapid-recruiting, fast-growing species of *Acropora*. Along with pocilloporids and some poritids, this has happened repeatedly, notably following crown-of-

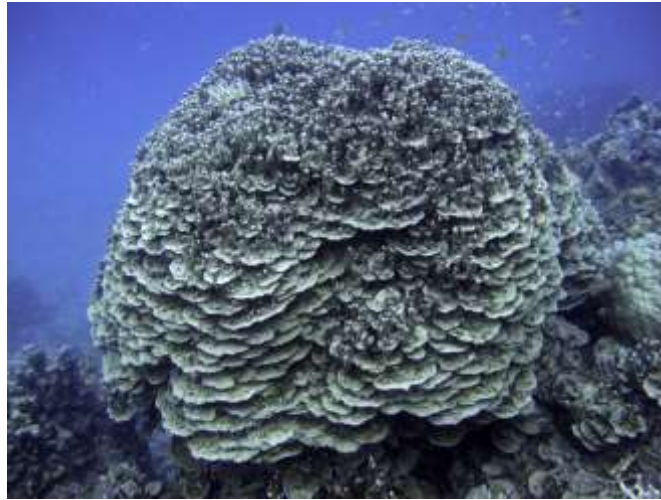


Figure 5. *Porites rus*, a hardy species that can form large colonies, as here in Anambas Islands, Indonesia, may increasingly dominate future reefs as less tolerant species are lost. Photo Emre Turak

thorns starfish irruptions (Wallace 1985, Done et al. 2010, Richards et al. 2021). On a reef of the central Pacific, *Porites* and *Acropora* restored cover following bleaching mortality, with declines in *Pocillopora* and *Montipora* (Adjeroud et al. 2009). In other places formerly diverse *Acropora* assemblages have successively been replaced by *Pocillopora* and then *Porites*, with significant cascading effects on

species dependent on *Acropora* for framework, nutrition and other ‘services’ (Bowden-Kerby 2023, Figure 5).

In Belize and elsewhere in the Caribbean Sea, millennia of formerly stable and robust *Acropora* assemblages had been replaced by encrusting-foliose *Agaricia* and macroalgae (Aronson and Precht 1997) – a trajectory on that ‘slippery slope to slime’, with non-accretional reefs considered harbingers of reef futures everywhere (Veron 2008a,b, Frieler et al. 2013). Functional redundancy clearly has its limits. Perhaps the best example was the 1980s disease die-off of *Diadema* urchins that had replaced heavily harvested herbivorous fishes as a major control of algae on Caribbean reefs. More than three decades later, *Diadema* slowly recovered in some areas, with positive effects on coral recruitment (Lessios 2015), but not in others (Tuohy et al. 2020), with a recent, disease-induced population crash (Hylkema et al. 2023, Hewson et al. 2023).

Although non-reefal work has found that functional redundancy may positively affect community stability and resilience to disturbance (Biggs et al. 2020), prevailing environmental conditions can alter species roles and interactions, affecting relations between biodiversity and ecosystem function (Fetzer et al. 2015). Given that the largest existential threat to reefs, and our biosphere more

generally, is posed by rapid environmental change (Ripple et al. 2023) via disruptions to climate and oceans, a reliance on redundancy is neither a wise nor reliable way to ‘hedge bets’ on reef futures.

A final inter-ocean lesson from the Caribbean: recent invasions by Indo-Pacific species of fish (*Pterois volitans* and *P. miles*, Hixon et al. 2016), corals, including *Tubastraea* spp. (Hennessey and Sammarco 2014) and *Unomia stolonifera* (Ruiz-Allais et al. 2021) and a coral photosymbiont (*Symbiodinium trenchii*, Pettay et al. 2015) were apparently let loose, wittingly or unwittingly, by aquarium hobbyists, or for the last potentially via shipping ballast water. Introductions are occurring across the world’s oceans (reviewed in Alidoost Salimi et al. 2021), including the East Pacific, with the purported release of *Siderastrea sidereal* (Forsman et al. 2005, LaJeunesse et al. 2016). These cases of ‘assisted migration’ have both foreseen and unforeseen consequences, not least including the risk of introduced diseases across oceanic barriers (Bowden-Kerby 2023).

Coral ‘magicians’: cryptic diversity, acclimation, and adaptation

Increasing impacts and risks notwithstanding, many corals, particularly in the Indo-West Pacific, still have large, widespread metapopulations (Dietzel et al. 2021) and several ‘tricks up their metaphorical sleeves’ (see Yonge 1931 for a thoughtful early essay on coral adaptation). These can contribute to resilience, offering a ‘nugget of hope’ (Coles and Brown 2003, Baker et al. 2004, Berkelmans and van Oppen 2006). Perhaps the most astounding is the complexity of the coral endo-symbiont and commensal community, enabling corals to thrive in nutrient-poor waters; Darwin’s paradox (Cui et al. 2023). Coral microbiomes are much more diverse than once thought (Taylor 1974, Muscatine 1990, Baker 2011, LaJeunesse et al. 2018). Some corals host several species of Symbiodinaceae, along with a diverse array of other microbiota – bacteria, viruses, and other micro-eukaryotes – their specific composition varying in response to local environmental changes and cophylogenetics (Cunning et al. 2015, Ziegler et

al. 2016, Sweet and Bythell 2017, Quigley et al. 2019, Johnston et al. 2022, Bonacolta et al. 2023, Howe-Kerr et al. 2023). This remains an area of vigorous research, initiated three decades ago by a provocative paper by Buddemeier and Fautin (1993), proposing the ‘adaptive bleaching hypothesis’.

Corals can acclimate, within physiological limits (Buddemeier and Smith 1999, Coles and Brown 2003, Baker et al. 2004, Maynard et al. 2008, Guest et al. 2012, Logan et al. 2021), including via symbiont shuffling, along with different modes of acquisition (Webster and Reusch 2017, Quigley et al. 2019, Palacio-Castro et al. 2023), and chimerism (Rinkevitch 2019). During intense stress, corals, Symbiodinaceae and the microbiome more generally, independently and together, are under significant selection pressure, with potential for future permutations of the relationship to coevolve (Forsman et al. 2020, Johnston et al. 2022). In Hawaii, for example, co-occurring colonies of *Montipora capitata* varied in acclimatization potential to thermal stress (Drury et al. 2022a), the genotypic differences representing a cryptic source of heritable variation. The authors concluded that adaptive plasticity, symbiont community and fixed differences between genotypes may contribute to the long-term persistence of corals under climate change (also see von Xylander et al. 2023).

Increasing impacts and risks notwithstanding, many corals, particularly in the Indo-West Pacific, still have large, widespread metapopulations and several ‘tricks up their metaphorical sleeves’ [...]. These can contribute to resilience, offering a ‘nugget of hope’.

A related positive consideration is that of species’ niche breadth and the range of micro-habitats available on many reefs, governed by depth, slope, illumination, wave energy and current flow, water quality, and species interactions. At least half of all

Indo-Pacific coral species have depth ranges extending into the upper mesophotic zone (Muir et al. 2019, Turak and DeVantier 2019), although only a small number are mesophotic specialists, with most preferring depths shallower than 30 m. However, substantial genotypic differences across some species' depth ranges (van Oppen et al. 2018, Bongaerts et al. 2021) add complexity, potentially signifying cryptic species' clines.

Perhaps counter-intuitively, in an experimental translocation of juveniles of four species of *Acropora*, survival and size of two species (*A. tenuis* and *A. valida*) were significantly higher at 40 m depth than at shallower depths (Tavakoli-Kolour et al. 2023). In contrast, juveniles of the other two species (*A. digitifera* and *A. hyacinthus*) showed higher survival rates at shallow depths. Of the four, all occur much more commonly on shallow reef slopes less than 10 m depth, with *A. valida* having the broadest distribution with depth (Turak and DeVantier 2019, unpubl.). Such findings may lend support to the deep reef refugia hypothesis (Bongaerts et al. 2010, Kahng et al. 2010), but questions remain. These include whether planulae of those species would naturally settle at those depths, and whether the juveniles can maintain growth to reproductive maturity. On the latter question, symbiotic algal density did increase with depth, most notably in *A. digitifera* and *A. hyacinthus* (Tavakoli-Kolour et al. 2023). Another concern, however, is the depth – temperature relation. Some deeper Caribbean reefs, 30–75 m depth, for example, have lower bleaching threshold temperatures than their shallow counterparts and hence were not considered refugia (Smith et al. 2016).

Some corals have more inherent capacity for acclimation and flexibility in the temporal dynamics of their holobiont communities than others (Camp et al. 2020, Voolstra and Ziegler 2020). In the Eastern Tropical Pacific (ETP, Palacio-Castro et al. 2023), some members of the dominant framework-building genus, *Pocillopora*, exhibited higher heat resistance in a series of bleaching events since the 1980s, whereas others did not. The lineage that increased its association with

thermotolerant algal symbionts (*Durusdinium glynnii*) during the 2015 to 2016 event experienced lower bleaching and mortality compared with those that did not acquire *D. glynnii*. Palacio-Castro et al. (2023) concluded: “Under projected thermal stress, ETP reefs may be able to preserve high coral cover through the 2060s or later, mainly composed of *Pocillopora* colonies that associate with *D. glynnii*. However, although the low-diversity, high-cover reefs of the ETP could illustrate a potential functional state for some future reefs, this state may only be temporary unless global greenhouse gas emissions and resultant global warming are curtailed.”

Inter-specific differences in flexibility between auto- and heterotrophy is another crucial consideration (Anthony and Fabricius 2000). Prey capture is an important source of nutrition for corals under stress, including from turbidity and high temperatures. For example, Levas et al. (2013) reported for *Porites lobata*, one of the most ubiquitous of all corals: “... bleaching resilience in the mounding coral *P. lobata* is driven by its ability to actively catabolize zooplankton-acquired carbon and seemingly utilize DOC [dissolved organic carbon] as a significant fixed carbon source, facilitating the maintenance of energy reserves and tissue biomass. With the frequency and intensity of bleaching events expected to increase over the next century, coral diversity on future reefs may favor not only mounding morphologies but species like *P. lobata*, which have the ability to utilize heterotrophic sources of fixed carbon that minimize the impact of bleaching and promote fast recovery.”

Differential coral responses in mass bleaching events (Marshall and Baird 2000, Loya et al. 2001, Grottoli et al. 2014, Neal et al. 2017, Sheppard et al. 2020, Baum et al. 2023) also exist in other physiological responses to stress. These include maintenance of homeostasis in regulating calcification with changing aragonite saturation state (Georgiou et al. 2015, Cornwall et al. 2018, Liu et al. 2020), with deoxygenation (Johnson et al. 2021a,b), resistance to disease (eg. Aeby et al. 2021), nutrient enrichment (Blanckaert et al. 2023) and

other metabolic processes. The last includes remarkable variability in reproductive modes, both sexual and asexual (Harrison and Wallace 1990, Baird et al. 2009), of critical importance in adaptation to environmental change.

For acidification, effects on coral calcification of the interaction of light intensity with the concentration of CO₂ differs among species (Suggett et al. 2013). Although low-light conditions can provide a refuge for stony corals from thermal and light stress, lower light availability will potentially increase susceptibility of coral species to acidification (also see Rogers 1979). However, experimental manipulations (Fine and Tchernov 2007) revealed another remarkable physiological ability. Some skeleton-producing corals grown in acidified conditions for a year sustained basic life functions, including reproductive ability, by reverting to a decalcified ‘sea anemone-like’ form. When reintroduced to normal conditions the corals resumed skeleton building, suggesting “... existence of physiological refugia, allowing corals to alternate between nonfossilizing soft-body ecophenotypes and fossilizing skeletal forms in response to changes in ocean chemistry” (Fine and Tchernov 2007).

What role for evolvability in an increasingly marginal realm?

Reef corals are subject to both Darwinian and reticulate patterns of evolution (Veron 1995), including a propensity for hybridization (Vollmer and Palumbi 2002, Willis et al. 2006, Richards et al. 2012); their evolution governed by selection pressures, oceanographic patterns, local and meta-population sizes and distributions. These evolutionary pathways have served the Scleractinia, extant since the end-Permian, well. Yet, as with other phyla, some lineages have radiated spectacularly, while others have not (Veron 1995, Huang 2012). This is perhaps best illustrated in the Indo-Pacific by the apparent evolvability (Payne and Wagner 2019) of two highly diverse genera in the family Acroporidae, *Acropora* and *Montipora*, on the one hand, with more than 200 species (roughly one-quarter of all reef-building

species), and the monotypic genera, including *Boninastrea*, *Craterastrea*, *Ctenella*, *Diploastrea*, *Gardineroseris*, *Gyrosmilia*, *Horastrea*, *Nemenezophyllia* and *Simplastrea*, on the other. Several of these monotypes have restricted distributions and small to very small populations (Veron 2000, Sheppard et al. 2008, DeVantier and Turak 2017). These are considered to have high evolutionary distinctiveness and extinction risk (Carpenter et al. 2008, Huang 2012, Benzoni et al. 2014, Sheppard et al. 2020).

Conversely, monotypic *Diploastrea heliopora* appears at less immediate risk, presently listed as Near Threatened on the International Union for Conservation of Nature (IUCN) Red List (DeVantier et al. 2014). It is very widespread across the Indo-Pacific (Veron et al. 2023) and can, in some habitats, be locally common, although more typically locally uncommon or rare (DeVantier and Turak 2017). It is phylogenetically closest to the widespread Atlantic species *Montastraea cavernosa* (Huang et al. 2011), which is presently listed as Least Concern by IUCN (Rodríguez-Martínez et al. 2022). With long fossil histories dating to the Oligocene (Veron 2000, Budd et al. 2012) both species presumably share a Tethys ancestor. Slow growing, both species can form large, long-lived massive colonies. Both are gonochoric, although in *D. heliopora* (and speculatively *M. cavernosa*), colonies can contain male, female and a low proportion of cosexual polyps (Guest et al. 2012). Polyps may switch sexes with oogenic and spermatogenic cycles occasionally overlapping within and between breeding seasons. This enables colonies to function as males and females, while reducing the probability of self-fertilisation and sibling crosses (Guest et al. 2012).

D. heliopora shows little morphological variation across its range. *M. cavernosa* is more polymorphic, although morphological and genetic analyses have not revealed cryptic species (Budd et al. 2012). Rather, the authors considered that high levels of gene flow, large population size, reduced rates of speciation and gonochoric reproductive mode maybe responsible for its unusually long duration and apparent morphological stasis (Budd et al. 2012). Apparent phenotypic robustness and

stability of these species may well mask genotypic adaptability (Wagner 2008, Chung et al. 2023), contributing to their evolutionary longevity and phylogenetic distinctiveness.

Ecological and evolutionary flexibility notwithstanding, there are physiological limits, albeit shifting, to tolerance of environmental extremes and emerging synergies among stressors, including heat waves and disease (Rogers 2009, Thurber et al. 2020). Those limits have been breached on an increasingly regular basis on reefs across biogeographic and physico-chemical ranges, from Lord Howe Island to Japan, the Eastern Pacific to central Indian Ocean, Red Sea and Caribbean, as recent compilations of mass bleaching events (Donner et al. 2017, van Woesik and Kratochwill 2022) and disease outbreaks (Thurber et al. 2020) attest. Modelling suggests that these changes will escalate, as formerly ideal reef habitat becomes increasingly marginal in coming decades (Guinotte et al. 2003, Hoegh-Guldberg et al. 2008, Fabricius et al. 2020, Obura et al. 2022, also see McMahan et al. 2013) with increasing heat waves, acidification, deoxygenation and sea level; worst under high emissions scenarios from failure to meet UNFCCC's aspirational targets (Zuo et al. 2021, Couce et al. 2023, Law and Huang 2023).

Some coral species, including several of those monotypes, have limited distributions and/or small population sizes. Even many widespread and common species may be at risk of extinction (Birkeland et al. 2013). Like all magicians, corals have only so many acclimative / adaptive 'tricks' with which to astound us. The looming threat of extinction of an increasing number of coral species, or cascading loss of other taxa that interact with or depend on corals for framework and habitat, nutrition or other services, is clear (Paine 1980, Glynn 2011, Ripple et al. 2016, Obura et al. 2022, Chow et al. 2023). Conversely, corals rely on an array of species at different life stages, notably crustose coralline algae (CCA) and their associated bacterial communities for larval settlement (Jorissen et al. 2021, Abdul Wahab et al. 2023). Reduction or loss of specific CCA, through disease or inimical environmental change (Webster et al.

2013, Siboni et al. 2015), would have cascading effects, initially on coral population dynamics, subsequently on coral associates and ultimately on reef communities more generally. Reefs are renowned for the complexity of relationships, with remarkable, non-intuitive examples regularly documented (eg. Grupstra et al. 2023).

'Buying time'

To return, finally, to the main theme of this perspective, corals and reefs are in a race against time (Buddemeier and Smith 1999, Hoegh-Guldberg 1999, Veron et al. 2009, Knowlton et al. 2021), at least on scales relevant to humanity; time between disturbances, time for individual corals to acclimate and attain reproductive maturity, time for adaptation, and, most crucially, time for humanity to change behaviour. Can the key constituents of modern reefs acclimate and adapt at a rate commensurate with the rate of change from our recent near-exponential expansion in population, increasing resource use and pollution? Many, perhaps most, of our senior colleagues, those with lifetimes of dedicated experience, are sceptical at best. But, as outlined above, there is evidence on both sides of this question, along with significant uncertainty.

Given differing views and the range of evidence, perhaps our consistent message needs to be less optimistic, or fatalistic, acknowledging complexity (Done 1999, Sale 2021) while emphasizing caution; the much heralded but rarely applied precautionary principle (i.e. Principle 15 of the Rio Declaration on Environment and Development 1992, Preamble of the United Nations Convention on Biological Diversity 2007).

Unfortunately, such complexity and attempts at balance can be interpreted as ambivalence, would not 'sell well' with media, and may work to further delay effective political action. After all, we have been studying reefs, increasingly intensively and extensively, for many decades, as the far-from-comprehensive citations herein demonstrates. Indeed, scores of relevant peer-reviewed papers are

now published each month. Our collective research effort is truly impressive.

Recent, and not so recent, practical suggestions and responses from the reef science community aim, unsurprisingly, at ‘buying time’. These include:

- ▶ recommendations for increases in scale and functionality of marine protected areas (MPA) networks, including identification of potential refugia, with traditional and novel design and management approaches (Salm et al. 2000, Wells et al. 2016, Lewis et al. 2017, Beyer et al. 2018, van Woosik et al. 2022)
- ▶ assisting natural adaptation and recovery by various forms of restoration. These include enhancing microbiome flexibility (Voolstra et al. 2020) and coral larval settlement (Abdul Wahab et al. 2023), coral outplanting, gardening and reefscaping (Munasik et al. 2020, Ware et al. 2020, Schmidt-Roche et al. 2023), through establishment of breeding programs for corals (Banaszak et al. 2023) and other species –‘biobanks’, on-reef (Bowden-Kerby 2023), in aquaria (Great Barrier Reef Legacy 2023), and by cryopreserving gametes (Daly et al. 2018)
- ▶ assisting coral evolution by creating ‘super-corals’ and symbionts via selective breeding and genetic engineering (van Oppen et al. 2015, Anthony et al. 2017, Levin et al. 2017, Drury et al. 2022b, Richards et al. 2023)
- ▶ diagnosing and treating coral and other diseases (Teplitski and Ritchie 2009, Thurber et al. 2020), including with probiotics (Peixoto et al. 2021)
- ▶ raising awareness to minimize risks of invasive species (Côté and Bruno 2015, Lajeunesse et al. 2016, Bowden-Kerby 2023)
- ▶ protecting reefs by shading (review in Tagliafico et al. 2022, but also see Rogers 1979) and geo-engineering (Tollefson 2021)
- ▶ informing decision-makers as to the impacts and looming threats to reefs and key species groups from human activities, local to global (Carpenter et al. 2008, Knowlton et al. 2021, Sherman et al. 2023).

The hope is that these various approaches may slow reef degradation as humanity transitions towards less environmentally destructive behaviour. But are we, as a research community, increasingly feeling like Alice and the Red Queen in Lewis Carroll’s ‘Through the Looking Glass’, running ever faster just to keep up? Or worse, falling behind as impacts escalate (International Science Council 2023) despite our best efforts? Is there more we can do to slow and halt the decline of reefs? One option is the international criminalization of ecocide, to be explored in the next issue of Reef Encounter. ▶

Acknowledgments

The Editors and several long-term mentors gave valuable advice on aspects of this Perspective. I thank them all sincerely.

About the Author



Lyndon DeVantier is a marine scientist whose career has focused on the ecology and biogeography of reef-building corals. He has worked with governments and non-government organizations across the Indo-Pacific on the design and development of Marine Protected Areas. He is a co-author of the open-access website www.coralsoftheworld.org.

