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Number 42

# REEF ENCOUNTER

United Nations Climate Change Conference
Education about Reefs and Climate Change
Climate Change: Reef Fish Ecology, Genetic Diversity and Coral Disease
Society Honors and Referendum
Digital Underwater Cameras Review

## The News Journal of the International Society for Reef Studies

ISSN 0225-27987

## REEF ENCOUNTER

Reef Encounter is the magazine style news journal of the International Society for Reef Studies. 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. Please submit items directly to the relevant editor (see the back cover for author's instructions).

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## INTERNATIONAL SOCIETY FOR REEF STUDIES

The International Society for Reef Studies was founded in 1980 at a meeting in Cambridge, UK. Its aim under the constitution is to promote, for the benefit of the public, the production and dissemination of scientific knowledge and understanding concerning coral reefs, both living and fossil.

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## CORAL REEFS - THE JOURNAL

The International Society for Reef Studies 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 (see http://www.springer.com/life+sciences/ecology/journal/338).

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# *PRESIDENT'S WELCOME*

*Dear ISRS Colleagues,*

*This issue of Reef Encounter comes at a time when high seawater water temperatures have driven a third global coral bleaching event. I have personally watched over 50 % of the coral in Kaneohe Bay bleach for the second year in a row….alarming! The extent and severity of the bleaching has highlighted a pivotal role for our society in raising awareness of changes on reefs that link to climate and human use. The United Nations Climate Change Conference in Paris in December (COP21) represents a venue where decisions will be made and where science based messages can have impact. Capitalizing on this opportunity, ISRS has now published a consensus statement detailing the state of knowledge regarding the impact of climate change on reefs, as well as providing a call for action. This is the first in a number of statements that ISRS hopes to produce tailored to specific audiences and opportunities.*

*ISRS is also partnering with and identifying organizations and individuals who can help amplify messages and communicate with more diverse audiences. For example, we are working with XL Catlin Seaview who have produced a range of free images, videos and infographics about coral bleaching. These materials are accurate and factual and are being heavily promoted to the media (see http://www.globalcoralbleaching.org). We have also begun to identify individuals in our society who are comfortable communicating with the media and defining our network of media contacts who can facilitate dissemination.*

*Moving forward, ICRS 13 in Honolulu provides as amazing opportunity for ISRS members to convene and strategize as a community. What should ISRS be doing to close the gap between our science, the public, and influencers whose decisions frame trajectories on coral reefs? The timing and need make it imperative that we assess where we are and decide who and what we want to be as a society. I see ISRS as an energetic, visible and vocal organization representing a proactive collaborative community and a hub for activities that make a difference. This is a vision shared by many, and there are many people already working hard to actualize elements of it. For example, we are refreshing our logo through a design competition; developing our social media presence; announcing honors and awards; working on a membership drive; constantly updating our website; communicating directly with our membership; building efficiencies in the ISRS business management; and, updating our constitution. There are many to thank for this incredible commitment and drive but today, I would like to call out the leadership team of Rupert, Don and Yim for their work in so many of these areas; Ove, Rupert and Sue for spearheading the COP21 statement; Kiho for the website and logo competition; Erinn Muller for the membership drive; David Baker for the social media campaign; and Andrea Grottoli for overseeing the new awards and honors. It is an exciting time; together we can build ISRS and influence the outcome for reefs.*

*All the best,*

***Ruth D. Gates***
*President, International Society for Reef Studies*
*Research Professor*
*Hawaii Institute of Marine Biology, University of Hawai'i at Manoa, Hawaii, USA*

# *EDITORIAL*

*My thanks to all those who responded to our requests for items for this issue of Reef Encounter. Again we are fortunate in being able to include a good variety of informative articles, of the type that no doubt explain why members have been kindly commenting that on receiving each edition of Reef Encounter they now read it straight through!*

*For this issue we particularly encouraged a number of student members to contribute. As a result we have articles by PhD students in three different sections, including an opinion piece by one of the recipients of this year's Graduate Fellowships – Giverny Rodgers. To mark the resurrection of the Graduate Fellowships, we also include an article by a past recipient, Annika Noreen, on the work she completed with the Society's support.*

*We have also taken the opportunity of the approach of the UN Climate Change Conference in Paris at the end of November and the very recent declaration of the third Global Coral Bleaching Event by NOAA and collaborating organisations to include several articles that relate to coral bleaching and climate change. There must be concern that we are beginning to see the end of vibrant coral reef communities as we have known them.*

**Rupert Ormond**
*ISRS Corresponding Secretary & Editor, Reef Encounter*
*Honorary Professor, Heriot-Watt University, Edinburgh, UK*

# *RECORDING SECRETARY'S REPORT*

*The most recent Council Meeting / Conference Call took place on July 16th/17th, 2015. Present were: D. Baker, JP Carricart-Gavinet, B. Casareto, R. Gates, A. Grottoli, S. Jupiter, K. Kim, I. Kuffner, E. Muller, K. Nadaoka, S. Norman, R. Ormond, D. Potts, L. Richardson and T. Yeemin. The meeting covered several key issues including the financial footing of the Society, the 13th International Coral Reef Symposium, and updates to the Society's Constitution and Bylaws.*

*Society finances are in good order due to increasing membership and a windfall from Springer (the publishers of the Society Journal "Coral Reefs"), based on the high ranking of the journal. However, longer-term financial stability will require continued growth in membership and equally important, the retention of existing members. The Council has been working on several fronts to these ends, including ongoing changes to the membership structure, adding membership benefits, and developing a more substantive social media effort.*

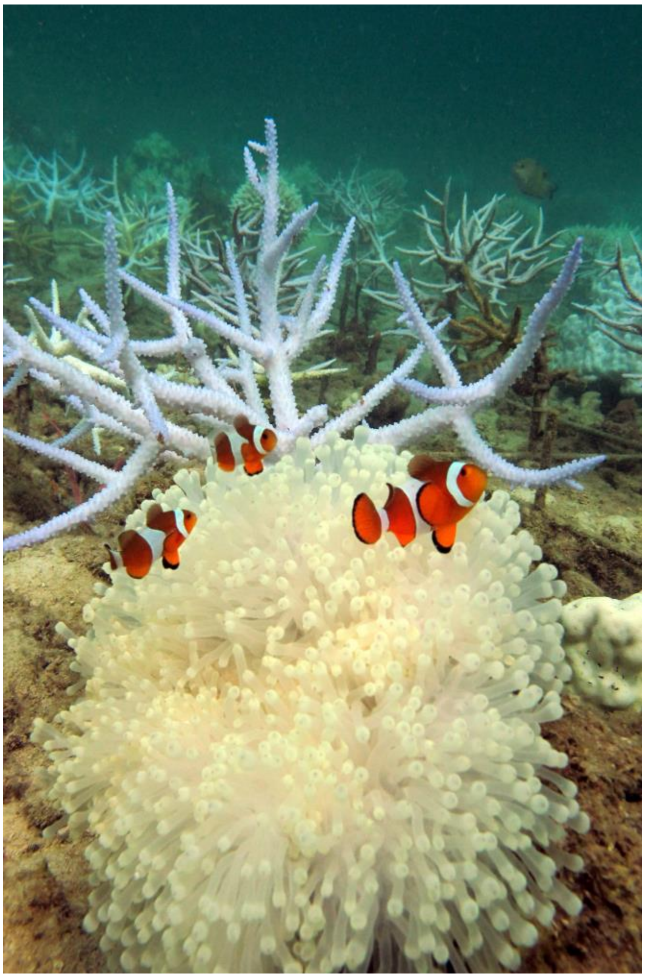
*Planning for the 13th ICRS is progressing steadily. The organising committees have considered the many session proposals and have been working on event and venue details. To increase the impact of the meeting, COMPASS and SeaWeb have been enlisted to help with media outreach. The Council unanimously approved a revised Constitution and Bylaws for ratification by the full membership. The original Constitution and Bylaws were written 35 years ago and were in need of updating to reflect society goals and changes in technology.*

**Kiho Kim,**
*ISRS Recording Secretary & Chair Website Committee*
*Professor, American University, Washington DC, USA*

# *TAKING ACTION ON CLIMATE CHANGE*

## *A Role for ISRS...Now!*

The 21st Conference of the Parties to the UN Framework Conference on Climate Change (the "Paris Climate Summit") will shortly be taking place over 30th November – 11th December. The 196 countries present are expected to sign a new climate change agreement, just when extensive coral bleaching linked to climate change is underway.



Bleached anemone and corals, near the Phi Phi Islands, Thailand, 2010. Pretty ...depressing! (photo: Nalinee Thongtham)

In response, ISRS has prepared a consensus statement on coral reefs and climate change, calling on all nations and negotiators at the Paris Conference to commit to limit atmospheric carbon dioxide ($CO_2$) concentrations to no more than 450 ppm in the short-term, and reduce them to 350ppm in the long-term. It is believed that such restrictions are required to keep average global temperature increase to less than 2°C (or 3.6°F) in the short-term, and less than 1.5°C (or 2.7°F) in the long-term, relative to the pre-industrial period – the maximum warming likely to prevent global collapse of coral reef ecosystems and to allow coral reefs to survive in to the future. The statement was drafted by a group led by Ove Hoegh-Guldberg, reviewed by a larger panel of members, and approved by the ISRS Council. The statement is being distributed to members and is available for download from the Society's website home page (www.coralreefs.org).

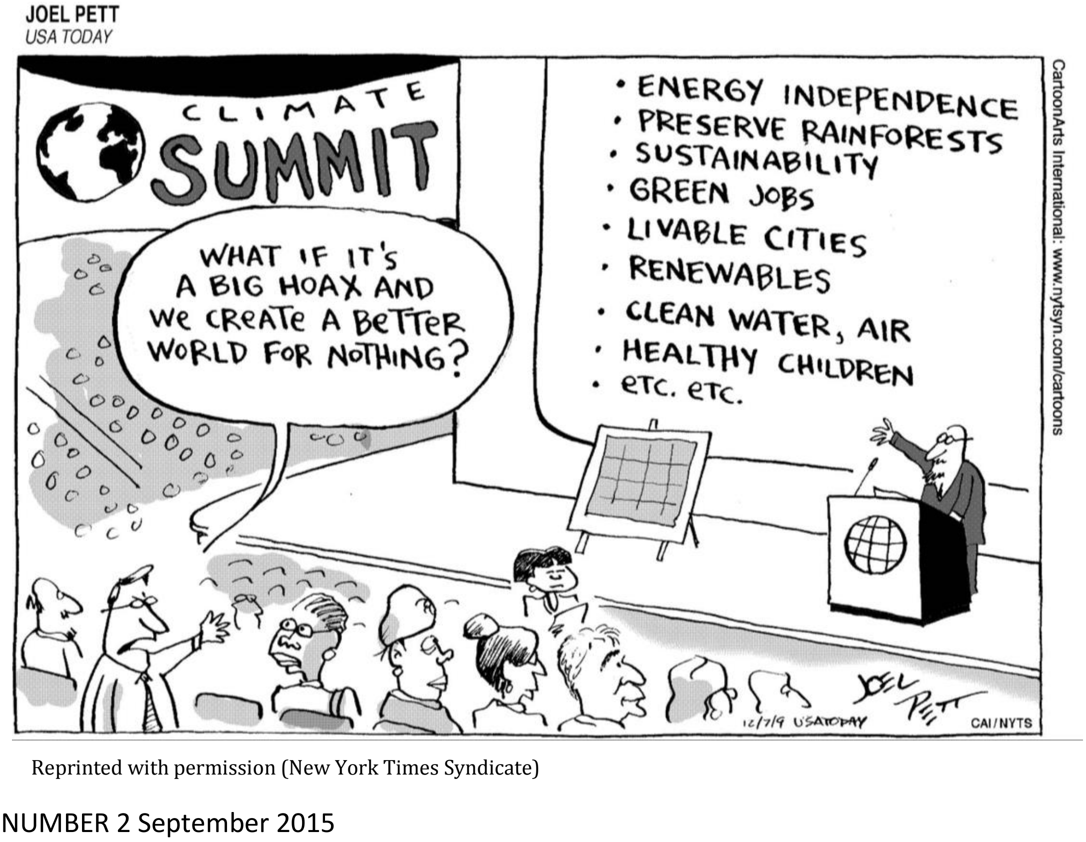
Officers are now working to distribute this statement to all in a position to influence the decisions to be made in Paris. We urge members to assist this effort, making sure that governments and delegates to the conference are informed, directly or indirectly, of the dire consequences for coral reefs of continued global warming.

All ISRS members can assist by raising public awareness of the threat to reefs and by minimising their carbon footprint, and encouraging others to do likewise. We can all play an important role, even as individuals. Here is a list of suggested actions. If you can only tackle one of these ….please do it!

1. *Distribute the ISRS statement as widely as possible, so that your colleagues, family, friends, etc. become aware of what will happen to coral reefs if emissions of greenhouse gases are not reduced.*
2. *Broadcast the message on social media:*
    a. *Post or publicise the ISRS Consensus Statement on Facebook.*
    b. *Post a message on Twitter – suggested message: #CoralDisaster expected due #CoralBleaching as oceans warm due #ClimateChange. #ISRS experts say emission reductions expected at #COP21 in #Paris2015 will not be enough. See #ISRS Consensus Statement at www.coralreefs.org.*
    c. *Send your Twitter post to any high profile personalities whom you follow and who themselves have large followings, particularly if you think they might re-tweet your post.*

3. *Email a copy of the statement to your relevant government minsters, and your local congressman or member of parliament, emphasising your concern with a short covering message.*
4. *If you teach or have students, make sure that they are all aware of the importance of this issue and of how they can help individually.*
5. *If you have contacts with schools and educational institutions, offer to give a talk about coral reefs and climate change – see James Crabbe's article on p. 13 of this issue of Reef Encounter.*
6. *If you are in the field and observe coral bleaching, please report this to one of the international organisations monitoring the situation, such as NOAA's Coral Reef Watch or Reef Check. NOAA's reporting forms can be found at: http://coralreefwatch.noaa.gov/satellite/research/coral_bleaching_report.php (do first check however that the symptoms shown by the corals you've observed do indeed match those characteristic of bleaching and that they are not being killed by other agents).*
7. *Especially over the El Nino year ahead follow the coral bleaching warnings as shown on the NOAA website: http://coralreefwatch.noaa.gov/satellite/bleachingoutlook_cfs/weekly_webpage/expanded_bleachingoutlook_20150908_cfs20150906_weekly_60.php.*
8. *If you are involved in research or monitoring of coral bleaching, make sure your results are written up and published promptly (but don't sacrifice scientific integrity for speed!)*
9. *Don't forget that climate change will not stop at the Paris summit! Regardless of the decisions taken there, we need to be thinking about the research and management actions that the reef science community can be taking to help mitigate the threat our ecosystem is facing – see e.g. Giverny Rodgers' article on p. 16.*
10. *Start to reduce your own carbon footprint and encourage others to do so. Key actions to take include:*
    - *Reduce your electricity and gas consumption – turn off lights, turn down heating & air-conditioning*
    - *Use public transport in preference to your car - whenever possible*
    - *Where practicable – avoid taking flights, and offset them if you do*
    - *If you have the means, install solar panels on your house*
    - *Support sequestration charities and projects*
    - *Reduce beef consumption – methane primarily produced by livestock is the second most important greenhouse gas................Do you really need that burger?*

Sue Wells
News Editor, Reef Encounter



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# *SOCIETY ANNOUNCEMENTS*

## Call for Nominees for the Darwin Medal and other Society Honors

The Council of the Society invites nominations for the 2016 **Darwin Medal** and for the 2016 round of the Society's other honors, including the four awards listed below, and for election to the rank of **ISRS Fellow**.

**The Darwin Medal** is the Society's premier honor, awarded once every 4 years to an eminent late-career scientist. To date only seven medals have been awarded since the first was given to the Society's founding president, David Stoddart. With this point in mind, last year the Society established a series of further honours to be awarded annually. These are:

1. ***The Young Scientist Award*** *(awarded each year to a scientist under the age of 35)*
2. ***The Mid-Career Scientist Award*** *(awarded each year in recognition of excellence in research by a mid-career scientist)*
3. ***The Eminence in Research Award*** *(awarded each year in recognition of an outstanding body of research over an extended period of time), and*
4. ***The World Reef Award*** *(awarded in recognition of scientific or conservation achievement by an individual who is a member of a group under-represented in the field of reef science or management).*

In addition the Society established the status of **ISRS Fellow,** to be awarded to up to 15% of members in recognition of scientific achievement and/or service to reef conservation or management and/or service to ISRS over a significant period of time.

The recipient of the **Darwin Medal** will receive their award at the forthcoming International Coral Reef Symposium in Hawaii, where he or she will be invited to deliver a plenary lecture (the **Darwin Lecture)** reviewing their field.

The winners of the other awards will also be provided at ICRS with special badges and an opportunity to speak. In addition a special reception is planned for all ISRS award holders and ISRS fellows.

Details of the nomination process for the Darwin medal may be found on the Society's website at: http://coralreefs.org/society-awards-and-grants/darwin-medal/. Nominations should be submitted (by email or by post) to the Corresponding Secretary (Prof. Rupert Ormond; rupert.ormond.mci@gmail.com) by **January 15th 2016**.

Details of the nomination process for the other awards and for election to the status of **ISRS Fellow** may be found on the Society's website at: http://coralreefs.org/society-awards-and-grants/awards-fellowships/. Nominations for these should be sent by email or post to the secretary of the Society's awards committee:
Dr Andrea Grottoli, School of Earth Sciences, Ohio State University, 125 South Oval Mall, Columbus, Ohio 43210 USA, email: grottoli.1@osu.edu. The closing date for these nominations is also **January 15th 2016**.

Please note that all nominees and those individuals making a nomination must be current members of the Society. Also, any one member may support only one nomination for the **Darwin Medal** and one each for each of the other four awards. Members may however be nominated if they qualify for more than one award; in particular members nominating another member for the **Darwin Medal** may wish to consider also nominating them separately for the **Eminence in Research Award or World Reef Award**. Likewise members nominating another member for one of the four other awards listed above may wish to consider also nominating them for election to the status of **ISRS Fellow**. There is no limit to the number of other members that a single member may nominate for election as an **ISRS Fellow**.

## Referendum to Approve Revised Constitution and Bylaws

As all members were notified by email in early September, the Council has authorised a referendum of members to approve a revised constitution and bylaws. **If you have not already voted in this referendum we urge you to please do so, now, if at all possible. The information you require to log-in and cast your vote was included in the email.**

As explained in the email, the reason for revising both Constitution and Bylaws was that various stipulations had become increasingly impracticable and expensive, and were either being ignored or holding up progress with Society business. In particular there were requirements for actual physical meetings of members at Council Meetings and Annual General Meetings and for important correspondence to be delivered as hard-copies by post. Thus, last year the Society's Council asked a sub-committee (John Ware and Donald Potts) to review and recommend revisions to both documents to make them more appropriate to the modern age, and more consistent with current practice.

After detailed consideration by the Council and officers at previous meetings of a series of drafts, final versions were approved by Council during a conference call on 16th/17th July. These final versions now need, according to the existing constitution, to be put to a vote of the entire Membership. To become effective the new Constitution needs (under the existing Constitution) to be approved by a two-thirds majority of at least 40% of the existing membership. **It is for this reason that we urge you to please check the details and vote as soon as practicable.** Changes to the bylaws by contrast require only a simple majority of those members voting.

A more detailed explanation of the case for revising the Constitution and Bylaws can be found on the Society's website at http://coralreefs.org/society-organisation/isrs-constitution-2/. The current or original Constitution and Bylaws can be found on the Society's website at http://coralreefs.org/society-organisation/isrs-constitution-2/current-constitution-and-bylaws/. The proposed revised Constitution and Bylaws can be found on the Society's website at http://coralreefs.org/society-organisation/isrs-constitution-2/proposed-revised-constitution-bylaws/.

To vote you will need your email address as held by the Society, and your membership number, as quoted on the email inviting you to vote. (If you have a problem recalling either of these please contact membership services.) Then please go to the referendum voting page at: http://sgmeet.com/isrs/ballots/referendum/. If possible, please vote by the end of October 2015.

## New Logo Competition!

The Council has decided that the time has come to replace the existing ISRS Logo – the one shown on the cover of this issue. The exiting logo has served us well but has two drawbacks. It is not clear what some of the items shown are intended to be and it does not reflect the variety of corals and invertebrates, as well as fish, that characterise most healthy reefs. It has therefore been decided to hold a competition, open to all members, to design a new logo. The logo should reflect the Society's mission, "… to promote the production and dissemination of scientific knowledge and understanding of coral reefs, both living and fossil." The logo should capture the iconic nature of coral reefs wherever those reefs occur. The competition is open to all members of ISRS and closes on December 20, 2015. For more information on the competition (AND ON THE PRIZES!) please go to our web site at www.coralreefs.org.

As surely all members will know, the **13th International Coral Reef Symposium** (ICRS) is taking place over 19th-24th June (2016) at the Hawai'i Convention Center in Honolulu, Hawai'i, USA. ICRS is the primary international meeting focused on coral reef science and management, and is anticipated to bring together 2,500 coral reef scientists, policy makers and managers from 70 different nations, to present the latest research findings, case histories and management activities, and to discuss the application of scientific knowledge to achieving coral reef sustainability.

The Hawai'i Convention Center itself is centrally located in the heart of Honolulu and located only 8 miles (12 km) from the Honolulu International Airport and within 1.5 miles of an array of shopping, dining and entertainment venues. The Convention Centre is a remarkable facility, combining the latest cutting-edge technology with authentic Hawaiian ambience. Warm ocean waters, Oahu's beauty, and the lure of Hawaiian legends are calling you - so come and join us at ICRS13!

Full information on the Conference is now available on the dedicated website at http://sgmeet.com/icrs2016/, also accessible via the ISRS website at http://coralreefs.org/conferences-and-workshops/13th-international-coral-reef-symposium-hawaii/. Latest key information includes the followings:

**Town Halls, Workshops, and Ancillary Meetings**: Requests for space for these and similar meetings are now being accepted through to 31st October 2015. All requests must be submitted using the online supplemental meeting application form [http://sgmeet.com/icrs2016/meetingapplication.asp] and must be received by the deadline.

Request for **Exhibition Space** are also being accepted at: https://www.sgmeet.com/icrs2016/exhibitorinfo.asp. Exhibit booths will be assigned based upon the date the exhibit registration form and payment are received.

Both **Attendee Registration and Abstract Submission** are set to open by early November. Once the call for abstracts is posted, submissions will be accepted through to 15th January 2016. Watch your email and the symposium web site for further news.

Contacts in case of queries

For information about the scientific program:
Dr. Robert Richmond,
Convener, 13th ICRS
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# *GENERAL ANNOUNCEMENTS*

## *Reef Conservation UK Meeting, London, November 28th*

Reef Conservation United Kingdom (RCUK) is back for its 18th annual meeting in London, on the 28th November 2015! Registration is now open, and we are accepting abstracts for talks, speed talks and posters. RCUK was formed to promote multidisciplinary conservation, public awareness and education about coral reefs. Contributions are encouraged from all involved in reef-related disciplines, such as: research students, university lecturers, aquarists, field conservation workers, consultants and those involved with ecotourism. This year we are particularly keen for presentations from practical reef conservation projects, and scientists working on colder water reefs. While the meeting is primarily attended by UK-based reef workers, others, especially from adjacent European countries, often attend, and all are most welcome. More information can be found here: www.zsl.org/rcuk.

## *Proposal for ISRS European Inter-Congress in 2017*

ISRS has received a proposal from Reef Conservation United Kingdom (RCUK) to host a 3-day ISRS Regional Meeting in either London or Oxford (UK) in December 2017. In the past ISRS has encouraged regional meetings as Inter-Congresses to be held mid-way between the four yearly International Coral Reef Symposia, the next of which is taking place in June 2016 in Hawaii. The most recent European Regional meeting was held at Wageningen, in the Netherlands, in 2010. A proposal was in hand for a meeting in 2014, but for various reasons the event did not materialise. Thus officers have welcomed the proposal from RCUK. The slightly earlier than scheduled date seems reasonable given that the last meeting did not take place and that Europe-based members in particular may find it difficult to get to Hawaii for ICRS13.