References

The full list of references is too long to be included here, but can be downloaded at: coralreefs.org/publications/reef_encounter_53_appendix

REEF PERSPECTIVES

Back-shifting the baseline of coral reefs: Give seas a chance

Jorge Cortés

Centro de Investigación en Ciencia del Mar y Limnología (CIMAR), Universidad de Costa Rica, San Pedro, 11501-2060 San José, Costa Rica (jorge.cortes@ucr.ac.cr)

Summary

A majority of coral reefs world-wide are degrading, and we have known this for 40 years. But we can reverse that trajectory by exploring, studying, sharing our knowledge, and protecting coral reefs at local, national, and global scales. To do so, we first need to know why a reef is where it is, determine its present state, study its historical trajectory, and monitor it so as to understand its future trajectory. This knowledge must be shared widely, from local school children and users of the reefs, all the way to government officials and international agencies. And finally, actions at all levels of government and society must be applied to protect and conserve the coral reefs. During my more than 40 years as a coral reef scientist, I have seen degraded reefs recover, degrade and recover

again. In some cases, simple government acts, such as the establishment of no-take marine protected areas, can have big impacts in promoting recovery. Unfortunately, identification of multiple stressors and actions to reduce them, in most cases requires initiatives such as multiple sectorial meetings, lobbying and public outreach to attain the level of protection to promote recovery. Parallel to this, coral replanting is helping to recover coral reefs at local levels, and at the same time greatly raising awareness of their importance. If we combine actions to halt climate change with perseverance, good science and patience, these small but significant steps toward reef rewilding can backshift the baseline. Give seas a chance, and most people will be surprised with how rapidly coral reefs and the ocean recover.

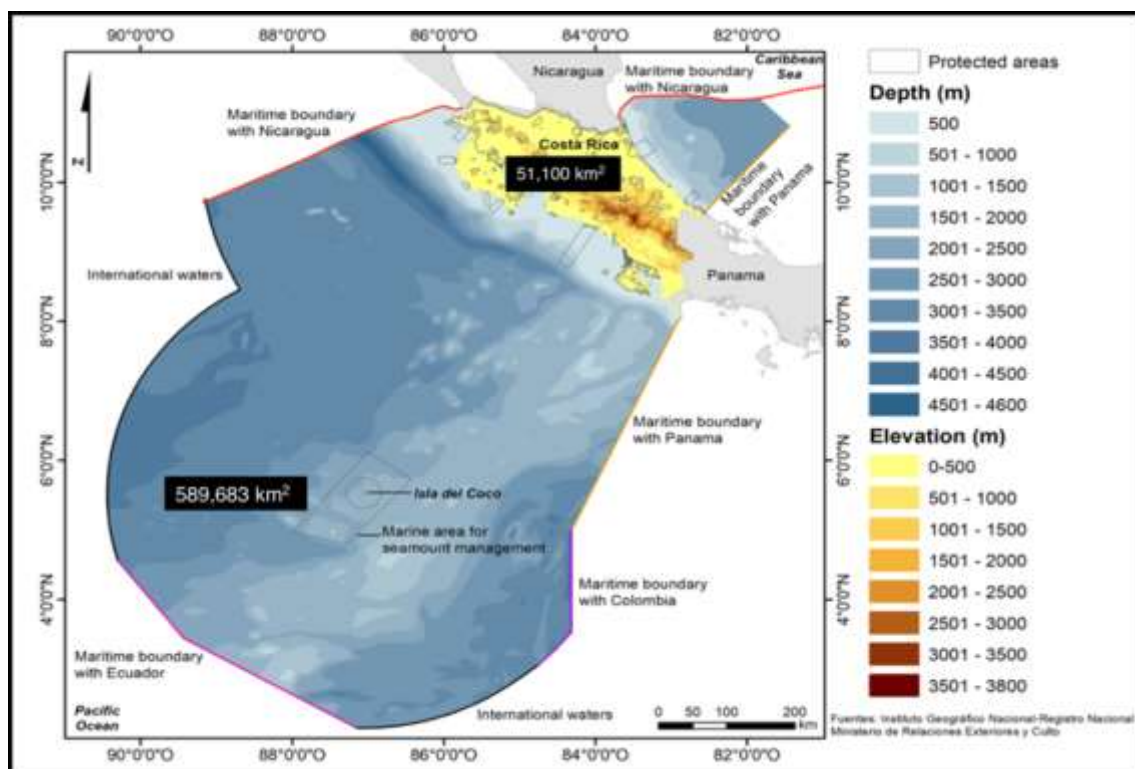


Figure 1. Costa Rica, 92% of its area is sea.

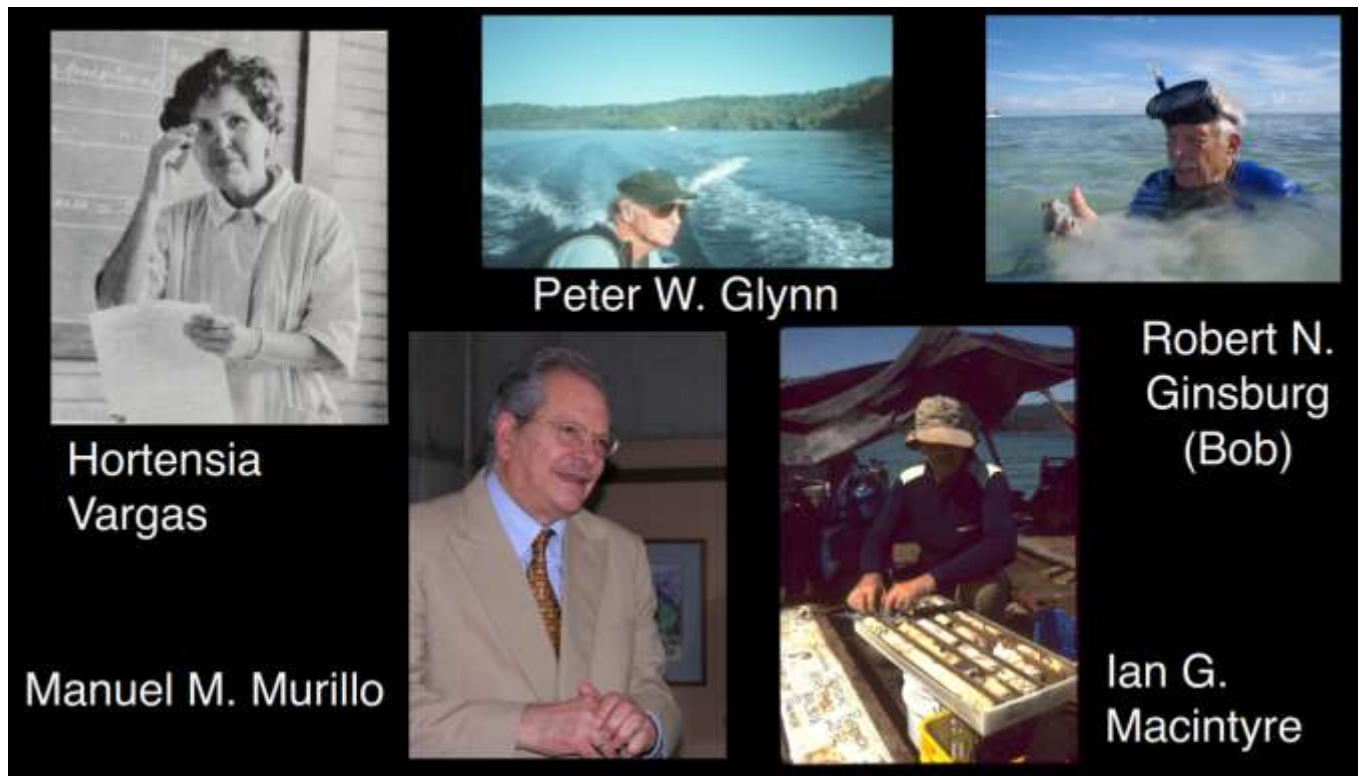


Figure 2. Mentors that were a very positive influence in my career.

Introduction

I come from a small country in Central America, Costa Rica, that has a history of environmental protection and conservation, which has coasts and coral reefs on the Caribbean and Pacific coasts, plus an oceanic island 500 km offshore, Isla del Coco, also with coral reefs (Fig. 1) (Cortés 2016a, b, c). Costa Rica has a very high terrestrial as well as marine biodiversity. The country is 92% sea and 63% is below 2,000 m depth (Cortés and Benavides-Varela in prep.).

Most scientists start their careers very early on, as early as high school and the influence of good teachers is fundamental. Hortensia Vargas, my chemistry, physics and math teacher at Lincoln High School, taught me to love science. Then during my undergraduate studies at the University of Costa Rica, Dr. Manuel M. Murillo introduced me to marine science and the enormous diversity of habitat and organisms in a bicoastal country like Costa Rica. My postgraduate education was greatly enriched by some of the best scientists in the field, Dr. Peter W. Glynn and Dr. Robert N. Ginsburg, at the University of Miami and Dr. Ian G. Macintyre at the Smithsonian Institution (Fig. 2).

The coral reefs of Costa Rica have been studied since the 1970's, and during the initial decades new reefs were discovered and described, as well as the natural and human impacts affecting them (Cortés & Risk 1985, Cortés & Jiménez 2003a, b). Over time, we recorded the decline and recovery of the coral reefs (Guzmán & Cortés 2001, 2007) (Fig. 3a). Long term monitoring is fundamental to determining the long-term changes and their possible causes. Monitoring can provide evidence that the less human pressure there is in a region the faster the reefs recover after a disturbance (Fig. 3b).

CARICOMP, the long-term Caribbean wide monitoring program (Cortés et al. 2019) set up by a small group of scientists with the support of the UNESCO Coastal Marine Program, and led by John Ogden since 1985, is an example of how they might be organized (Fig. 4a). Local scientists must be principal investigators, not just data gatherers. Also, funding must, as much as possible, come from local sources so that the monitoring is incorporated in the regular activities of the laboratories or agencies (Cortés et al. 2019). The initial 1985 meeting was attended by lecturers from the USA and Europe, and Caribbean and Latin American listeners. But that changed over time and local

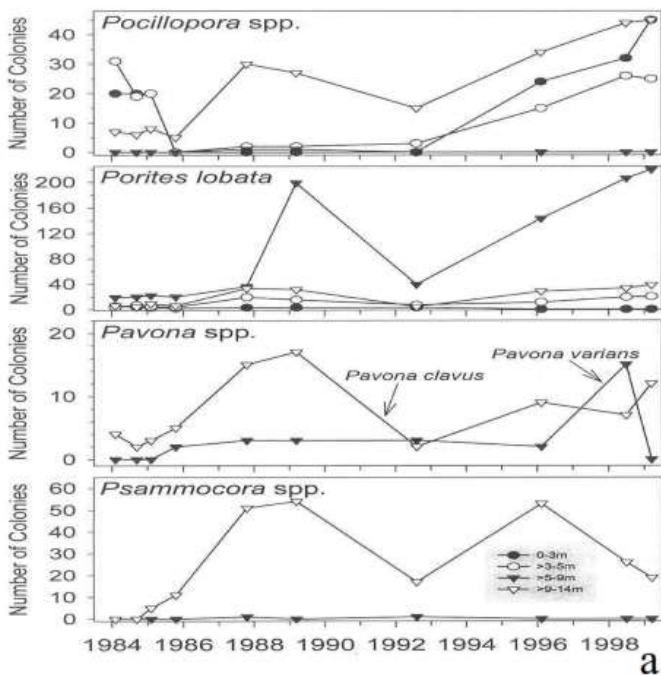


Figure 3. Down, up, down, up, at Isla del Caño (Guzmán & Cortés 2001) (a, left). Recovery at Isla del Coco was faster than at Isla del Caño, and much faster than along the coast (b, right).

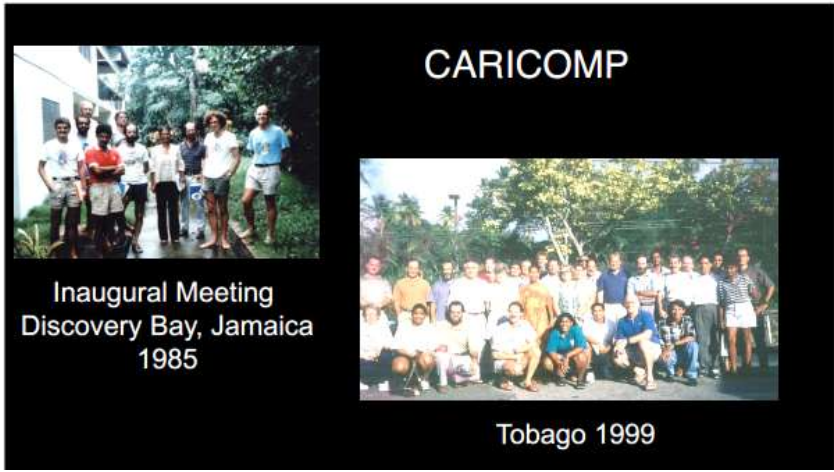


Figure 4. John Ogden at Discovery Bay Marine Laboratory in 1985, meeting to discuss the possibility of a Caribbean wide monitoring program (a, left). Pictures of the initial group in 1985, and the CARICOMP site directors in 1999 (b, right).

scientists started and continued for many years the CARICOMP program (Fig. 4b). It was a wonderful, instructive, and important period of data sharing amongst colleagues from the region and their students (many of them, established scientists now). CARICOMP also made me appreciate other tropical coastal ecosystems, and that is when I started working on seagrass meadows and mangrove forests. Even though CARICOMP ended in 2007, we continue exploring and monitoring several ecosystems in Costa Rica (Samper-Villarreal et al. 2012, Loría-Naranjo et al. 2018), as is also happening in other regions in the Caribbean.

Paraphrasing Cosby, Stills, Nash and Young, Teach Your Children:

“Teach your students well
 Their mentor’s frustrations did slowly go by
 And feed them on your dreams
 The one they pick’s the one you’ll know by”

Students are our legacy, and I have been extremely lucky to have many excellent ones, that at some point started teaching me. Most of them are my friends and some are colleagues at the University of Costa Rica and other institutions (Fig. 5).



Figure 5. Some of my students who are now friends and colleagues.

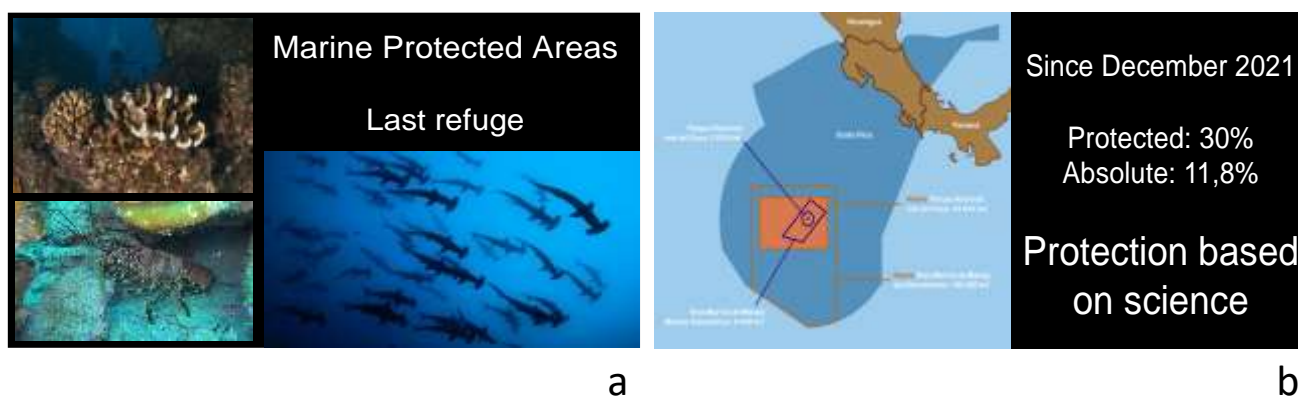


Figure 6. Marine protected areas are important for the preservation of many species (a). Long awaited expansion of Isla del Coco National Park protected area (b).

Coral reefs are the most diverse of marine ecosystems, so the more I studied them, the more I became interested in marine biodiversity. I started developing research projects and motivated students to dedicate themselves to the study of the rich biota of the ocean. An example is the Marine Biodiversity of the Guanacaste Conservation Area (BioMar-ACG, Biodiversidad Marina del Área de Conservación Guanacaste). This project is a four-way partnership, between the government (the Conservation Area), the local community (two marine parataxonomists and local tour operators of a nearby coastal town, Cuajiniquil), a funding NGO (Guanacaste Dry Forest Conservation Fund) and academia (scientists mainly from the University of Costa Rica, but also from other institutions; Cortés & Joyce 2021).

The research agenda has several objectives, first, generate new knowledge, second, reinforce the formation of new scientists, and third, apply that knowledge in local and international outreach, and for the protection and conservation of the ocean. Marine protected areas are important for the preservation of many species, in many cases they are the last refuge of many species, especially commercially or overexploited ones (Fig. 6a). Good science is necessary to justify the creation or expansion of existing marine protected areas. A good example has been the long-awaited expansion of Isla del Coco National Park protected area in December 2021, a 12-year process (Fig. 6b). We were fighting for 30% absolute protection, but you can't always get what you want.



Figure 7. Coral gardening and reef restoration are good for the environment and for creating awareness of the sea and its creatures.

In closing, we need to continue generating new knowledge, applying it for the well-being of the ocean and for Humanity. One way of recovering what has been lost is the rewilding of impacted areas with coral gardening and transplantation (Fig. 7). This not only gives corals and the reefs a long-term survival but is a very powerful tool to create awareness on local communities about their marine environment.

Remembering John Lennon and The Plastic Ono Band:

"All we are saying is
give peace a chance"

All we marine scientists, and conscientious citizens
of the world are saying is:
give seas a chance!

References

- Cortés J. 2016a. The Pacific coastal and marine ecosystems, Pp. 97-138. In: M. Kappelle (Ed.). Costa Rican Ecosystems. University of Chicago Press, Chicago and London. <https://doi.org/10.7208/chicago/9780226121642.003.0005>
- Cortés J. 2016b. Isla del Coco: Coastal and marine ecosystems, Pp. 162-191. In: M. Kappelle (Ed.). Costa Rican Ecosystems. University of Chicago Press, Chicago and London. <https://doi.org/10.7208/chicago/9780226121642.003.0007>
- Cortés J. 2016c. The Caribbean coastal and marine ecosystems, Pp. 591-617. In: M. Kappelle (Ed.). Costa Rican Ecosystems. University of Chicago Press, Chicago and London. <https://doi.org/10.7208/chicago/9780226121642.003.0017>
- Cortés J, Jiménez, C. 2003a. Past, present and future of the coral reefs of the Caribbean coast of Costa Rica: p: 223-239. In: J. Cortés (Ed.), Latin American Coral Reefs. Elsevier Science B.V., Amsterdam
- Cortés J. & Jiménez C. 2003b. Corals and coral reefs of the Pacific of Costa Rica: history, research and status: 361-385. In: J. Cortés (Ed.), Latin American Coral Reefs. Elsevier Science B.V., Amsterdam
- Cortés J, Joyce F. 2020. BioMar-ACG: A successful partnership to inventory and promulgate marine biodiversity. *Biotropica*, 52, 1104-1107. <https://doi.org/10.1111/btp.12841>
- Cortés, J. & M.J. Risk. 1985. A reef under siltation stress: Cahuita, Costa Rica. *Bulletin of Marine Science*, 36: 339-356
- Cortés J, Oxenford HA, van Tussenbroek BI, Jordán-Dahlgren E, Cróquer A, Bastidas C, Ogden JC. 2019. The CARICOMP network of Caribbean Marine Laboratories (1985-2007): History, key findings, and lessons learned. *Frontiers in Marine Science*, 5:519. <https://doi.org/10.3389/fmars.2018.00519>
- Guzmán HM, Cortés J. 2001. Changes in reef community structure after fifteen years of natural disturbances in the eastern Pacific (Costa Rica). *Bull Mar Sci* 69: 133-149
- Guzmán HM, Cortés J. 2007. Reef recovery 20 years after the 1982-83 El Niño massive mortality. *Mar Biol* 151: 401-411. <https://doi.org/10.1007/s00227-006-0495-x>
- Loría-Naranjo M, Samper-Villarreal J, Sandoval-Siles M, Cortés J. 2018. Intra- and inter-annual variation in a seagrass meadow on the Caribbean coast of Costa Rica: 2009-2015. *Revista de Biología Tropical*, 66: 1149-1161. <http://dx.doi.org/10.15517/rbt.v66i3.31035>
- Samper-Villareal J, Cortés J, Benavides C. 2012. Description of the Panamá and Iguanita mangrove stands within Bahía Culebra, north Pacific coast of Costa Rica. *Revista de Biología Tropical*, 60 (Supplement 2), 109-120



Figure 8. A reef head thinking about its future. Let's give it a chance!

REEF RECRUITS

Correlates of corallicolid presence in Caribbean octocorals

Akacia K. Halliday-Isaac¹

¹Department of Biology, University of Mississippi

akhallid@go.olemiss.edu

Background

The phylum Apicomplexa consists of unicellular protists that are elongated in shape, and use a unique structure called an apical complex to adhere to their host's cells and create an opening to inject invasion factors that further develop into a parasitophorous vacuole (invasion pore) in which the parasite will reside (Katris et al. 2014). They are obligate intracellular organisms that need host cells to live and reproduce and inhabit a wide array of hosts in terrestrial and marine ecosystems (Morrisette and Sibley 2002, McFadden 2014). The phylum is commonly considered exclusively parasitic and includes economically and ecologically important parasites, such as *Plasmodium falciparum*, one of the causative agents of malaria, and *Cryptosporidium* spp., which cause gastrointestinal diseases in humans and animals worldwide (Kopečná et al. 2006).

Apicomplexans that infect corals, known as corallicolids, were first documented in 1984, with the occurrence of *Nematopsis* spp. in colonies of the scleractinian *Porites porites* in Puerto Rico (Peters 1984). Subsequently, other reports of the existence of apicomplexans in corals followed, such as apicomplexan oocysts infecting nine scleractinian coral species across the Caribbean (Upton and Peters 1986) and an apicomplexan coccidian protozoan (“Genotype-N”) occurring within bleached *Orbicella annularis*, a taxon that forms a species complex with *O. faveolata* and *O. franksi* (Medina et al. 1999, Toller et al. 2002).

Apicomplexan sequences from *Corallicola aquarius*, *Gemmocystis cylindrus* (renamed *Anthozoaphila gnarlus*), and other apicomplexans have been documented in various presumably healthy (Kirk et

al. 2013a,b) Scleractinia corals (hard corals), Alcyonaceans (soft corals), and Antipatharians (black corals) across the Caribbean, Florida Keys, Panama, Belize, and the Great Barrier Reef. They occur predominantly in offshore tropical and warm subtropical waters (Janouškovec et al. 2012) at shallow, deep-sea, and mesophotic depths (Vohsen et al. 2020).

The detection of apicomplexans as a byproduct in previous studies indicates a larger need to examine octocoral species for alternative symbionts which could play a part in the octocoral's response to environmental changes. Deciphering the prevalence of the dinoflagellate relatives in octocorals and characterizing the bacterial microbiome in additional octocoral species are integral to understanding octocorals' continued success in the Caribbean. The objectives of this research were to characterize the holobiont of several species of octocorals in the United States (US) Virgin Islands, by determining the existence and prevalence of apicomplexan symbionts in Caribbean octocorals and their associated microbiome.

Research Undertaken

Samples were collected from colonies of *Briareum asbestinum*, *Eunicea flexuosa*, *Muricea muricata*, *Plexaura homomalla*, and *Gorgonia ventalina* at 1–2-meter depths in John Brewer's Bay and Coki Bay on St. Thomas, USVI (Fig. 1).

Two cm samples were collected from each colony, and genomic DNA was extracted using the DNEasy PowerSoil Pro Kit. A total of 46 samples were collected and processed: 13 samples from colonies of *G. ventalina*, 8 samples from colonies of *P. homomalla*, 8 samples from colonies of *B. asbestinum*, 7 samples from colonies of *M. muricata*, and 10 colonies of *E. flexuosa*. The samples were screened for corallicolid 18S rRNA presence using PCR with the 18N primers (Toller et al. 2002) and confirmed using Sanger sequencing. The bacterial composition of the samples was determined by amplifying the V4 region of the 16S rRNA gene of the extracted DNA and sequencing via Illumina MiSeq. Bacterial sequences were assembled, read, and filtered using the DADA2 R-package. 16S rRNA gene amplification and

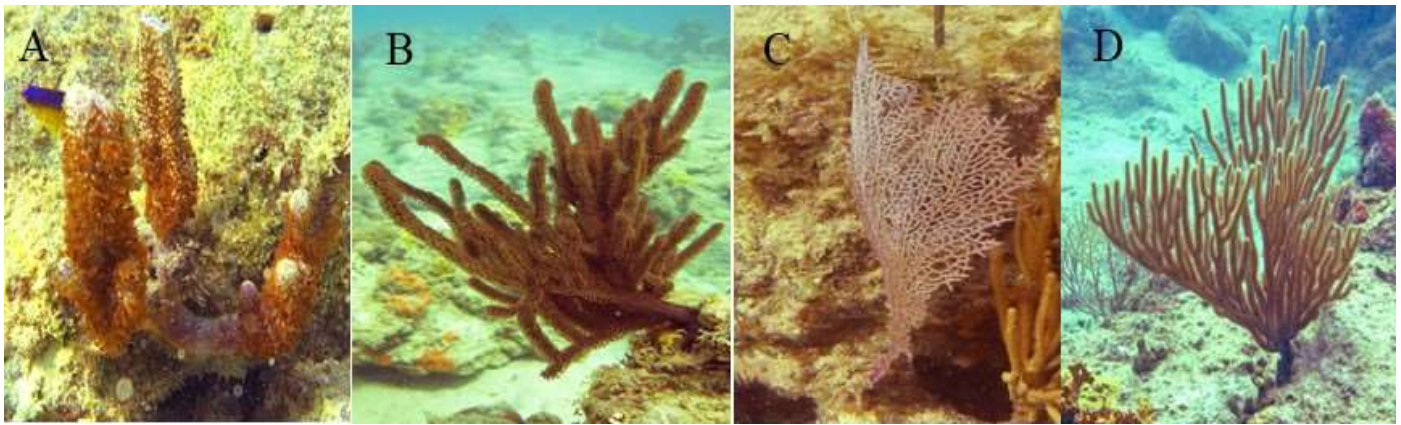


Figure 1. Species sampled at study sites in St. Thomas, US Virgin Islands A) *Briareum asbestinum*, B) *Muricea muricata*, C) *Gorgonia ventalina*, D) *Plexaura homomalla*. *Eunicea flexuosa* not pictured.

sequencing was successful on 42 of the 46 samples resulting in the exclusion of two samples of *B. asbestinum*, one sample of *E. flexuosa*, and one sample of *M. muricata*. A subset of the samples was screened for dinoflagellates using Symbiodiniaceae primers to amplify dinoflagellate algae in the family Symbiodiniaceae (Hume et al. 2013). These PCR products were sequenced via Sanger sequencing. Differences in community composition based on sites, species, and apicomplexan prevalence were tested for using PERMANOVA. Finally, the samples were screened for eukaryotes using primers to amplify micro-eukaryotes (del Campo et al. 2019).

Planctomycetes, Firmicutes, and some unclassified bacteria (Fig. 2). There was a significant interaction effect of site and species on the composition of the bacterial profile (PERMANOVA, $p = 0.002$). Post hoc tests reveals that these differences were primarily driven by the Coki bay site. However, there was not a significant difference in composition correlated with apicomplexan presence.

The samples that were screened for Symbiodiniaceae amplified as *Breviolum* sp. or *Symbiodium* sp. Thirty-eight of the 42 samples had amplification with the microeukaryote primer but further processing requires Illumina sequencing which is outside the scope of this project’s budget.

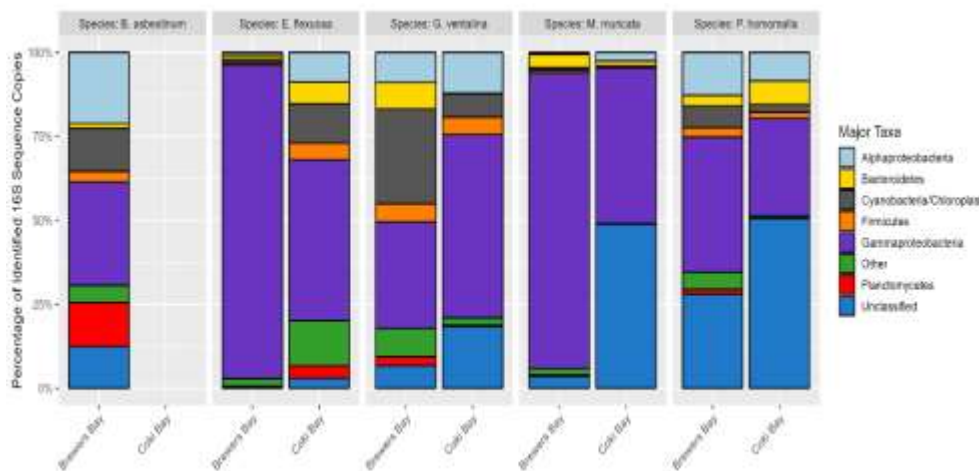


Figure 2. Bacterial composition of octocoral samples by site and species.

Results

The 18N apicomplexan primer amplified in 12 of the 42 samples (prevalence = 0.28) and these apicomplexans were further confirmed to be the apicomplexan *Corallicolla aquarius*. The microbiome present in the samples was composed primarily of Gammaproteobacteria, Alphaproteobacteria, Cyanobacteria, Bacteroidetes,

Concluding Remarks

In this study, we showed that the apicomplexan *Corallicolla aquarius* is present in octocorals in the U.S. Virgin Islands and primarily in the coral *G. ventalina*. While there was not a significant difference in the microbiome associated with these octocorals that correlate with apicomplexans presence

vs absence, this may be largely due to the distribution of apicomplexan presence in the samples. Apicomplexans were present in 11 out of 13 of the *G. ventalina* samples collected and those samples make up 11 out of 12 of the total samples containing apicomplexans. There was also a significant effect of site on the microbiomes seen within the species sampled. The possible

environmental factors influencing these differences warrant further investigation. Funding is currently being sought to include more samples and sites in this study as well as to explore the observed microeukaryote amplification. While some work has been done to identify apicomplexans within hard corals and octocorals within shallow-water and deep-sea corals, no research has been done yet on how that presence is distributed throughout reef communities in the Caribbean. Additionally, no studies have been done on how presence may alter the host holobiont. Further investigation should be done in these areas as characterizing the potential alterations to the holobiont due to apicomplexan presence is a first step in determining their likely host effects.

Akacia Halliday-Isaac



Stay connected

 **ResearchGate:** Akacia-Halliday-Isaac

References

- Del Campo J, Pons MJ, Herranz M, Wakeman KC, Del Valle J, Vermeij MJ, Leander BS, Keeling PJ (2019) Validation of a universal set of primers to study animal-associated microeukaryotic communities. *Environ Microbiol* 21:3855–3861
- Hume B, D'Angelo C, Burt J, Baker AC, Riegal B, Wiedenmann J (2013) Corals from the Persian/Arabian Gulf as models for thermotolerant reef-builders: prevalence of clade C3 *Symbiodinium*, host fluorescence and ex situ temperature tolerance. *Mar Pollut Bull* 72:313–22
- Janouškovec J, Horák A, Barott KL, Rohwer FL, Keeling PJ (2012) Global analysis of plastid diversity reveals apicomplexan-related lineages in coral reefs. *Curr Biol* 22:R518–R519
- Janouškovec J, Horák A, Barott KL, Rohwer FL, Keeling PJ (2013) Environmental distribution of coral-associated relatives of apicomplexan parasites. *ISME Journal* 7:444–447
- Kirk NL, Thornhill DJ, Kemp DW, Fitt WK, Santos SR (2013a) Ubiquitous associations and a peak fall prevalence between apicomplexan symbionts and reef corals in Florida and the Bahamas. *Coral Reefs* 32:847–858
- Kirk NL, Ritson-Williams R, Coffroth MA, Miller MW, Fogarty ND, Santos SR (2013b) Tracking transmission of apicomplexan symbionts in diverse Caribbean corals. *PLoS ONE*:8(11)
- Kwong WK, del Campo J, Mathur V, Vermeij MJA, Keeling PJ (2019) A widespread coral-infecting apicomplexan with chlorophyll biosynthesis genes. *Nature* 568: 103–107

- Kwong WK, Irwin NA, Mathur V, Na I, Okamoto N, Vermeij MJA, Keeling PJ (2021) Taxonomy of the Apicomplexan Symbionts of Coral, including Corallicolida ord. nov., Reassignment of the Genus Gemmocystis, and Description of New Species *Corallicola aquarius* gen. nov. sp. nov. and *Anthozoaphila gnarlus* gen. nov. sp. nov. *Journal of Eukaryotic Microbiol* 68:e12852
- McFadden GI (2014) Apicoplast. *Curr Biol* 24:262–263
- Medina M, Weil E, Szmant AM (1999) Examination of the *Montastraea annularis* species complex (Cnidaria: Scleractinia) using ITS and COI sequences. *Mar Biotech* 1:89–97
- Morrisette NS, Sibley LD (2002) Cytoskeleton of Apicomplexan Parasites. *Microbiol Mol Biol Rev* 66:21–38
- Peters EC (1984) A survey of cellular reactions to environmental stress and disease in Caribbean scleractinian corals. *Helgol Wiss Meeresunters* 37:113–137
- Toller WW, Rowan R, Knowlton N (2002) Genetic evidence for a protozoan (phylum Apicomplexa) associated with corals of the *Montastraea annularis* species complex. *Coral Reefs* 21:143–146
- Upton SJ, Peters EC (1986) A new and unusual species of coccidium (Apicomplexa: *Agamococcidiorida*) from Caribbean scleractinian corals. *J Invert Pathol* 47:184–193
- Vohsen SA, Anderson KE, Gade AM, Gruber-Vodicka HR, Dannenberg RP, Osman EO, Dubilier N, Fisher CR, Baums IB (2020) Deep-sea corals provide new insight into the ecology, evolution, and the role of plastids in widespread apicomplexan symbionts of anthozoans. *Microbiome* 8:1–15

Identifying Conservation Priorities for Invertebrate-Based Ecosystem Services in Fiji

Katherine Lawson¹

¹SUNY College of Environmental Science and Forestry

kanewcom@syr.edu

Background

Coral reef ecosystems comprise a multi-layered complex through which nutrients, species, and people interact. Reefs are bastions of biodiversity (Knowlton 2001), and in places like the Western Pacific, high species richness and remote locations result in a dearth of scientific research on many species. Reefs in the Pacific face challenges from climate change (Spalding and Brown 2015), increased storm frequency and intensity (Cheal et al. 2017), unsustainable fishing practices (Rhodes et al. 2018), and rising coastal populations (Bell et al. 2006). Preserving biodiversity on coral reefs is a



Figure 1: Photo of an ARMS structure deployed in sandy substrate in the Yasawa Islands, Fiji.

high priority conservation goal (Knowlton 2001; Munday 2004; Pratchett et al. 2011). In addition to their important ecological roles, reefs provide local communities with many well-studied ecosystem services, such as fisheries, building materials, and tourism (Woodhead et al. 2019). In addition, reefs are culturally significant and conservation efforts need to balance both their social and environmental qualities to be successful.

This study characterizes the biodiversity of coastal reef habitats in Fiji and the ecosystem services that reef species provide to the local community. The goals of international coral reef conservation programs often involve optimizing multiple ecosystem services, including fisheries, medical advances, and tourism. However, effective conservation requires local engagement (Hoffman 2002; Bell et al. 2006; Gavin et al. 2015), especially in areas where communities maintain strong and intergenerational ties to the environment (Sterling et al. 2017).

Marine invertebrates build biogenic structures, fill ecosystem niches, cycle nutrients, and provide crucial food sources, but published surveys or guides are rare for many western Pacific taxa due to disproportionate attention given to fish and coral. For this project, we will measure the diversity of invertebrate biota in coral reefs, evaluate the value and importance of these species as ecosystem service providers, and describe the relationship

between biodiversity and perceived importance of the resource.

Work Undertaken

The first phase of this research project began in summer 2022, but some of the work was paused due to COVID-19 related delays and will restart in summer 2023. The first phase of the project involves detailed biodiversity surveys and developing relationships with local collaborators and communities. The results from the data collected so far reflect the first stage of biodiversity surveys conducted on autonomous reef monitoring structures (ARMS) deployed in 2022 (Figure 1) and partially retrieved in January 2023. Settlement panels were

deployed at two sites ($n = 6$ per site) and after 6 months, two were retrieved from each site, photographed, and surveyed microscopically to identify all sessile and mobile species living within the 3D ARM structure. We have begun to compile extensive species lists, counts of species richness, and percent cover estimates from panels retrieved in January, and will remove two additional panels after 1 year, and 1.5 years to monitor how the community develops over time. Additional biodiversity surveys will continue throughout 2023 and we will conduct transect surveys on the reefs where the ARMS are deployed.

We have also made important connections with local communities in Fiji and with collaborators at the University of the South Pacific. Community survey questions, and the ecosystem services provided by the diversity of taxa present in each community, have been compiled and drafted. Surveys planned for June and July 2023 will quantify the ways that community members use reef resources through a series of participant observations and interviews, with approval from Syracuse University's IRB human subject board. We will conduct structured interviews asking community members what ecosystem services they value. Then we will follow community members as they go fishing or gleaning, and ask them to identify each species and its uses (diet, income, building materials, etc.). By shadowing various stakeholders,

we will gain a better understanding of the heterogeneity of species use (e.g., what parts of the reef are used by whom, when and how) and the importance of those services to community members. Surveys and interviews will be conducted primarily in Fijian with the help of a translator and recorded.

Ranked importance of each ecosystem service will be analyzed using Bray-Curtis dissimilarity indices and compared to beta diversity and species richness through PERMANOVA tests that are robust to continuous ecological variables. These analyses will explain how perceptions of ecosystem services may vary in relationship to reef biodiversity. At the end of the study, I will identify which species provide the services that matter most to stakeholders and the level of redundancy among species in the system.

Preliminary Results

To compile extensive species lists, ARMS were observed live under microscopes immediately after removal to identify all discrete taxa found attached or within the ARM structure. Two ARMS were retrieved and analyzed from two sites, and more will be surveyed over the course of 2023 and 2024. Species richness measurements are based off of initial identifications of unique taxa in the field, but final taxonomic identifications will be made only after careful comparison and consideration of the literature, in collaboration with expert taxonomists.

We found that the first wave of recruitment to settlement panels was dominated by encrusting bryozoans (Figure 2A). Bryozoans are typically some of the first to settle on open space, and are commonly overgrown or settled upon by other invertebrate species. We also found many Porifera taxa, which may prevent future coral settlement. Many sessile species are filter feeders, promote coral recruitment, and provide food and habitat for other species. Further observations at 1 year and 1.5 years will identify other taxa that are present and abundant in these coral reef ecosystems.

The two sites from which panels were retrieved in January also had some clear differences. Panels from the south site had higher species richness overall and had more Tunicata taxa than panels from the north site. Tunicates typically occur more frequently in water with more suspended particles, and the south site is closer to both a freshwater input and the international shipping port of Suva. Continued observation is required to determine the cause of higher Tunicata diversity in the south. The richness and diversity of species, in addition to the types of species present at each site, may impact the perception of biodiversity by community members or the redundancy of taxa providing certain ecosystem services.

Mobile taxa were also abundant on all ARMS (Figure 2B) and were sampled by first placing mesh bags around the ARM before removal from the seafloor. Crabs, shrimp, and snails were the most common mobile species.

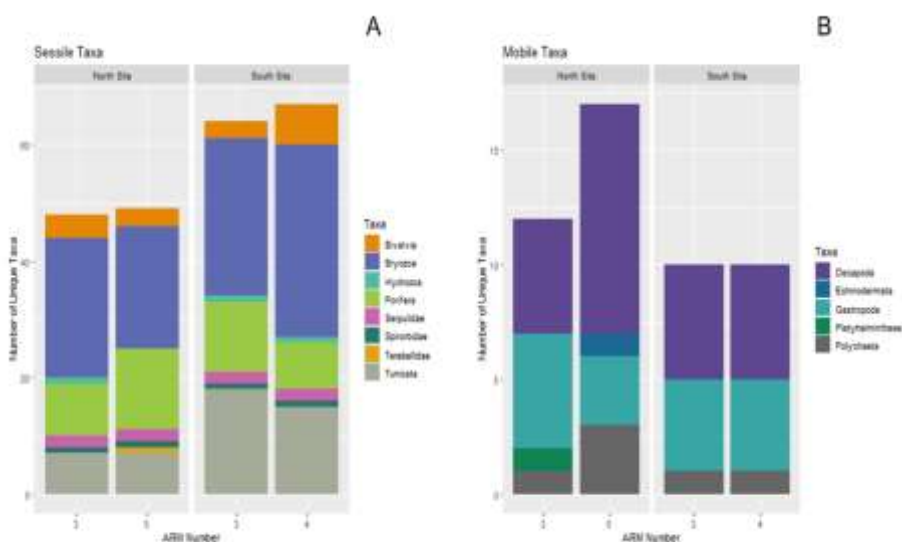


Figure 2: Initial species richness counts on ARMS panels collected in January 2023 for (A) all sessile, attached species, (B) and all mobile species.

Discussion

Preliminary results from this study indicate that Fijian reefs are highly diverse systems with clear pioneer communities of bryozoans, sponges, and algae. In addition, we found a high diversity of gastropods, crabs, and other mobile species. We saw initial differences between the two sites sampled to date, with higher diversity and more tunicate growth at the site closer to freshwater inputs and an international port. Further monitoring of these sites will reveal what patterns are influencing community composition and development.

Coral reefs are essential ecosystems ecologically and socially, providing Fijian communities with many important ecosystem services (Woodhead et al. 2019). We aim to determine how the biodiversity of coral reef systems relates to the ecosystem services provided by those species, and whether the biodiversity of the systems impacts the perception of the ecosystem held by local users.