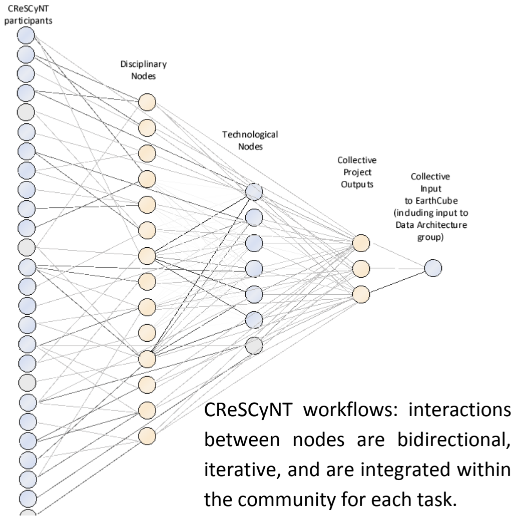
However, before accepting the proposal from RCUK, it has been agreed that a call should be put out in case other members might also like to express interest in hosting either this meeting (in late 2017 or in 2018) or the subsequent one. For more information on what is required please contact the secretary of the Conferences sub-committee Dr. David Baker (email: dmbaker@hku.hk).

CReSCyNT
Coral Reef Science & Cyberinfrastructure Network
An EarthCube Research Coordination Network

The Coral Reef Science & Cyberinfrastructure Network (CReSCyNT) is a multi-tiered and multidisciplinary network of coral reef researchers, ocean scientists, cyberinfrastructure specialists, and computer scientists, and we invite you to join us. As an EarthCube Research Coordination Network, our goals are to foster a dynamic, diverse, durable, and creative community; to collectively consider and develop standards and resources for open data, research documentation, and data interoperability while making best use of work already accomplished by others; and to offer input to those groups within EarthCube who will ultimately create the data architecture for all of EarthCube. Along the way CReSCyNT expects to collect and share community resources and tools, and to offer training opportunities in topics prioritized by our members through widely accessible formats such as webinars and their recordings. We will also work to nurture unforeseen collaborative opportunities that emerge from our integrated collective work.

EarthCube is a National Sciences Foundation initiative whose goal is to create a community-driven data and knowledge environment across the geosciences that will ultimately improve our understanding of Earth as a complex and changing planet. It is a cornerstone of NSF's Cyberinfrastructure for the 21st Century initiative, whose chief objective is to develop a nationwide, sustainable, and community-based cyberinfrastructure for researchers and educators. CReSCyNT is one of just six Research Coordination Networks within EarthCube. Work on identifying science drivers and cyberinfrastructure needs for the coral reef community took place at two workshops in late 2013 by 53 participants representing a broad geographic range of the U.S. academic coral reef research community, and serves as the starting point for further work by a diverse array of CReSCyNT nodes.

Because the coral reef community has exceptionally diverse data structures and analysis requirements needed to forward integrative science, it is an exemplar for cyberinfrastructure-enabled advances to other geosciences communities. The CReSCyNT network is working to match the data sources, data structures, and analysis needs of the coral reef community with current advances in data science, visualization, and image processing from multiple disciplines to advance coral reef research and meet the increasing challenges of conservation. The network has begun to assemble to coordinate, plan, and prioritize cyberinfrastructure needs within the coral reef community.



CReSCyNT workflows: interactions between nodes are bidirectional, iterative, and are integrated within the community for each task.

The structure of CReSCyNT is a network of networks, currently including 18 disciplinary nodes and 7 technology nodes, where each network node represents an area of coral reef science (disciplinary nodes: e.g., microbial diversity, symbiosis regulation, physiology & fitness, reef ecology, fish & fisheries, conservation & management, oceanography, paleontology) or an area of computer science or technical practice (technology nodes: e.g., visualization, geospatial analysis & mapping, image analysis, legacy & dark data). These nodes will be allowed to expand, coalesce, or divide to meet the needs and interests of the subdisciplinary communities, while maintaining connections to CReSCyNT through node coordinators and ongoing network activities. We invite you to become a member of CReSCyNT, join one or more nodes that would advance your own work, collaborate on shared resources and tools for the coral reef community, and ensure that the data architecture and cyberinfrastructure of EarthCube will meet the needs of the coral reef community, and that broader data interoperability within EarthCube will benefit both coral reefs and our ability to answer complex questions.

For more information or to participate with CReSCyNT, please visit http://tinyurl.com/crescynt or email crescyntrcn@gmail.com. You can learn more about EarthCube at http://earthcube.org.

# REEF PERSPECTIVES

***Personal comment on reef science, policy and management***

# THE EARLIER THE BETTER!

## EDUCATION ABOUT REEFS AND CLIMATE CHANGE

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In 2008, when I was directing an Earthwatch coral reef project on the Sapodilla Cayes on the MesoAmerican Barrier Reef near Belize, I came across a poster (Fig. 1) outside a primary school in Punta Gorda where I was staying. Everyone passing the school, which was on a major thoroughfare, could see it. The impact of the simple message made by the children in the school struck me then as more impressive than many close and detailed arguments about coral reefs that I had read, and indeed contributed to.

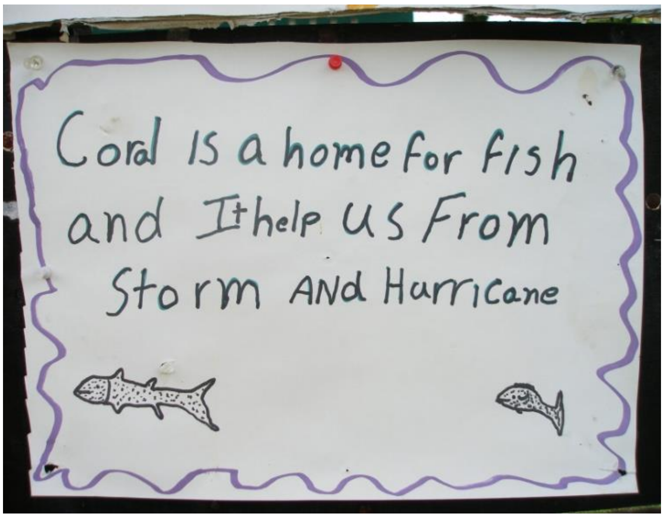

**Figure 1.** A poster outside a primary school in Punta Gorda, Belize.

Education at primary level, between the ages of about 5 and 11 years, is critical to the formation of mental processes, knowledge and skills. In complex societies, whether in the East or the West, or on small island states in the tropics, education needs to nurture positive, independent individuals who are going to make a valuable contribution to society. Individuals should progress through the education system with an increasing knowledge and understanding of the world around them, a love of learning and the skills, aspirations, confidence and values to make the most of their adult lives. They should have gained the confidence to dream beyond their sense of place, so that every person may reach and fulfil their potential.

The aspirational nature of a young person's early environment is also important, both to the individual and to society as a whole. For example, in the UK over 200,000 children have one or more parents in prison, and 65% of the children of those parents who have offended go on to offend themselves (UK Ministry of Justice statistics, 2014). In the U.S., where at the end of 2011 a total of 6,977,700 adults (2.9% of the U.S. adult population) were under correctional supervision (probation, parole, jail, or prison) (U.S. Bureau of Statistics), this effect could be even more significant. Such major trends are obviously not the consequence of formal teaching during childhood, but reflect the way in which a young person's social environment and physical experience influence their attitudes and beliefs.

In the same way it is now widely recognised that both physical experience and passive learning are critical to achieving effective education, especially at an early stage. The 1931 Hadow Report on primary education announced that "the curriculum is to be thought of in terms of activity and experience, rather than knowledge to be acquired and facts to be stored" (UK Board of Education, 1931), although subsequent discourses on primary education have tended to veer between two 'opposite' standpoints, presumed to be mutually exclusive. Substituting an 'and' for the 'rather than' in the statement above allows for a more nuanced approach, more appropriate to a rich and lasting learning experience.

A recent milestone in current thinking in the UK was *The Cambridge Primary Review* (2010), which included consideration of children's views, not least because it was recognized that they are 'expert witnesses on many of the issues with which the Review is most fundamentally concerned' (Alexander, 2010, p.143). Prominent among the questions posed was 'What is primary education for?' Submissions to the review were keen to go 'beyond the 3Rs', emphasising the 'whole child', and addressing disadvantage. It became clear that 'One size does not fit all', locally, nationally, or internationally. The Review drew together a number of "Principles", which, as becomes clear on examination, are equally important as we consider education about the environment, coral reefs, and the people who depend on them. These are:

- Entitlement
- Equity
- Quality, standards and accountability
- Responsiveness to national need
- Balancing national, local and individual
- Balancing preparation and development
- Guidance, not prescription
- Continuity and consistency
- Respect for human rights
- Sustainability
- Engagement in a democratic manner
- Respect for evidence
- Resources and support

These principles lead to encouraging respect and reciprocity, promoting interdependence and sustainability, empowering local, national and global citizenship, and celebrating culture and community.

Different countries and communities can develop these principles in different ways. In the UK, the *Open Futures* educational programme is both skills- and knowledge-based, and uses a philosophical approach – Philosophy for Children, or P4C (Topping and Trickey, 2007) – that embeds respect for the individual, the culture and the environment in all aspects of the curriculum (see www.openfutures.com). A recent study, funded by the Education Endowment Fund, found that inclusion of this philosophical aspect can boost young children's reading, writing and maths results (see https://educationendowmentfoundation.org.uk/news/philosophy-sessions-for-disadvantaged-ten-year-olds-can-boost-their-reading-writing-and-maths-result/). Such an approach can, I have argued, also help in tertiary and skills education (Crabbe et al., 2015).

So no longer is it 'cool' or good pedagogical practice to separate activity and experience from knowledge to be acquired and facts to be stored, as seemed the case in 1931. A holistic approach, concentrating on the learner, and the importance of their voices in education, yields high results at all levels. Educators are no longer 'the sage on the stage' but much more 'the guide on the side'.

The principles that apply to the education of the young in both social attitudes and basic transferable skills may be expected to apply equally to the development and adoption of environmental attitudes and understanding. The attitude of young people to wildlife and their appreciation of the need for the environment to be exploited only on a sustainable basis may be determined long before they attend tertiary, or even secondary, education. To paraphrase Baba Dioum's much quoted dictum (Valenti & Tavana, 2005), children need to experience their natural environment and something of the biodiversity it supports if as adults they are not only to understand it, but value and care for it.

It may not be enough endlessly to try to explain to adult politicians or engineers or businessmen the science behind climate change or the impending loss of coral reefs, if they have not as youngsters appreciated, preferably at first hand rather than through the media, the nature of this or similarly complex natural environments. Thus efforts to secure the future of coral reefs must include wide-scale opportunities for young children, in particular those living in countries bordered by coral reefs, to experience the character and wonder of the marine environment.

A good example of how this may be attempted is seen at the Discovery Bay Marine Laboratory, Jamaica, part of the University of the West Indies (UWI), which runs a series of Eco-camps each summer. Each year the youngsters are treated to three weeks (one week per age class) of exciting, fun-filled and environmentally-focused educational activities, based on a chosen theme. Campers are provided with the opportunity to learn more about the marine environment through

**Figure 2.** Jamaican children being taken out to view the reef in Discovery Bay, Jamaica, as part of their summer Eco-camp.

talks, video presentations, hands-on activities, experiments, games, and field trips (Figs. 2 & 3).

Campers can also swim or snorkel at dockside. The camps provide an exciting and interactive way for young people to learn about the reefs and their marine environment. The campers are involved in a wide variety of activities, including producing theatre to explain the problems faced by reefs. At the end there are quizzes, and prizes for the best students, not only in terms of knowledge but also for their interactions with, and support for, others. The feedback they give about the eco-camps is always highly positive, and they leave with a great sense of vitality as well as understanding about reef ecosystems. As the camps have been in action successfully for several years, it would be timely to study the short-, medium, and long-term effects that eco-camps have had on their students.

Similar programmes are also run by a variety of other institutions and organisations, for example by the Cape Eleuthera Institute in Bahamas, and within marine protected areas in the Seychelles. But in comparison to the seriousness of the threat to reefs, what is being done at present is little more than a token effort pursued by a relatively small number of committed idealists, in order to benefit limited numbers of local people. We need a global scale co-ordinated approach to providing young people with a holistic educational experience of the natural environment in general, and of coral reefs in particular. Only in this way can we win hearts as well as minds, and subsequently hope by changing behaviour to reduce the scale of threats to coral reefs.

We can all help with this, both as individuals and institutions, and indeed should perhaps be obliged to do so, as a condition of any project undertaken in a coral reef location. As we approach the United Nations Climate Change Conference, to be held in Le Bourget, Paris, from November 30th to December 11th 2015, let us all do all we can to ensure that it is not too late for future generations to be able to experience and enjoy reefs as we have known them.

**Figure 3.** Jamaican children and some of their tutors at an Ecocamp in the Discovery Bay Marine Laboratory, Jamaica. The author is second from the left in the back row.

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# CLIMATE CHANGE ECOLOGY OF REEF FISH: KEY CONSIDERATIONS GOING FORWARD

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Climate change is occurring at a frightening pace, particularly when one considers how quickly science now needs to progress in order to make predictions that will be relevant to decision-making processes and management planning. For these reasons it is critical that we conduct the best science possible, if we are to have any chance of managing the changes occurring in our environment. As ecologists we understand that the effects of climate change will not occur in isolation, and that additional stressors may ameliorate or exacerbate the effects of others. Further to this, even understanding the implications of a single stressor can be complex, as will be discussed in this article. When it comes to understanding the effects of important environmental stressors such as climate warming or ocean acidification, single measure short-term studies may seem most attractive due to the logistical and time constraints of longer-term research. However, the benefits of the latter more complex experimental designs have been consistently demonstrated.

Here I will discuss three key issues which I believe it is important to keep in mind moving forward with ecological climate change studies in the coral reef environment, if we are to optimise our understanding of the long-term effects of climate change on marine fish populations, and make the best possible predictions concerning the effects of climate change.

## Undertake multigenerational studies

An organism's ability to cope under future climatic conditions will depend on its capacity to adapt and/or acclimate in response to environmental change. Genetic adaptation occurs through the selection of favourable genotypes over multiple generations, while by acclimation we refer to expression of phenotypic plasticity in physiological, behavioural or morphological traits. Acclimation is of particular interest in climate change ecology as it can occur faster than adaptation and is capable of occurring over climate change relevant time scales. There are three categories of acclimation; reversible, developmental and transgenerational. Reversible acclimation involves short-term, regulated responses to environmental variation and is often associated with species that live in heterogeneous environments. Developmental acclimation involves an irreversible response to a stimulus experienced during ontogeny. Finally, parents can influence the phenotype of their offspring by non-genetic means, leading to transgenerational acclimation. A comprehensive examination of these processes and the mechanisms behind them can be found in a recent review by Sunday et al. (2014).

For at least some tropical marine species, the potential for reversible acclimation to future projected temperatures is extremely limited (Nilsson et al. 2009; Gardiner et al. 2010; Nilsson et al. 2010; Rummer et al. 2014). Despite this, some studies still only test a species response to stressors over short time periods and within a single generation, using adult test subjects. The results of such studies have the potential to overestimate the impacts of climate change, since they are more likely to describe only a short-term stress response, rather than an organism's ability to persist over longer time periods. This concern is supported by recent studies of developmental and transgenerational acclimation, since they are beginning to show that even species that display low thermal or $CO_2$ tolerance in short-term or single generation studies, nevertheless have some ability to cope with climate change in the longer term (Donelson et al. 2012; Miller et al. 2012). This contrast has most commonly been demonstrated for physiological traits such as metabolic or reproductive measures, although newer studies are now beginning to investigate behavioural measures, with mixed results. Of the three points that I present in this article, the use of long-term and multigenerational research is perhaps the best applied, with a range of studies now being published (within the past 5 years) covering these concepts.

### Broaden the range of species studied

Single species studies can provide useful information, particularly for understanding the specifics of certain physiological or behavioural responses. From a wider perspective however, we are increasingly finding that generalisations based on only one species may not provide a reliable indication of the effects of climate change. This is demonstrated when comparing the metabolic performance of closely related species. For example, studies by Nilsson et al. (2009), Gardner et al. (2010) and Rummer et al. (2014) each compared the thermal tolerance of a range of closely related reef fish species and showed subtle differences in temperature-related performance. In the most striking comparison, *Acanthochromis polyacanthus* damselfish were shown to be extremely thermally sensitive, and apparently already living at or above their thermal optimum (Nilsson et al. 2009; Gardner et al. 2010; Rummer et al. 2014); by contrast, a closely related *Pomacentrus moluccensis* has been shown to increase its thermal performance with increasing temperature, in some cases up to 33˚C (Gardner et al. 2010; Rummer et al. 2014). This is only 1˚C lower than temperature lethal to *A. polyacanthus*. How these differences in thermal sensitivity translate over longer time frames is yet to be investigated, however it seems likely that these short-term differences will translate into comparable or even greater long-term variation.

Given that such examples show significant variation in thermal tolerance across species, it becomes also important for us to understand why such differences occur. This highlights another important point – the need to understand the ecology of particular study species. At first glance the above mentioned species seem very similar in the environment they occupy and the ecological niche they fill; however, closer examination reveals subtle differences in life history strategy that may contribute to the differences in thermal tolerance. Because it is impossible to investigate the impacts of climate change on every single species, it would be of significant benefit if we could understand the main factors contributing to the differences in response to a stressor between species. We could then use this knowledge to make more general predictions. We must not assume that certain species will respond in a similar way to the same stressor, just because they are closely related.

### Consider multiple fitness measures

The final important point is the need to consider multiple fitness measures. Hypotheses such as oxygen- and capacity-limited thermal tolerance (OCLTT) encourage single measure studies and have become extremely popular, since they suggest that scientists should be able to use a single measure to infer the effects of a stressor on overall organism health (Pörtner 2001; Pörtner & Farrell 2008). As a result many recent studies have focused on a single measure of an organism's performance, but failed to recognise the ecological relevance of that measure. Authors should strive to design studies which both consider multiple measures of fitness and provide for comparison of findings across studies. This will allow us to understand not only the specific ways in which a stressor affects an organism, but also the ecological/fitness implications of such effects. In addition, such studies can reveal trade-offs between traits that otherwise might not be considered.

Considering multiple measures may be as simple as including a fitness measure, such as growth rate, when conducting a study. For example, Donelson et al. (2011) showed reduced growth in thermally acclimated fish, indicating a physiological trade-off made to maintain performance in a more thermally stressful environment. Other examples may reveal complex interactions between various measures.

Not all measures will respond in a similar way to a specific stressor. Two studies that used the same population of anemone fish, *Amphiprion melanopus,* (Fig. 1) to examine the potential for transgenerational acclimation to increased $CO_{2,}$ both of aerobic scope and of escape response to a predator, showed that whilst this species was fully able to acclimate its resting metabolic rate when exposed to a high $CO_2$ environment (Miller et al. 2012), full restoration of impairments in behaviour that occurred in response to this stressor were only observed for some traits (Allen et al. 2014). For other behaviours there was only partial restoration or none at all. This highlights the fact that whilst a major physiological measure may be able to acclimate to change, other more indirect causes of mortality may still be present.

Donelson et al. (2014), working with *A. Polyacanthus*, also compared acclimation of metabolic measures to increased temperatures, this time with that of repro-

**Figure 1.** *Amphiprion melanopus* has the capacity to acclimate its resting metabolic rate to increasing $CO_2$ levels over multiple generations, but shows a mixed capacity for behavioural acclimation. (Photo: Gabrielle Miller)

-ductive acclimation to the same stressor. While both measures showed a capacity to acclimate, the temperature at which this occurred differed between the two measures. Adult fish raised at +1.5˚C above their present-day temperature range showed no acclimation capacity for metabolic traits, but showed marked acclimation for reproductive traits. The proportion of pairs that reproduced, the number of eggs per clutch and the final reproductive output were all restored with acclimation. Conversely, at temperatures +3˚C above that normally experienced, the opposite was true; fish exhibited acclimation of resting metabolic rate but demonstrated little capacity for acclimation of reproductive attributes. This study suggests a thermal limit to acclimation of reproductive traits. The question remains as to whether these traits could acclimate over further generations, or whether reproductive ability would in fact be the limiting factor for this species if temperatures were to increase with climate change by more than 1.5˚C. These findings obviously have significant implications for the persistence of the species.

## Conclusions

Sheppard (2015) made an excellent point in the last issue of Reef Encounter when, on the topic of marine protected areas, he encouraged researchers to “push through, wherever and however you can, the big ideas”. We have to do the same thing for climate change science and push studies that explore the big issues, such as adaptation and acclimation, multiple measures, and variation in tolerance across species. In this piece I have discussed only issues that relate to the testing of a single stressor. The situation will become even more complex when considering the effects of multiple stressors acting simultaneously on a given species. The difficulty of the situation leads me to believe that it is not necessarily the science that is published fastest that will be of the most benefit, but the studies that are most comprehensive. Only by considering the issues outlined here will we be able to acquire a full understanding of the likely impacts of climate change on coral reef species and gain the knowledge required to manage our reefs into the future.

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# REEF CURRENTS

***General articles and overviews of reef science and management***

## Coral Populations on Subtropical Reefs Contain a Unique Genetic Diversity

### Annika Noreen

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In 2006 I received the International Society for Reef Studies/Ocean Conservancy Graduate Fellowship in support of my PhD research into coral diversity and connectivity at geographically peripheral, ecologically marginal reef locations in subtropical eastern Australia[1]. Understanding the genetic basis of maintenance of populations, such as the frequency and source(s) of immigration, genetic diversity, and level of inbreeding is an important part of assessing their vulnerability to climate changes and other impacts. The potential "core" source population for subtropical eastern Australia is the Great Barrier Reef (GBR), due to the southward flowing Eastern Australian Current. The Eastern Australian Current brings larvae to the subtropical reefs and coral communities that are both geographically isolated as well as ecologically marginal (ca. 18°C winter sea surface temperature in the subtropics compared to 22°C on the southern GBR, and an aragonite saturation state of ca. 3.3—the minimum for reef development—compared to ca. 4 on the southern GBR). This subtropical region is also expected to experience potentially antagonistic climate effects from increased sea surface temperature (Harrison et al. 2011), favorable for tropical organisms, concurrent with an increase in acidification which could favor subtropical organisms already adapted to lower pH (van Hooidonk et al. 2014). I investigated the genetic diversity and connectivity of corals, as well as other aspects - such as coral-symbiont associations, to provide a greater understanding of the potential resilience of high-latitude coral populations.

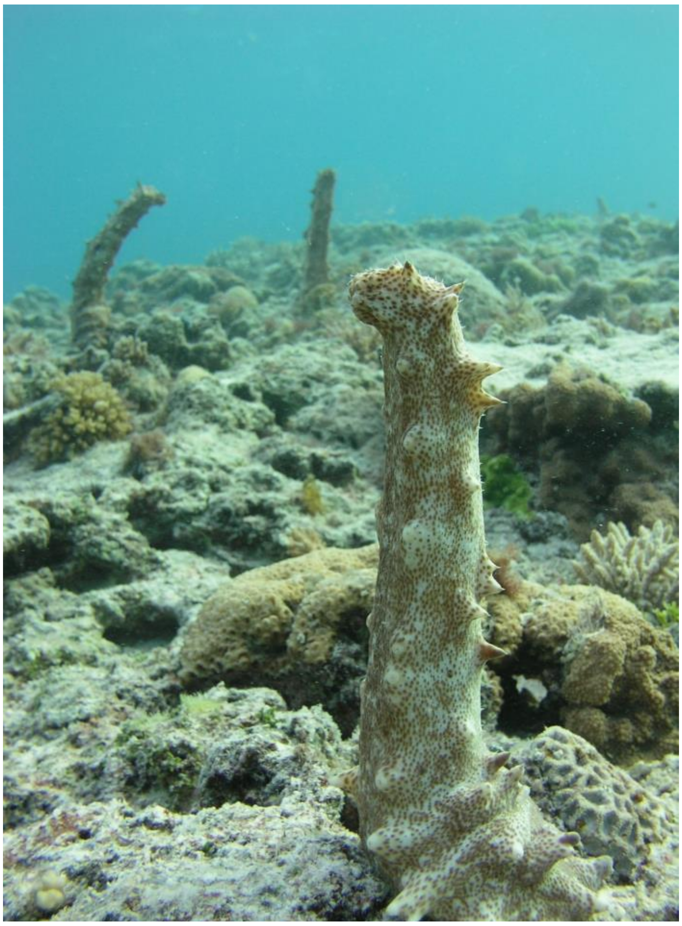

**Figure 1.** Pre-dusk spawning of sea cucumbers at Elizabeth Reef. Photo: Simon Hartley

I sampled corals at two coastal subtropical locations, three offshore subtropical reefs, and three southern GBR reefs (Figs. 1 & 2). The field work experience and results that I summarize here are particularly focused on the remote, offshore Middleton and Elizabeth reefs. When I started this work, no genetic data were available from these locations. However, it was known that the mix of

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[1] The work was undertaken while at Southern Cross University and the Australian Institute of Marine Science and under the supervision of Peter Harrison and Madeleine van Oppen

**Figure 2.** Map of sampling locations in this study. The Eastern Austalian Current is highlighted in orange. There are occasional coastal coral communities south of the Great Barrier Reef and between Flinders Reef and the Solitary Islands, but there are no other offshore subtropical reefs east of the Austalian mainland until Norfolk Island, ca. 900 km further east of Lord Howe Island and Middleton and Elizabeth reefs.

species present demonstrated connectivity from both the tropical north (as the southernmost record for a number of reef species) and the temperate south (as the northernmost record for a number of subtropical/temperate species), as well as significant isolation (i.e. the presence of a few narrow endemics from a variety of taxa, e.g. a coral, mollusc, and fish) (Noreen 2010 and references therein). Previous research on subtropical eastern Australian coral populations had been done at Lord Howe Island and several coastal sites (Ayre and Hughes 2004; Miller and Ayre 2008), but the potentially unique position of Middleton and Elizabeth reefs as a biogeographic transition zone made sampling at these locations imperative. I was able to secure a berth on the Department of Environment, Water, Heritage and the Arts trip to Middleton Reef and Elizabeth reefs in February 2007.