Katherine Newcomer
Lawson



Stay connected

 **GitHub:** [newcomerk](#)

References

- Bell JD, Ratner BD, Stobutzki I, Oliver J (2006) Addressing the coral reef crisis in developing countries. *Ocean Coast Manag* 49:976–985.
- Cheal AJ, MacNeil MA, Emslie MJ, Sweatman H (2017) The threat to coral reefs from more intense cyclones under climate change. *Glob Change Biol* 23:1511–1524.
- Gavin MC, McCarter J, Mead A, Berkes F, Stepp JR, Peterson D, Tang R (2015) Defining biocultural approaches to conservation. *Trends Ecol Evol* 30:140–145.
- Hoffmann TC (2002) The Reimplementation of the Ra’ui: Coral Reef Management in Rarotonga, Cook Islands. *Coast Manag* 30:401–418.
- Knowlton N (2001) Coral Reef Biodiversity-Habitat Size Matters. *Science* 292:1493–1495.
- Munday PL (2004) Habitat loss, resource specialization, and extinction on coral reefs. *Glob*
- Pratchett MS, Hoey AS, Wilson SK, Messmer V, Graham NAJ (2011) Changes in Biodiversity and Functioning of Reef Fish Assemblages following Coral Bleaching and Coral Loss. *Diversity* 3:424–452.
- Rhodes KL, Hernandez-Ortiz DX, Cuetos-Bueno J, Ioanis M, Washington W, Ladore R (2018) A 10-year comparison of the Pohnpei, Micronesia, commercial inshore fishery reveals an increasingly unsustainable fishery. *Fish Res* 204:156–164.
- Spalding MD, Brown BE (2015) Warm-water coral reefs and climate change. *Science* 350:769–771.
- Sterling EJ, Betley E, Sigouin A, Gomez A, Toomey A, Cullman G, Malone C, Pekor A, Arengo F, Blair M, Filardi C, Landrigan K, Porzecanski AL (2017) Assessing the evidence for stakeholder engagement in biodiversity conservation. *Biol Conserv* 209:159–171.
- Woodhead AJ, Hicks CC, Norström AV, Williams GJ, Graham NAJ (2019) Coral reef ecosystem services in the Anthropocene. *Funct Ecol* 33:1023–1034.

Coral rubble. Just a pile of dead coral skeletons, right? Definitely not!

Michelle Taylor¹
¹University of Aberdeen

m.taylor2.21@abdn.ac.uk

Introduction

Coral rubble beds are ecosystems comprising dead coral skeletons and associated infauna. Rubble can be produced through natural processes such as storms, earthquakes, bioerosion, and wave disturbance, or anthropogenic events such as ship groundings, anchor damage, mortality following coral bleaching, and dynamite fishing (Holmes et al. 2000; Rasser and Riegl 2002). Coral reefs worldwide are currently under immense pressure from anthropogenic threats, but those in the Caribbean are also facing Stony Coral Tissue Loss Disease, which is rapidly resulting in unprecedented coral death (Estrada-Saldívar et al. 2020; Heres et al. 2021). Climate change and its effects on coral reefs will only increase the abundance and scale of coral rubble beds globally, creating an urgent need to understand the ecosystem function and diversity and whether they require future conservation.

Despite being created from coral skeletons, the rubble ecosystem maintains a high biodiversity including all major marine phyla (Biondi et al. 2020). Although coral rubble beds are much less structurally complex than live coral reefs, the presence of interstitial spaces in the rubble provides heterogeneity and rugosity in the system (Takada et al. 2007), allowing a multitude of animals to use the habitat. Coral rubble beds are an essential habitat for cryptic marine invertebrate species, with over 360 species of invertebrates found under rubble in the Netherlands Antilles (Meesters et al. 1991). Recently, a new coral rubble-dwelling crab species was discovered in Guam (Mendoza and Ng 2017). In Okinawa, Japan, specimens of crustaceans, flatworms, roundworms, echinoderms, segmented worms, and molluscs have been found in coral rubble beds (Biondi et al. 2020). However, research on biodiversity in Caribbean rubble beds is lacking. The value of these ecosystems in the Caribbean could rise



Figure 1. A representative area of coral rubble surveyed in Providenciales, Turks and Caicos Islands.

exponentially if we discover previously unknown species that use this habitat.

Despite our best efforts in coral reef protection and restoration, we will continue to see a loss of live coral cover over the coming decades. This mortality of corals will result in the exponential addition of coral rubble to existing beds and the creation of new coral rubble beds across the globe. We, as researchers and advocates for the ocean, need to characterize the biodiversity present in coral rubble beds and understand how the ecosystem functions both independently and as part of the larger tropical marine environment to ensure that the habitat is adequately protected as it continues to grow.

Methods

Field research took place in coral rubble beds surrounding Providenciales, Turks and Caicos Islands, in July and August 2022 (Figure 1). At each of 30 sites, an hour-long stationary video was used to determine fish species presence. On each dive, three 25 cm x 25 cm quadrats were placed randomly on the rubble substrate. A 1 L sample of water was collected from above the matrix for eDNA analysis, photographs were taken of the quadrat to characterize benthic composition, and then all rubble and infauna were collected for further investigation. All rubble pieces were photographed for categorisation by rubble type and size analysis. All organisms were photographed for identification and preserved for taxonomic identification using DNA barcoding.

Over 1300 specimens were collected in 2022 and are in the process of being identified. DNA extraction and barcoding of the specimens will begin in May 2023. Over 85 eDNA filters were preserved and will be sent out for metabarcoding later in 2023 if funding allows. The stationary videos have been used by an undergraduate student for their honours project on fish species richness in coral rubble beds, and the species presence data will be included in the community composition analysis for this project. Machine learning is being used for size and surface area analysis of the rubble pieces as well as for categorising them as different rubble types. Benthic

community composition, rubble depth, and proximity to live coral cover are some of the factors to be included in the statistical analysis. Additional fieldwork in summer 2023 is currently being planned and will take place around different Caribbean islands.

Preliminary results and discussion

The diversity of organisms that have been collected from rubble beds thus far is greater than anticipated. Numerous species of molluscs, sponges, fishes, crustaceans, echinoderms, and annelids have been photographed (Figure 2). DNA barcoding will further expand our knowledge of these



Figure 2. A selection of species collected from coral rubble beds in Providenciales, Turks and Caicos, during July and August 2022.

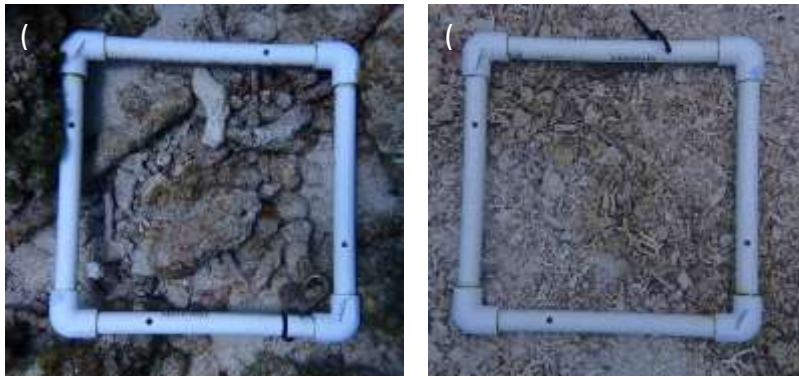


Figure 3. Examples of rubble sites sampled. Quadrats will be categorised by the benthic composition present, such as (a) massive coral rubble with algal growth, (b) branching coral rubble and shells with no algal growth.



Figure 4. Representative rubble pieces collected in Providenciales, Turks and Caicos. Categories used for classifying rubble were (a) branching coral, (b) massive coral, (c) shell, (d) undetermined coral rubble.

organisms. This research project will produce the first biodiversity reference library (including morphological information, images, and genetic sequences) for these incredibly understudied ecosystems. This resource will directly contribute to biodiversity conservation by, for the first time, shedding light on the species that utilize coral rubble beds.

A variety of rubble sites were surveyed to allow comparison between areas with differing rubble characteristics, including rubble size and composition, size of interstitial spaces and epilithic algal growth (Figure 3). Determining the community composition and ascertaining the differences in biodiversity present in different rubble types (Figure 4) and with differing proximity

to live coral will provide a better understanding of the function of these habitats and how to implement appropriate management strategies.

Acknowledgements

I would like to thank the International Coral Reef Society graduate fellowship for the funding provided for this project. I would also like to thank IDEA Wild, the University of Aberdeen, the Genetics Society, Santander Bank, and the Gilchrist Education Trust for also providing funding towards the fieldwork of this project. Thanks are also due to Valeport, Star Oddi, Olympus, Whirlpak, WeatherWriter, SlipIns, Finfock Productions and Geosupplies for providing equipment for use in the field.

Michelle Taylor



References

- Biondi P, Masucci GD, Reimer JD (2020) Coral cover and rubble cryptofauna abundance and diversity at outplanted reefs in Okinawa, Japan. *PeerJ* 8, e9185.
- Estrada-Saldívar N, Molina-Hernández A, Pérez-Cervantes E, Medellín-Maldonado F, González-Barrios FJ, Alvarez-Filip L (2020) Reef-scale impacts of the stony coral tissue loss disease outbreak. *Coral Reefs* 39:861–866.
- Heres MM, Farmer BH, Elmer F, Hertler H (2021) Ecological consequences of Stony Coral Tissue Loss Disease in the Turks and Caicos Islands. *Coral Reefs* 40: 609–624.
- Holmes KE, Edinger EN, Hariyadi, Limmon GV, Risk MJ (2000) Bioerosion of live massive corals and branching coral rubble on Indonesian coral reefs. *Mar Pollut Bull* 40:606–
- Meesters E, Knijn R, Willemsen P, Pennartz R, Roebbers G, van Soest RWM (1991) Sub-rubble communities of Curaçao and Bonaire coral reefs. *Coral Reefs* 10:189–197.
- Mendoza JCE, Ng PKL (2017) *Harryplax severus*, a new genus and species of an unusual coral rubble-inhabiting crab from Guam (Crustacea, Brachyura, Christmaplacidae). *ZooKeys* 647:23–35.
- Rasser M, Riegl B (2002) Holocene coral reef rubble and its binding agents. *Coral Reefs* 21:57–72.
- Takada Y, Abe O, Shibuno T (2007) Colonization patterns of mobile cryptic animals into interstices of coral rubble. *Mar Ecol Prog Ser* 343:35–44.

Coral Recruitment and Survival in Pemba Island, Tanzania

Natalie Andersen
Centre for Ecology and Conservation,
University of Exeter, Penryn, Cornwall, TR10 9FE, UK
na503@exeter.ac.uk

Introduction

Worldwide, coral reefs are facing a variety of pressures, threatening their survival and the ecosystem services they provide (Hoegh-Guldberg et al. 2018). Increased water temperatures and ocean acidification as a result of climate change are global threats, and many reefs are also subject to localised problems including overfishing, habitat destruction, pollution and disease. Once a reef is damaged or disturbed, a key driver of recovery is the supply of coral planula larvae and subsequent recruitment and survival (Hughes et al. 2000). To understand how the threats facing coral reefs may impact their long-term persistence and functioning, it is critical to understand the processes of coral recruitment and post-settlement survival (Turner et al. 2018).

The process of coral recruitment involves the perception of physicochemical cues by the larvae and requires suitable biological conditions and appropriate water chemistry, temperature and hydrodynamic processes (Nzali et al. 1998; Manikandan et al. 2017). It is not evident from the literature which of these factors plays a dominant role, but it does appear that multiple factors work concurrently. Scleractinian corals are subject to high mortality in early life stages (Penin et al. 2010), with survival rates of settled corals ranging from 0.2 - 7.4% within the first 9 months post-settlement (Wilson and Harrison 2005; dela Cruz and Harrison 2017; Ligson et al. 2022). Physical parameters such as light availability, seawater temperature and sedimentation rates are known to influence coral reproduction and subsequent recruitment, along with other factors such as the proximity of viable seed populations, herbivory and substrate stability (Nzali et al. 1998; Manikandan et al. 2017; Turner et al. 2018; Chow et al. 2023).

Reefs worldwide continue to decline, with a 50% loss of coral cover globally since 1950 (Eddy et al. 2021). Although natural recovery of coral populations has been observed when key stressors are controlled and natural rates of larval supply result in sufficient recruitment (Graham et al. 2015), the management of many degraded reef habitats is inadequate to control ongoing threats and promote recovery (dela Cruz and Harrison 2017).

The Western Indian Ocean supports about 5% of the world's coral reefs, covering an estimated 11,919 km² (Obura et al. 2022). On the East African coast, coral reefs are almost continuous from Somalia to South Africa and form a subdivision of the tropical Indo-Pacific. Within this range, Tanzania contains some of the most biodiverse reefs (Grimsditch et al. 2009), with the reefs of Pemba Island, which is situated within the semi-autonomous Zanzibar Archipelago, accounting for 45% and covering 1,100 km² (McClanahan et al. 2000). To date, only five publicly available studies have examined Pemba's reefs, four of which focused on Misali Island in the southwest, with the other covering a wide area of the island's western coast (Grimsditch et al. 2009). Hence, compared to other reefs in the Western Indian Ocean, such as those in the Seychelles, Kenya, Mozambique, Mauritius and Zanzibar, Tanzania, the status of Pemba's reefs is relatively unknown.

Study Area

The Kwanini Marine Protected Area (KMPA) is a small marine protected area established in 2013 in northwestern Pemba, Tanzania, through a voluntary agreement between the local community and a resort hotel. The KMPA was formally recognised in 2018 through a by-law under Part V of the Fisheries Act No.7 of 2010. The KMPA covers an area of approximately 0.5 km² and comprises a variety of habitats including a sandy lagoon, small seagrass beds, reef flat and a fringing coral reef. Fishing is prohibited on the outer reef, which is enforced by rangers 24 hours a day. The reefs within the KMPA have been heavily damaged by historic fishing activity, including suspected dynamite fishing, which is no longer practiced due to the protection afforded by the KMPA. Much of the fringing reef within the KMPA has been reduced to rubble fields (Figure 1) which are unstable due to strong currents and a steep reef slope. The rubble fields within the KMPA are at least 10 years old, with suspected dynamite fishing occurring between 2000 and 2009 (D Mwashigadi

2019, personal communication). With the threat of fishing removed, recovery of the reefs within the KMPA is dependent on sources of viable coral planula larvae and growth and survival of corals to adulthood. However, studies of reef systems in South-East Asia that have experienced large-scale damage from dynamite fishing have found rubble fields to persist for years (Fox and Caldwell 2006) to decades (Williams et al. 2019), with limited recovery of the coral community.

This study seeks to determine the natural rates of coral settlement and juvenile coral growth and survival within the KMPA and to evaluate how the characteristics of the juvenile coral community contribute to the recovery, or lack of it, on the reef within the KMPA.



Figure 1. Rubble-dominated reef slope within the Kwanini Marine Protected Area (KMPA) damaged by historical dynamite fishing.

Methods

Surveys of the juvenile coral community were undertaken within the KMPA on the outer fringing reef at two representative sites: House Reef (4° 53.198'S, 39° 40.535'E) and Scorpion's Secret (4° 53.022'S, 39° 40.493'E). Surveys were conducted over five periods between April 2019 and October 2022 (April and October 2019, October 2021, April and October 2022). Originally it was intended to sample at six-month intervals from April 2019 through April 2021, but no surveys were conducted in 2020 or in April 2021 due to restrictions on international travel as a result of the COVID-19 pandemic.

To quantify the juvenile coral community and the rates of survival, mortality and growth, 40 replicate permanently marked reference points were installed in April 2019 at each reef, with 20 at both 7 m and 15 m. The location of each quadrat was marked using a rebar rod hammered into the substrate to ensure that the same sites were

surveyed during each field season. During each survey, a 0.5 x 0.5 m quadrat was placed on the substrate and a thorough inspection of the substratum, including underneath soft corals, was undertaken to identify coral recruits as small as 2 mm. All visible coral recruits and juveniles were measured, photographed, mapped (Figure 2), and where possible, identified to genus. To ensure the same quadrat alignment in all field seasons, a photograph of the whole quadrat was taken and laminated for orientation in subsequent survey periods. Penin et al.'s (2010) definitions for the three benthic life stages of scleractinian corals were used, with coral recruits defined as 1 - 10 mm in diameter, juveniles between 1 - 5 cm in diameter and adults > 5 cm in diameter. Coral fragments or remnants of a previous colony were excluded from analysis.



Figure 2. Juvenile coral survey using the 0.5 x 0.5 m quadrat at a permanently marked monitoring location.

To quantify recruitment, survival, and mortality rates of the coral community during early life stages between survey periods, a comparison of the same individual juvenile corals was undertaken using photographs and maps from two consecutive field seasons (Figure 3). Where possible, all recruits and juveniles were identified to genus. The key morphological characteristics of growth form, corallite size, budding state and corallite structure were used to aid identification. In instances where genus could not be determined, such as for corals at the single-polyp stage or colonies that were too small, juveniles were identified to family level. Corals that could not be categorised to family were listed as 'unidentified'.



Figure 3. The same *Pocillopora* colony in 1) April 2019 2) October 2019 and 3) October 2021 when it reached adulthood.

Preliminary Results

Analysis of the juvenile coral data has been completed for one of the four sites – House Reef Shallow. At this site, the juvenile coral community was dominated across all survey periods by *Pocillopora* spp., representing 67 - 82% of the recruits and juveniles per survey period, followed by *Porites* spp. and *Pavona varians*, representing 6 - 16% and 6 - 10%, respectively. Recruits and juveniles of the key reef-building species (*Echinopora lamellosa*, *Galaxea astreata* and *Pavona clavus*) in north-western Pemba were entirely absent from House Reef Shallow. Recruits and juveniles belonging to nine genera were identified, although further identification of some currently unidentified corals is ongoing, so this number may increase.

Between each survey period, less than 4% of juvenile corals became adults and mortality rates ranged from 39.5 – 67.1% for surveys conducted within six months (Table 1). Survival rates of recruits and juveniles were between 31.7 and 58.8% over a six-month period. Over the two-year gap between surveys in October 2019 and October 2021, the mortality rate was 94.5% and survival rate amongst juveniles was 2.4%, with 3.1% of juveniles reaching adulthood.

Concluding Remarks

The lack of recruitment of key reef building species to reef substrate and low survivorship from juvenile to adulthood within the KMPA are concerning and likely contribute to the limited recovery of the reef following damage by historic dynamite fishing. Analysis of the other three sites will indicate whether these trends persist throughout the KMPA.

Table 1: Recruit and juvenile coral numbers in each survey period from April 2019 to October 2022, and rates of mortality, survival, and progression to adulthood between survey periods at House Reef Shallow (7 m).

	April 2019	October 2019	October 2021	April 2022	October 2022
Total recruit and juvenile corals	119	127	164	156	107
Mortality rate between surveys	-	39.5%	94.5%	67.1%	57%
Survival rate between surveys	-	58.8%	2.4%	31.7%	41.7%
Progression to adulthood rate between surveys	-	1.7%	3.1%	1.2%	1.3%

Future study plans will use additional data to identify factors influencing survival of scleractinian corals in early life stages in Pemba. The following parameters will be considered: adult coral community, substratum cover including coralline algae, substrate stability, presence and abundance of corallivorous and herbivorous invertebrates (i.e., sea urchins, Crown-of-Thorns starfish (*Acanthaster planci*) and cushion star (*Culcita* spp.)), and abundance and diversity of key families of corallivorous and herbivorous fishes. Using constrained ordination, these data will be tested to explore which variables drive variation in the juvenile coral community. The findings of this study will inform appropriate management actions within the KMPA to promote recovery of the coral reef following historic dynamite fishing.

Natalie Anderson



References

- Chow CFY, Bolton C, Boutros N et al (2023) Coral settlement and recruitment responses to reef fish foraging and trait diversity. *Coral Reefs* 42:519-533.
- dela Cruz DW, Harrison PL (2017) Enhanced larval supply and recruitment can replenish reef corals on degraded reefs. *Sci Rep* 7:1-13.
- Eddy TD, Lam VWY, Reygondeau G et al (2021) Global decline in capacity of coral reefs to provide ecosystem services. *One Earth* 4:1278-1285.
- Fox HE, Caldwell RL (2006) Recovery from blast fishing on coral reefs: A tale of two scales. *Ecol Appl* 16:1631-1635.
- Graham NAJ, Jennings S, MacNeil MA, Mouillot D, Wilson SK (2015) Predicting climate-driven regime shifts versus rebound potential in coral reefs. *Nature* 518:94-97. <https://doi.org/10.1038/nature14140>
- Grimsditch G, Tاملander J, Mwaura J, Zavagli M, Takata Y, Gomez T (2009) Coral reef resilience assessment of the Pemba Channel Conservation Area, Tanzania. IUCN, Gland, Switzerland
- Hoegh-Guldberg O, Kennedy EV, Beyer HL, McClennen C, Possingham HP (2018) Securing a Long-term future for coral reefs. *Trends Ecol Evol* 33:936-944.
- Hughes TP, Baird AH, Dinsdale EA, Moltschaniwskyj A, Pratchett MS, Tanner JE, Willis BL (2000) Supply-side ecology works both ways: the link between benthic adults, fecundity, and larval recruits. *Ecol* 81:2241-2249.
- Ligson CA, Cabaitan PC, Harrison PL (2022) Survival and growth of coral recruits in varying group sizes. *J Exp Mar Biol Ecol* 556:151793.
- Manikandan B, Ravindran J, Vidya PJ, Shrinivasu S, Manimurali R, Paramasivam K (2017) Resilience potential of an Indian Ocean reef: an assessment through coral recruitment pattern and survivability of juvenile corals to recurrent stress events. *Environ Sci Pollut Res* 24:13614-13625.
- McClanahan TR, Sheppard CRC, Obura DO (eds) (2000) Coral reefs of the Indian Ocean: their ecology and conservation. Oxford University Press, New York
- Nzali LM, Johnstone RW, Mgaya YD (1998) Factors affecting scleractinian coral recruitment on a nearshore reef in Tanzania. *Ambio* 27:717-722.
- Obura D, Gudka M, Samoilys M et al (2022) Vulnerability to collapse of coral reef ecosystems in the Western Indian Ocean. *Nat Sustain* 5:104-113.
- Penin L, Michonneau F, Baird AH, Connolly SR, Pratchett MS, Kayal M, Adjeroud M (2010) Early post-settlement mortality and the structure of coral assemblages. *Mar Ecol Prog Ser* 408:55-64.
- Turner JA, Thomson DP, Cresswell AK, Traçon M, Babcock RC (2018) Depth-related patterns in coral recruitment across a shallow to mesophotic gradient. *Coral Reefs* 37:711-722.
- Williams SL, Sur C, Janetski, N et al (2019) Large-scale coral reef

rehabilitation after blast fishing in Indonesia. *Restor Ecol* 27:447-456.

Wilson J, Harrison P (2005) Post-settlement mortality and growth of newly settled reef corals in a subtropical environment. *Coral Reefs* 24:418-421.

Population density and genetic diversity of the fluted giant clam, *Tridacna squamosa*, in Peninsular Malaysia

Li Keat Lee¹, Po Teen Lim¹, Mei Lin Neo^{2,3}, Kieng Soon Hii⁴, Haifeng Gu⁴, Albert Apollo Chan⁵, Chui Pin Leaw¹

¹Bachok Marine Research Station, Institute of Ocean and Earth Sciences, University of Malaya, 16310 Bachok, Malaysia; ²Tropical Marine Science Institute, 18 Kent Ridge Road, Singapore 119557, Singapore; ³Department of Biological Sciences, 14 Science Drive 4, Singapore 117543, Singapore; ⁴Third Institute of Oceanography, Xiamen, China; ⁵Marine Park and Resource Management Division, Department of Fisheries, Ministry of Agriculture, Putrajaya, Malaysia

Introduction

Giant clams Tridacninae (Family Cardiidae) can be found throughout tropical and subtropical coral reefs and play a significant role in this ecosystem, ecologically and culturally (Neo et al. 2015, Neo 2020). However, intensive and unsustainable exploitation in the Indo-Pacific region has rapidly reduced giant clam stocks (Gomez 2015, Larson 2016). The intervention of mariculture and restocking has slowed down the pace of the giant clam population decline (Heslinga et al. 1990, Braley 1992, Calumpong & Solis-Duran 1993, Teitelbaum & Friedman 2008).

Malaysian coral reefs are home to seven of the twelve recognized species of giant clams (Tan et al. 2021): *Tridacna crocea* Lamarck, *T. derasa* Röding, *T. gigas* Linnaeus, *T. maxima* Röding, *T. squamosa* Lamarck, *Hippopus hippopus* Linnaeus, and *H. porcellanus* Rosewater (Tan & Yasin 2001, Neo et al. 2017). While all species of giant clams are protected, habitat destruction and illegal poaching

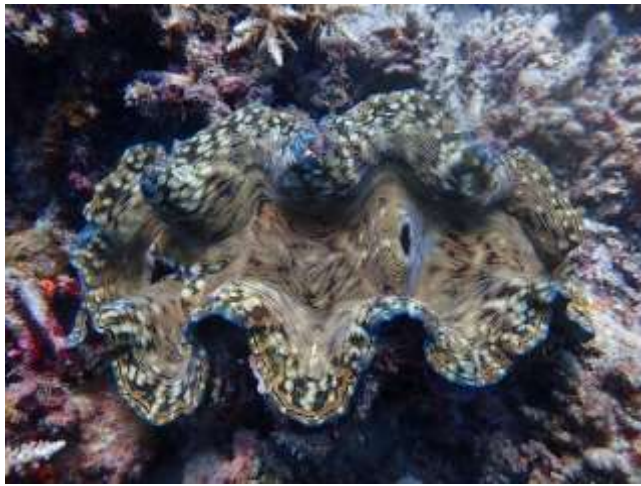


Figure 1. *Tridacna squamosa* (Photo LKL)

have been identified as Malaysia's primary cause of concern (Tan & Yasin 2003, Ezekiel 2018). Giant clam restoration programmes were carried out in the early 2000s using *T. squamosa* (Tan, 2001) (Fig. 1) after rounds of surveys deemed the species were endangered with low population numbers across Peninsular Malaysia (Mohamed-Pauzi et al. 1994, Yasin, 1996, Tan et al. 1998, Yasin 1998).

Despite a similar distribution to *T. maxima*, less attention has been paid to *T. squamosa* populations. To our knowledge, no population genetic study of *T. squamosa* has been conducted with microsatellite markers, although several marker sets have been developed primarily for *T. maxima* and *T. crocea* and have shown successful cross-amplification with *T. squamosa* (DeBoer & Barber 2010, Hui et al. 2011, Grulois et al. 2014). A study in Perhentian Islands, an island off the east coast of Peninsular Malaysia, has showcased a relatively healthy population of *T. squamosa* (Lee et al. 2022) compared to other populations across the South China Sea (Neo et al. 2017, Neo et al. 2018, Neo et al. 2019, Liu et al. 2020). Hence, this study aimed to continue assessing the abundance of other giant clam populations across Peninsular Malaysia, complementing the work with population genetic analysis.

Methods

Surveys and sampling were carried out on islands off the

east coast of Peninsular Malaysia (Fig. 2). At each site a reef area of approximately 400 m² was surveyed using belt transect methods. The giant clams' mantle tissue was biopsied (Fig. 3), and tissue samples kept in 96% modified ethanol and stored at -20 °C until genome extraction. Genomic DNA was extracted using MagExtractor® Genome kits (TOYOBO, Japan), following the protocol recommended by the manufacturer. The mitochondrial regions of the cytochrome c oxidase I (COI) gene (mtCOI) and the 16S ribosomal gene were amplified with the primer pair SQUA-F3 (5'-CATCGTTTAGAGTAATAATTCG-3') and SQUA-R1 (5'-ATGTATAAACAAAACAGGATC-3') (DeBoer et al. 2008) and with 16Sar (5'-CGCCTGTTTATCAAAAACAT-3') and 16Sbr (5'-CCG GTCTGAACCTCAGATCACGT-3') (Richter et al. 2008). Microsatellite genotyping was performed following Grulois et al. (2014). PCR for gene amplification was carried out following steps from Lee et al. (2022). Amplicons were examined using 2 % agarose gel electrophoresis before sequencing. Sequences obtained were proofread using Sequence Scanner v1.0 (Applied Biosystems), examined with the EMBOSS (Rice et al. 2000), and then multiple sequences aligned with MUSCLE (Edgar 2004). For population genetic analysis, software DnaSP v6.12 (Rozas et al. 2017) and Arlequin v3.5.2.2 (Excoffier & Lischer 2010) were used to compute molecular diversity indices. Haplotypes inference was constructed with minimum spanning networks (MSN) under PopART v1.7 (Leigh & Bryant 2015)

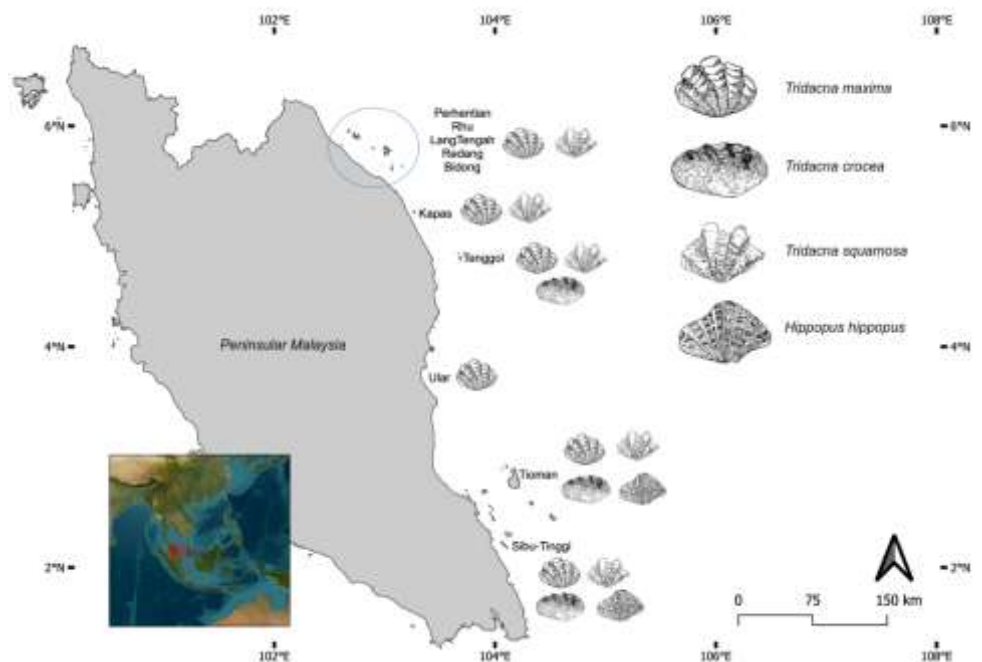


Figure 2. Locations of islands surveyed off the east coast of Peninsular Malaysia, showing the species recorded in each region



Figure 3. Diver sampling mantle tissue from *Tridacna* (Photo Affan Zanila)

Results

The survey was completed at ten sites on east coast islands with a total reef area of 39025 m² (Fig. 1). Of the seven known giant clam species of the genus *Tridacna* and *Hippopus* found in Malaysia, only four species (*T. maxima*, *T. squamosa*, *T. crocea* and *H. hippopus*) were observed along the islands of the east coast of Peninsular Malaysia. However, this report only presents data on *T. squamosa*; this species was found throughout the sampling sites, except for Ular. Overall, the density of the *T. squamosa* population was in the range of 0.3 to 2.0 clams per 100 m². A significant difference in density across locations was detected (Kruskal-Wallis, P =

0.02), with Bidong having the highest mean density of 2.0 ± 1.2 clams per 100 m².

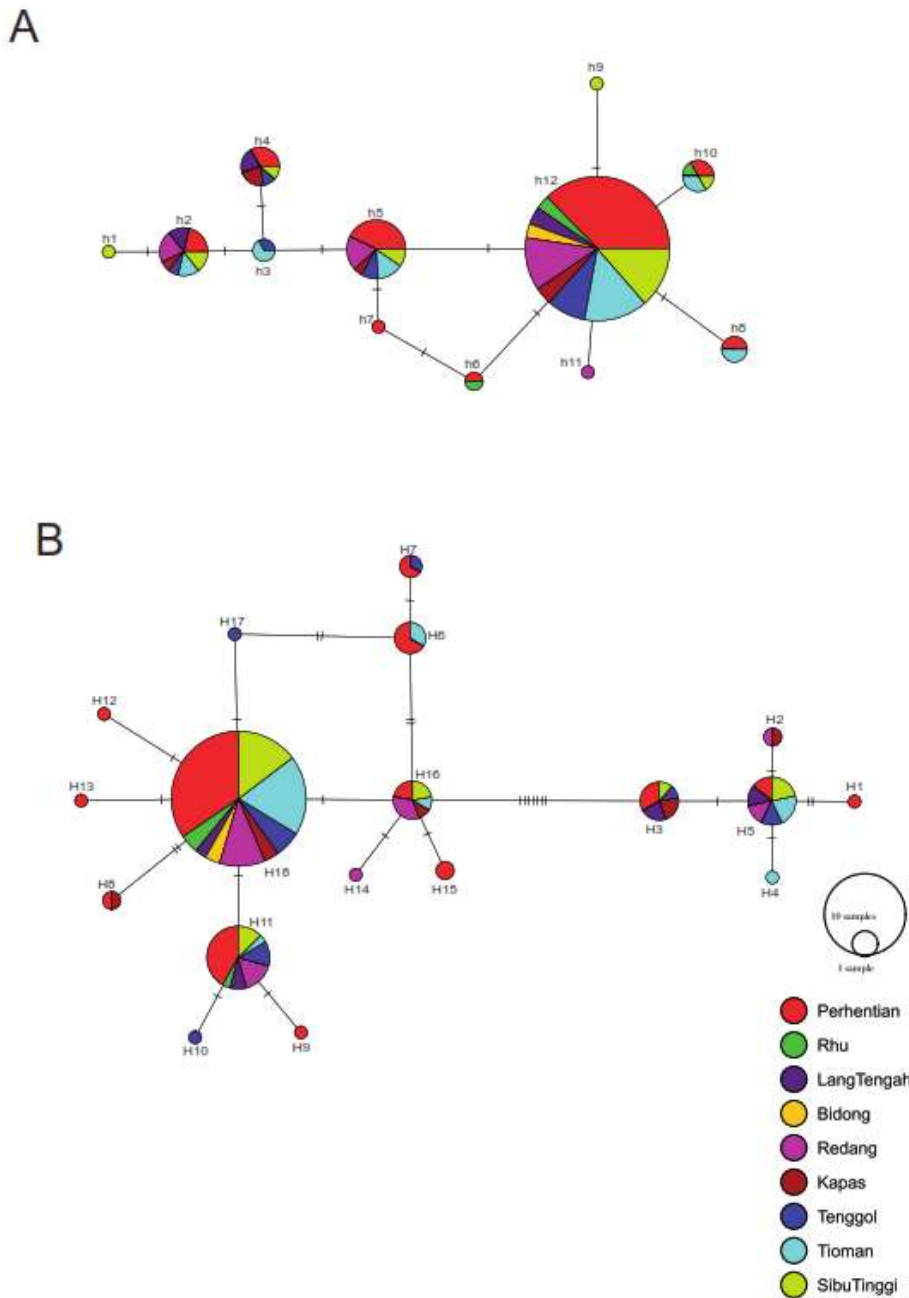
378 COI and 16S sequences were generated and collated for population genetic analysis. The *T. squamosa* population recorded 18 and 12 haplotypes in the COI and 16S datasets (Fig. 4). The haplotype diversity (Hd) was 0.64 ± 0.04 (COI) and 0.54 ± 0.04 (16S), with nucleotide diversity (π) of 0.53 ± 0.03 % for COI and 0.03 ± 0.01 % for 16S (Table 1). Perhentian's population exhibited the highest number of haplotypes, while Lang Tengah's population had

the highest haplotype diversity (Hd) of 0.83. The lowest haplotype diversity was observed in Rhu's population, with 0.33. Similar observation for nucleotide diversity showed that Rhu had the lowest value with 0.06 ± 0.08 %, while values for the rest of the population ranged from 0.44 ± 0.27 to 0.87 ± 0.53 %.

The screening of microsatellite genotyping on *T. squamosa* with 10 out of 15 markers (Grulois et al. 2014) produced less satisfactory results. With 19 samples tested, only four markers: Tm06526(15/19), Tm24162(19/19), Tm11666(19/19), and Tm14538(10/19) showed successful amplifications, while the other six markers showed no amplification.

Table 1. Molecular diversity of *T. squamosa* populations across 9 islands based on COI and 16S rRNA

Site	COI (580 bp)					16S (487 bp)				
	<i>n</i>	<i>N</i> _{hc}	S	<i>H</i> _d	π (%)	<i>n</i>	<i>N</i> _{hc}	S	<i>H</i> _d	π (%)
Perhentian	68	13	19	0.67 ± 0.06	0.44 ± 0.27	68	8	7	0.51 ± 0.07	0.18 ± 0.14
Rhu	6	2	1	0.33 ± 0.22	0.06 ± 0.08	6	3	2	0.60 ± 0.22	0.14 ± 0.14
LangTengah	9	4	10	0.83 ± 0.08	0.92 ± 0.56	9	3	4	0.67 ± 0.13	0.39 ± 0.28
Redang	23	6	12	0.70 ± 0.09	0.50 ± 0.30	23	4	4	0.55 ± 0.10	0.21 ± 0.16
Bidong	4	1	0	0	0	4	1	0	0	0
Kapas	9	5	12	0.81 ± 0.12	0.87 ± 0.53	9	4	4	0.69 ± 0.15	0.34 ± 0.25
Tenggol	16	7	14	0.79 ± 0.09	0.69 ± 0.41	16	5	4	0.53 ± 0.14	0.21 ± 0.17
Tioman	29	6	13	0.47 ± 0.11	0.49 ± 0.29	29	6	5	0.61 ± 0.10	0.21 ± 0.16
SibuTinggi	25	5	10	0.58 ± 0.11	0.49 ± 0.30	25	7	7	0.54 ± 0.12	0.25 ± 0.18
Overall	189	18	23	0.64 ± 0.04	0.50 ± 0.05	189	12	10	0.54 ± 0.04	0.21 ± 0.02



levels of sedimentation (Lee et al. 2022). While sequence data for *T. squamosa* is available for comparison (COI and 16S), work on microsatellite markers still needs further development.

Acknowledgements

The authors would like to acknowledge funding from the Ministry of Higher Education Malaysia Fundamental Research Grant Scheme (FRGS/1/2019/WAB13/UM/02/2) to CPL, and from the China-ASEAN Maritime Cooperation Fund (2016YFE0202100) to HG. A research permit for sampling and field studies was obtained from the Division of Marine Park and Resource Management, Department of Fisheries, Malaysia. The authors also thank the International Coral Reef Society for the awarding of a Graduate Fellowship to Lee LK.

◀ **Figure 4.** The haplotypes network of *T. squamosa* population based on (A) 16S (h1-12) and (B) COI (H1-18) sequences data across nine sites in Peninsular Malaysia

Summary

The density of *T. squamosa* populations in Peninsular Malaysia was found to be appreciably higher than that of other populations across the South China Sea (as summarised in Lee et al. 2022). While the density of *T. squamosa* in Rhu was comparable to other sites, the genetic diversity indices were not. One of the reasons could be the lack of marine protected area status, as Rhu is not a Marine Protected Area. In addition, Rhu Island is close to the mainland and hence susceptible to illegal poaching and to constant stress from high