The Middleton and Elizabeth reefs are remarkable locations, largely due to the confluence of tropical, subtropical, and temperate species, besides which their remote location provides a natural defence against many direct anthropogenic pressures. These reefs contain shallow, extensive lagoons that provide a (relatively) warm and protected nursery area for Galapagos sharks. In one particular spot, we would surface from a dive to have dozens of young, curious Galapagos sharks in our midst. They brushed up against us and also took the occasional nip at our fins—rather unnerving behaviour from (what seemed like!) dozens of juvenile sharks. On another dive ending near dusk, dozens of foot-long sea cucumbers slowly rose up from the bottom, swaying, and spawned (Fig. 1). Perhaps most impressive was the number of large, aggressive black cod. They would approach without hesitation, very interested in my clear camera case (perhaps it resembled a jellyfish?) (Fig. 5). The presence of these massive, utterly fearless fish provided impressive evidence of what other reefs could be like without fishing pressure and other human impacts.

The scientific importance of Middleton and Elizabeth reefs parallels their unspoilt beauty and incredible wildlife, these two offshore subtropical reefs containing distinct populations of the corals *Seriatopora hystrix* and *Pocillopora damicornis*, respectively (Noreen et al. 2009; Noreen et al. 2015; Figs. 3 & 4). For *Seriatopora hystrix*, the high values of genetic differentiation (Fst values) between adjacent sites at Middleton and Elizabeth, and between the Middleton Reef lagoon site and Lord Howe Island, indicate genetically very distinct populations (Fig. 3). However, as this research was conducted using a type of genetic marker that does not resolve deep phylogenetic differences, further work involving sequencing will need to be done to confirm the number and identity of these types and place them in a larger Pacific-wide context (Warner et al. 2015).

For *Pocillopora*, mitochondrial DNA sequences showed both a 'tropical' *Pocillopora* genotype (i.e. *P. damicornis*) and a 'subtropical' genotype at the offshore reefs (Fig. 4). In addition, the symbionts on the GBR and offshore reefs could be classified into a Lord Howe Island profile, and two GBR profiles. The dominant GBR profile, named "GBR1", was detected as the sole symbiont type at the two southernmost GBR reefs and Flinders Reef and was also present at Elizabeth and Middleton reefs — ca. 1000 km south of the GBR and ca. 600 km south of Flinders Reef. The sole symbiont profile at Lord Howe Island was also detected at Middleton and Elizabeth reefs, and we detected the presence of the "GBR1" symbiont type in a "subtropical" type *Pocillopora*, and the "Lord Howe Island" symbiont type in a "GBR" type *Pocillopora* (Noreen et al. 2015). These results are highly suggestive of flexible coral-symbiont associations that may have important implications for adaptive potential, especially considering the increased acidification and sea surface temperature expected for this region.

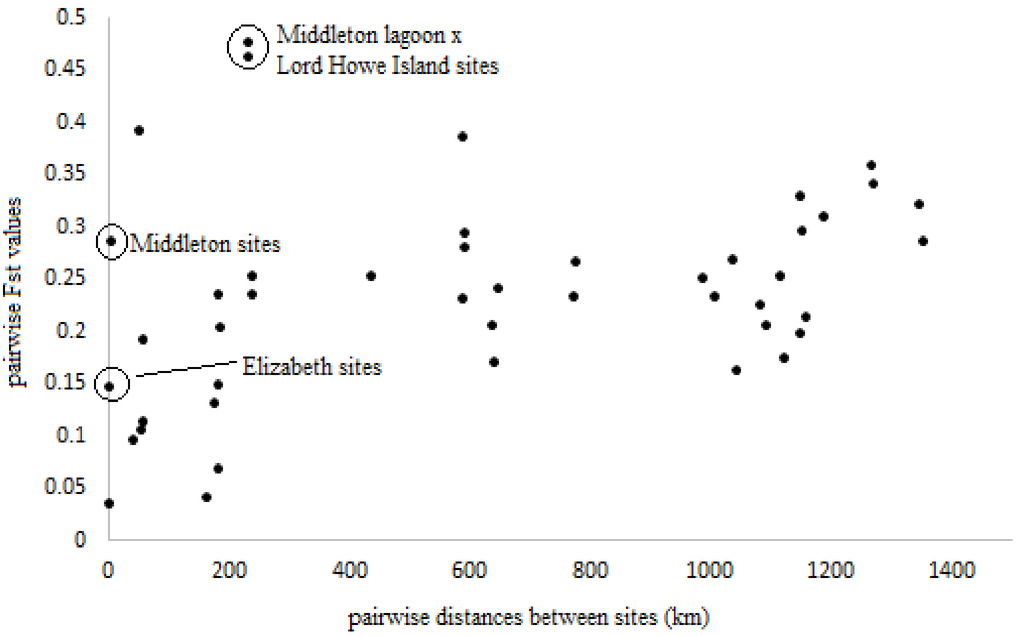

**Figure 4.** Pairwise Fst values (zero = no detectable genetic differentiation; 1 = extremely high genetic differentiation, e.g. different species) compared to pairwise distances between sites (in km) for the coral *Seriatopora hystrix* sampled at subtropical eastern Australian and southern GBR reefs (i.e. an isolation-by-distance plot). A characteristic isolation-by-distance plot would show increasing genetic differentiation with increasing geographic distance—a result not found in this species. The majority of pairwise Fst values were significant at $p < 0.001$: the highest values detected in this study were between the Middleton Reef lagoon site and the two Lord Howe Island sites (circled above), which are relatively close to each other over the geographic scale of the study. In addition, high and significant pairwise Fst values were detected between the Middleton Reef site pairs and Elizabeth Reef site pairs, both of which are <10 km apart (circled above).

The importance of the subtropical coastal region should also not be understated. A majority of the *Pocillopora* at the Solitary Islands have a divergent genotype compared to the sole mtDNA type (i.e. *P. damicornis*) detected at the southern GBR and Flinders Reef—the latter only being 330 km to the north of the Solitary Islands (Noreen et al. 2015; Fig. 6). The Solitary Islands have two unique symbiont profiles not detected elsewhere. The initial mtDNA results from Solitary Islands *Pocillopora* led to a detailed investigation of this population, and populations further south, by Sebastian Schmidt-Roach, resulting in the description of a new species, *Pocillopora aliciae* (Schmidt-Roach et al. 2013). Samples I collected for this present project were included in a detailed study and subsequent taxonomic revision of the genus *Pocillopora* within eastern Australia (Schmidt-Roach et al. 2012, 2014). In addition, samples of *Stylophora pistillata* collected at Lord Howe Island as part of my project were included in Keshavmurthy et al. (2013).

A low level of genetic connectivity via larval dispersal from the GBR to subtropical reefs is likely for both *Seriatopora hystrix* and *Pocillopora,* which may have mixed consequences. On the positive side, tropical immigration will increase effective population size and genetic diversity; however, it may also introduce maladapted alleles. In contrast, an exchange of migrants between two or more peripheral populations can be more beneficial to resilience than gene flow from a core region, as this would also increase effective population size and genetic diversity (similar to immigration from a core population), but could also increase fitness (Sexton et al. 2012). Gyres south of 32°S could transport larvae between the coast and offshore populations—a supposition supported by drifter drogue tracking devices (Wilson and Harrison 1998). However, given the small population sizes at subtropical reefs and coral communities and the vast distances of open ocean between them, trying to detect migration exclusively between subtropical locations required a special approach. We sampled a coral, *Acropora solitaryensis*, that is ecologically important and often numerous in subtropical eastern Australia but is extremely rare on the GBR. Genetic data from *A. solitaryensis* showed a strong likelihood of successful larval migration in both directions between the Solitary Islands and Lord Howe Island (Noreen et al. 2013).

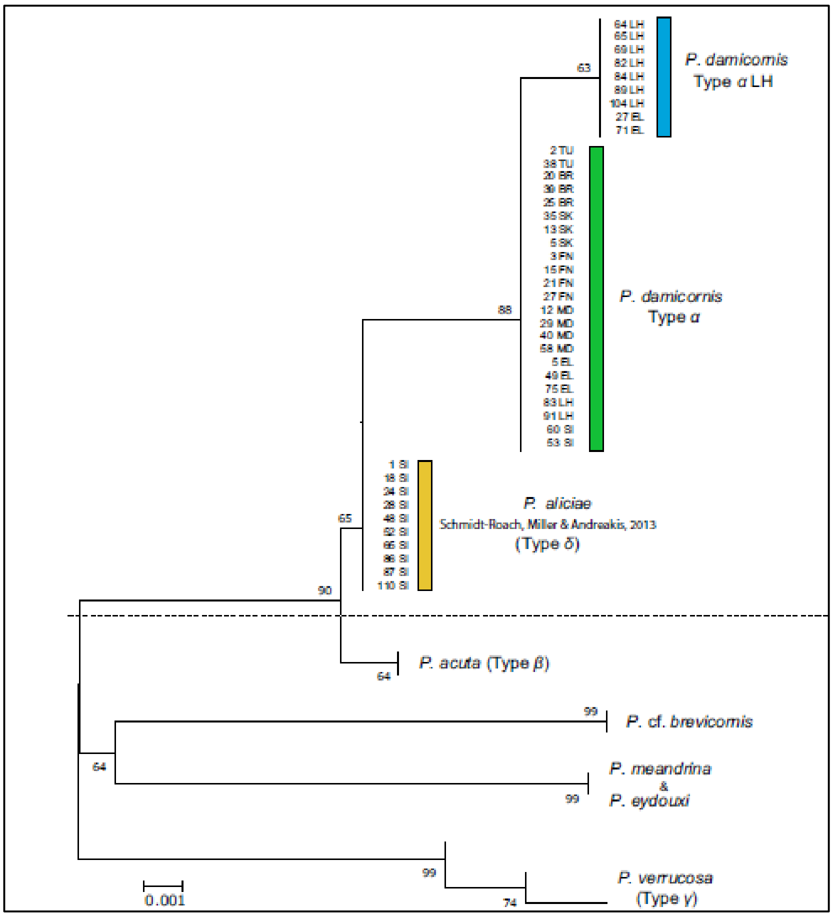

**Figure 3.** Mitochondrial DNA phylogeny of *Pocillopora* sampled in this study (above the dotted line) and outgroups (below the dotted line, consisting of several species found on the Great Barrier Reef but not present in subtropical eastern Australia). Samples in blue are the "Lord Howe Island" genotype that was detected at Lord Howe Island and Elizabeth Reef, and is likely present at Middleton Reef based on another genetic analysis (data not shown). The samples in green are the "Great Barrier Reef" type coral, *P. damicornis* Type α, which was detected at all locations sampled in different proportions (from 100% on the GBR and Flinders Reef to less than 5% at the Solitary Islands). Samples in orange are from the Solitary Islands. The data from this study spurred further research into the *Pocillopora* populations at the Solitary Islands, and populations to the south, which were described as a new species, *Pocillopora aliciae* (Schmidt-Roach et al. 2014). Figure taken in part from Noreen et al. (2015).

Occasional migration within the subtropical region would be vital for the continued maintenance of the relatively high diversity of the gene pool and also provide source population(s) for recolonization after a local extirpation. Focused sampling of *Acropora solitaryensis* inadvertently highlighted the vulnerability of these locations to regional extirpation, as I did not encounter a single *A. solitaryensis* at either Middleton Reef or Elizabeth Reef—a species which had been common until the massive crown-of-thorns outbreak in the 1980s (J.E.N. Veron, pers. comm.) This provides the strongest evidence yet that recolonization in this region likely occurs over extremely long time scales. We suggest that eventual recolonization of locally common species is likely after extirpation events, due to multiple source populations in the region and ocean currents that could bring larvae from one or more of these populations. The recent merging of Lord Howe Island Marine Park with Middleton and Elizabeth Reefs Marine National Nature Reserve to create a Lord Howe Commonwealth Marine Reserve reflects the inter-dependency of these reefs over an evolutionary time frame, and hence provides a context for managing framework to manage these reefs as a larger whole.

In summary, the ISRS/OC fellowship enabled me to document the vital importance of subtropical reefs as biogeographic transition zones that harbour both tropical and unique subtropical genetic diversity. I also found evidence from *Pocillopora* that this region contains important evolutionary novelty. However, the vulnerability of this region to local extinction events and the evidence for extended time scales for recolonization is also notable. In addition, some initial results from this project spurred more detailed research into coastal, subtropical *Pocillopora* populations by a fellow researcher; this resulted in the description of a new coral species, *Pocillopora aliciae* (Schmidt-Roach et al. 2013) and was part of a taxonomic revision of the genus in eastern Australia (Schmidt-Roach et al. 2014). Climate changes are expected to affect high-latitude reefs first, so further research into biogeographic transition zones could provide important insights into the genetic diversity, resilience and adaptive potential of their organisms.

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Peplow, Andy Muirhead, Simon Hartley, Paul Anderson, Greg Luker, Terry and Barbara Done, and many others who kindly provided assistance.

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**Figure 5.** Black cod *Epinephelus daemelii* at Middleton and Elizabeth reefs were large, aggressive, and very interested in my clear camera housing. Photo: Simon Hartley

# The Crinoid Paradox

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The status of coral reefs around the world is almost exclusively gauged by data on reef-building corals (live coverage, diversity, prevalence of diseases or bleaching), macroalgae (coverage, diversity), and fish (diversity, abundance). Long-term monitoring data on the myriad of other reef biota are quite scarce. Exceptions are population density of the echinoderms *Diadema antillarum* or *Acanthaster planci*, or the Queen Conch, *Lobatus gigas*. In most cases, as we are well aware, long-term trends in population density are declining. Gradual long-term or drastic increases are well known for macroalgae, lionfish or *A. planci*. Here I am calling attention to changes in population density of reef-dwelling comatulid crinoids ("feather stars", Echinodermata) on some western Atlantic reefs in Jamaica and the Netherlands Antilles, that are paradoxical as they are counter to long-term trends in the better-known indicators of coral coverage and fish abundance.

Feather stars are often common, large and conspicuous macroinvertebates living on coral reefs worldwide. In my experience, western Atlantic reefs have a maximum of around five species at depths of 10 – 30 m, while Indo-West Pacific reefs have up to 10 times the species diversity, with greater abundance than on the western Atlantic reefs at comparable depths (Messing 1994). Although some species are cryptic and nocturnally emergent, others are visible by day, perching on prominences on corals, sponges, or octocorals. In the late 1960s I embarked on a career-long quest to investigate the ecology and distribution of crinoids as a guide to understanding the paleobiology of ancient crinoids, well known in the marine fossil record as far back as the Early Paleozoic (>450 my). At my principal study sites in Curaçao and Jamaica, I obtained data on population density for the two most common comatulid species, *Davidaster rubiginosa* and *D. discoidea* (both formerly included in the genus *Nemaster* with its type species, *N. grandis*, for which I also had data from Curaçao; Meyer 1973a,b). During the 1980s and 1990s I made repeated research visits to Curaçao and Bonaire. In 1996, following an absence of seven years, I was alarmed to find a marked decline in *D. rubiginosa* and *D. discoidea* on both Curaçao and Bonaire. With graduate student help I resurveyed sites on the leeward reefs of both islands where I had quantitative transects and confirmed the initial "impression" that crinoid abundances were down, including virtual disappearance of the once most-common species, *D. discoidea* (Meyer et al. 2009). Exactly when this decline began, as well as its cause, remain undetermined, but it was sometime after 1989 and before 1996. There was a severe coral bleaching event in 1995 throughout the southern and western Caribbean (Nagelkerken 2006) suggesting that thermal stress might have been the culprit. It was very concerning to me, considering that crinoids had declined on both islands – Curaçao, with a much higher human population, industry, and coastal development, and Bonaire, with fewer people, almost no industry except tourism, and some of the best-protected coral reefs in the world.[2] Was this decline happening over the broader area of the Caribbean and tropical western Atlantic?

The reefs of Discovery Bay, Jamaica, were the other principal study sites from which I had crinoid population density data from 1968. With the support of the National Geographic Society I was able to make two trips to Discovery Bay in 2013 and 2014 to relocate and resurvey my original study sites. Because I had not been to Jamaica since 1972, I had no idea what I would find, and given the well-known impacts of *Diadema* die-off, hurricanes, coral disease and bleaching events, and chronic overfishing, I anticipated another drastic decline. I was able to relocate the same reef buttress on the shallow forereef terrace where I censused the crinoids in 1968. Despite the widespread evidence of the "phase shift" on this reef (absence of the once extensive *Acropora cervicornis* coverage, loss of large coral

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[2] In June, 2015, a group of divers working under a newly formed non-profit for reef education and conservation, "Reef Expeditions" (reefexpeditions.org) visited Bonaire and dived at numerous sites where I had recorded crinoids going back to 1970. No *D. rubiginosa* or *D. discoidea*, and only a few *N. grandis* were found.

colonies (*Orbicella, Diploria*) and extensive macroalgal coverage), I could see on the first dive that the two dominant crinoid species, *D. rubiginosa* and *D. discoidea*, were still very common along the seaward edge of the forereef terrace where they had been in 1968 (Fig. 1). Resurvey of this site over the same depths and comparable transect area confirmed that the density of *D. rubiginosa* is at least as great as in 1968, while that of *D. discoidea* has markedly increased about 6 times. Similar densities and distribution were found on several adjacent reef buttresses on the shallow forereef west of Discovery Bay and off Rio Bueno.

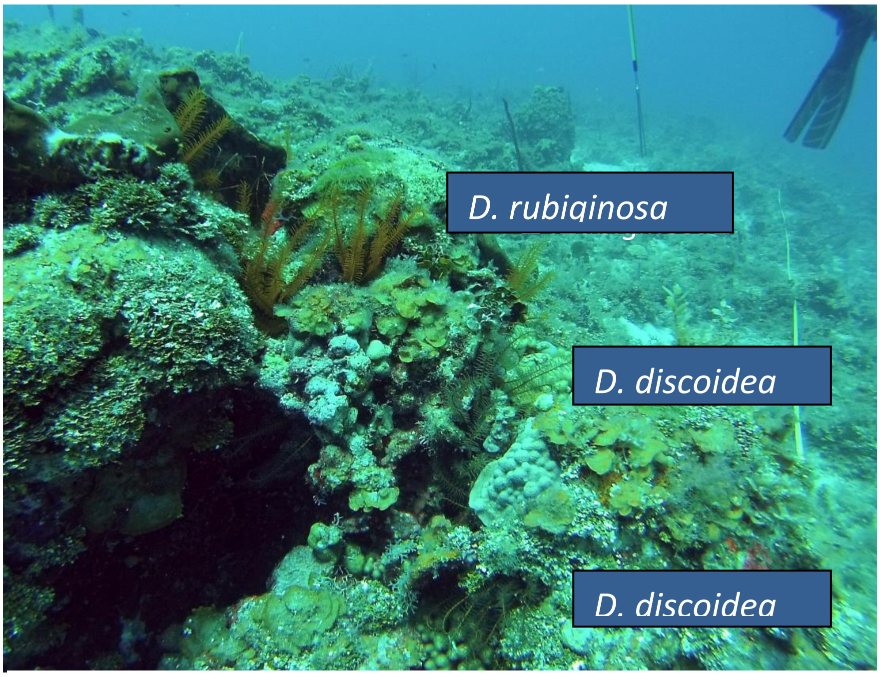

**Figure 1.** Crinoid cluster at seaward margin of forereef terrace, 15 m depth, Discovery Bay, Jamaica, 2013. Several *D. rubiginosa* at center and left of center; two *D. discoidea* lower right. Note encrustation by sponges (black) and macroalgae, also, tiering of crinoids: *D. rubiginosa* situated higher on promontory than *D. discoidea*.

The recent meta-analysis of Caribbean reefs (Jackson et al 2014) indicates that regions of the Caribbean differ in their percentage of live coral coverage, macroalgal coverage, and fish density. Some regions, such as the Netherlands Antilles, actually show coral coverage at over 30% and on the rise. Jamaica is among reef areas with still very low coral coverage and fish density, and very high macroalgal coverage. Thus, the combined results of my resurveys of the Netherlands Antilles and Jamaica crinoid populations show the exact opposite of the trends for the usual indicators of reef health (coral coverage and fish density). In the Netherlands Antilles, where coral coverage has not declined as severely as other regions, crinoids have declined, but in Jamaica, where some of the most severe reductions of coral coverage are known, crinoids appear to be more resilient.

How can these opposing trends be explained? Crinoids are aclonal, heterotrophic, passive suspension feeders, whereas reef-building corals are colonial and photosymbiotic (despite their fundamental nature as micro-predatory, suspension-feeding cnidarians), suggesting that different environmental factors, biotic and abiotic, must control the two groups. Thus far I have considered at least two working hypotheses to account for the different responses of crinoids in the two regions. First, severe, long-term overfishing in Jamaica may have reduced predation pressure on the crinoids. However, evidence for predation on mature Caribbean crinoids, such as damaged or regenerating arms and viscera is lacking, whereas these indicators are significantly stronger for Indo-West Pacific reef crinoids (Meyer 1985; Schneider 1988). Crinoids were absent from the extensive inventory of the food preferences of West Indian reef fishes by Randall (1967). It is possible that larval or juvenile crinoids could be limited by predation or grazing by benthivores, but there is no information available by which to test this possibility.

The second hypothesis is that suspension feeders like crinoids have benefited from an increased supply of suspended particulate organic carbon (POC) derived from the huge biomass of macroalgae dominating the exposed surface area. All studies of the food content of crinoids have noted a high proportion of organic detritus, as well as larger items of phyto- and zooplankton. One of these studies (LaTouche & West 1980) suggested that this detritus could provide a major source of nutrition, boosted by bacteria adhering to the POC. As a purely qualitative observation, underwater visibility has declined markedly since my earliest days of reef research in the late 60s. In Jamaica in 2013-14, there was very good visibility, on the order of 20-30 m, but I feel it was much greater in 1968, perhaps 50 m, in the days of "gin-clear waters" (how often do we hear that term used anymore?) Surely, an increased amount of suspended particulate matter, including POC, accounts for much of this increased turbidity.

Long ago it was suggested that reef sponges were benefiting from intake of extremely fine POC derived from breakup of excess mucus shed from corals (Reiswig, 1973). The myriad of other reef-dwelling suspension feeders could also exploit suspended POC over a wide range of particle sizes. Does the particulate matter derived from breakup of macroalgae provide a significant boost to the nutrition of reef crinoids and possibly other suspension feeders that might result in the increased abundance of recent years? Of course reefs where crinoids have declined, such as Curaçao and Bonaire, also have heavy macroalgal growth even though coral coverage is greater than in Jamaica. Could there be regional differences in the species composition of the macroalgae, with some species having greater nutritive value to crinoids?