Lee Li Keat



Stay connected

 **ResearchGate:** Lee-Keat

References

- Braley RD (1992) The giant clam: A hatchery and nursery culture manual, ACIAR Monographs, No. 15. Canberra, ACT, Australia: Australian Centre for International Agricultural Research
- Calumpong HP, Solis-Duran E (1993) Constraints in restocking Philippine reefs with giant clams, the biology and mariculture of giant clams. In W.K. Fitt (Eds.) ACIAR Proceedings No. 47. Canberra: Australian Centre for International Agricultural Research, pp. 94–98
- DeBoer TS, Barber PH (2010) Isolation and characterization of 9 polymorphic microsatellite markers for the endangered boring giant clam (*Tridacna crocea*) and cross-priming testing in three other Tridacnid species. *Conserv Genet Resour* 2:353–356
- DeBoer TS, Subia MD, Ambariyanto, Erdmann MV, Kovitvongsa K, Barber PH (2008) Phylogeography and limited genetic connectivity in the endangered boring giant clam across the Coral Triangle. *Conserv Biol* 22:1255–1266
- Edgar RC (2004) MUSCLE: Multiple sequence alignment with high accuracy and high throughput. *Nucleic Acids Res* 32:1792–1797. <https://doi.org/10.1093/nar/gkh340>
- Excoffier L, Lischer HE (2010). Arlequin suite ver 3.5: A new series of programs to perform population genetics analyses under Linux and Windows. *Mol Ecol Resour* 10:564–567
- Ezekiel A (2018) Review of marine wildlife protection legislation in ASEAN. Selangor, Malaysia: TRAFFIC Southeast Asia
- Gomez ED (2015) Rehabilitation of biological resources: Coral reefs and giant clam populations need to be enhanced for a sustainable marginal sea in the Western Pacific. *J Int Wildl Law Policy* 18:120–127
- Grulois D, Tiavouane J, Dumas PP, Fauvelot C (2014) Isolation and characterization of fifteen microsatellite loci for the giant clam *Tridacna maxima*. *Conserv Genet Resour* 7:73–75
- Heslinga GA, Watson TC, Isamu T (1990) Giant clam farming. Honolulu, Hawaii: Pacific Fisheries Development Foundation (NMFS/NOAA)
- Hui M, Kochzius M, Leese F (2011) Isolation and characterisation of nine microsatellite markers in the boring giant clam (*Tridacna crocea*) and cross-amplification in five other tridacnid species. *Mar Biodivers* 42:285–287
- Larson C (2016) Shell trade pushes giant clams to the brink. *Science* 351:323–324
- Lee LK, Neo ML, Lim ZF, Hii KS, Lim HC, Chan AA et al. (2022). Population status and genetic diversity of two endangered giant clams (*Tridacna squamosa* and *Tridacna maxima*) on the fringing reefs of Perhentian Islands, Malaysia. *Aquat Conserv* 32:1005–1021
- Leigh JW, Bryant D (2015) Popart: Full-feature software for haplotype network construction. *Methods Ecol Evol* 6:1110–1116
- Liu J, Cui D, Wang H, Chen J, Liu H, Zhang H (2020) Extensive cryptic diversity of giant clams (Cardiidae: Tridacninae) revealed by DNA-sequence-based species delimitation approaches with new data from Hainan Island, South China Sea. *J. Molluscan Stud.* 86:56–63
- Mohamed-Pauzi AM, Adib HAA, Abdul-Aziz Y (1994) A preliminary survey of giant clams in Malaysia. Proceedings Fisheries Research Conference Department of Fisheries Malaysia IV, pp. 487–493
- Neo ML (2020) Conservation of giant clams (Bivalvia: Cardiidae). In: MI Goldstein, DA DellaSala (Eds). *Encyclopedia of the World's Biomes*. Oxford: Elsevier, pp. 527–538
- Neo ML, Eckman W, Vicentuan K, Teo SLM, Todd PA (2015) The ecological significance of giant clams in coral reef ecosystems. *Biol. Conserv.* 181:111–123
- Neo ML, Lim KK, Yang SY, Soong GY, Masucci GD, Biondi P et al. (2019) Status of giant clam resources around Okinawa-Jima Island, Ryukyu Archipelago, Japan. *Aquat. Conserv.* 29:1002–1011
- Neo ML, Liu LL, Huang D, Soong K. (2018) Thriving populations with low genetic diversity in giant clam species, *Tridacna maxima* and *Tridacna noae*, at Dongsha Atoll, South China Sea. *Reg. Stud. Mar. Sci.* 24:278–287
- Neo ML, Wabnitz CCC, Braley RD, Heslinga GA, Fauvelot C, Van Wynsberge S. et al. (2017) Giant clams (Bivalvia: Cardiidae: Tridacninae): A comprehensive update of species and their distribution, current threats and conservation status. In: S.J. Hawkins, A.J. Evans, A.C. Dale, L.B. Firth, D.J. Hughes, I.P. Smith (Eds.) *Oceanography and Marine Biology: An Annual Review*. Boca Raton, FL: CRC Press, pp. 87–388
- Rice P, Longden I, Bleasby A. (2000) EMBOSS: The European molecular biology open software suite. *Trends Genet.* 6:276–277
- Richter C, Roa-Quiaoit H, Jantzen C, Al-Zibdah M, Kochzius M (2008) Collapse of a new living species of giant clam in the Red Sea. *Curr. Biol.* 18:1349–1354
- Rozas J, Ferrer-Mata A, Sánchez-DelBarrio JC, Guirao-Rico S, Librado P, Ramos-Onsins SE (2017) DnaSP 6: DNA sequence polymorphism analysis of large data sets. *Mol. Biol. Evol.* 34:3299–3302
- Tan EYW, Quek ZBR, Neo ML, Fauvelot C, Huang D (2021). Genome skimming resolves the giant clam (Bivalvia: Cardiidae: Tridacninae) tree of life. *Coral Reefs* 2021:1–14
- Tan SH (2001) Distribution, reproduction cycle, and factors affecting the exchange of larval and gamete of the giant clam *T. squamosa* (Lamarck) from islands of Pahang and Johore in Malaysia. PhD Thesis, University Sains Malaysia.
- Tan SH, Yasin Z (2001) The use of giant clam conservation in Johore as a community-based project towards developing of a caring and responsible society. *Prosiding Persidangan Kebangsaan P&P IPTA* 2001
- Tan SH, Yasin Z, Ibrahim S, Abdul-Aziz Y (1998) Status of giant clams in Pulau Tioman, Malaysia. *Malay. Nat. J.* 52:205–216
- Tan ASH, Yasin Z (2003) Status of giant clams in Malaysia. *SPC Trochus Information Bulletin* 10:9–10
- Teitelbaum A, Friedman K (2008) Successes and failures in reintroducing giant clams in the Indo-Pacific region. *SPC Trochus Information Bulletin* 14: 19–26
- Yasin Z (1996) Extinction of giant clams in Johore Islands. Johor, Malaysia: Malaysian Marine Park Advisory Council, Pulau Besar, Malaysia
- Yasin Z (1998) The effect of tourism on natural marine ecosystem of Pulau Payar, *Kedah. Kedah*, Malaysia: Kedah State Economic Planning Committee

The Global Coral Reef Monitoring Network (GCRMN)

Values of a long-term partnership

Britta Schaffelke^{1,2}, Jennifer Koss^{3,4}, Francis Staub^{1,3}, Thomas Dallison^{1,3}, Jérémy Wicquart^{1,7,8}, Erica Towle^{1,4}, Amanda Brigdale^{1,2}, Margaux Monfared¹, John Burt⁵, Swaleh Aboud⁶, David Obura⁶, Mishal Gudka⁶, Serge Planes⁷, Tadashi Kimura⁸, Christophe Blazy⁹, Patricia Kramer¹⁰, Judith Lang¹⁰

¹Global Coral reef Monitoring Network (GCRMN); ²Australian Institute of Marine Science (AIMS), Australia; ³International Coral Reef Initiative (ICRI); ⁴National Oceanic and Atmospheric Administration (NOAA), United States; ⁵Arabian Centre for Climate and Environmental Sciences, New York University Abu Dhabi, Abu Dhabi, UAE; ⁶Coastal Oceans Research and Development – Indian Ocean (CORDIO); ⁷Centre de Recherches Insulaires et Observatoire de l'Environnement (CRIOBE) CNRS/EPHE; ⁸International Coral Reef Center, Palau; ⁹Regional Activity Centre for the Protocol Concerning Specially Protected Areas and Wildlife for the Wider Caribbean Region (SPA-W-RAC); ¹⁰Atlantic and Gulf Rapid Reef Assessment (AGRR)



Since 1995, the Global Coral Reef Monitoring Network (**GCRMN**), an operational network of the International Coral Reef Initiative (ICRI), has nurtured a global community dedicated to coral reef conservation by providing a platform to exchange data and share knowledge, expertise, innovative ideas and diverse perspectives.

Utilising data from a range of techniques, from ground-level surveys to cutting-edge technology, GCRMN assimilates comprehensive assessments of coral reef status and trends, tracking the pulse of these priceless ecosystems.

“We cannot manage a system that we do not understand” is an often-heard phrase. The GCRMN’s influential reports on the status and trends of coral reefs provide a trusted source of information to the global community, based on rigorous scientific methods. Accurate information on the status of coral reefs is essential to assess their condition, identify changes over time, and predict future outcomes. This creates a powerful force for change, equipping stakeholders, managers, and policy makers with the information needed to address threats, build resilience and protect coral reefs at local, national, and international levels. This evidence-based management and policymaking is needed more than ever, as climate change impacts are a reality and local pressures on coral reefs continue largely unabated (Kleypas et al. 2021, Knowlton et al. 2021).

Figure 1. Introducing the **GCRMN Core Team**: (left column) Britta Schaffelke, Jennifer Koss, Francis Staub, Thomas Dallison, (right column) Jérémy Wicquart, Erica Towle, Amanda Brigdale, Margaux Monfared

The most recent GCRMN reports are the *Status of Coral Reefs of the World: 2020* (Souter et al. 2021), *Status and Trends of East Asian Coral Reefs 1983 – 2019* (Kimura et al. 2022) and *The Global Socioeconomic Monitoring Initiative for Coastal Management Report 2022* (Wongbusarakum et al. 2022).

Future opportunities

Over the next decades, the GCRMN has the opportunity to serve as a key implementing tool for the Kunming-Montreal Global Biodiversity Framework (GBF), adopted in Montreal (December 2022) by Parties to the Convention on Biological Diversity. ICRI supported CBD parties to ensure the due representation of coral reefs within the Framework. ICRI developed [Three asks #ForCoral](#), showcased the many mechanisms and tools available to CBD parties to implement the GBF, and encouraged the Framework to include broadly applicable ‘headline’ [indicators](#) on both ecosystem area and ecosystem integrity. The efforts of ICRI, partners and the coral reef community saw the retaining of a coral-specific indicator – coral reef extent. This provides an opportunity for the GCRMN to directly support CBD Parties in reporting against the GBF indicators. ICRI also contributed to the development of a [monitoring framework](#) specifically for GBF Target 2 (Ecosystem Restoration)¹, proposing a composite of the coral cover and ‘Restored Reef Areal Dimension’ (see Goergen et al. 2020) indicators as a measure for the integrity of the area of coral reefs under restoration.

Managing coral reefs is about managing people. For this reason, the network also includes the Global Socioeconomic Monitoring Initiative for Coastal Management (SocMon), hosted by ICRI, to complement insights from ecological monitoring.

Current challenges and activities

The data integration process to enable the statistical analyses for the “*Status of Coral Reefs of the World: 2020*” report was a significant task (Wicquart et al. 2022). However, the value of the aggregated, and growing, global coral reef monitoring dataset is immense. Its further use is actively championed by GCRMN members, not only for future regional and global GCRMN reports, but more importantly for

informing local decision-making, scientific analysis, and use in new applications such as the regional IUCN Red List of Ecosystems assessments (e.g., Obura et al. 2022).

The global analysis was of a scale never attempted before and was only possible because data providers were willing to share their data for this purpose. The ongoing value of the dataset depends on the quality of the data behind it, and the accessibility to it. This means that improving data standardisation, data management, and the development and application of transparent and reproducible, code-based, analysis tools are both important and urgent. Availability of common data management and analysis tools in turn will benefit the data providers as they will enable comparative assessments and studies within and across regions. Providing data in an accessible, easily understandable way, such as in information ‘dashboards’ has also become more and more important and demanded by data users. Key initiatives such as [ReefCloud](#), [MERMAID](#) and [AGGRA](#), driven by GCRMN members, are progressing this and will drastically change the way we will be doing coral reef monitoring in the future, from data collection to reporting and knowledge exchange.

Building on the lessons learnt and the approaches developed for the “*Status of Coral Reefs of the World: 2020*” report, the GCRMN recently established a dedicated ‘Data Taskforce’. This small team of experts will recommend approaches to improve data integration, standardisation, and analyses methods to promote good data management practices amongst the network and across the coral reef community.

The wider application of good practices will be enabled by the explicit goal of the network to build human and technical capacity to collect, analyse, and report biophysical and socio-economic data on coral reefs. This is an ongoing focus of the GCRMN regional nodes.

Regional to Global

The 10 regional nodes are the engine rooms of the network, representing the countries that are custodians of coral reefs across all ocean basins.

¹Ensure that by 2030 at least 30 per cent of areas of degraded terrestrial, inland water, and coastal and marine ecosystems are under effective restoration, in order to

enhance biodiversity and ecosystem functions and services, ecological integrity and connectivity.”

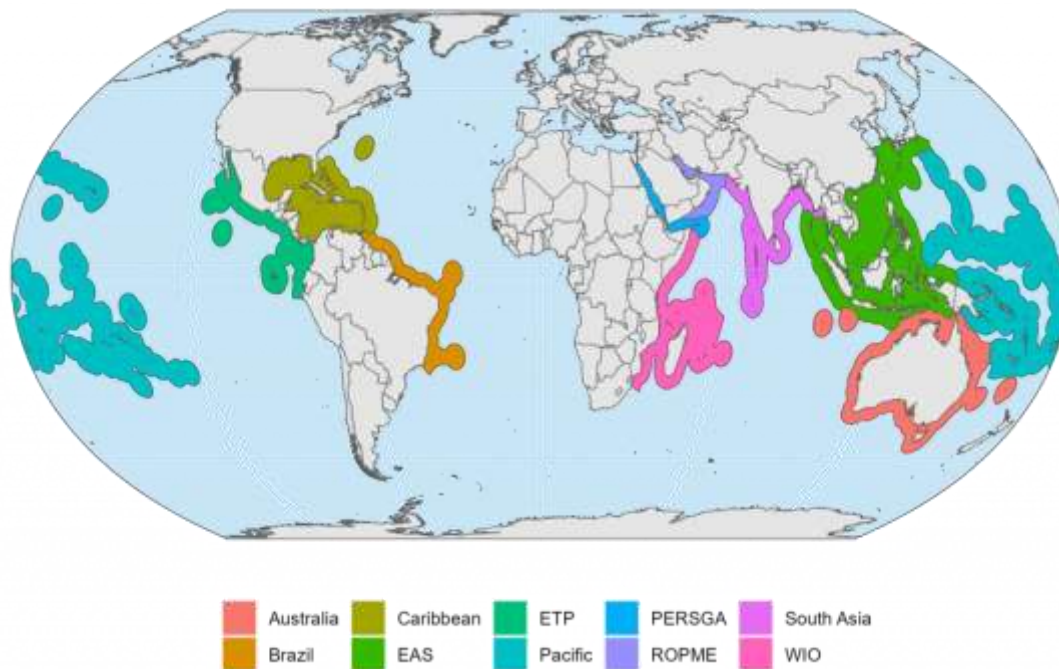


Figure 2. The 10 GCRMN regions, more information about each is at <https://gcrmn.net/regions/>.

Each region has its own priorities and challenges for coral reefs, from protection and resource use to management, governance and research needs, reflecting the diverse perspectives of all parties involved. The result is a network that is bound together through the ability to learn from each other and exchange knowledge. The continued improvement of best practices for coral reef monitoring, and the sharing and integrating data and information at various scales, from local to global levels, are just two examples.

The value of quantitative analyses of multiple, aggregated datasets is immense. For example, local patterns can be interpreted within regional and global contexts and may lead to better decisions about potential management actions. Also, if causes for observed changes are still unknown at local scales, understanding of cause-effect relationships from similar environments may be informative. And, last but not least, trends detected at larger, multi-regional, spatial scales provide a powerful basis for scientists and managers to develop solutions, advocate for the need to address and reduce environmental pressures, as well as identify positive responses to interventions and management strategies. We cannot emphasise enough the importance of the network's regional

nodes, as actions and solutions are largely implemented at the local to regional level.

[Updates from GCRMN Regional Nodes](#)
[ROPME region² – by John A. Burt \(New York University Abu Dhabi\)](#)

A North-eastern Arabia Coral Reef Monitoring Network Workshop (9-11 May 2023), aimed to consolidate regional efforts to conserve the important but declining coral reefs in the Arabian/Persian Gulf and the Sea of Oman (ROPME Sea Area). Despite the ecosystems' ecological and socio-economic value, monitoring data have been scarce, limiting effective management. This workshop brought together regional reef experts to standardize coral reef monitoring practices and share survey data. Using the United Arab Emirates' (UAE) national program as a case study, the workshop demonstrated field methods, metadata standards, and data archival techniques and provided hands-on training in survey methods and data analyses as well as archival platforms - ReefCloud and MERMAID. A primary outcome of the workshop was an agreement to establish a cohesive and comprehensive regional assessment of reef conditions by May 2024 so that the data can feed into the GCRMN's next global report.

²Regional Organization for the Protection of the Marine Environment composed of: Bahrain, I.R. Iran, Iraq, Kuwait, Oman, Qatar, Saudi Arabia and the United Arab Emirates.

Western Indian Ocean (WIO) region – by Swaleh Aboud, David Obura, and Mishal Gudka (CORDIO East Africa)

Using the same data as the 2020 global status report, the GCRMN WIO node implemented a regional Red List of Ecosystems (RLE) assessment of WIO coral reefs. After 18 months of analysis and workshops, CORDIO East Africa and scientists from over 35 organizations found that reefs of the WIO are vulnerable to collapse (Obura et al. 2022). Work is currently underway to increase the utility of the RLE analysis in national contexts for coral reef management and policy. This work will support national ecosystem reporting required under the Global Biodiversity Framework of the Convention on Biological Diversity. A virtual data analysis course on processing GCRMN data (14 June - 2 August 2021) was completed with the goal to build skills in data assimilation and analysis, in preparation for the publication of the WIO and other GCRMN regional reports. The course is currently being adapted for self-learning, so it can be used in other GCRMN regions. The regional network was also revitalized with a workshop held in Moroni, Comoros (1-3 March 2023), and supported by the Nairobi Convention, establishing a new Technical Working Group on coral reefs under the umbrella of the Convention. A workplan was agreed on priority areas such as improving monitoring for fish, building capacities and collaboration to develop a regional database for monitoring data, and addressing new priorities such as coral reef restoration.

Pacific region – by Jérémy Wicquart and Serge Planes (CRIOBE – CNRS/EPHE)

Five years after the [2018 GCRMN Pacific report](#), the Pacific GCRMN node is currently working on a new regional report, planned to be published in 2024, which will update the results previously obtained, particularly for the trends in hard coral and algae cover at the national level. As GCRMN reports are now based on a quantitative analysis of biological indicators, the first step is to gather and standardize monitoring data acquired by the members of the GCRMN Pacific regional node. The 2023 GCRMN Pacific report will be used as a case study for the implementation of a novel approach dedicated to data integration, by using [GitHub](#) as a code repository, making the work of the GCRMN aligned with open science standards and the FAIR

data principles. In addition, to provide the necessary background to interpret trends of biological indicators, quantitative analyses of tropical storms and marine heatwaves in coral reefs of the Pacific territories will be carried out. Finally, socio-economic information will be included within the report by using the data acquired through the [SocMon program](#).

East Asia region – by Tadashi Kimura (Palau International Coral Reef Center)

To follow up the global and regional data analysis undertaken in 2020, the East Asia node will begin discussions on the next analysis and regional database/repository during an East Asia Regional Workshop (17-18 June 2023, back-to-back with the 5th Asia Pacific Coral Reef Symposium (APCRS)). This annual regional workshop is funded by the Ministry of the Environment, Japan, to provide face-to-face conversation among the national coordinators of the region to discuss direction and activities for enhancing coral reef monitoring. The APCRS is organized every four years by the Asia Pacific Coral Reef Society (APCoRS) that spun off from the network of national coordinators of GCRMN East Asia.

Caribbean region – by Christophe Blazy (SPAW-RAC), Patricia Kramer and Judith Lang (AGRRA)

Following the publication of the “Status of Coral Reefs of the World: 2020” report, the Caribbean Node has been preparing to address the main recommendations of the report and maintained momentum within the network. A new work plan (2023-2024) has been developed to strengthen capacity building in reef monitoring, increase the integration of SocMon in monitoring effort, adapt GCRMN protocols and guidelines to better address emerging issues for Caribbean corals, and improve data management, integration and analysis for future regional/global reporting. Upcoming activities include a session on ecosystem monitoring programmes during the GCFI Conference³ where GCRMN-Caribbean members will present progress of monitoring efforts (biophysical and socio-economic) and data handling tools to support MPA managers, and a training programme on integrated reef monitoring for MPA managers.

The Atlantic & Gulf Rapid Reef Assessment (AGRRA), one of the key GCRMN-Caribbean

³76th Annual Conference of the Gulf and Caribbean Fisheries Institute, Nassau, 6-10 November 2023

members, launched the new [AGRRA Caribbean Coral Reef Health Data Explorer](#) to make its data and learning platform more interactive to support regional GCRMN management and conservation efforts through dashboards and learning resources, updated the [AGRRA SCTLTD Tracking Map](#) to monitor the status of the stony coral tissue loss disease outbreak affecting 34 coral species in the Caribbean, and released the [Field guide to monitoring coral disease outbreaks in the Mesoamerican Region](#). Since 2022, an international collaboration was established under the [Diadema Response Network](#), of which AGRRA is a founding member, to monitor the recent regional mass mortality of *Diadema antillarum* in 25 countries in the Caribbean and provide tissue samples used to identify the cause of the 2022 die-off.

How can you engage with the network?

Are you actively monitoring coral reefs? Do you have data to share and contribute to regional and future global reports? All data are valuable, even data from an individual site or a single time point. The GCRMN welcomes the submission of data. If you would like to get in contact, you can directly contact regional coordinators (<https://gcrmn.net/regions/>) or contact the ICRI Secretariat via Francis Staub (fstaub@icriforum.org) or Tom Dallison (thomas.dallison@icriforum.org).

You can also engage with the GCRMN on social media via Twitter (@ICRI_Coral_Reef) and LinkedIn (<https://www.linkedin.com/company/international-coral-reef-initiative>), as well as through #WorldCoralReefStatus, #GCRMN or #ForCoral.