**Figure 2.** *Davidaster rubginosa* (orange arms at center) surrounded by conspicuous black sponge, *Agelas dispar*. Shallow forereef terrace, ~15 m, Discovery Bay, Jamaica, 2013.

In Jamaica, in 2013-14, I noticed that sponges seemed to be quite diverse and as abundant as I recalled from earlier years, but one type of sponge caught my attention as being very common and conspicuous, cloaking dead coral heads and forming thick, projecting sheets behind which the feather star *D. rubiginosa* frequently attached with the arms extended (Fig. 2). Janie Wulff tentatively identified this sponge from my photos as *Agelas dispar*, a species that was historically common on the Discovery Bay reefs (J. Wulff, personal comm.) However, my photographs of the Jamaican crinoids from 1968 do not show them associated with this sponge on the same reef terrace, so I suspect they have increased in occurrence there. In this regard I was intrigued by the proposal from researchers in the Netherlands (DeGoeij, 2015) that reef sponges may be taking in *dissolved* organic matter (DOM) as a significant source of nutrition and converting it into particulate fecal pellets that in turn might benefit other suspension feeders. Could such an association be connected with increasing crinoid abundance? Answers to all these questions are going to require a lot more investigation of the trophic linkages among many components of reef communities. There may well be other explanations for the contrast in crinoid abundance compared to coral coverage between Jamaican and southern Caribbean reefs, and I would be very interested in any suggestions from readers.

If crinoids are showing resiliency where other indicators of reef health are ominous, this news should not necessarily be considered "good", as it may be a corollary of reef eutrophication. Ultimately, reef crinoids are bound to be dependent on the maintenance of reef framework and topographic relief. In the geologic past, crinoids associated with reefs have declined during times of extinction when their reef settings have collapsed. Finally, my saga points up the need for anyone who has historical quantitative data on relative abundance of reef organisms, particularly taxa beyond the range of typical reef surveys (focused on coral, fish and algae), as well as photographic or specimen-based documentation, to consider resurveying their original research sites. Not only do we need long-term, site-specific data for other components of reef communities, but also there may be other surprises to be found that may tell us a lot about how reef ecosystems are responding to long-term environmental changes.

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# Coral Reef Ecosystems and Biogenic Sulphur

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Coral reefs are important marine biodiversity hotspots, that offer refuge and nursery areas for a wide variety of pelagic and benthic organisms and provide crucial services (e.g. food, medicine, revenue, tourism) to millions of people around the world. They are also very sensitive to changes in their ocean setting, and they can also play an important role in regulating both marine and atmospheric conditions at local and regional scales. They produce biogenic sulphur compounds, which are involved in a range of processes that affect reef ecosystem function and influence cloud cover. The three important contributors to sulphur cycling by coral reefs are dimethyl sulphide (DMS), dimethyl sulphoniopropionate (DMSP) and dimethyl sulphoxide (DMSO) (collectively DMS/P/O).

### Dimethyl sulphide

Interest in DMS was triggered in 1987, when it was first suggested that atmospheric DMS oxidation products could act as cloud condensation nuclei (CCN), seeding the growth of new clouds or expanding the size of existing ones (Charlson et al. 1987). The CLAW hypothesis (named as an acronym for the surnames of the hypothesis proposers Charlson, Lovelock, Andreae and Warren) suggests that DMS production may be altered in response to changes in temperature and light. This process is explained in more detail later, but in short it is thought that DMS production is increased when marine algae produce more of its precursors, DMSP and DMSO, in response to elevated temperature or light, eventually resulting in an increase in seawater concentrations of DMS. The DMS produced by marine algae then fluxes from the oceans to the atmosphere, where it is oxidised to sulphate particles that act as cloud condensation nuclei (CCN); this leads to increased cloud cover, which promotes cooling (Fig. 1). However, if temperatures are lower, less DMS is produced and there is less cloud growth, resulting in net warming. This negative feedback loop (Fig. 1) thus potentially exerts an almost homeostatic control of earth's climate. Whilst the hypothesis is still hotly debated, it has spawned a generation of research into its various facets, improving our knowledge of marine sulphur cycling. More recently, research has suggested that corals are a significant source of these compounds and do, in fact, affect cloud cover at local and regional scales (Deschaseaux et al. 2012).

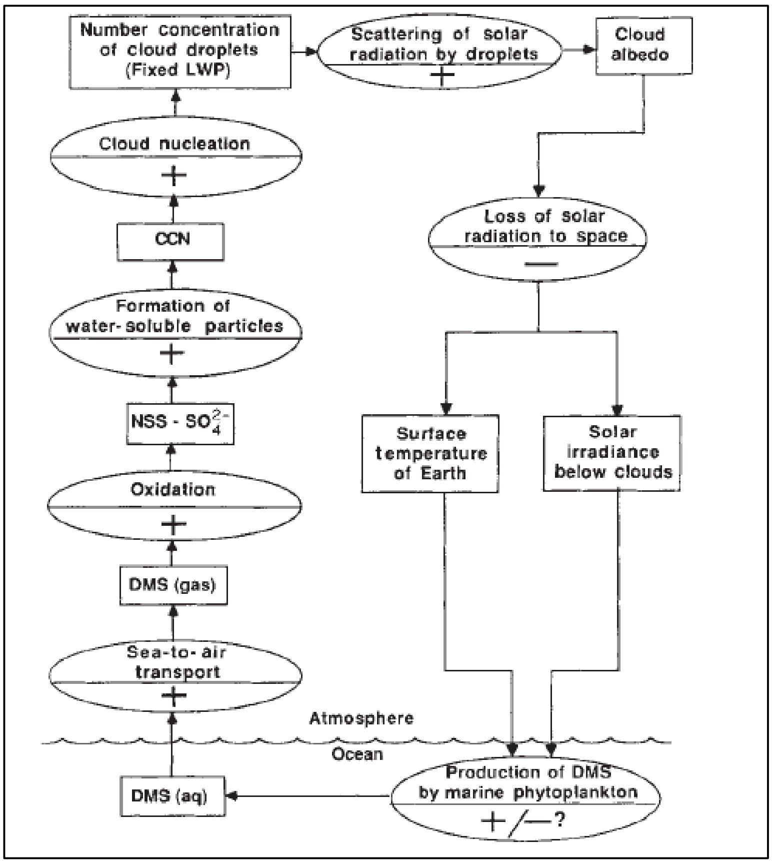

**Figure 1**: Conceptual diagram of the CLAW hypothesis. Rectangles are measureable quantities, and the ovals are processes linking the rectangles. Image taken from Charlson et al. (1987)

Since the CLAW hypothesis was first proposed, a great deal of research has focussed on production and removal of DMS in marine systems. We now know, for example, that DMS is not made directly by any marine organism. Instead, it is derived from two different sulphur compounds, DMSP and DMSO. Both compounds are produced by a variety of marine macro- and microalgae, with the highest intracellular concentrations being found in dinoflagellates, coccolithophores and diatoms (Hatton and Wilson 2007). The microalgae hosted by corals, *Symbiodinium,* are members of the dinoflagellate family, making coral reefs significant contributors of biogenic sulphur to the atmosphere. In addition to their role as precursors of DMS, DMSP and DMSO can act as osmolytes, enabling organisms to deal with living in a saline environment, and as antioxidants, providing protection from potentially harmful compounds or elevated temperatures and light (Sunda et al. 2002). Both DMSP and DMSO are typically upregulated in response to cellular stress induced by environmental factors such as changes in temperature, salinity, or light, and are therefore considered “stress compounds”, meaning changes in environmental conditions can alter the levels of each compound produced by marine algae (Sunda et al. 2002).

## The significance of DMS/P/O in coral reef systems

But if most people are concerned with the health of coral reefs and the effects of climate change on them, why are DMS/P/O so important? Most people have never heard of any of the compounds, and many of us would never think they exert any significant effect on climate that could rival carbon dioxide or methane (both carbon based compounds). However, there are several reasons we should be concerned about the production and cycling of DMS/P/O. First, the transport of DMS from the oceans back to land is a significant source of terrestrial sulphur, in itself, a vital element for cellular function, amino acids and DNA; sulphate aerosols derived from the oceans represent the largest source of sulphur back to land**.** In addition, DMS/P/O plays a pivotal role in ecosystem health and functioning of coral reefs. Moreover, DMSP has been shown to act as a chemoattractant for microbial species (Garren et al. 2014) and reef fishes (DeBose and Nevitt 2007). Finally, the impact of DMS/P/O is not limited to marine waters; previous reports have shown that air-borne DMS is part of an ‘olfactory landscape’, which can be detected by certain species of seabird in search of productive areas for foraging (Nevitt 2000).

Currently, investigations into the role played by marine derived sulphur compounds are limited and no studies have specifically included DMSO, which is a highly effective antioxidant (Sunda et al. 2002), occurring both in zooxanthellae cells and coral reef waters (Broadbent and Jones 2006). Investigations into its production under conditions of antioxidant stress (such as that caused by elevated temperature) could help improve our understanding not just of coral-reef sulphur biogeochemistry, but also of the mechanisms involved in coral bleaching. DMSP and DMSO concentrations, as well as thermal tolerance, vary considerably between *Symbiodinium* species. The ability of corals to deal with the changing environmental conditions forecast over this century, primarily increasing sea surface temperatures and declining seawater pH, is therefore likely to vary according to their algal associations and ability to produce sulphur based antioxidants.

### Production of DMS in marine systems

DMS production from DMSP and DMSO is achieved by bacteria, but DMS can also be converted back to DMSO both by bacteria and by photochemical reactions (del Valle et al. 2009). Bacteria capable of converting DMSP/O to DMS are ubiquitous in the marine environment, and the process occurs throughout the world's oceans at varying rates. Photochemical and bacterial transformation of DMS to DMSO is, unfortunately, less well understood, as DMSO has proven to be a difficult compound to measure accurately and precisely in oceanic samples (Hatton et al. 2004). But we do know that DMS can be converted to DMSO in high light environments in temperate/polar waters (del Valle et al. 2009). It is possible based on this evidence that this pathway may also be significant in coral reefs, which receive high levels of light, although more work needs to be done to establish if this pathway does exist in reef environments.

### Coral zooxanthellae and DMS/P/O production

*Symbiodinium* is a large and varied group of dinoflagellates (>400 species) and are capable of producing high intracellular concentrations of DMSP/O (Hatton and Wilson 2007). The nine phylogenetic *Symbiodinium* clades (each labelled with a letter A through I) are each comprised of a large number of different subclades (also known as phylotypes); corals associate predominantly with *Symbiodinium* in clades A-D. But they do not associate solely with one clade or phylotype; instead each coral may host phylotypes from all four clades in varying proportions (Silverstein et al. 2012).

Despite this complexity, there are some generally recognised biogeographic patterns in *Symbiodinium* distribution; clades A and B are more common in the Caribbean and tropical Atlantic, whilst tropical Indo-Pacific corals are dominated by clades C and D (Baker 2003). Physiological characteristics e.g. tolerance to temperature, have been ascribed in a very general sense to different clades. Clade C *Symbiodinium* may be more thermally sensitive than clade D algae, which have been reported to be the most thermally tolerant of all *Symbiodinium* clades (Baker 2003). We may reasonably expect that thermal stress will result in increased production of DMSP and DMSO, since both compounds are associated with the kind of cellular stress caused by elevated temperatures, and are produced in higher quantities under times of elevated temperature (Sunda et al. 2002). This has been shown to be the case in a few examples; DMSP concentrations are higher in a clade B *Symbiodinium* phylotype cultured under increased temperatures (McLenon and DiTullio 2012), and clade C *Symbiodinium* consistently produce more DMSP & DMS than clade D regardless of temperature (Deschaseaux et al. 2014). However, no correlation has been observed between DMSP and DMS production and thermal tolerance in four clade A and B phylotypes (Steinke et al. 2011). Since DMS production from DMSP is bacterially mediated, it seems that DMS production is not linearly correlated with DMSP production.

### Coral reef production of DMS/P/O

Research into coral reef production of DMS/P/O began ~30 years ago on the Great Barrier Reef (GBR) and since then a number of studies have shown that these compounds are present in and around reefs of the GBR (Jones et al. 2014 and references therein), often in greater concentrations that other oceanic non-reef environments. Sulphur compounds have not only been detected in coral, algae and reef waters on the GBR, but also in coral mucus, surface films and sediment pore waters (Broadbent and Jones 2004). Other studies into DMS/P/O outside the GBR have also supported the notion that globally coral reefs are a potentially significant source of these compounds (Yost et al. 2012; Burdett et al. 2013).

Of course, a coral reef is not exclusively composed of corals, and investigations into DMSP production by macroalgae in reef systems have also been conducted (Burdett et al. 2013). Interestingly, water column DMS/P concentrations are highest over areas containing predominantly seagrasses, macroalgae and phytoplankton, rather than corals (Burdett et al. 2013). Since macroalgal growth and photosynthesis rates increase under elevated [$CO_2$], this may mean that DMSP and DMSO production is increased at the cellular level, with a concomitant increase in DMS emissions to the atmosphere. Alternatively, it may be that since seagrasses and macroalgae fare better under elevated $CO_2$ conditions, there will be a proportional increase in DMS emitted from these reef systems to the atmosphere. At the moment, it is unclear which scenario will play out, and it is similarly unclear how this process will contribute to the tropical heat budget.

**Figure 2.** A coral juvenile (*Acropora tenuis*). Photo by Dirk Petersen

Perhaps the biggest development in sulphur biogeochemical research is the recent discovery that DMSP may also be produced by the coral animal (Fig. 2), as well its zooxanthellae. Raina et al. (2013) demonstrated that not only do coral juveniles produce DMSP in the absence of algal symbionts, but they also increase DMSP production when thermally stressed. This represents a particularly interesting focus for future research in coral reef ecosystems, and several questions remain. Do coral animals continue to produce DMSP as adults, do they also produce DMSO, what are the likely reasons for production of DMSP by the animal, and what effects does this have on the coral reef ecosystem? We clearly need to better understand the role of DMSP-producing animals.

## Summary and future work

Whilst great strides have been made in the field of coral sulphur biogeochemistry, and we know considerably more than we did even 10 years ago, there are still significant gaps in our knowledge. Coral reefs are significant producers of DMS/P, but our knowledge of the mechanisms and feedbacks associated with DMSO production is extremely limited. Future studies should investigate production of this compound at cellular, organism and ecosystem levels, not least because it may act as a stress biomarker as well as an indicator of coral health. Furthermore, geographically studies have mostly been limited to the Great Barrier Reef (Jones et al. 2014), with single studies in the Red Sea (Burdett et al. 2013) and Bermuda (Yost et al. 2012). Given the different *Symbiodinium* compositions of corals in these areas, and the variation in production of DMS/P/O at the cellular level, there remains a great deal to do in order to better understand sulphur cycling in reef systems globally. Our understanding of coral reef sulphur cycling is still in a relatively embryonic stage, but as we improve our knowledge of the processes involved, it is likely we will be better equipped to manage reef health, as well as gain a better understanding of the importance of these systems in climate control and sulphur cycling.

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# Modelling Climate-Change Effects on Coral Disease

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## Coral Reefs and Disease

Emerging-infectious diseases are threatening wildlife, domesticated livestock and crops, and human populations (Daszak et al. 2000). There is a clear scientific consensus that climate-change-related stressors, particularly rising global temperatures, have increased the risk of disease in most ecosystems (Harvell et al. 1999, 2002; Burge et al. 2014). Yet, in marine ecosystems in general, and on coral reefs in particular, there is an ongoing debate on the epizootiology and pathology of many coral diseases. There is still no general agreement on whether coral diseases are infectious or instead are opportunistic infections, and the nature of the etiological agents remain elusive (Lesser et al. 2007; Lesser and Jarett 2014). Thermal stress, caused by high sea-surface temperatures in combination with high irradiance, disrupts coral physiology, causes coral bleaching (Fitt et al. 2001, Lesser 2011), and is also a prerequisite for the occurrence of many coral diseases (Burge et al. 2014). Indeed, thermal stress potentially mediates coral disease by lowering host resistance, increasing pathogen abundance, increasing pathogen virulence, or through combinations of these responses (Bruno et al. 2007, Brandt and McManus 2009a, Sokolow 2009, Reed et al. 2010, Muller and van Woesik, 2014, Randall et al. 2014, Zvuloni et al. 2015). If there is any hope of ameliorating the effects of coral diseases, not only do we need to understand these diseases more thoroughly, but we also need to make accurate predictions of disease prevalence through modelling.

We should not expect, however, to increase our understanding of diseases through ‘big’ data-driven models, without a better understanding of key processes that drive diseases. Moreover, models are not necessarily a source of new knowledge. Instead, models are tools that allow us to capture the essence of our ‘best’ understanding of nature in a logical, universal framework using mathematics. As Box et al (1978) suggested; “All models are wrong but some are useful”. Useful models accurately predict biological patterns that are observable in nature, but only because they capture the key processes that we consider responsible for driving our system of interest. Without a predictive framework, however, results and conclusions are too often implied by the assumptions, and the argument is tautological (Peters 1976). There are multiple challenges to any modelling approach, including: (i) the complexity of the problem, (ii) the spatial and temporal heterogeneity of the environment, (iii) defining the appropriate scale of interest, and (iv) the quality of data used for model training and evaluation.

## Modelling Disease Dynamics on Coral Reefs

Despite considerable data showing that the prevalence of many coral diseases increased during the warmest months of the year (Burge et al. 2014), many modelling approaches do not include environmental factors as predictive variables (Brandt and McManus 2009b, Sokolow et al. 2009). Such models, although conceptually useful, have limited utility for predicting the ecological effects of coral disease under current models of climate change. Models of disease prevalence that include changes in the environment, such as increases in sea-surface temperature, reveal that thermal stress compromises host function and causes coral bleaching, which precedes most occurrences of coral disease (Maynard et al. 2011). Furthermore, several models have revealed that many coral diseases are not infectious, or that diseases within a coral population do not fit a contagious-disease model (Yee et al. 2011). Most studies are more consistent with the notion that disease prevalence is the result of exceeding environmental thresholds, which leads to opportunistic coral disease outbreaks (Muller and van Woesik 2012, Randall and van Woesik 2014).

Despite this evidence, and although there is a low prevalence of coral disease on many reefs e.g. <1% for *Montipora* white syndrome (Aeby et al. 2010), there is a fervent perception that infectious coral diseases are a significant, and primary factor causing the demise of coral populations around the world (Altizer et al. 2013, Burge et al. 2014). Germ theory has certainly helped us understand many diseases (Koch 1876), and there is a necessary equilibrium between the fitness of the host and the fitness of the infectious pathogens that cause disease. There is no evolutionary advantage in a pathogen exhibiting such high pathogenicity that it eliminates a local host population. We also are beginning to understand that the complexity of the coral microbiome is immense and varies significantly across species. Yet, opportunistic infections, which are not necessarily transmissible, may have evolutionary advantages over those with a need for a transmission vector and a specific host, especially in habitats that support low densities of hosts. Taken together, our understanding of the complexities of the interactions between hosts, pathogens, and the environment is rudimentary and is often species specific, and so does not permit broad generalizations entailing that all coral diseases are infectious and transmissible.

Recently, Maynard et al. (2015) developed a model of coral disease using three main parameters: (i) host susceptibility, (ii) pathogen abundance, and (iii) pathogen virulence. The authors then predicted a coral response under these parameters using a Representative Concentration Pathway (RCP) of 8.5 W $m^{-2}$ (~1370 ppm $CO_2$ equivalent, IPCC 2014) by the year 2100. The model output showed that coral disease will be as significant a driver of coral mortality as coral bleaching. We ask whether their model reflects our best understanding of the system by re-considering the parameter assumptions in Maynard et al. (2015).

Firstly, host susceptibility was assumed to be a function of temperature. More specifically, coral susceptibility was considered to be a function of degree heating weeks (DHW), derived from satellite temperature data. The concept of DHW (°C-weeks) is a well-known metric (Liu et al. 2003) that accumulates thermal stress, above a given average at a given locality, over a 12-week period. The values range from 0 to 16. Maynard et al. (2015) use the DHW value of 8 °C-weeks to define expected widespread bleaching and significant coral mortality. The authors then asked whether coral disease occurred earlier or later than this expectation. They suggested that disease is most likely by the time DHW values reach 4 °C-weeks, because it captures disease-permissive temperatures and sub-lethal bleaching. Using these parameters, sub-lethal bleaching and disease were 'predicted' to occur before mortality caused by bleaching. However, have we gained any predictive insight? Is this our best understanding of the system? Or, are the results simply tautological implications of the model constraints, showing us that 4 °C-weeks is more likely to lead to coral disease than 8 °C-weeks? Extreme-value theory already suggests that the probability of 4 °C-weeks is greater than 8 °C-weeks (Fuentes et al. 2013), and that the latter temperatures would cause the greatest physiological stress and bleaching in corals. While Maynard et al. (2015) suggested that stressful environmental conditions, such as elevated temperatures, lower access to energetic and other unnamed resources, and in turn lower resistance to disease, there is no empirical evidence available to support this premise, as none of the references provided by the authors quantify any of these parameters. There is also no inclusion in their model of seasonal (e.g., Donner 2011) or depth related thermal variation, adaptive variability in the response of corals (e.g., Logan et al. 2014), variability in coral community assemblages (e.g., Loya et al. 2001), and the potential independent and synergistic roles of irradiance. Irradiance is an essential component of the bleaching phenomenon (Fig. 1), both independently and in combination with increased ocean temperatures (Fitt et al. 2001, Lesser 2011). Integrating irradiance, such as with the NOAA Light Stress Damage product, into a predictive framework would significantly improve predictions of coral bleaching globally. While incorporating these parameters would add significant complexity to the model it would also add ecological realism.

Secondly, considering pathogen abundance, Maynard et al. (2015) depend on a single regional modelling study, by Heron et al. (2010), of one disease syndrome that does not include any data on actual pathogen abundance. Heron et al. (2010) simply estimated disease risk (of white syndrome) based on climatology and on past disease prevalence. Disease risk was extrapolated to represent pathogen abundance. There was no empirical data to support the assumption that pathogen loading does, or does not, occur under the conditions defined in the study. That is not to suggest that there are no data available that could be potentially informative. For example, Vezzulli et al. (2012) showed a long-term increase in planktonic *Vibrio* abundances that was associated with the rise in the temperature of the North Sea. *Vibrio* spp. have also been shown to increase in concentration during the warmest months of June to September (~3.4 x $10^4$, most probable number [MPN] $l^{-1}$), and then decline to undetectable concentrations from December to May in the Mediterranean Sea (Vezzulli et al. 2010). This increase in *Vibrio* spp., including *V. coralliilyticus,* in the water

**Figure 1.** Two colonies of *Seriatopora hystrix* on a shallow Philippine reef, during a thermal stress event. The *Seriatopora* colony (right) under the bleached corymbose *Acropora* colony has retained pigment, whereas the adjacent colony of *Seriatopora* (on the left) in full sunlight is bleached (Photo by R. van Woesik).

column of the Mediterranean Sea caused significant disease and mortality of a dominant coral. In diseased colonies, the concentrations of *Vibrio* spp. were $10^4$ cells $g^{-1}$ versus $10^3$ cells $g^{-1}$ in healthy corals (Vezzulli et al. 2010). In addition, both total *Vibrio* spp. abundance and the abundance of *V. coralliilyticus* increased in the coral *Pocillopora damicornis* when exposed to thermal stress (31°C), with highly variable concentrations of *V. coralliilyticus* averaging around $6.3 \times 10^4$ cells $cm^2$ (Tout et al. 2015). But these studies consider only one group of easily culturable bacteria in the ocean with several known, mostly opportunistic, pathogens.

Thirdly, Maynard et al. (2015) included pathogen virulence as a driving parameter of their model. The approach taken by the authors is that the traits of one potential pathogen, *Vibrio coralliilyticus,* can be generalized to all coral diseases. In particular, the infection studies quoted by the authors use $10^6$-$10^7$ cells $ml^{-1}$ to induce infection (e.g., Sussman et al. 2008, Ushijima et al. 2012), which is a 100-fold greater concentration than in the field records discussed above. Also, the calculation of the integrated-local threat metric (ILT), cited in Maynard et al. (2015), is not well described in the original reference, and it is unclear whether the citation was peer reviewed despite statements that it was from the source. The components of the metric itself, a categorical index based on coastal development, watershed-based pollution, marine-based pollution and damage, and overfishing and destructive fishing also appears to be additive in nature and does not consider the possible synergisms between these factors.

## The Case for Improving Models of Coral Disease and their Predictive Power

Taken together, the model presented by Maynard et al. (2015) is not generalizable, does not identify the model limitations, and better reflects one potential disease, on a limited number of coral species, within a specific region. Despite the authors' contentions, the model does not improve early-warning capabilities of detecting coral disease, because the approach is tautological, and the system simply behaved according to the explicit premises. So, what will improve our early warning capacity? We need a clear understanding of species-level coral holobiont response to temperature and irradiance stress. We also need a more thorough understanding of pathogen dynamics and virulence in response to dynamic environmental conditions, ideally based on studies conducted under controlled conditions prior to making *in situ* predictions. We should also consider alternative paradigms in which not all coral diseases are infectious and transmissible. A corollary of such a paradigm is the need to know which opportunistic pathogens are present, and how they respond to environmental changes. Most importantly, we need a suite of useful models that will accurately predict the response of coral populations to ocean warming so that risk estimates are clearly defined, and conservation decisions become beneficial.

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# Investissement Privé et Gestion des Récifs Coralliens: un nouveau couple?

## (Private investment and coral reef management: a new couple?)

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De nombreuses études récentes ont confirmé que le financement total pour les aires protégées et conservation de la biodiversité doit être augmenté de façon spectaculaire pour atteindre les objectifs fixés au niveau national ou international (par exemple, les objectifs de la CDB d'Aichi (Pascal et al. 2014b)).

Aujourd'hui, 80% du financement de la biodiversité est généré à partir de mécanismes non-marchands (Parker et al. Éd. 2012). À l'exception de la philanthropie, les mécanismes non-marchands sont des mécanismes du secteur public qui ont recours à la réglementation pour leur mise en œuvre. Ils couvrent des allocations budgétaires internes, des aides publiques au développement, les échanges dette-nature (« swaps ») et les réformes de certaines subventions. L'allocation des finances publiques est cependant avant tout une question de volonté politique (et d'opinion publique) et ces mécanismes ont donc tendance à varier en fonction de cycles politiques.

Bien que ces mécanismes devront s’intensifier à l'avenir, les financements en provenance des marchés présentent un grand potentiel de croissance. Certaines études montrent que les mécanismes fondés sur le marché pourraient générer jusqu'à 50% du financement de la biodiversité en 2025 (Parker et al, Éd. 2012). À long terme, des sources fiables de financement de marché pour la conservation de la biodiversité doivent être établies et renforcées (Forest Trends et Le Groupe Katoomba 2010).

Les recommandations récentes de la Convention sur la Biodiversité (CBD) identifient l’exploration de mécanismes financiers innovants pour soutenir les trois objectifs de la Convention. Sept domaines d'innovations financières ont été énoncées et 5 d'entre eux concernent le financement privé: les paiements pour services écosystémiques (PSE); les mécanismes de compensation de la biodiversité; les marchés pour les produits verts; les partenariats entreprise-biodiversité et les nouvelles formes des fonds de dotations.

La plupart des mécanismes de financement de la conservation doivent être adaptés à l'environnement marin, où les droits de propriété sont limités (ou remplacés par des droits d'accès) et où les biens “communs” nécessitent un accès continu. En termes de profil de risque pour les investisseurs, ce manque de droits habituels de propriété est une question importante qui doit être adressée comme une priorité.

L'environnement marin et côtier dispose de très peu d'expériences pratiques des mécanismes de financement de la biodiversité (Pascal et al. 2014A) et l'une des principales priorités pour les prochaines années est de fournir des expériences empiriques des mécanismes de financement non-public pour la gestion intégrée des zones côtières (GIZC).

Le véritable potentiel des divers instruments financiers doit encore être prouvé à travers de la génération de flux financiers concrets de la part du secteur privé (comme par exemple, les aires marines protégées entrepreneuriales (Bush et al. 2015; Teh et al. 2007). En ce sens, la perspective de l'investisseur doit être analysée pour lui proposer des possibilités de financement concrètes ainsi que des modèles d'affaires attractifs.

Sur la base des activités en cours du projet Blue-finance (2014-2019), dédié au développement d’instruments financiers pour la conservation marine, les résultats préliminaires suivants ont été trouvés:

(i) Les bénéficiaires des services écosystémiques (SE) des récifs coralliens avec une capacité potentielle de paiement sont principalement l'industrie du tourisme, les utilisateurs finaux, les propriétaires immobiliers et les investisseurs avec impact.
(ii) Ces bénéficiaires pourraient investir, avec profit, pour améliorer les SE de la beauté scénique, la protection du littoral (contre les inondations côtières et l'érosion des plages) et la production de biomasse des poissons.
(iii) Les modèles d'affaires pour rendre le projet « investissable » doivent maintenant être testés empiriquement.
(iv) Des accords avec le secteur public, grâce à des partenariats public-privé (PPP), doivent définir clairement la gestion des fonds, les obligations de chaque partie ainsi que les règles de propriété ou d'accès. Ceci est une étape préliminaire importante qui doit être définie avant de concevoir des paiements pour services écosystémiques (PSE) ou d'autres mécanismes financiers.

En ce qui concerne les modèles d'affaires, leur but est de fournir des financements qui couvriront les investissements initiaux et le coût de la gestion des activités de la GIZC. Étant donné le stade précoce de développement de ces investissements dans la conservation marine, les investisseurs initiaux comprendront des individus “à grande fortune” ainsi que le secteur de la « nouvelle philanthropie ». Chacun de ces groupes a ses propres attentes en terme de risque-rendement, d'exigences de liquidité, d'horizons d'investissements et de préférences de produits d'investissement.

Les partenariats public-privé (PPP) peuvent apporter des éléments de solution pour les spécificités du milieu marin. Ce sont des accords entre le gouvernement et le secteur privé qui permettent le partage du financement, de l'expertise, et l'accès à la technologie et des ressources. Leur but est de définir une certaine forme de privatisation de la gestion de l'espace marin. Ils peuvent prendre un large éventail de formes, qui varient dans le degré de participation de l'entité privée dans une infrastructure traditionnellement public. Un PPP est généralement commémorée dans un contrat à long terme (plus de 10 ans), qui décrit les responsabilités de chaque partie et attribue clairement le partage du risque.

5 principales catégories d'accords ont été sélectionnés comme ayant le plus grand potentiel pour les récifs coralliens: organisme parapublic, contrats de gestion, contrats de location, concessions et des entreprises mixtes. Les objectifs sont de rechercher un équilibre entre la conservation de la biodiversité et le rendement financier (Delmon 2010).

Certains de ces concepts sont à l'étude dans le projet Bluefinance (www.blue-finance.org), coordonné par le SPAW-RAC (http://www.car-spaw-rac.org) et GRID ARENDAL (http://www.grida.no). Bluefinance représente un portefeuille de projets qui visent le développement de mécanismes de financement pour leur conservation et leur gestion. Le projet Blue-finance est financé principalement par le Programme des Nations Unies pour l'environnement (PNUE), le projet BlueSolutions-GIZ (http://bluesolutions.info) et l'Organisation des États américains (www.oas.org).

Les sites de démonstration sont à la Barbade, la Colombie, la Croatie, la Martinique et Tahiti. Une approche similaire est mise en œuvre dans chaque site; développer des modèles d'affaires avec le secteur privé équilibrant résultats financiers avec les objectifs de conservation. À la Barbade, par exemple, une île avec une forte dépendance sur l'industrie du tourisme et un secteur touristique extrêmement bien informé et actif, l'accent est mis sur un PPP avec ce secteur pour la gestion des Aires Marines Protégées.

La mise en œuvre démontrera le potentiel de ces instruments avant d'envisager leur application à plus grande échelle et la réplication dans d'autres pays. Plus précisément, il est prévu que ces expériences contribueront à la mise à jour des directives existantes sur les PSE, les PPP et les concessions de tourisme pour soutenir leur utilisation accrue dans les écosystèmes coralliens.

*English language translation:*
Many recent studies have confirmed that total funding for protected areas and biodiversity conservation has to be increased dramatically to achieve the targets set at national or international levels e.g. CBD Aichi targets (Pascal et al. 2014b).

Today, 80% of biodiversity finance is generated from non-market mechanisms (Parker et al. 2012). With the exception of philanthropy, non-market mechanisms are public sector mechanisms relying on regulation for their implementation. They cover domestic budget allocation, Official Development Assistance (ODA), debt-for-nature swaps and subsidies reform. The allocation of public finance is primarily a question of political will (and public opinion) and these mechanisms therefore tend to vary with political cycles. Although these mechanisms could scale-up in the future, market-based mechanisms have a greater potential to increase in scale. Market-based mechanisms could generate up to 50% of biodiversity finance for coral reefs by 2020 (Parker et al, ed. 2012). Long-term, reliable sources of market financing for biodiversity conservation must be established and strengthened (Forest Trends and The Katoomba Group 2010).

Instruments for conservation finance are diverse and several classifications, such as tools to internalize the damages and profits, based on the "polluter-pays" or "beneficiary pays" principle, environmental taxes, taxation of contamination and compensatory measures of impacts (avoid-reduce-compensate sequence), have been proposed (TEEB 2010; UNEP 2006). Recent recommendations from the CBD identify exploring new and innovative financial mechanisms at all levels with a view to increasing funding to support the three objectives of the Convention. Seven areas of financial innovations have been set out and five of them concern private finance: schemes for payment for ecosystem services; biodiversity offset mechanisms; markets for green products; business-biodiversity partnerships and new forms of charity; development of new and innovative sources of international development finance.

Most of the conservation finance mechanisms have to be adapted to the marine environment, where property rights are limited (or replaced by access rights) and where common pool resources necessitate continued access. In terms of risk profile for investors this lack of conventional property rights is an important issue and needs to be addressed as a priority. The marine and coastal environment has very few practical experiences of mechanisms to finance biodiversity (Pascal et al. 2014a) and one of the main priorities for the coming years is to provide empirical experiences of non-public funding mechanisms for integrated coastal management (ICM).

The real potential of various non-public financial instruments for sustainable long-term financing of ICM has still to be proven though concrete financial flows from the private sector (e.g. Entrepreneurial Marine Protected Areas (Bush et al. 2015; Teh et al. 2007). In that sense, the investor perspective has to be analysed to propose concrete funding opportunities to the supply side. From on-going activities of the Blue-finance project (2014-2019), the following preliminary results have been found:

(i) Coral reef ES beneficiaries with potential payment capacity are mainly the tourism industry, end-users, real estate owners and impact investors.
(ii) These beneficiaries might invest with profit to enhance the ES of scenic beauty, coastal protection (against coastal flood and beach erosion) and fish biomass.
(iii) Business models to make the project investable must now be tested in the field.
(iv) Agreement with the public sector, through Public-private partnerships (PPPs), must define clearly the management of funds, the obligations of each part as well as marine tenure rules. This is a preliminary step that must be defined before designing PES or other financial mechanisms.

Regarding business models, their aim is to provide funding for the initial investment and the management costs of the ICM activities - through classic financing (e.g. equity, debt, Tourism User fees) and some innovations (e.g. Payment for Ecosystem Services, bio-banking). Given the early stage of development of investment opportunities in marine conservation, initial investors targeted will include local high-net-worth individuals, as well as venture philanthropists. Each of these groups has its own risk-return expectations, liquidity exigencies, investment horizons, ticket sizes and investment product preferences.

Public-private partnerships (PPPs) can be part of the solution. They are agreements between government and the private sector that allow sharing of funding, expertise, and access to technology and resources, and often end up leveraging significant new funds and interest in and for conservation. Their aim is to define some form of privatization of protected area management and they can take a wide range of forms, which vary in the degree of involvement of the private entity in a traditionally public infrastructure. A PPP is generally memorialized in a long term contract or agreement (over 10 years), which outlines the responsibilities of each party and clearly allocates risk.

Five main categories of agreements have been selected as having the greatest potential for coral reef ICM: parastatal agency, management contracts, leases, concessions and joint ventures. Which agreement will ultimately be used will be decided via negotiations between the public and private stakeholders. The objective is to obtain a **balance between biodiversity conservation and business enhancement** (Delmon, 2010).

Some of these concepts are being explored in the Bluefinance project, which is coordinated by SPAW-RAC (http://www.car-spaw-rac.org) and GRID ARENDAL (http://www.grida.no). Bluefinance represents a portfolio of projects which aim to develop financing mechanisms for marine conservation and management. The Bluefinance project is funded primarily by the United Nations Environmental Programme (UNEP), GRID ARENDAL BlueSolutions (http://bluesolutions.info) and the Organisation of American States (OAS) (www.oas.org).

Demonstration sites are in Barbados, Croatia, Colombia, Martinique and Tahiti. A similar approach is taken in each site : developing challenging business models with private sector balancing financial bottom line with conservation objectives. In Barbados, for example, an island with a heavy reliance on the Tourism Industry and an extremely well informed and active tourism sector, the focus is on utilising this sector in the management of marine areas and involving them in a PES system with the Fishers. Implementation will demonstrate the potential of these instruments in a coral reef setting, prior to considering their application at a larger scale and replication in other countries. More precisely, it is expected that the experience of these projects will contribute to updating existing guidance on PES, PPPs and tourism concessions to support their increased use in coral reef areas.

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# iSeahorse: seahorse conservation through citizen science

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## Context

Urgent action is needed to track and protect seahorse populations around the world — and the few researchers focused on these important animals worldwide are not going be able to do it alone. Seahorses are threatened by overfishing, harmful fishing practices, and habitat degradation and loss — including the destruction of coral reefs. Every year, 15 to 20 million seahorses are caught and then traded, dead and alive, all over the world. They are displayed in aquariums, used as ingredients in traditional medicine, and turned into curios. Seahorses inhabit coral reefs, seagrasses, mangroves, and other coastal marine ecosystems that are highly affected by human activities leading to habitat destruction, while overfishing adds more pressure as large quantities of seahorses are captured as bycatch (Fig. 1).

To date, 12 seahorse species are listed as threatened in the IUCN Red List of Threatened Species, while 27 species are listed as ‘Data Deficient,’ meaning we simply do not have enough information to assess their conservation status (see review papers by Foster and Vincent 2004 and Vincent et al. 2011, and references therein, for supporting information.)

The problem is enormous, yet globally there are fewer than two dozen scientists dedicated to studying these animals in the wild. Scientists simply don’t have the resources to determine where most populations are or what’s happening to them. As a result, conservationists, governments and local communities lack the information they need to take effective action to protect seahorses.

**Figure 1.** Seahorse caught as bycatch. Photo by S. Foster/Project Seahorse

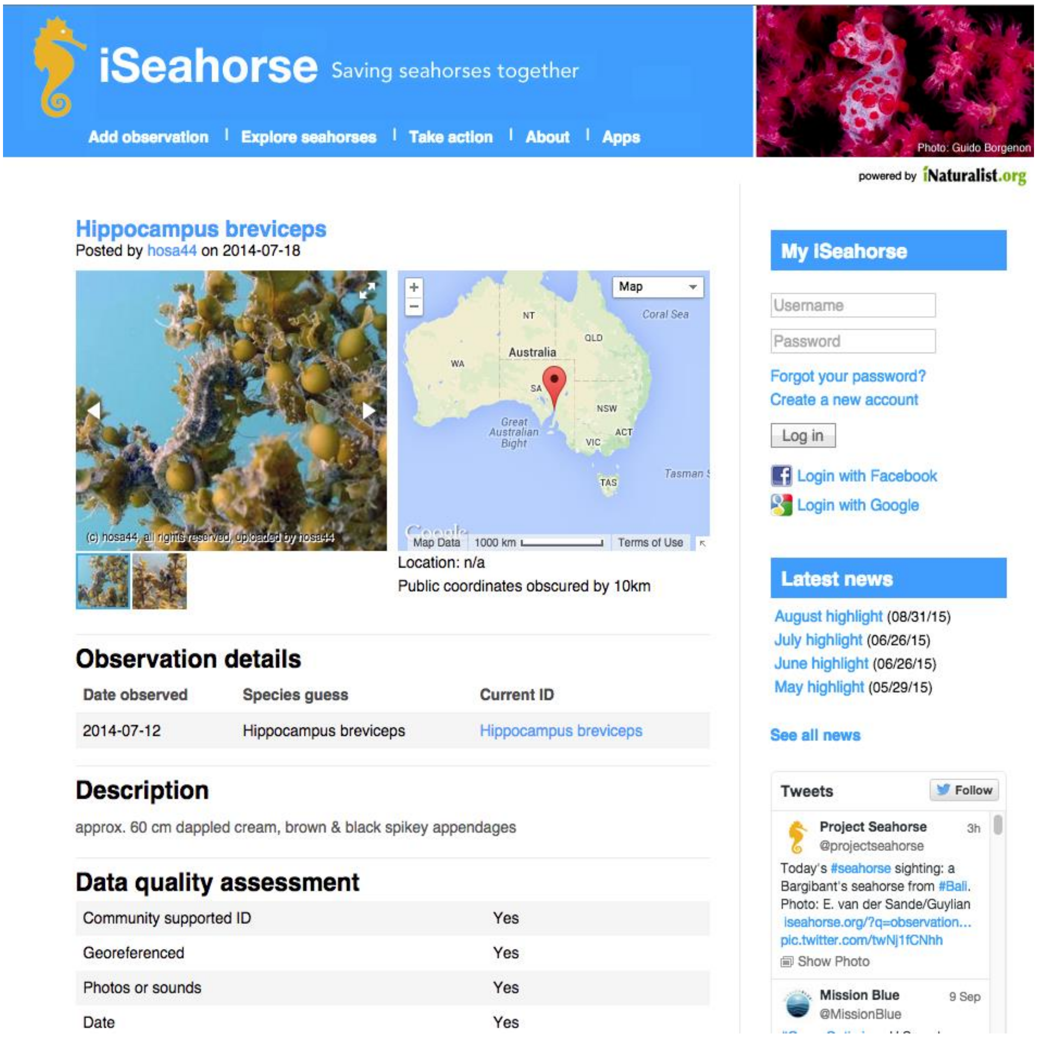
Fortunately, the rise of smartphone technology and data gathering apps has made it possible to create a global network of seahorse citizen scientists and conservationists — a combination of experts and non-experts working together to secure a future for these charismatic species. That’s where iSeahorse comes in.

## What is iSeahorse?

iSeahorse is a web tool and smartphone app that harnesses the power of citizen science to expand our understanding of seahorses, so we can better protect them. Created by Project Seahorse, the IUCN global authority on seahorses and their relatives, iSeahorse allows anyone, anywhere in the world — whether you're a diver, a fisher, a seahorse enthusiast, or a reef scientist who occasionally sees seahorses during fieldwork — to submit observations about seahorses in the wild, including images and location and habitat data. Users can share their sightings via the website (http://iseahorse.org) or the app, which is available for download at http://iseahorse.org/apps.

Once submitted, observations are available for the user community to view. Other users can provide assistance with species identifications, which are also actively vetted by Project Seahorse staff. Ultimately, sightings become part of a growing global database that is accessible to scientists and conservationists around the world, and will be used to create and improve conservation measures, such as new legal protections and marine protected areas.

iSeahorse isn't only a tool for citizen science and conservation. It's also a community of researchers, citizen scientists, conservationists, and more, all working to increase our understanding of these important animals and protect the marine ecosystems they call home.



Hippocampus breviceps
Posted by hosa44 on 2014-07-18

Location: n/a
Public coordinates obscured by 10km

Observation details

| Date observed | Species guess | Current ID |
|---|---|---|
| 2014-07-12 | Hippocampus breviceps | Hippocampus breviceps |

Description

approx. 60 cm dappled cream, brown & black spikey appendages

Data quality assessment

| | |
|---|---|
| Community supported ID | Yes |
| Georeferenced | Yes |
| Photos or sounds | Yes |
| Date | Yes |

August highlight (08/31/15)
July highlight (06/26/15)
June highlight (06/26/15)
May highlight (05/29/15)

Project Seahorse @projectseahorse 3h
Today's #seahorse sighting: a Bargibant's seahorse from #Bali. Photo: E. van der Sande/Guylian iseahorse.org/?q=observation... pic.twitter.com/twNj1fCNhh

Mission Blue @MissionBlue 9 Sep

**Figure 2.** Screen capture of a user-submitted observation on http://iSeahorse.org

**A global early warning network for seahorse conservation**

This year, iSeahorse has expanded to include a population trends monitoring program (http://iseahorse.org/trends-underwater), which will help to assess seahorse population changes over time and prioritize areas for conservation action. Interested individuals who dive or carry out research in areas where seahorses are found — especially coral reefs, seagrasses, and mangrove forests — are invited to get in touch via email at iseahorse@projectseahorse.org. With your help, we can establish a truly global network of monitors poised to raise the alarm when there are sudden changes in local seahorse numbers or habitat.

A PADI Seahorse Distinctive Specialty is also available and teaches divers how to identify and search for seahorses, and the many actions divers can take to secure sustainable seahorse populations. Interested divers can contact Lindsay Aylesworth (l.aylesworth@projectseahorse.org) for more information.

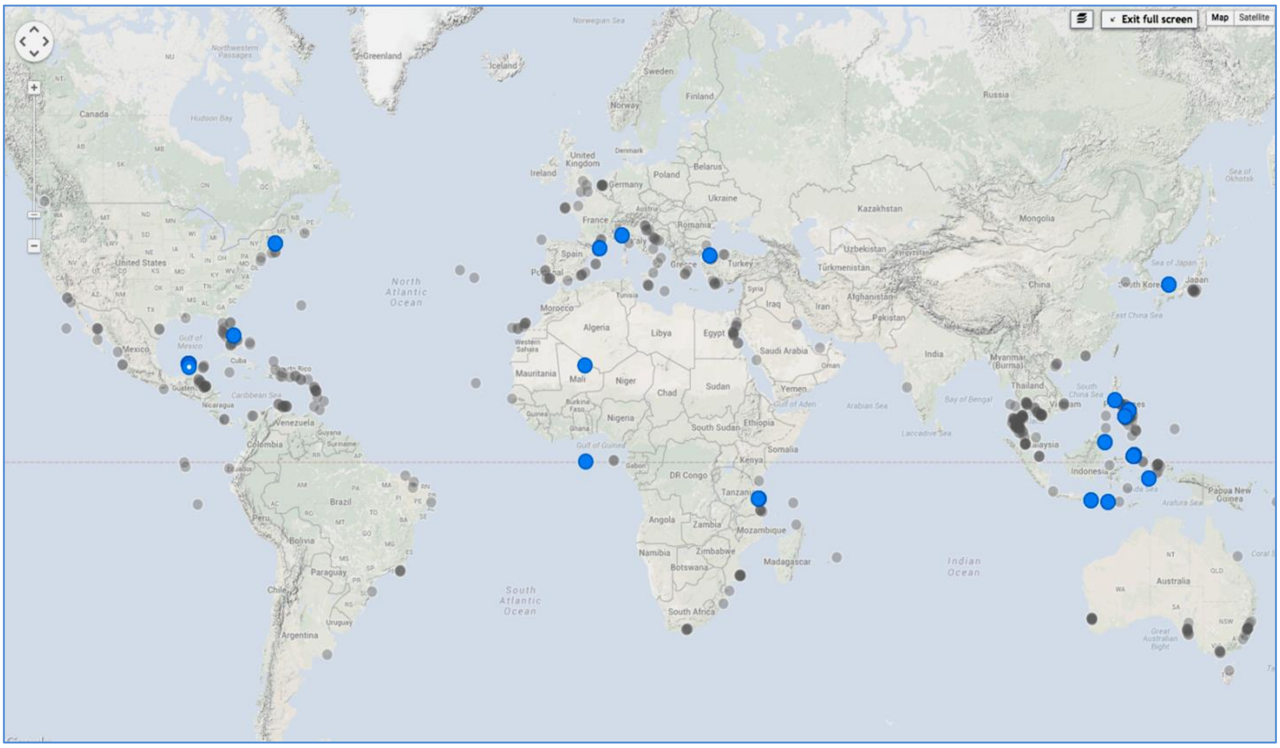


**Figure 3.** A comprehensive map of all user-submitted wild seahorse observations on http://iSeahorse.org. Blue dots show most recent sightings. Grey dots show clusters of older sightings. The darker the dot, the more sightings in the area.