References

- Goergen EA, Schopmeyer S, Moulding A, Moura A, Kramer P, Viehman S (2020) Coral reef restoration monitoring guide: Methods to evaluate restoration success from local to ecosystem scales. NOAA Technical Memorandum NOS NCCOS 279. Silver Spring, MD. <https://doi.org/10.25923/xndz-h538>
- Kimura T, Chou LM, Huang D, Tun K, Goh E (2022) Status and Trends of East Asian Coral Reefs: 1983–2019. <https://gcrmn.net/wp-content/uploads/2022/09/Status-and-Trends-of-East-Asian-Coral-Reefs-%E2%80%93-1983-2019.pdf>
- Kleypas J, Allemand D, Anthony K, Baker AC, Beck MW, Hale LZ, Hilmi N, Hoegh-Guldberg O, Hughes T, Kaufman L, Kayanne H, Magnan AK, McLeod E, Mumby P, Palumbi S, Richmond RH, Rinkevich B, Steneck RS, Voolstra CR, Wachenfeld D, Gattuso J-P (2021) Designing a blueprint for coral reef survival. *Biol Conserv* 257: 109107 doi <https://doi.org/10.1016/j.biocon.2021.109107>
- Knowlton N, Grotto AG, Kleypas J, Obura D, Corcoran E, de Goeij J, Felis T, Harding S, Mayfield A, Miller M, Osuka K, Peixoto R, Randall CJ, Voolstra CR, Wells S, Wild C, Ferse S (2021) Rebuilding Coral Reefs: A Decadal Grand Challenge. International Coral Reef Society and Future Earth Coasts. <https://doi.org/10.53642/NRKY9386>
- Obura D, Gudka M, Samoilys M, Osuka K, Mbugua J, Keith DA, Porter S, Roche R, van Hooidonk R, Ahamada S, Araman A, Karisa J, Komakoma J, Madi M, Ravinia I, Razafindrainibe H, Yahya S, Zivane F (2022) Vulnerability to collapse of coral reef ecosystems in the Western Indian Ocean. *Nature Sustainability* 5: 104-113. <https://doi.org/10.1038/s41893-021-00817-0>
- Souter D, Planes S, Wicquart J, Logan M, Obura D, Staub F, (eds) (2021) Status of coral reefs of the world: 2020 report. Global Coral Reef Monitoring Network (GCRMN) and International Coral Reef Initiative (ICRI). DOI: 10.59387/WOTJ9184. <https://gcrmn.net/2020-report-v1-2023/>
- Wicquart J, Gudka M, Obura D, Logan M, Staub F, Souter D, Planes S (2022) A workflow to integrate ecological monitoring data from different sources. *Ecological Informatics* 68: 101543 doi <https://doi.org/10.1016/j.ecoinf.2021.101543>
- Wongbusarakum S, Allen M, Pena M, Garcia Imhof C, Gorstein M, Hoon V, Mudong W, Pereira Medeiros R, Pido M, Sanders A, Wanyonyi I (2022) Global SocMon Report 2022: More than 20 years of assessments, challenges, opportunities and the way forward. Global Socioeconomic Monitoring for Coastal Management Initiative (SocMon), National Oceanic and Atmospheric Administration (NOAA), Washington D.C., USA. Global SocMon Technical Report No. 2, 47 pp. <https://icriforum.org/socmon-resource/global-socmon-report-2022/>

The International Coral Reef Initiative

A Global Partnership for United Action for Coral

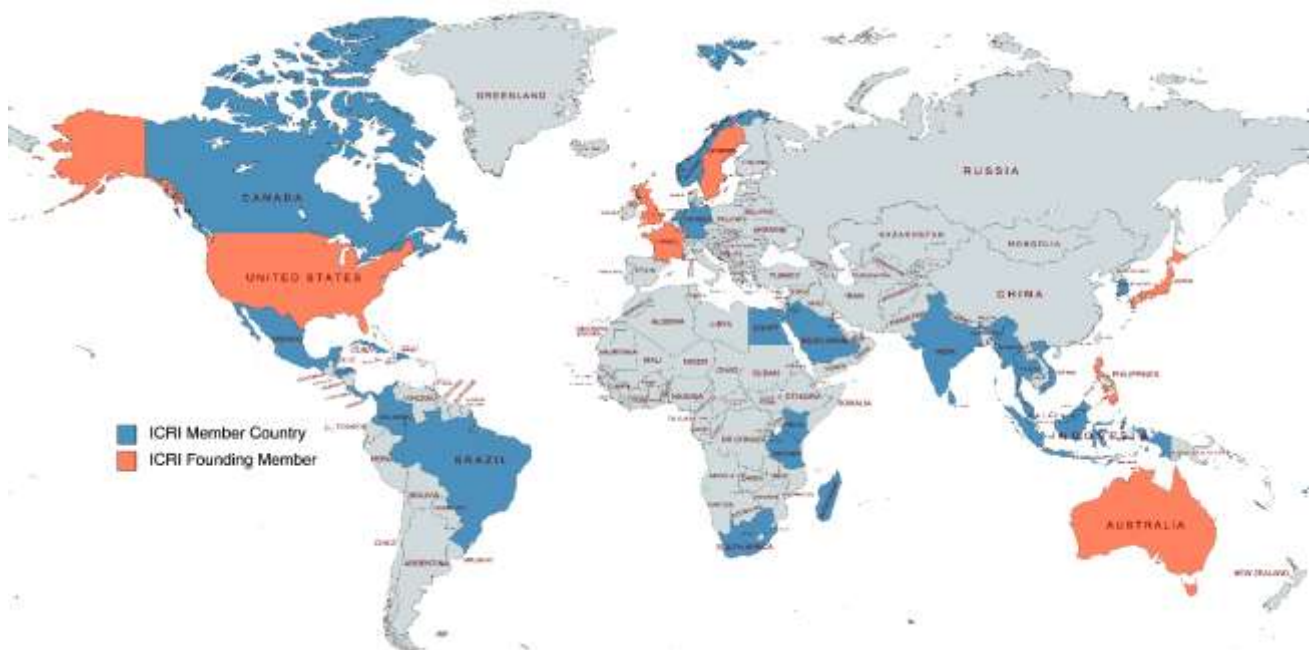
Marie Touchon
International Coral Reef Initiative (ICRI)

Coral reefs have declined at alarming rates in recent years, with 14 percent of the coral on the world's coral reefs lost between 2009 and 2018 (GCRMN, 2020), and current predictions indicate no signs of relief, with the latest IPCC report estimating that a +1.5°C increase in temperature above pre-industrial levels would lead to a 70-90 per cent decline in coral reef cover (IPCC, 2022). Faced with a wide range of anthropogenic-induced threats at global and local scales, ranging from climate change to pollution and overfishing, coral reefs require urgent action to ensure their survival. Global, concerted efforts are thus needed for the conservation, management, and restoration of coral ecosystems worldwide.

In this context, the **International Coral Reef Initiative (ICRI)** plays a vital role, leading the way in bringing together coral reef nations, organisations, and stakeholders. This global

partnership between nations and organisations that strives to preserve coral reefs and related ecosystems around the world, counts over 90 members, including 45 countries that are custodians of over 75% of the world's coral reefs. ICRI informs international efforts to conserve reefs and associated ecosystems and provides both a forum for global advocacy on coral reefs to supporting policymakers and stakeholders at the local and national levels.

From the UN Ocean Conference to COP27 and COP15, the second half of 2022 has been marked by a wide array of international conferences, with parties convening to discuss critical actions to address the twin crises of climate change and biodiversity loss. This key decision-making period for biodiversity has enabled ICRI to bring coral reefs to the forefront of discussions, rallying its members for united action.



In June 2022, ICRI held a high-level breakfast event on the sidelines of the UN Ocean Conference to present the ICRI Plan of Action 2021-2024, under its new chair nation, the United States of America. The event brought together high-level attendees known for their unwavering support for coral reefs and prompted collaborative action from countries and organisations in line with the Plan of Action through to 2024. Held in the context of a [Reef Action Hub](#), co-organised by ICRI and featuring 25+ coral reef side events at the UN Ocean Conference, the breakfast and the Action Hub generated a new wave of support for coral reefs, successfully followed by the organisation of collaborative events at [COP27](#) in November, and at [COP15](#) in December, as well as other actions to draw attention on coral reefs.

For instance, the global alliance of ICRI, the Global Fund for Coral Reefs (GFCR) and the G20 Coral Research & Development Accelerator Platform (CORDAP) issued an Open Letter, at the occasion of the Ocean 20, a G20 initiative under the G20 Presidency of Indonesia. The Open Letter calls on the G20, parties of UNFCCC COP27 and CBD COP15, and private sector leaders to urgently implement the policy change, increase the level of investment and leadership needed to ensure coral reef conservation, protection, and restoration commensurate with their value to people and the world economy. ICRI's role within the international arena is evident and has been critical in the instigation of valuable initiatives and platforms. ICRI was critical in the creation of CORDAP and continues its contribution through the Initiative Governing Committee (IGC), and the GFCR as a founding and institutional partner, supporting coral reef restoration and long-term sustainable financing.

Along with this call ahead of the G20, and collaborative events at UNFCCC COP27, ICRI has been pushing for collective action at COP15, as a once-in-a-generation opportunity to halt biodiversity loss and restore nature, including ensuring a future for coral reefs. Indeed, the Global Framework for Managing Nature Through 2030, which will set the global agenda for biodiversity for the next 10 years, was due to be adopted in December 2022 COP15 in Montreal (Canada).

The need for coral reefs to be represented at COP15 and in the Post-2020 Global Biodiversity



Framework drove ICRI to establish an Ad Hoc Committee in December 2018, for the development of a [recommendation](#) on the inclusion of coral reefs in the GBF. Based on extensive consultations with the coral reef community, this recommendation was adopted by ICRI Members in May 2020 (with an addendum to reflect a new proposed target on restoration adopted in December 2021). The recommendation urges CBD Parties to: *ensure that the GBF prioritises coral reefs as one of our most vulnerable and important ecosystems; apply a strategic approach that focuses on retention; and adopt key indicators for coral reefs to incentivize action and increase accountability.*

There is hope that COP15 will lead to appropriate commitments for coral reefs at global, national, and local scales, as the future of coral reefs depends on

it. ICRI will shift its efforts from advocacy to implementation, and support CBD Parties, nations and organisations to deliver a strong, nature-positive, Post-2020 framework to prevent the collapse of coral reef ecosystems.

Marie Touchon



To note:

New ICRI contact point: Margaux Monfared
(margaux.monfared@icriforum.org)

References

- Pörtner HO, Roberts DC, Adams H, Adelekan I, Adler C et al.(2022) Technical Summary. In: Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.eds. Pörtner HO, Roberts DC, Tignor M, Poloczanska ES, Mintenbeck, et al. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 37-118, doi:10.1017/9781009325844.002
- Souter D, Planes S, Wicquart J, Logan M, Obura D, Staub F (2021) Status of coral reefs of the world: 2020 report. Global Coral Reef Monitoring Network (GCRMN)/International Coral Reef Initiative (ICRI). Accessed: <https://gcrmn.net/2020-report/>

International agreements approved with ICRI input:

- ▶ 2020 - WCC-2020-Res-105-EN – Conserving and protecting coral reefs through the post-2020 global biodiversity framework– World Conservation Congress
- ▶ 2019 - UNEP/EA.4/Res.13 – Sustainable coral reefs management – UNEA 4th Session
- ▶ 2017 - Coral reef life declaration – Our Ocean Conference
- ▶ 2016 - UNEP/EA.2/L.13/Rev.1 – Sustainable coral reefs management – UNEA 2nd Session
- ▶ 2016 - WCC-2016-Rec-106-EN – Cooperation for the conservation and protection of coral reefs worldwide – World Conservation Congress

The Land-based Hawai'i Coral Restoration Nursery

Using micro-fragmentation and fusion to produce large colonies for restoration

Morgan Short^{1*}, Christina Jayne¹, Chelsea Wolke¹

¹ Hawai'i Coral Reef Initiative/State of Hawai'i Division of Aquatic Resources

* Email: mshortg@hawaii.edu

In 2015, the State of Hawai'i Department of Land and Natural Resources Division of Aquatic Resources (DAR) established the Hawai'i Coral Restoration Nursery (HCRN), the first state-run coral nursery in the United States. The creation of the HCRN was driven by the need for mitigation in response to planned (e.g., dredging, coastline construction) and unplanned (e.g., ship groundings, pollution, climate change) reef damage and degradation. Since its inception, the HCRN has focused efforts on coral restoration using land-based propagation techniques with the purpose of expediting the restoration of ecosystem functions and services. The nursery is maintained by a team of 7 coral husbandry professionals and is overseen by the DAR Mitigation, Aquaculture, Resiliency, and Restoration Program Manager.

Coral restoration in Hawai'i presents several unique challenges. Native Hawaiian corals have some of the slowest coral growth rates in the world, with reef-building species averaging 1 - 2 cm per year. Hawaiian reefs are dominated by large mounding coral species, rather than the fast-growing, branching *Acropora spp.* common in the Indo-Pacific and Caribbean. Due to geographic isolation approximately 25% of species are also endemic to Hawai'i (i.e., not found outside of Hawai'i). In addition, using common in-ocean nursery techniques is not possible in most areas due to strong seasonal wave action. These unique challenges require the design and implementation of Hawai'i-specific practices for coral conservation and restoration.

To address these challenges, the HCRN developed a fast-growth protocol using micro-fragmentation and fusion at its land-based coral nursery to produce large coral colonies for restoration. Small

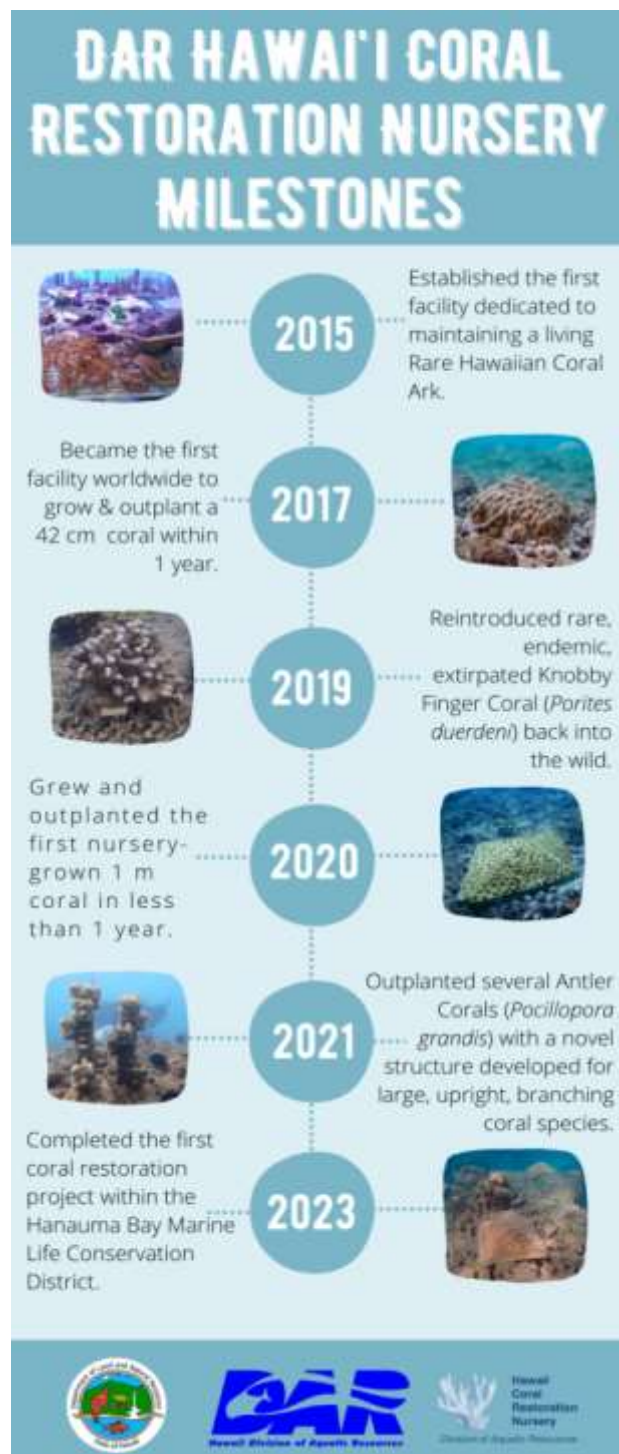


Figure 1. HCRN milestone infographic. ▶

coral colonies are cut into 1 cm² micro-fragments that are glued onto a concrete pyramid module and fast-grown indoors in controlled aquaria maintained by professional aquarist staff. These micro-fragments grow and fuse together, producing a large coral colony in a fraction of the time it would take in the ocean. This process takes a 10 - 15 cm coral and produces a 42 cm coral in 1 - 2 years, which is equivalent to a 20 - 25 year old coral on a natural reef. The HCRN has further scaled up this process to produce 1 m corals, which are equivalent to 100 - 150 year old natural corals. This innovative restoration strategy produces extremely large, 3-dimensional coral colonies that can greatly accelerate the recovery of ecological functions (e.g., habitat provision, reproduction) and ecosystem services (e.g., coastline protection) on damaged or degraded reefs.

The HCRN also preserves the corals of Hawai'i in its Rare Hawaiian Coral Ark, which contains 50 uncommon, rare, or endemic species. This serves as a gene bank for these unique populations and can also be used for reintroduction back into the rare species' native habitats, when appropriate. The importance of this Ark has recently been demonstrated with the restoration of a rare endemic Hawaiian species Knobby Finger Coral (*Porites duerdeni*) on the island of O'ahu using the fast-growth process.

Since 2015, the nursery has outplanted over 150 coral modules, including several 1 m modules. By outplanting large colonies rather than small colonies or fragments we increase the likelihood of survival of each coral, in addition to providing a rapid "return on investment" in terms of ecosystem services and functions. Thirty-six

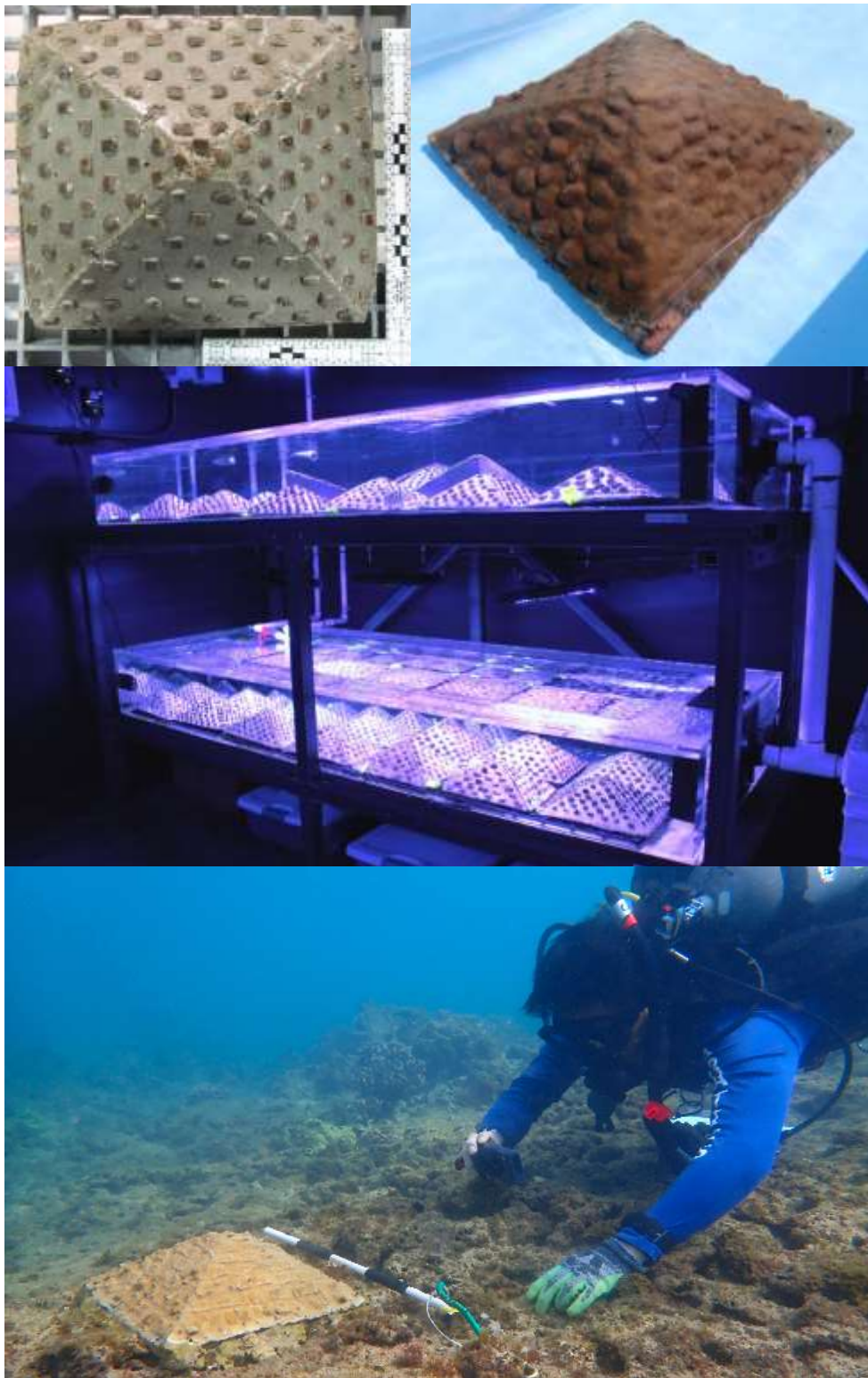


Figure 2 (Top). Left, a 42 cm coral module following initial micro-fragmentation and, right, a fully fused module ready for outplant. **Figure 3 (Centre).** Recently cut coral modules in an indoor, controlled aquarium optimized to accelerate coral growth rates. **Figure 4 (Bottom).** HCRN staff, Norton Chan, monitoring a recently outplanted coral module.

percent of outplanted modules are of endemic species, helping to preserve these species. While the HCRN developed these techniques with Hawai'i-specific challenges in mind, this approach for large colony restoration could as well be applied to restoration strategies around the world. Techniques

involving micro-fragmentation and fusion to rapidly produce large colonies in land-based nurseries are extremely useful for restoring ecological functions and providing valuable ecosystem services.