## Progress so far

The past six months have been the best so far for our iSeahorse program. We've redoubled our outreach efforts to recruit citizen scientists and dedicated seahorse population monitors. In addition to our usual targeted outreach via traditional and social media, we've begun to recruit at dive expos and reach out to zoo and aquarium partners around the world. As a result, iSeahorse has, since January, reached a number of exciting milestones:

- 1612 wild seahorse sightings (current as of 11 September 2015), with over 700 added in 2015 — a nearly 100% increase over the previous 15 months.
- 324 contributing users
- 15% of all sightings have occurred out of the species' known geographical range; these discoveries will have an impact on the management and conservation of populations.
- We've confirmed sightings of a number of rarely seen seahorse species, including *Hippocampus angustus*, *H. borboniensis, H. camelopardalis and H. coronatus*.

Most important, nine population 'trends' monitors are now actively tracking at-risk seahorse populations and habitats in Mozambique (x 2), Tanzania, Spain, Australia, Cambodia, Thailand (x 2), and the Philippines. Our plan to build an early warning system for seahorse conservation is coming to fruition, with these and many more trends monitors poised to raise the alarm wherever and whenever seahorse populations are threatened.

If you dive or work in an area where seahorses are found, and would like to contribute seahorse sightings or become a population trends monitor, we would love to hear from you!

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# REEF EDGE

*Scientific letters or notes describing observations or data*

## Carbonate budgets of coral reefs: recent developments in excavating sponge research

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Carbonate budgets of coral reefs are maintained by the balance of calcification, decalcification and the export of detrital materials from the reefs. The first two processes are largely biologically driven, with biological decalcification being defined here as bioerosion and carried out by a wide range of bioeroders from microbes to vertebrates (Neumann 1966; Glynn 1997; Wisshak and Tapanila 2008). Bioerosion plays an important role, as it counteracts carbonate production and thus affects the regulation of biological factors in reef carbonate budgets. However, coral reef research has largely focused on calcification, while the importance of bioerosion was often ignored or investigated to a far lesser extent. The four examples below illustrate the situation:

- Between 1965 and 2014, the total number of publications on bioerosion was about one third of those on calcification on coral reefs (see Fig. 1 in Schönberg 2015a).
- For the 12 International Coral Reef Symposia (1969-2012), the studies associated with bioerosion only contributed 4% of all articles published in the Proceedings (Fig. 1).
- In July 2015, the internet forum Coral-List (2015) with a large interest in corals and calcification processes had about 8,600 members, compared to the internet forum Skolithos (2015) with main focus on trace fossils and bioerosion that only had about 130 members, i.e. 1.5% of that on Coral-List. This reflects on the numbers of scientists in research relevant to corals or bioerosion.
- In some important review articles on coral reefs, bioerosion processes were insufficiently described (e.g. Roberts et al. 2006; Hoegh-Guldberg et al. 2007).

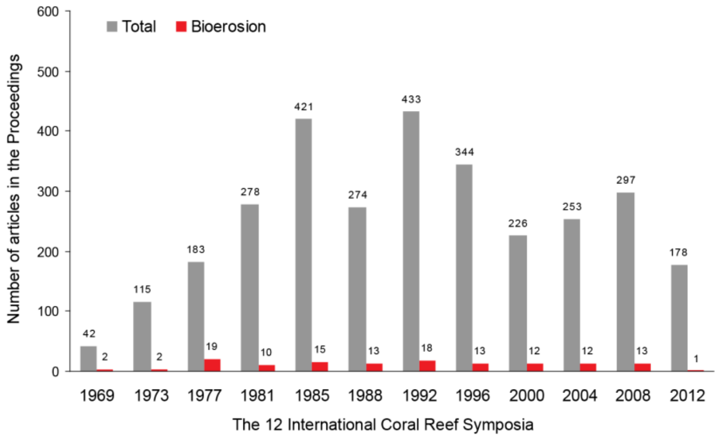

**Figure 1**. Number of total articles (grey) and those on bioerosion (red) published in 12 Proceedings of the International Coral Reef Symposia (1969-2012). The articles on bioerosion were searched on ReefBase using the keyword 'bioerosion', 'bioeroding', 'excavating', 'boring' or 'decalcifying'. A total of 3,044 articles were found in the 12 Proceedings (http://www.reefbase .org/ resource_center/publication/icrs.aspx accessed on 13th August 2015).

Among all bioeroders, excavating sponges (e.g. Fig. 2) were often the most important internal bioeroders on coral reefs, responsible for up to 90% of macro-bioerosion and producing up to 40% of fine sediments on the reefs (e.g. Fütterer 1974; Rützler 1975; MacGeachy 1977; Acker and Risk 1985; Glynn 1997; Mallela and Perry 2007; Hernández-Ballesteros et al. 2013). Bioerosion rates of single species of excavating sponges occasionally exceeded 20 kg m$^{-2}$ year$^{-1}$, which were often higher than those estimated for other groups of bioeroders (see e.g. Tables 4-1 and 4-2 in Glynn 1997; Table 4 in Schönberg 2002). On some reefs, bioerosion rates determined for excavating sponges were similar to or even higher than coral calcification rates, potentially driving reefs towards net erosion (e.g. Acker and Risk 1985; Nava and Carballo 2008; Perry et al. 2013). Due to their significant role in reef decalcification, excavating sponges have attracted much attention compared to other common groups of bioeroders. According to an internet literature search, the number of publications on excavating sponges contributed to a relatively high proportion of all accessible publications on bioerosion during 1945-2014, and as a result sponges ranked as the third most studied bioeroders (Fig. 3). However, compared to hermatypic corals, bioeroding sponges are still vastly under-represented in the literature, and the number of publications on bioeroding sponges only accounts for 11% of those on hermatypic corals over the last 70 years (Fig. 4). The significantly slower progress in excavating sponge research may be partly due to the complex taxonomy of sponges, their cryptic nature, and the difficulty associated with estimating their endolithic growth or biomass without destructive sampling (e.g. Schönberg 2001; Schönberg and Beuck 2007). Moreover, the number of scientists studying bioerosion is limited, and we also perceive a lower rate of funding opportunities compared to studies on coral calcification. All these factors have hampered related research on bioeroding sponges (see also Schönberg 2008).

Apparently the situation has started to change since the early 2000s. Growth of research on hermatypic corals may have slowed down, while the relative number of publications on excavating sponges has dramatically increased over the last decade (7% to 15% compared to publications on corals; Fig. 4). Presently, more than 8% of all people working on extant marine demosponges significantly contribute to research on bioeroding sponges (Schönberg 2015b), and this scientific community is expected to grow in the future. The recent development may have been stimulated by several key findings, including that some bioeroding sponges are able to overpower neighbouring live corals (e.g. Schönberg and Wilkinson 2001; Rützler 2002; López-Victoria et al. 2006). These findings confirmed earlier observations (e.g. Rützler 1975; Vicente 1978) and raised awareness of the importance of excavating sponges in coral reef ecology. Moreover, a range of laboratory methods were developed or improved to facilitate research on excavating sponges, e.g. quantification of sponge biomass and bioerosion (e.g. Zundelevich et al. 2007; Schönberg and Shields 2008; Fang et al. 2013b), assessment of energy

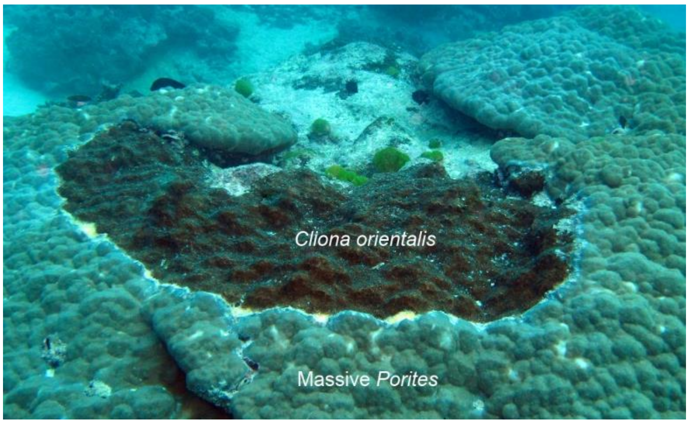

**Figure 2**. The excavating sponge *Cliona orientalis* Thiele, 1900 infesting a colony of massive coral of the genus *Porites* in 8 m depth on the southern Great Barrier Reef. The *Porites* colony is approximately 1.5 m wide.

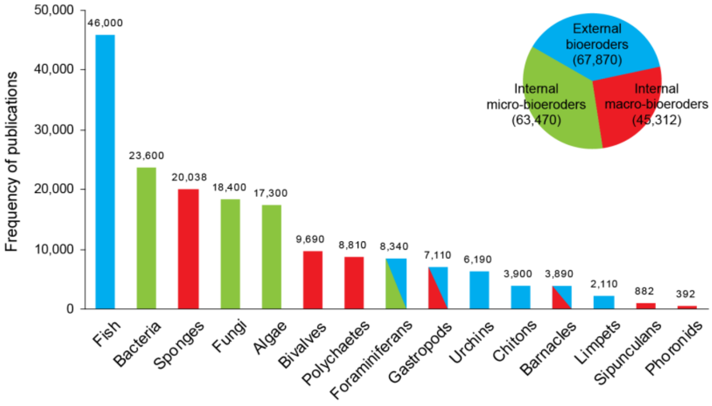

**Figure 3**. Frequencies of publications on common groups of bioeroders divided into three modes of bioerosion. The literature search was performed through the internet search engine Google Scholar for the last 70 years (1945-2014; http://scholar.google.no accessed on 17th August 2015). Citations and patents were excluded. The search used the above bioeroder groups as keywords, combined with at least one of the words 'bioerosion', 'bioeroding', 'excavating' or 'boring'. Bioerosion processes that do not have a large impact on reef carbonate budgets were not specifically targeted in the search (e.g. predatory shell drills). When searching for bioeroding algae, the word 'coralline' was excluded. The word 'grazing' was not included in the search, considering that some grazing processes only remove surface algae but not necessarily substrate as well, and therefore the frequencies for external bioeroders were potentially underestimated. Frequencies for the bioeroder groups that have calcium carbonate shells were potentially overestimated under the search criteria, as retrieved publications could also include those on bioerosion in their own shells. Foraminiferans, gastropods and barnacles are both external and internal bioeroders, and the frequencies for these groups were presently halved to reflect the different modes. A total of 176,652 publications were found. As multiple bioeroders were often studied in single articles, our total count does not equal the number of existing articles.

budgets and other vital physiological processes (e.g. Beer and Ilan 1998; Schönberg et al. 2005; Weisz et al. 2010; Fang et al. 2014), and analytical techniques in biochemistry and molecular biology (e.g. Fattorusso et al. 2004; Porta and Figlin 2009; Xavier et al. 2010; Riesgo et al. 2014). Schönberg (2015a) furthermore compared three common field methods to monitor bioeroding sponges and provided recommendations on using them.

Lately the interest in bioeroding sponges has broadened to include discussions of changing bioerosion in the face of global warming and ocean acidification. Among independent experiments that used various species from different climate zones and oceans, excavating sponges usually displayed faster growth or bioerosion under more acidic conditions, with or without the added effect of temperature (e.g. Duckworth and Peterson 2013; Wisshak et al. 2012, 2014; Fang et al. 2013a, 2014; Stubler et al. 2014; Enochs et al. 2015). Considering that hermatypic corals are expected to become increasingly impaired by future ocean warming and acidification (e.g. Hoegh-Guldberg et al. 2007), the contrasting responses of excavating sponges and other bioeroders (e.g. microendoliths; Reyes-Nivia et al. 2013) will likely lead to increased reef bioerosion that may eventually outweigh reef calcification, and ecological consequences could be devastating.

Present and future trends of carbonate budgets for coral reefs can only be reliably estimated if information is sufficient to address all the processes involved. Perry et al. (2012, 2013) and Schönberg (2015a) have suggested protocols that incorporate bioerosion into traditional monitoring studies. In addition, it has been long known that up to half of the carbonate produced on modern coral reefs is commonly reduced to sediment, largely by bioerosion, and that significant quantities are removed from the reefs, especially during storms (e.g. Fütterer 1974; Acker and Risk 1985; Hubbard et al. 1990). Clearly, there is a need to generate more knowledge of reef-building processes beyond just calcification, and of bioerosion processes, particularly those of excavating sponges which play an important role in the equation.

## Acknowledgements

*Jane Fromont, Max Wisshak and Dennis Hubbard are acknowledged for their comments on this article.*

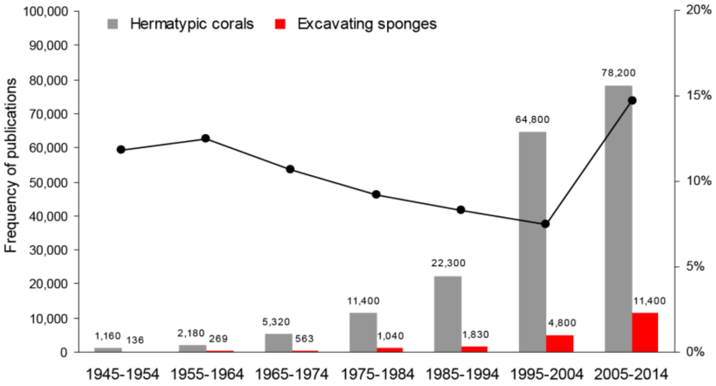

**Figure 4**. Frequencies of publications on hermatypic corals (grey) and excavating sponges (red) found by the internet search engine Google Scholar for the last 70 years (1945-2014; http://scholar.google.no accessed on 16th August 2015), excluding citations and patents. The search for publications on corals used the keyword 'coral' with at least one of the words 'calcification', 'calcifying', 'hermatypic', 'scleractinian', 'stony' or 'hard'. The search for publications on sponges used the keyword 'sponge' with at least one of the words 'bioerosion', 'bioeroding', 'excavating' or 'boring'. A total of 205,398 publications were found. As corals and sponges were often studied in the same articles, our total count does not equal the number of existing articles. The trendline indicates the percentage change in publications on excavating sponges relative to those on corals.

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# Reef Rehabilitation using Transplanted Hard Corals at Con Co Island, Quang Tri Province, Vietnam

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## Introduction

In the past 15 years, nearly 200 coral reefs have been surveyed in Vietnam's coastal areas. The data demonstrate that the current level of coral cover on these reefs is not good (Tuan et al. 2005). The results support the conclusion of Burke et al (2002) that coral reefs are threatened throughout Southeast Asia, and in Vietnam in particular. There most inshore reefs are threatened by human activities, with 50% of reefs considered to be under a high level and 17% an extremely high level of threat. Destructive fishing especially is rated as very common, with over 85% of reefs being impacted by it at moderate to high levels.

To address this issue, Vietnam has undertaken a growing number of studies of hard coral recovery. In 2002, at Trao reef area, Khanh Hoa Province, coral transplantation was carried out by the International Marinelife Alliance (IMA), in cooporation with both the Nha Trang Institute of Oceanography and local communities. In 2005, the Nha Trang Institute of Oceanography carried out another coral transplantation project at Hon Ngang Island, Binh Dinh Province (An 2005). At the same time, an artificial reef project was undertaken at Cat Ba Island, Hai Phong City, by the Research Institute of Marine Fisheries (RIMF). In general, the hard coral survival and growth rates were good, with, at some of the trial locations, the survival rates being from 65% - 100% after 3 - 5 months (Tuan et al. 2009). These positive results indicate that in Vietnam coral transplantation can contribute to the recovery of coral reefs, that otherwise are degrading year by year. In this article we present the results of a longer-term coral transplantation experiment conducted at Con Co Island, Quang Tri Province (Fig. 1).

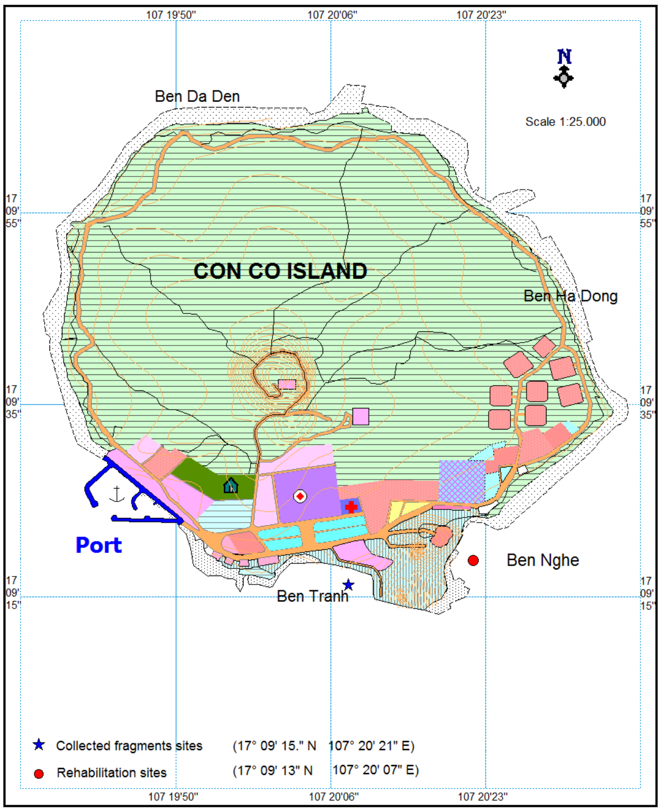

**Figure 1.** Sites for collection and transplantation of coral fragments at Con Co Island, Quang Tri Province.

## Methods

Five coral species were used in this transplantation trial; these were taken from an area on the south coast of Con Co Island ($17^0$ 09' 15''N; $107^0$ 20' 21''E) where they are common. The corals transplanted were 325 colonies of two branching species (*Acropora nobilis, Acropora robusta*) with colony heights of 70-300 mm, and 35 colonies of three massive and encrusting species *(Montipora efflorescens, Porites austaliensis, Cyphastrea serailia*) with diameters of 60-150 mm. The coral fragments were transplanted to a site on the south-east coast of Con Co Island ($17^0$ 09' 13''N; $107^0$ 20'07''E) during the period 20-27 October 2011. Data on the health of the transplants were collected from 15-16 June, 2012. The work was conducted in cooperation with the Con Co Marine Protected Area's staff.

Site selection was undertaken following rapid assessment by Manta tow (Kenchington 1984). Donor sites were chosen on the basis that they should have high existing cover coral and species diversity. The criteria for selection of transplantation sites (including abiotic, biotic and social factors) followed those described in Heeger & Sotto (2000). Water quality parameters (temperature, pH, salinity, dissolved oxygen) at donor and transplantation sites were recorded using a WagtechU10/HORIBA monitoring unit. Following transplantation site selection, a Reef Check type line transect (Hodgson and Waddell, 1997), 80m in length at 3-6m depth run perpendicular to the shore, was used to undertake a substrate survey. Then transplanted coral colonies were planted out about 2.5m away from each side of the line transect**.** The total rehabilitation area was 400m$^2$.

Coral fragments were collected as follows: *Branching coral* - The coral fragments were collected using pliers, hammer, and chisel; this needed to be done carefully to avoid excessive harm to the original coral colonies. In most cases the coral fragments taken accounted for only 10-20% of the donor colony by volume, with the maximum being about 50%. *Massive, sub-massive and encrusting coral* - Large donor colonies (more than 30 cm diameter) were chosen for fragment production. Fragments were chiselled off from the colony margins close to the substratum. We refrained from cutting a massive colony in half, in case the whole colony might become detached from the substratum. Once the collecting basket was filled with fragments, the basket was taken back to the boat at the surface, where it was held until the end of the dive. The boat then immediately proceeded to the transplant site for coral fragment fixation.

After review of available methods (Birkeland et al, 1979) coral fragments were attached to the transplantation site as follows: *Branching coral* - Iron nails (length = 20cm, diameter = 12 mm) were hammered into dead corals or the coral rock substrate, and the coral colonies then tied to the nails using 2-3 x 40 cm long pieces of plastic cord (Fig. 2). *Massive and encrusting coral* - These were positioned using springs (length = 10 cm, diameter= 5 mm), to the outer end of each of which were attached two crossed nails, positioned so as to cover each coral colony's center so that it could not move (Fig 2c). Each coral colony was tagged with a numbered plastic card.

Coral growth rates of the tagged corals were monitored using a ruler. We measured the maximum height of branching coral fragments and the maximum width of massive and encrusting corals. In addition, we recorded the number of the axial corallites at the start and end of the experiment, and determined the numbers of each species showing partial or complete mortailty by the end of the experiment (230 days).

### Results

The site selected for transplantation had only low hard coral cover (8.75%), but a high percentage of dead hard corals (6.88%), which proved suitable for attaching the transplanted coral fragments. Water quality was good and silt cover low (0.0%), indicating that these sites were suitable for coral development. Other mean values of substrate cover were soft coral 1.88%, fleshy seaweed 3.75%, sponge 3.13%, rubble 9.38%, bare rock 9.38% and other 0.63%. The site also met all the other criteria for coral transplantation as proposed by Heeger & Sotto (2000).

The results showed that the overall survival rate of the hard coral fragments (n=360) after 230 days was high (71.1%). The branching corals had a higher survival rate (72.9%) than the massive and encrusting corals (60.0%). Coral survival appeared to have been affected by substrate disturbance, with a portion of the securing nails having been covered by stones as a result of wave action. Other corals had been dislodge by wave action (the site was especially affected by heavy waves during a storm in November, 2010) and some damaged by drifting rubbish or fishermen's nets and other fishing activities. Most of the remaining 258 live colonies appeared healthy, with overall 87.5%

**Figure 2.** Methods of fixation of coral fragments – branching corals (left & centre) and massive coral (right).

showing no mortality, and only 12.5% showing partial mortality. None of the corals showed any signs of bleaching. The branching corals in good condition were mostly those that had adhered to the substrate, while partially dead colonies had often not attached well. In contrast, massive and encrusting coral that were well attached to the substrate were found in both good and poor condition.

In June 2012 we checked 112 randomly selected coral colonies (of the 258) to measure growth and assess development. 85.4% of branching corals had increased in size by a mean of 23.4 mm (+/- 13.6) and 81.2% of massive and encrusting corals had increased in size by a mean of 11.9 mm (+/- 4.1). 81.3% of branching (*Acropora* spp.) colonies showed an increase in the number of axial corallites, with the increase in their number ranging from 1 to 21 (n = 76 colonies, mean = 7.4 ± 4.2). 10.4% of the colonies showed no change in number of axial corallites, and 8.3% a decrease. Notably, some branching colonies that showed a reduction in size nevertheless showed an increase in the number of axial corallites.

## Discussion

Despite the low hard coral cover of the transplantation site, survival of the coral transplants after 230 days was high (overall 71.1%), with the great majority of these showing no signs of mortality (branching corals 72.9%, massive & encrusting corals 60%). Water conditions appeared quite favorable to coral growth, which raises the question of why previously coral cover was so low with so much dead coral present. It may be that substrate mobility limits the natural rate of larval recruitment, or that natural or anthropogenic impacts have reduced coral cover to a greater extent than might otherwise have been the case.

The trial provided experience that should benefit future reef rehabilitation efforts in Vietnam. It proved possible to transplant corals successfully using cheap, readily available tools and materials, but the task would be accomplished more easily and effectively if other materials could be made available (e.g. alternatives to the use of springs). Transplantation should be done in March and April so that the coral fragments have time to adhere to the substrates before they are subject to the effects of winter storms and wave action. Nevertheless, the experiments showed that coral transplantation can be accomplished under the conditions prevailing in Vietnam, and could be a useful conservation tool despite the impacts and neglect affecting the country's coral reefs. As might be anticipated, branching corals were much easier and hence more cost-effective to transplant than massive or encrusting corals; however use of massive corals is more likely to stimulate growth of a framework reef.

**Figure 3.** Growth of a massive coral over fixing nails after 320 days.

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# Invasion of the exotic seaweed, *Kappaphycus alvarezii,* on coral areas in two islands (Krusadai & Mulli) in the Gulf of Mannar, Southeastern India - status and control measures

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## Introduction

The Indian part of the Gulf of Mannar (GoM), located on the southeastern coast of Tamil Nadu State, is considered a biodiversity-rich coastal area. The GoM has a long coastline of 364.9 km, extending from Rameswaram in the north to Kanyakumari in the south. The area of 560 km$^2$, encompassing 21 uninhabited islands (Fig.1) and surrounding shallow coastal waters (8° 47' to 9° 15' N latitude, and 78° 12' to 79° 14' E longitude) in the Northern GoM, was declared as a Marine National Park (MNP) by the Government of Tamil Nadu in 1986 to protect its rich biodiversity. The GoM is one of the four major coral reef areas in India, and the reefs are distributed around each of the islands. The MNP is the core zone of the GoM Biosphere Reserve, which was declared in 1989 by the Government of India under UNESCO's Man and the Biosphere Programme and covers an area of 10,500 km$^2$. Along the coast of the GoM MNP, over 100,000 people live in small villages and hamlets, and depend mainly on artisanal fishing.

The coral reefs of GoM face complex management issues due to a high dependence on fishery resources by the local small-scale fishers living along the coast, and other anthropogenic impacts. For example, coral mining was rampant for about 4-5 decades, but completely stopped in 2005. Destructive fishing practices are common, including shore seine and push net operation, and industrial and domestic pollution and poaching of marine life threaten the reef ecosystem. The reefs around the islands are predominantly shallow (depth ranging from 0.5-3.0 m), and climate change is also likely to affect reef health (Patterson et al. 2007, 2012).

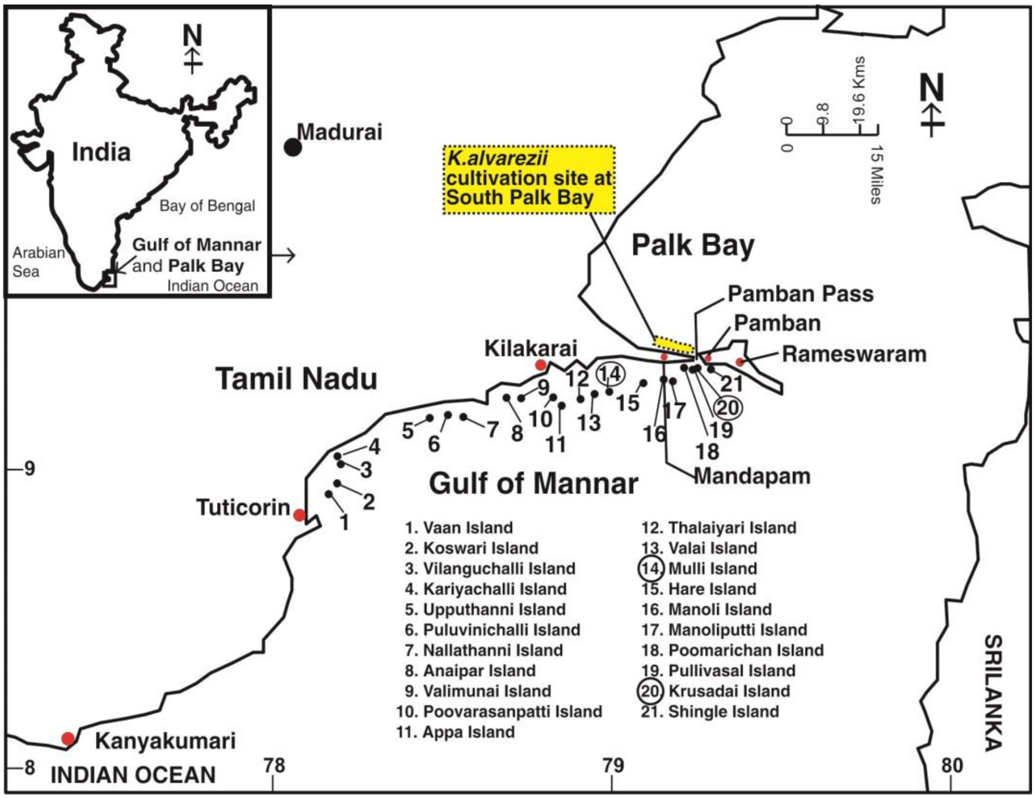

**Figure 1.** Map showing the 21 islands in the Gulf of Mannar Marine National Park

The Suganthi Devadason Marine Research Institute (SDMRI) - Reef Research Team (RRT) has been involved in surveying, monitoring and rehabilitation of coral reef and seagrass areas in GoM and Palk Bay from 2000 onwards. A comprehensive baseline data set on the diversity, distribution and status of coral reefs of the GoM was developed by SDMRI-RRT in 2005 (Patterson et al. 2007), and regular annual monitoring has also been conducted since2005. The reefs of GoM have shown resilience to disturbance, particularly after the halt of mining and implementation of several conservation and management schemes by

Union and State Governments and international agencies. For example there has been a GEF-UNDP project on “Conservation and sustainable use of Gulf of Mannar Biosphere Reserve’s coastal bio-diversity”. Consequently, live coral cover has increased from 37% in 2005 to 43% in 2009, although coral mortality due to bleaching reduced live coral cover to 33% in 2010 (Patterson et al. 2012). Subsequent recovery has increased live coral cover to 38% in 2014.

### Bio-invasion of *Kappaphycus alvarezii*

The ecological danger posed by the exotic seaweed, *Kappaphycus alvarezii* (Rhodophyta: Solieriaceae) was first highlighted by Pereira and Verlecar (2005). It is a macroalga originating in the Philippines and was first introduced in to South Palk Bay (in the northern part of the GoM MNP) when it was being assessed for use in aquaculture without a proper environmental impact assessment of the potential risks. It then began to invade branching corals (*Acropora* sp.) around Krusadai Island (Chandrasekaran et al. 2008).

### Impact and status of the bio-invasion around Krusadai Island

The SDMRI - RRT has been conducting regular underwater surveys on the extent of the invasion by *K. alvarezii* on coral reefs from October 2008 using the Line Intercept Transect (LIT) method (English et al. 1997). Transects were laid parallel to a series of islands at 0.5 - 2.0 m depth at high tide, the number of transects depending on the size of the reef. Originally, the invasion of *K. alvarezii* in Shingle, Krusadai and Poomarcichan Islands covered a small area (10 m$^2$) in October 2008 (SDMRI Report, 2008). Within two years, 116, 298 and 54 coral colonies were dead in Shingle, Krusadai and Poomarcichan Islands respectively due to the bio-invasion, and the affected reef area was 0.20, 0.42 and 0.16 km$^2$ respectively (Patterson and Bhatt 2012a). The results of a short-term study conducted by Patterson et al. (2012) revealed that the biomass of the *K. alvarezii*, which overgrew both small and larger coral colonies, increased from 300±0 to 734±25 g per colony within the 4 months. The trend of spreading of *K. alvarezii* was in both vertical and horizontal directions over the live coral colonies. As this alga spreads, it forms a tight thick green mat over the coral colonies, and the colonies eventually die through suffocation (Fig.2).

The seaweed invaded over 1.185 km$^2$ of reef area in Krusadai Island, and largely affected the reefs at four

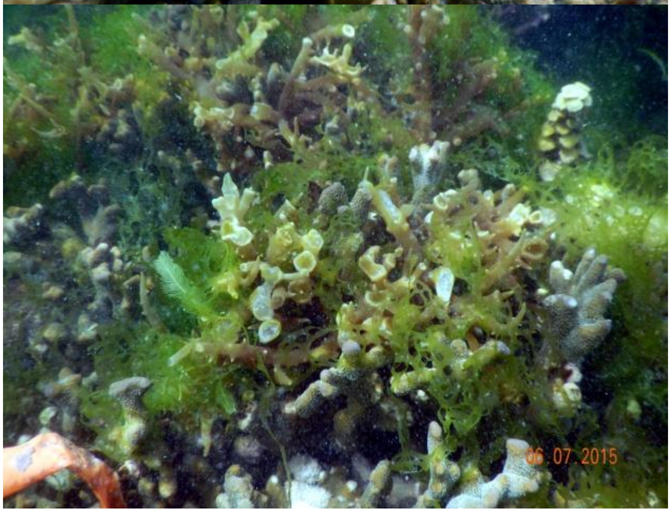

**Figure 2** (top). *K. alvarezii* invasion in *Acropora* sp. in Krusadai Island.

**Figure 3** (centre). *K. alvarezii* invasion in *Montipora* sp. in Mullii Island.

**Figure 4** (bottom). Dead *Montipora* sp. colonies overgrown with *K. alvarezii* and other native algal species in Mulli Island.

sites off the southern seaward coast (09$^{0}$14'730"N 79013’030"E; 09$^{0}$14'777"N 79$^{0}$13'265"E; 09$^{0}$15'009"N 79$^{0}$12'841"E and 09$^{0}$14.954”N 79$^{0}$13.351”E). Apparently, the detached algal fragments from the cultivation sites at South Palk Bay had drifted through the Pamban pass to the shores of Krusadai Island. The seaward side of the Krusadai Island is a sheltered area and hence the fragments settled on the live corals and grew undisturbed. The affected coral species in Krusadai Island were *Acropora nobilis, A. formosa, A. cytherea, Monipora digitata, M. foliosa* and *Porites lutea,* with coral colony sizes 5-160cm. Out of the total live coral area of 5.4 km$^{2}$ in Krusadai Island in 2009, over 20% of the area is now affected by the invasion of *K. alvarezii*.

**Impact and status of bio-invasion in Mulli Island**

It was observed during the survey in January 2014 that *K. alvarezii* has invaded the reef areas on the Northeast side of Mulli Island at two sites (09$^{0}$11'341"N 78$^{0}$58'018"E and 09$^{0}$11'295"N 78057’964"E) on the Kilakarai coast, where the coral genus *Montipora* is dominant. Mulli Island is located about 40 km south of Krusadai Island and there are 5 islands (Pullivasal, Poomarichan, Manoliputti, Manoli and Hare) with coral reefs in between Krusadai and Mulli islands, but there is no sign of invasion around these other islands. Out of 285 coral colonies surveyed in an area covering 0.40 km$^{2}$ and with colony sizes 5-40cm, over 70% of corals, mainly *Montipora divericata* and *M. digitata*, were dead due to the invasion around Mulli Island (Fig.3).

The invaded area was shallow (less than 2 m depth) and the dead coral area in Mulli Island is now overgrown with *K. alvarezii* and other, native algal species *Chaetomorpha* sp., *Enteromorpha* sp., *Ulva* sp., *Caulerpa* sp., *Turbinaria* sp., and *Padina* sp. (Fig.4). About 20 m away from the affected sites, scattered coral colonies of *Acropora nobilis, A. formosa, A. cytherea, M. digitata, M. divaricata, Pocillpora damicornis, Porites* sp., *Favia* sp. and *Favites* sp. are present, and no invasion of *K. alvarezii* has been noticed.

**Control and management measures**

The Union Ministry of Environment, Forests and Climate Change (MoEF&CC) sanctioned a 3 year research project by SDMRI from September 2013 to undertake a comprehensive study on the impact of the exotic seaweed *K. alvarezii* on corals and associated biodiversity, and to suggest management measures in the GoM MNP.

The Government of Tamil Nadu (GoTN) issued orders in December 2005 [G.O. Ms. No.229, E&F (EC.3) Department dated 20.12.2005] that allowed cultivation of *K. alvarezii* only in sea waters north of Palk Bay and south of Tuticorin coast, to protect coral reef and seagrass areas with rich biodiversity in the GoM and Palk Bay. Patterson and Bhatt (2012b) reported that the entire *K. alvarezii* cultivation in the South Palk Bay (near the northern GoM MNP) was conducted on luxuriant seagrass beds and corals which were previously very productive fishing areas for the local fisher folk. Underwater surveys revealed that the cultivation reduces light penetration, which is essential for seagrass growth and health, resulting in stunted growth with less shoot density and a turbid environment.

**Figure 5.** Re-growth of K. *alvarezii* after removal in Krusadai Island

The Forest Department undertook several measures to control the bio-invasion, and as a result manual removal of invasive seaweed was initiated in a small area in Krusadai Island in July 2010. In addition, from 2011-2012 onwards, members of a female “Self-Help Group” were involved in manual removal in a phased manner to reduce further impact and stress. They were able to remove the thick green mat that formed on top of the coral colonies. However, re-growth of the algae following removal was rapid (Fig. 5) due to the ability of the algae to regrow from minute attachment points, and also the low palatability of the algae to native herbivorous fishes (Conklin and Smith 2005). In Krusadai Island, the re-growth was measured as 1.5 cm per month. The removal practices are being continued presently with the funding support from MoEF&CC as a part of conservation and management of coral reefs. The invasion is now under control in Krusadai Island, although the alga is not fully eradicated. In Mulli Island, except off the northeastern side, the corals are not affected by invasion. The reef areas are being regularly monitored by the staff of the Forest Department and researchers of SDMRI-RRT.

Ever since the exotic seaweed *K. alvarezii* was introduced into the GoM, print and television media in both English and the local language (Tamil) have played a leading role in making policy makers, administrators, researchers and fisher folk aware of its impact on coral reefs, and the associated biodiversity and livelihoods.

### Conclusion

Regular manual removal and monitoring has helped to control the invasion of *K. alvarezii* at Krusadai Island, while in Mulli Island most corals have not so far been affected. The removal of the seaweed has also helped to control a further invasion at Shingle Island. In addition, the cessation of *K. alvarezii* cultivation for over 18 months, due to the occurrence of 'ice-ice disease' on the alga, has also helped in controlling the invasion. However, the rapid regrowth of the alga after removal poses a big challenge to conservation managers in protecting the corals in the GoM from the invasion of *K. alvarezii,* because regular removal and monitoring uses a considerable proportion of yearly budgets.

### Acknowledgements

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# Syndepositional cementation in the reef 'Twilight Zone'

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Marine cementation is an essential process for the stabilization of reef framework and resistance to mechanical erosion. It greatly controls carbonate platform geometry and the evolution of porosity in carbonate systems (Marshall 1983; Grammer et al. 1999). Beyond contributing to early coral-reef diagenesis, cementation is believed to encourage reef development both by producing new available substrate for benthic colonization and by maintaining the rigidity of modern and ancient reef structures (Marshall 1983).

Marine cements have been well documented globally in numerous shallow reef habitats (see review by Macintyre and Marshall 1988). Contrastingly, there has been much less research regarding types and rates of syndepositional (geologically "instantaneous") cementation in low-angle shelf mesophotic coral ecosystems (d = 30-150 m) that potentially provide refugia for impacted shallow-water systems as well as new sources of biodiversity (see review by Kahng et al. 2014).

### Methods

Following a protocol modified by Grammer et al. (1999), in August 2011 4 nylon mesh bags (50 µm) were placed at 3 mesophotic reef habitats, the Primary Bank, the Hillock Basin, and the Deep Patch, as described by Weinstein et al. (2015), and 2 shallow-water reefs, all in the northern U.S. Virgin Islands. At each site, 2 bags were attached to the seafloor and 2 were hung ~1 m above. Bahamian ooids, selected for their uniform carbonate texture, were put into the mesh bags after being examined with a scanning electron microscope (SEM) to confirm the absence of previous cement (Fig. 1a). Half of the mesh bags were collected in May 2012 and the remainder in May 2013. Collected bags were washed with distilled water, dried, and sieved to isolate cemented clumps >1mm. Clumps were split with razorblades, mounted onto stubs, and sputter coated with palladium prior to SEM inspection for marine cement. When present, the dominant cement habit was recorded, and representative images (3-15 per stub) were taken.

For each image in which aragonite fibrous cement occurred, the lengths of 5-10 of the longest "needles" were measured using *Adobe Photoshop*. Selection criteria included: (1) the start and end points of the needle could be estimated (i.e., the view was not obstructed); and (2) the angle between the "needle" length and the two-dimensional photo plane was less than ~45°. These criteria ensured that all reported lengths were underestimated. Based on these measurements and the time since deployment, minimum values were computed for crystal growth.

### Results

Ooids cemented into clumps after one year at all sites (Fig. 1b). Four distinguishable cement types were identified: (1) fibrous, isopachous (i.e., constant length) aragonite needles (Fig. 1c, d); (2) spheroidal clusters of needles (Fig. 1e, f); (3) stringy, elongated crystals embedded parallel to thick biofilm accumulations (Fig. 1g); and (4) anhedral, semi-equant aragonitic minimicrite (<1µm: Fig. 1h, i). There was no measurable difference in content between seafloor and elevated bags or between bags at shallow and mesophotic reef sites. Fine micrite cement was detected on samples collected after one year at all sites except Deep Patch; the elongated embedded needle cement was only found after two years on seafloor samples from the Primary Bank site. Besides forming between attached grains, cements also formed on unattached ooid surfaces, though only the fibrous needle cement completely covered grains (Fig. 1c). Needle clusters periodically formed atop earlier episodes of cementation (Fig. 1e). Some aragonite needles formed along with organic biofilms (Fig. 2a, b) and microbial cells (Fig. 2c). In cross-section, mini-micrite-sized crystals were often observed (Fig. 2d, e), but it was unclear if these reflected an early cement stage or were part of the ooid interior surface.

Fibrous aragonite needles were the most common cement type overall, though there were no consistent size or abundance trends between sites. The needle lengths for samples within mesh bags elevated above mesophotic reef sites averaged 5.11 ± 0.14 µm and 6.43 ± 0.94 µm (standard deviation) after the first and second collections, respectively. After the first collection, needles from mesh bags on the substrate were found at 1 of the 3 mesophotic reef sites (the Deep Patch); average needle length was 2.34 ± 0.66 µm. Sample bags were collected from the substrate surface at only two of the mesophotic sites during the second collection (the Hillock Basin site sample was not recoverable). Needle length averaged 5.69 ± 0.57 µm. Although needle lengths did not increase significantly between the collection periods, qualitative analysis indicated a higher needle density at all second-collection sites.

### Discussion

Results show that syndepositional cementation on gently sloping mesophotic coral reef habitats can be similar to that which has been found in other tropical marine carbonate environments (e.g. shallow coral

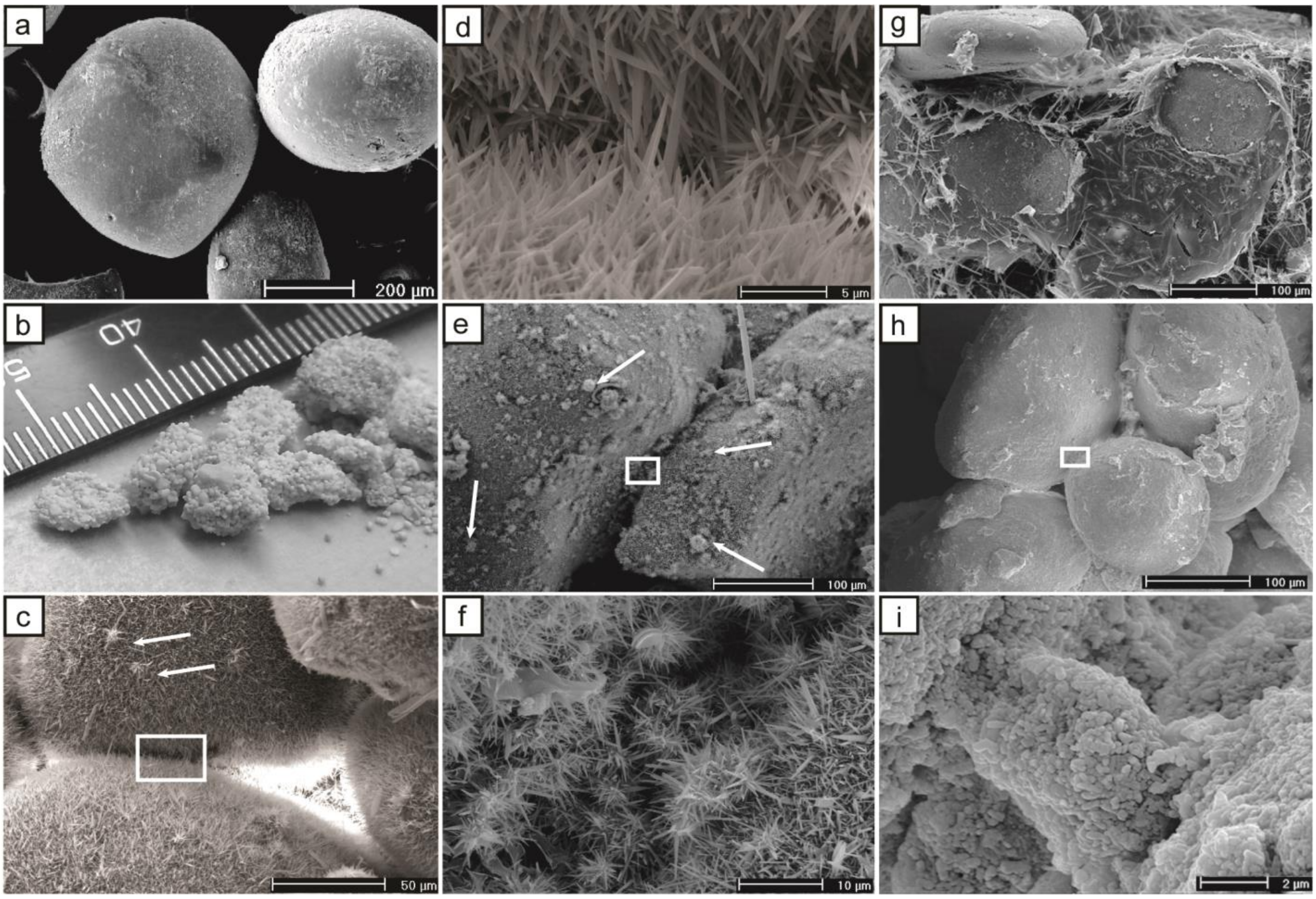

**Figure 1.** Photographs and scanning electron micrographs (SEM) illustrating syndepositional cementation. (a) Smooth Bahamian ooids prior to deployment. (b) Cemented ooid clumps. Scale is in millimeters. (c) SEM of ooid surfaces after 641 days, 1 m above the seafloor at the Hillock Basin site. (d) Inter-fingering fibrous, isopachous aragonite needles between cemented ooids. See white box in c for location. (e) Spheroidal clusters of aragonite needles after 637 days on the seafloor at a shallow-reef site. White arrows indicate secondary cement nodules on top of first generation cement. (f) Fibrous spheroidal cluster cement between attached ooids. See white box in e for location. (g) Elongated cement crystals embedded in biofilm accumulations (parallel to ooid surface) after 625 days on the seafloor at the Primary Bank site. (h) Minimicrite cementation after 277 days on the seafloor at the Primary Bank. (i) Close-up of minimicrite cement between attached ooids. See white box in h for location.

reefs: Friedman et al. 1974, steep mesophotic reefs: James and Ginsburg 1979, deep platform margins: Grammer et al. 1999). Needle lengths were comparable to those reported by Grammer et al. (1999). The depth at which these cements were found confirms that syndepositional cementation is not always influenced by wave conditions, as previously speculated (Marshall 1983; Macintyre and Marshall 1988). Beyond implying the possibility that submarine cementation facilitates the maintenance of structural complexity within mesophotic reefs, the rapid syndepositional cementation described here supports arguments for geologically instantaneous stabilization of depositional carbonate slopes at mesophotic depths prior to the Holocene (Della Porta et al. 2003). Although no recognizable trends were identified within or between shallow and mesophotic reefs, results from this study still imply high potential for the preservation of sedimentary subfacies and subsequently the ability to identify habitat heterogeneity in ancient mesophotic reef deposits (Weinstein et al. 2015).