If you are interested in learning more about this process, please reach out to Ryan Okano (Program

Manager, ryan.ly.okano@hawaii.gov) or Christina Jayne (Coral Nursery Curator, christina.r.jayne.researcher@hawaii.gov), follow us on social media (Facebook: "DAR Coral Restoration, Instagram: @hawaiicoralrestoration), or visit our webpage <https://dlnr.hawaii.gov/coralreefs/hawaii-coral-restoration-nursery/>.



Figure 5 (left). HCRN Staff (left to right): Angel Demers, Honor Weber, Taylor Engle, Morgan Short, Samara Neufeld, Christina Jayne, and Norton Chan. **Figure 6 (right).** Ryan Okano, DAR Program Manager for Mitigation, Aquaculture, Resiliency, and Restoration.

REEF HUMOUR



Cartoon reproduced with kind permission of Megan Herbert (meganherbert.com)

REEF DEPARTURES

Tributes to recently departed members and reef scientists

Angel Alcalá (1929-2023)

Alan White, with Sue Wells



Dr. Angel Alcalá, known as “Angel” (pronounced “Anhil”) to many of his friends and colleagues and as “Aca” to others, was a leading figure in reef conservation in the Philippines. Appointed National Secretary of the Department of Environment and Natural Resources (DNER) in 1993, during the administration of President Fidel Ramos (a fellow scuba enthusiast and acquaintance since the 1980s), he had enormous impact, recognizing the importance of socio-economic as well as ecological needs for successful management of the marine environment and making the Philippines a global champion for reefs in that decade.

His passion for the underwater world arose out of his childhood: he grew up in Caliling, a coastal village in the province of Negros Occidental, where his father was a fish farmer. The family lived in a wooden hut with a nipa palm thatch roof and floor slats made of bamboo. As the eldest of 10 children, he helped his father take care of fishponds, and he credited this experience with his deep love for

marine life. As he said at the age of 88, in a newspaper interview: “As a young boy of seven ...I was always out in the sea. That was my playground”. His path through life, from a fishing village to DNER and academia, is remarkable.

He was a herpetologist by training, having obtained his doctorate from Stanford University in 1966, with a dissertation on the lizards and geckos of the Philippines. He carried out extensive research on Philippine reptiles and amphibians, and was responsible for setting in motion the initiative to save the Philippine population of the saltwater crocodile, through captive breeding programs at Silliman University and in Palawan Island.

He had a long affiliation with Silliman University, the primary private university of the southern Philippines on Negros Island, where he obtained his undergraduate degree in 1951. He founded the Silliman University Marine Laboratory in 1974 and, as a result of this, and his love of the marine environment much of his career was subsequently dedicated to marine science and conservation and it was here that he started the work that led to him being considered the “father” of marine protected areas (MPAs) and community conservation.



Angel Alcalá enjoying life on an outrigger

Alan White writes:

“I first met Angel in 1978 as a Peace Corps Volunteer, when he invited me to join him at the Marine Lab to assist with reef monitoring and other work at the newly established Sumilon Island Marine Sanctuary. This experience, which strongly influenced my career, was a window into the dedication with which Alcala approached marine conservation in the Philippines. On field trips with Angel, we were always in the water surveying whatever there was to see, and taking samples or photos of everything from algae and invertebrates to large vertebrates. He wanted to document everything on the reef, and diligently published his new findings, always with strong reference to the need for protection and management. He would get very upset with local, and even national, government officials who failed to enforce bans on the use of dynamite or cyanide when fishing, often publicly reprimanding them even if they were powerful people.”



Angel Alcala and colleagues on Sumilon Island during work on a Pew project

In particular, Angel understood that one of the best ways to stop overfishing on reefs was to encourage communities and local governments to set up no-fishing areas, a method that was highly novel to a government that operated through the top-down approach. I and many others learned from this model, which led to the establishment of small MPAs all over the Philippines (there are over 2000 today) and subsequently the adoption of the model globally. Initially Sumilon, and then more

successfully, the nearby Apo Island Marine Reserve became templates for community-based marine resource conservation. Countless students and interested visitors, divers and tourists have learned from Apo Island Marine Reserve, showcased at the Shedd Aquarium in Chicago and described in numerous case studies and publications – and unlike so many MPAs, still a success today.”

Alcala was appointed as the 9th president of the University in 1991 and, in 1992, received the national Ramon Magsaysay Award for “pioneering scientific leadership in restoring and protecting coral reefs”. He was a consultant for numerous national and regional projects supported by the UNEP, UNDP, World Bank GEF, and the Marine Science Institute of the University of the Philippines, including the Australian-ASEAN marine project. He helped to ensure that the Philippines was one of the eight founding host nations of the International Coral Reef Initiative (ICRI), and chaired ICRI’s first meeting in Dumaguete. He was made a Pew Fellow in Marine Conservation in 1999, and throughout his later years stayed hugely active in all aspects of his work at Silliman, never hesitating to share his knowledge when it came to environmental protection. In 2014, President Benigno Simeon Aquino III conferred on him the Order of National Scientist of the Philippines award in the field of Biological Sciences for his research work on amphibians and reptiles, marine biodiversity and marine protected areas. His life was documented in a 2017 book *A Love Affair with Nature*, authored by Bettina Rodriguez Olmedo and Amadis Ma. Guerrero, and, in 2019, a Special issue of the *Philippine Journal of Systematic Biology* was dedicated to his work for his 90th birthday⁵. He was still the vice chairperson of the Silliman University Board of Trustees at the time of his death.

He authored over 160 scientific papers and several books, but perhaps Angel Alcala’s most important legacy are his numerous past students, both Filipino and foreign, who learnt so much from him – both in terms of knowledge and the ethics of effective field and conservation work.

⁵ (<https://asbp.org.ph/2020/07/27/volume-14-issue-2-special-issue-no-2/>)

Robert A. (“Dr. Bob”) Kinzie III (1941-2022)

Scott R. Santos (srsantos@buffalo.edu) and Deb Gochfeld

On behalf of his former students and colleagues



Dr. Robert A. (“Dr. Bob”) Kinzie III at home in Kane’ohe, Hawai’i.

The University of Hawai’i at Manoa (UH) and the Hawai’i Institute of Marine Biology (HIMB) ‘Ohanas, along with the entire coral reef community, grieve the loss of Professor Emeritus Robert A. Kinzie III on December 31st, 2022. Dr. Bob, as he was widely known among colleagues and students, was a faculty member in the Zoology Department at UH from 1972 until his retirement in 2009, and maintained a laboratory at HIMB’s Coral Reef Ecology Lab at the “Point” on Moku o Lo’e in Kane’ohe Bay until his unexpected passing. Always enthusiastic and curious, his research interests were broad, spanning the ecology of aquatic systems, including freshwater streams and coral reefs around the Pacific Basin in general and Hawai’i in particular. In his own words, Dr. Bob had no difficulty summarizing his research program at an expansive scale: “While coral reef ecology and zooxanthella symbiosis may seem unrelated to the ecology and life history of biology in freshwater streams, on high oceanic islands, with amphidromous fauna, the link between terrestrial and marine systems is very close.”

Born and raised in Santa Cruz, California, Dr. Bob grew up in a family that enjoyed camping and

going to the beach. When he was a teenager at Holy Cross School, one of his teachers, a nun, sparked his interest in biology. Dr. Bob earned his undergraduate degree at the University of Santa Clara, where he was instrumental in founding the 1960s-70s rock band Jefferson Airplane. After graduating in 1963, he traveled by ship to Hawai’i to join the graduate program in the Zoology Department at UH. His work as a master’s student focused on a potentially introduced mantis shrimp species in the genus *Gonydactylus* and its possible competition with the native Hawaiian mantis shrimp in the genus *Pseudosquilla*. This early work contributed to the growing recognition of competitive interactions and the ecological impacts of invasive species on coral reefs. Notably, the manuscript documenting this work was entitled “*Aloha also means goodbye: a cryptogenic stomatopod in Hawaii*” and serves as testimony to the humor for which Dr. Bob was well known.

Following completion of his master’s degree, Dr. Bob enrolled in the Ph.D. program at Yale University. He worked with G. Evelyn Hutchinson, who some have described as the “father of modern ecology”. His thesis research was the first to examine Caribbean gorgonian ecology in and around Discovery Bay, Jamaica, and this work included analyses of the chemistry and species-specific distributions of prostaglandins, a group of lipids with hormone-like pharmaceutical properties that can influence a range of physiological processes in humans. While in Jamaica, Dr. Bob became friends with Thomas F. Goreau, one of the most well-known marine biologists at the time and founder of the Discovery Bay Marine Laboratory, which further kindled his career-long interest in the biology of coral reefs.

Dr. Bob received his Ph.D. in 1970 and soon after, returned to UH as an Assistant Professor, at the time when coral reef ecology was beginning to gain strong interest. It is in this capacity that, for nearly



Top: Bob as a graduate student in 1968 (photo by Bill Sacco). Bottom: Bob using SCUBA to study Caribbean gorgonians in Jamaica in the early 1970s.

four decades, he and his students, postdoctoral fellows, and colleagues, generated foundational knowledge towards our understanding of cnidarian-dinoflagellate biology. For example, one of his most cited publications reported that nitrogen enrichment increased dinoflagellate symbiont densities in cnidarian hosts, demonstrating that nutrient levels are not entirely regulated by the animal host and that eutrophication could potentially destabilize and negatively impact algal populations in symbiosis with coral reef cnidarians. Another area of special interest to Dr. Bob was exploring the degree of partner specificity between cnidarian hosts and their dinoflagellate symbionts. Here, his work showed that symbiont-free adult hosts could acquire algal symbionts in an apparently dose-dependent relationship from the environment and that strong specificity between partners was evident. Taken together, Dr. Bob's pioneering research contributed to our overall understanding of how coral reefs operate and how they might respond to environmental perturbations, such as pollution or phenomena like coral bleaching due to thermal stress.

It was also following his return to UH that Dr. Bob attended the transformative 1976 Coral Taxonomy Workshop held at [the Mid-Pacific Marine Laboratory on Enewetak Atoll](#). There he was captured on camera, both with John Wells and Brian Rosen, and with a larger group of subsequently well-known reef researchers (see pictures and appendix).

Along with being an accomplished researcher, Dr. Bob was an engaging teacher. Many students eagerly enrolled in his lectures and field courses covering topics that included Animal Ecology, Limnology, and Natural History of the Hawaiian Islands. Dr. Bob also taught in HIMB's Edwin W. Pauley Summer Program in Marine Biology, which led to the development of many coral reef scientists around the world. Dr. Bob continued to teach in the Zoology Department at UH following his retirement. It is unfortunate that future students will miss the opportunity to appreciate his challenging, but enjoyable, courses.



Bob (center) in a rare serious moment during a coral taxonomy workshop at the Mid-Pacific Marine Laboratory on Enewetak Atoll in 1976, with John W. Wells, Professor Emeritus of Geology at Cornell University (right) and Brian Roy Rosen of the Natural History Museum, London (left).

The UH and coral reef scientific community benefitted from the extensive service provided by Dr. Bob during his career. This includes his serving as a member and Chair of the Zoology Department Promotion and Tenure Committee as well as leading the Ecology, Evolution and Conservation Graduate Program at UH for several years. His expertise was also tapped at the international level, where he served on a joint UH/Victoria University at Wellington (NZ) Conservation Biology Program planning committee, and as a member of the International Review Committee for the Coral Reef Monitoring Program administered in Okinawa. This latter activity highlights the strong relationship Dr. Bob shared with colleagues in the Ryukyu Islands, Japan, over the years.

Just as his research embraced the natural environment of Hawai'i, Dr. Bob respected and

loved the culture of the islands. Readily identified by his signature long hair and beard, he was a Sensei at the Windward Aikido Club and active in the local Cross-Fit community. His reach was exemplified by the encouragement and enthusiasm he bestowed upon those around him. This is particularly true for the students of all ages, ethnicities, and career tracks who had the opportunity to work with him and whom Dr. Bob always treated as colleagues throughout his, and their, careers. There is no doubt that his always smiling, gentle nature will be dearly missed by all who knew him.



Bob conducting Aikido Boken training on Kailua Beach, Oahu, Hawai'i.

Dr. Robert A. Kinzie III was the beloved husband to Joy, loving father to sons Michael (wife Ruby) and Hokukoa, and funny grandpa to Hunter and Emerson. He will be fondly remembered by the many students he mentored over his career.



Bob collecting data from a Hawaiian stream in the 1980s.



Bob (2nd from left) with students while conducting fieldwork in Kona, Hawai'i in 2010.

APPENDIX: The Enewatak Coral Taxonomy Workshop



The 1976 Coral Taxonomy Workshop held at the Mid-Pacific Marine Laboratory on Enewetak Atoll, in the Marshall Islands, was attended by a large group of then early-career reef scientists, many of whom later became well known in their respective fields. A majority of those in attendance are shown in the widely known “Truck” photo, shown above in color. The names are shown on a black and white photograph taken at the same time. They include John Wells and Bob Kinzie, as well as previous Reef Encounter editor Brian Rosen. The results of the workshop were published in Devaney DM, Reese ES, Burch BL and Helfrich P (1987) *The Natural History of Enewetak Atoll*.

Volume 2. *Biogeography and systematics*. Office of Scientific and Technical Information, U.S. Department of Energy.

Brian Rosen



Richard Kenchington (1943-2023)

Based on information and text supplied by Jon Day, Tundi Agardy, Alastair Birtles, Kristina Gjerde, Pat Hutchings, Helene Marsh, Dermot Smyth, John Tanzer, Di Tarte, Michelle Voyer, Simon Woodley, Alan White and Sue Wells



Recognised by many as one of the “giants of marine conservation”, Richard was at the heart of the emerging field of coral reef conservation in the 1970s and had a huge influence on its subsequent evolution, not only in Australia, his “adopted” country, but also globally. His guiding hand was behind the establishment and management approach of the Great Barrier Reef Marine Park (GBRMP) and numerous other marine protected areas (MPAs). Well-thumbed copies of *Guidelines for Establishing Marine Protected Areas*, co-written with Graeme Kelleher and published in 1991 by IUCN and the Great Barrier Reef Marine Park Authority (GBRMPA), can be found in many MPA managers’ offices today. He fervently understood that a collaborative, participatory and multi-use approach to MPA management was essential and that government agencies, industry, and local communities need to meet together in order to reach flexible management agreements.

Richard’s passion for the coast and ocean started with holidays at the seaside as a boy in Great Britain in the 1950s. A young Richard also read a book about the Great Barrier Reef, which kindled his life-long enthusiasm for reefs. After graduating in 1965 with a BSc in Marine Biology from Queen

Mary College, University of London, Richard completed his MSc at the University of Wales in 1968 and that year moved to Australia as Senior Tutor in Marine Biology at the fledgling University College of Townsville (now James Cook University or JCU). In 1972, he became a Research Fellow in the Marine Biology Department at JCU, and worked on the Crown of Thorns Starfish (COTS), initiating the COTS transect surveys using manta tows, a method still used widely today.

Having been part of a small group that developed, in 1974-1975, the principles that subsequently informed the *GBR Marine Park Act*, in 1977 Richard was one of the very first staff appointments to GBRMPA. Here he played a foundational role, becoming an integral part of the agency which grew from a small regulatory body to a globally respected environmental management agency – managing what was, for many years, the largest marine park in the world. As the first planning officer and subsequently the Director of Planning, he was instrumental in designing and implementing a multiple-use zoning plan for the



A younger Richard; he moved to Australia from UK as a tutor at JCU

GBRMP – the first application of zoning in an MPA, and now an approach that is used worldwide. He also realised the value of international designations for places as globally significant as the GBR: he helped to draft the nomination for the listing of the GBR as a UNESCO World Heritage Site (at the time, the largest on the planet), and was influential in getting the GBR listed as the first Particularly Sensitive Sea Area by the International Maritime Organization, one of only 15 such areas to this day.

A six months break from the GBRMPA in 1988 as a Marine Policy Fellow at the Woods Hole Oceanographic Institution, USA, led to a broadening of his career. It was then that he began writing *Managing Marine Environments* (1990) which became a seminal publication worldwide with its early endorsement of marine spatial planning. Not surprisingly, in 1990 he was seconded to the Commonwealth Government's Resource Assessment Commission as Secretary to its *Coastal Zone Inquiry*, a three-year investigation of the management and use of the resources of Australia's coastal zone. The resulting report was ahead of its time in addressing coastal and environmental aspects in a holistic way. Richard played a particularly significant role with a lasting legacy: the Inquiry's Terms of Reference had no mention of Indigenous people's rights, uses and values, but he lobbied strongly and successfully for their inclusion in the consultation. This provided Indigenous people with their first opportunity to share their connection to, and concerns about, their Sea Country, and paved the way for major legislative and policy changes to Indigenous governance, use and management of Sea Country.

In 1994, he returned to GBRMPA, setting up the External Services Branch and being appointed as one of two Executive Directors in 1997. Throughout the latter part of the 1990s, with others in GBRMPA, he spearheaded many of the processes and initiatives which are key to reef conservation today, working with a wide range of international and

regional agencies and governments. Richard championed the application of satellite and remote sensing technology to reef mapping, seeing the cost-effective potential of the growing USGS Landsat datasets to provide interpretations of coral reef habitats, reef morphology, bathymetry, and water quality at large spatial scales. Richard's support for remote sensing via GBRMPA, helped pave the way for numerous related national and global initiatives.

He helped the UN Environmental Program (UNEP), helping to rebuild their marine program and guiding their marine conservation work, and going on to spend many years advising them at every scale, from coral reef conservation to Large Marine Ecosystems and strategic environmental assessment work. In 1996, as a senior consultant to the Government of Indonesia and World Bank, he helped design the Coral Reef Rehabilitation and Management Program (COREMAP) for MPAs in eastern Indonesia. From 1996-1998, Richard was the Global Coordinator of the International Coral Reef Initiative (ICRI), which he had helped establish, with Australia as one of the initial eight host nations. He provided much of the energy in the early days of ICRI, helping to steer its first meeting in 1995 in the Philippines, and formulating the four pillars of the ICRI Call for Action and its Framework for Action, which still provide the strategic direction for this globally important body.

Typical of Richard's focus on management and conservation, and his realisation that there was a real urgency to provide managers in coral reef countries with support and guidance, he was also the primary instigator of the International Tropical Marine Ecosystem Management Symposia (ITMEMS), designed to take place every 4 years, between the International Coral Reef Congresses. The first ITMEMS was held in Townsville in 1998, with a highly practical aim, expressed by Richard⁶ as follows: *"Most coral reef conferences are predominantly conferences about reef science. To*

⁶ Kenchington, R and Baldwin, A, 2002. The International Tropical Marine Ecosystems Management Symposium (ITMEMS): Management questions for science. *Proceedings*

9th International Coral Reef Symposium. Bali, Indonesia 23-27 October 2000. Vol.2

some extent this reflects the traditional role of conferences in the cultures of science and environment management. To address this, a deliberate feature of ITMEMS, made possible with the support of ICRI partners and donors was the significant representation and active participation of coral reef managers and decision makers from developing countries. The intention was to develop a clear view of management priorities and to be in a position to provide feedback to a number of forums concerned with the future of coral reefs including this International Coral Reef Symposium.” He had four key questions, as relevant today as then:

- What are the implications of scientific findings?
- So what?
- What should be done? and
- What can be done?

On leaving GBRMPA in 1999, Richard launched his own consultancy business, and from 2000 to 2010 was an Honorary Visiting Professor at the University of Wollongong (UOW), and subsequently joining the Australian National Centre for Ocean Resources & Security (ANCORS) which is based there. He continued to teach, mentor, and publish widely on planning, management, governance, marine ecology and conservation before his second retirement in 2020, his reputation helping to attract international scholars to ANCORS. Richard was awarded an Honorary Doctor of Science (DSc) by JCU in 2001, for his marine conservation efforts at national and international levels and, in May 2022,

an Emeritus Professorship at UOW in recognition of his vast and highly impactful contributions to international scholarship, policy and teaching.



“famously witty and loved good jokes”

He was a long-term supporter of ICRS and an invaluable mentor to those of us who, like him, wanted to see the fruits of academic research used promptly for hands-on action for reefs. He saw more clearly than many how vital it is to enable sharing and understanding of relevant research findings and to use these to resolve management questions. A life-long interest in the theatre no doubt contributed to his other most memorable characteristic – a wicked sense of humour. He was famously witty, loved good jokes and would make everyone feel welcome – a gathering of marine researchers and conservationists was never more exhilarating than when Richard was at the centre of it. He will be missed.



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 involved with coral reefs and associated ecosystems, and 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 hard 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 in particular, (1) general overview articles (3-5 pages) on particular reef science topics in which the author(s) has a special interest, (2) short communications / scientific letters (1-2 pages) reporting recent observations, and (3) general interest articles describing personal views and experiences. It also carries Announcements, Conference Reports, Book and Product Reviews, and Obituaries.

Authors are encouraged to include colour pictures or other illustrations (normally 2-4 per article). There are no specifications regarding the format of articles for submission to the editors, but we particularly ask 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 those from members 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).



Corals, chromids and royal angelfish on a reef near Wayag Island, in the Raja Ampat Marine Park, Indonesia.
Photo by Caroline Rogers



ICRS
International
Coral Reef Society