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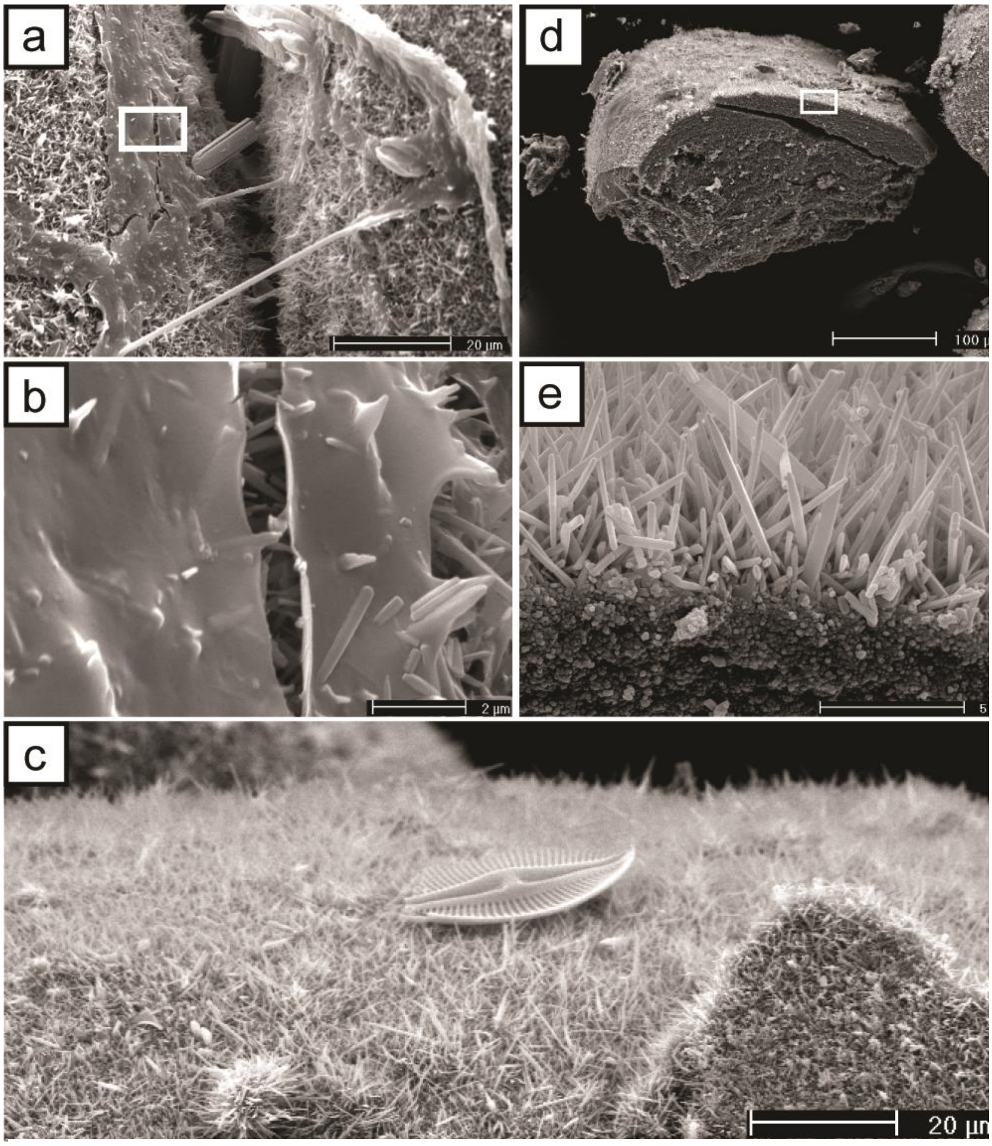

**Figure 2.** Scanning electron micrographs of cement associations. (a) Ooids coated with fibrous aragonite cement and stringy extracellular polymeric substances after 289 days, 1 m above the seafloor at the Hillock Basin site. (b) Close-up of sheet-like biofilms draped over needles. See white box in a for location. (c) Grain exposed 277 days, 1 m above the seafloor at the Primary Bank site shows common association between cements and biological entities such as the diatom near the center of the field of view. (d) Ooid cross section covered with radiating fibrous aragonite cement after 635 days, 1 m above the seafloor at the Deep Patch. (e) Close-up of the basal connection between fibrous cement (above) and minimicritic (below) along the ooid surface. See white box in (d) for location.

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# BOOK & PRODUCT REVIEWS

***Reviews of books, software, hardware and other products***

## Snap Decisions: Searching for the Perfect Underwater Digital?

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Nowadays, imaging the underwater world would seem to be a simple task, especially given the wide range of underwater cameras available from a swath of manufacturers, most featuring underwater modes as well as point-shoot interfaces. In the last issue of Reef Encounter (Vol. 30, No. 1, March 2015) I discussed the "Heroes" among the underwater video cameras available for reef research. In that article we saw how camera sizes had shrunk and resolution spiralled almost out of control, with the range of potential applications limited as much by the researcher's imagination, as by the technical achievements of the camera. In contrast, the previous edition of Reef Encounter described the history of the Nikonos, providing a glimpse into the roots of underwater research photography (Jaap, 2014).

In this article I will look at the bread and butter task of many reef research programs, that of still image capture. Whether for individual ID through significant markings, such as for sharks, or for species cover assessments through image analysis (Kohler 8 Gill, 2006; Ayroza et al. 2015), or indeed for documenting experimental design, the selection of a camera to match one's need is critical, since the variety of gear is more diverse and the applications often more specific than with video. All cameras take photographs, but their strengths and weaknesses in form and function can vary quite widely between models. It is worth noting, however, that a specific camera model frequently has only a short market life span, before it is replaced, so some of the specific comments offered here may soon become dated. Indeed, often a new model will not work in the older model's housing; hence, it can make sense to get a backup camera (or two!) if you are particularly satisfied and comfortable with a particular model[3].

To start with however, a disclaimer! I will admit a bias towards Canon cameras and, in particular, their range of compact cameras. This is partly because when working at the prime UK underwater camera centre (Ocean Leisure in London) I had the opportunity of conversation with many excellent photographers, a majority of whom were this way inclined. Further, despite being published working photographers, they were almost all happy to pronounce the effective death of even the digital single-lens reflex (DSLR) camera, at least when it comes to dive travel, since the compact camera, if nothing else, not only avoids the potentially back-breaking work of lugging housings, lenses, strobes and other paraphernalia around the world, but also saves on excess baggage charges, chiropractor bills, and the costs of early retirement!

During my employment at Ocean Leisure they actively marketed many types of camera (including DSLR housings), but it was the Canon Powershot "S Series" in particular that received praise for its functionality, affordability, size, and image quality. The camera apart, Canon has developed an excellent reputation for its own, made-to-measure housings. The housings for the S Series, G Series, SD/SX Series, and LEGRIA video cameras are the best known of these; they offer lightweight, buoyant, well-built, easy to use housings, with access to all controls at a very reasonable price. The housings are robust and display no distortion of the polycarbonate case at depth, as found in some cheaper camera housings. Further, the click-locking system is strong and the O-Ring substantial – to the point that many users report neglecting their maintenance due to the robust nature of the equipment (although of course this is not something to be advocated). An alternative are the quality housings made for these and other cameras by "Ikelite".

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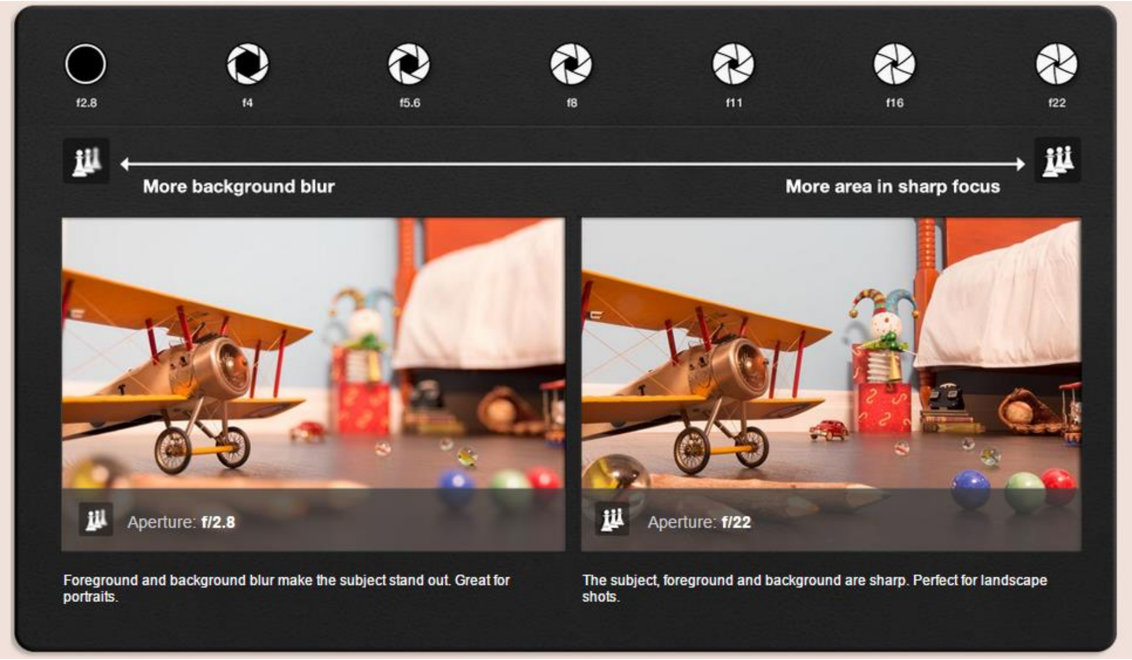
[3] Walt Jaap admits to owning a collection of older housings from cameras that are in Vallhalla.

The Canon S120 and G16 compact cameras

The responses to the survey that I conducted through an appeal to users via Coral-List very much supported the virtues of the Canon brand, especially for those looking for a catch-all camera. The G series and S series seem to be the most popular, with the current models being S120 and the G16/G1X MkII. In consequence I will focus on the Canon range when mentioning the key features to bear in mind when choosing a model.

Underwater the ability to resolve differences between light and dark is crucial. As we dive deeper less light penetrates the water, yet for photographs to be of scientific value we need to be able to distinguish the fine detail of our subjects. Note that megapixels don't count for much here since, unless you are printing billboard ads, the extra pixels won't do much for your image quality. There are other features that are important. The first is the f-stop. The f-stop of a lens indicates how large the aperture can go; the larger the aperture, the more light a lens will allow in, so the better the low light capability of the camera. The Canon S120 and G16 have an f-stop of 1.8 and thus are excellent for low-light photography. The second key factor is shutter speed - how fast the shutter opens and closes. To compensate for low light a camera may reduce its shutter speed, but this readily causes the images to blur, especially if you are swaying in the ocean or your subject is swimming around. There is however a trade-off to be made, since the wider the aperture the narrower the 'depth of field'. A reduced depth of field means that, for example, on a particularly rugose reef system, some of your quadrat may be somewhat out of focus.

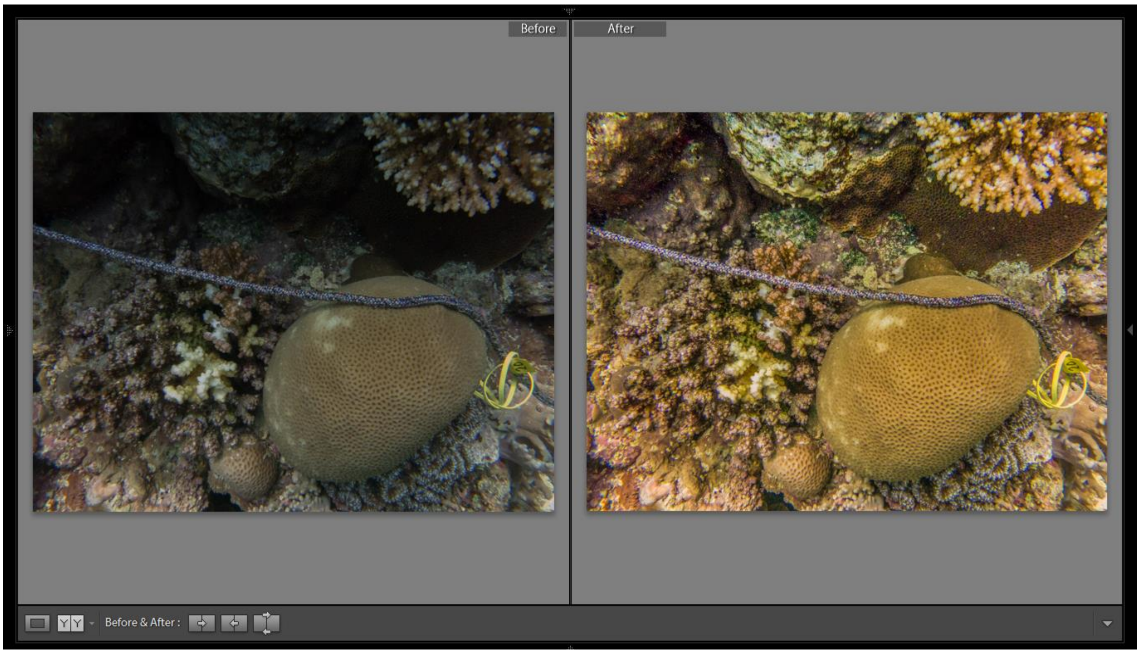
Use of still cameras for benthic monitoring is made more difficult where rocks, reefs and sand create a patchwork of light and dark; this can make species identification from the photograph (e.g. when using software such as CPCe) difficult, since the biota in the dark patches can be effectively hidden from view. To correct for this, it is possible to adjust the exposure, making the picture brighter by using a slower shutter speed, higher ISO, or wider aperture. But be warned! Over-exposure may result in the bright areas of your image getting 'blown out' – that is appearing as bright white patches showing little or no detail.



Foreground and background blur make the subject stand out. Great for portraits.

The subject, foreground and background are sharp. Perfect for landscape shots.

A demonstration of the effect of F-Stop: on the left we have an in focus foreground but a blurred background, on the right everything is sharp. However the impact that aperture size makes on light levels is not illustrated here.



A screen grab showing how, using "Lightroom", an underexposed image (Before) can be edited to illuminate darker areas (After). Had the dark areas been correctly exposed, the brighter areas would have been difficult to correct or been completely blown out. (photo Adam Porter)

It is almost always better to ensure that your brighter areas are not over-exposed, since it is usually possible to resolve the detail in dark areas using suitable photo-editing software, such as "Lightroom" or GIMP, to adjust the brightness and contrast. By contrast blown-out areas are generally impossible to recover, since only white is recorded, rather than shades of grey. Ben Pruett (Florida Fish and Wildlife Service) highlights this issue in his use of the Canon SD1400. *"With no external light source, the camera uses a longer exposure time to get the quality of images we need for our Point Counting (Image Analysis), making camera stability a crucial factor with deeper depths. Luckily, a majority of our reefs are shallow <30fsw, so light is abundant in a majority of images. I sometimes have to deal with white blowout over patches of* Palythoa caribaeorum *or carbonate sand."*

The final key consideration that influences light sensitivity and the ability to resolve detail is sensor size. Image sensors consist of millions of light-sensitive spots called photosites that record the digital information. A bigger sensor can gain more information than a smaller one and produce a better image; for this reason a 16 MP compact isn't ever going to be as good as a 12 MP Full Frame DSLR, because of its smaller sensor size. Nevertheless f-stop and ISO sensitivity are the most important considerations if selecting a camera with its low light capabilities in mind. The Canon website has a nice visual summary of the effects of these various adjustments at http://www.canonoutsideofauto.ca/learn/. Of course all these issues can be fixed with external lighting but for the purposes of this article we will steer clear of that topic, except to say that if you need external lighting, then the new generation of LED video lights made by Light & Motion are well worth considering for their size, weight, and power.

Other features of the Canon S and G Series are that they can shoot in RAW (a large format, that allows for better subsequent image manipulation to recover image information such as light and shadow, but eats lots of memory), have dedicated underwater modes, have "one–touch" white balance programming - essential to correct for colour changes at depth, and are relatively small and lightweight (the S Series being much more so).

Several minor issues also bear consideration when selecting a camera. One is start-up time, from "off". Both the G and S series cameras are quick to start up. Another is battery life. The S120 will take 230 shots on a battery charge and the G16 - 360, or roughly 1 hour of 1080p video. Note however that these tests refer to continuous shooting with little change in light or zoom, so take the quoted battery life as a best case scenario, not a promise! Water temperature, depth, and available light, also affect battery life. A comment by Sean Clement about the G16 illustrates this point: *"from a full charge, we've gotten a full day's snorkelling out of it, including hi-res still capture and* *filming in 1080p. Diving, we'll get two full dives of 50-60 mins out of it before it runs out mid way through a 3rd. Deeper dives seem to drain it more, probably due low light conditions taxing the processor more."*

Another issue is memory. However virtually all new cameras come with minimal or no memory. But don't skimp when purchasing memory SD cards! Both memory and write speed are important. Nikon recommends using a class 6 or faster write speed - meaning SAN DISK, TOSHIBA, or PANASONIC SDHC or SDXC memory cards. The San Disk web site reports that a hypothetical 22 GB camera capturing fine or extra fine JPG images (6.6 MB per image) can hold up to 8,300 images on a 64 GB SD card, but, if capturing RAW (24 bit per pixel, 66 MB per image) images, then only 820 of the images can be stored. (Still a great change from the days of film with only 24 or 36 exposures per dive to work with!)

As mentioned above, Canon's own camera housings (the "WP-DC" range) are excellent. They allow access to all the buttons. They come with a snap-on flash diffuser that will soften and spread the light from the internal flash with reasonable results when up close to the subject and the option of attaching external flash units that are triggered optically by the cameras internal flash. Both types of housing also have the ability to have wet lenses attached to them. These are lenses that snap over the housing to provide a wide angle or macro function. In my on-line survey via coral-list all the users of Canon housings reported these strengths, including the excellent build quality. The only negative remarks revolved around size. The G-Series is relatively large for a compact, but still smaller that a DSLR in its housing, and inany case there are some benefits to slightly larger housings, such as they are easier to mount on a unipod or quadrapod, and generally easier to aim and shoot.

It is worth noting however, that in locations with remarkable thermoclines, Lexan / polycarbonate plastic camera housings have a tendency, due to the thermal characteristics of the material, to fog with moisture when descending through a cold water mass. The problem is exacerbated if working aboard a vessel with air conditioned cabins. The condensation can impact focus as well as image quality, and in extreme cases the camera may not function or an alarm may go off because of the dampness. Placing small bags of desiccant (provided by the manufacturer or bought separately) in the housing largely controls the problem, but often does not eliminate fogging entirely. The other main camera manufacturers - Olympus, Nikon, and Panasonic - also have their own underwater models, but they tend to plump for the 'tough action cam' style of camera; a "catch–all" design that allows the camera to get wet without a formal housing. These models do have some positives, but it must be emphasised that they are not intended by the manufacturers for prolonged underwater use. Most manufacturers state in the user manuals that they are intended for a maximum of 60 minutes underwater use, typically to a maximum of only 10 m depth. Their design did not anticipate the repeat long-term underwater use of those participating in survey or monitoring programs. Some of these manufacturers also supply external housings for their tough series cameras, which in itself tells you all you need to know about the waterproof qualities of the camera itself. A number of coral-list respondees identified leaky "tough cams" as a show-stopper and mentioned their additional purchase of the external housing, although some also noted receiving a replacement camera for free after flooding the original!

The problem with the tough cams is that the ratio of body thickness to O-ring thickness is relatively low, while they also feature a "press and slide" closure system. The issue here is that a lateral force exerted over an O-ring is inferior to a direct pressure force such as on a scuba tank A-Clamp, or indeed on a proper camera housing. Coral-listers also noted the ease with which these compartments could come open. Without a strong mechanical clasp, such as on a camera housing, it is all too easy to graze a hand past one of the compartments and flood the camera. A final issue with these tough cams is the zoom: since they are sealed units the zoom is housed within the body rather than being able to extend past it, thus compromising the quality of the lens.

Canon itself also offers a camera that is waterproof (without housing) - to 25 m (82 ft), and shock-resistant - if dropped two meters or less; this is the PowerShot D30, 12 MP. The focal length is 28 to 140 mm with a 5X zoom, F/ 3.9 to 22. But it is not fully programmable; for example, you cannot select aperture or shutter priorities, and RAW image file and manual focus are unavailable. Exposure compensation is adjustable ± 2 in 1/3 EV steps, but ISO is automatic between 100 and 3200, as are shutter speeds, from 1/15 to 1/1600 of a

An image secured using the impressive Olympus TG3 'Microscope' function (Photo: Phanor H Montoya-Maya)

second. However the camera is a reasonable choice for simple surveys and training courses. Walt Jaap reports having now used one in this way for over a year during which time it has performed satisfactorily.

Despite the above reservations these tough cams do offer a number of advantages when coupled with an external housing. First, the fact that the cameras are themselves waterproof gives a certain peace of mind. Second, most of these cameras come with a GPS function which for snorkel surveys can be really handy for pinpointing where a picture was taken. The GPS doesn't work underwater, since GPS signals are very weak and do not penetrate even a thin film of water, but the feature will function whilst snorkelling if the camera is held briefly above water, as well of course as on the boat or shore. Some of the tough cameras also have 'wet lens' capability, allowing a macro and wide angle lens to be clipped on to the housing. Thus a feature highlighted by coral-list respondees was the ability of these cameras to work as a standalone macro unit. The Canon S120 can focus 3cms from its subject, but the new Olympus TG3 beats this, allowing focusing down to 1mm using its 'microscope function'.

The beautiful results that can be achieved using this feature are illustrated by untouched images provided by Phanor Montaya-Maya. She explains: *"I was determined to stop taking coral fragments out of the water for macro-scopic analysis. Therefore, I needed a camera that could allow me to take very good macro-photos of coral fragments; good enough to photograph eggs and sperm bundles underwater right from the coral fragment. I bought this camera because it had the best reviews for its Macro capabilities. This camera has a Microscope function, which allows you to scale the photograph; very useful for my work."*

However, to combine general purpose photography with macro capability my Ocean leisure contacts are currently recommending the Canon S120 coupled with an Inon 6-dioptre (or even 10-dioptre) close-up wet lens with attachment ($415 / £270).

In general the fact that wide-angle lenses (to get closer to subjects in turbid water or get fine detail across a large area), or macro-lenses, or LED video lights (see Light & Motion products) can now all be attached underwater to most underwater compacts makes them extremely versatile. As Elayne Looker (Five Oceans Environmental Services LLC, Muscat) comments: "*We use wet lenses for our work (primarily for CPCe image analysis) here in Oman, as we often have fairly turbid seas with mediocre visibility, so a wide angle lens enables us to get closer to the substrate whilst allowing the whole quadrat to fit within the frame. I much prefer using my Canon S95 compared to the other Canons the office has had over the years; I find it very user friendly and it's not let me down yet after all its travels.*"

Inon's "wet lens" adapter, the 28LD Mount Base DC51, on and off the camera (left) and with the Inon UCL-100LD 10 dioptre macro wet lens attached (right) [Credit: Inon, 2014]

Of course there is still a place for the DSLR, and perhaps always will be. Resolution is the key with DSLRs since they have larger sensors and better lenses, meaning they produce brighter, sharper, clearer and less "noisy" images. Chad Scott points out "we don't receive any funding, but run our projects based on the courses we can sell, so beautiful pictures for marketing and Facebook are also important." But such kit comes at a cost, as Erik Messters, who takes images of 3x3m quadrats, describes:*"I'm monitoring 3x3m quadrats in Curacao and Bonaire. I think the whole set cost something like $20k, so yes terrible, and I hate it and love it. I love it for the quality and the fact that I can zoom in till I see boring sponges oscules of less than 1cm$^2$. I hate it as I always have to pay extra on flights; the whole set is 15-20kg; this also takes its toll on my back! Having something so expensive can worry me underwater and repairs are expensive too! Finally there is always distortion on the edges, no matter how expensive the lenses, when you're shooting wide angle."* This account highlights the trade-off confronting many reef researchers. Images of 3x3m quadrats capture a considerable amount, but with a small compact 1x1m quadrats are as easily secured. Rupert Ormond goes in the other direction to secure good resolution images, taking close-up photographs of 0.25x0.25m mini-quadrats to cover the same ground.

In summary, when considering purchase of a new underwater camera consider carefully the application(s) for which it is needed and, if asking in camera shop, explain your intentions and research aims[4]. Low light capability, battery life, start-up time, wide angle capability, and image resolution are all thing to consider. But don't fall into the megapixel trap. The approximate balance of gear preferred by those researchers who responded to our coral-list survey was: Canon G Series - 20% of total photo applications, Canon S Series – 40%, Tough Cam Models – 35%, SeaLife Cameras – 3%, and DSLRs – 2% of total photo applications.

A DSLR may be necessary to obtain the highest quality publishable pictures, but for most scientific purposes the compact is now king!

*Many thanks to Rupert Ormond, Walt Jaap, Beth Taylor, Chelsea Bennice, Benoit Tchepidjian, Nicole Crane, Sean Clement, Chad Scott, Elayne Looker, Ian Butler, Steve Piontek, John Ogden, Ben Prueitt, Ryan Nash, Brian Reckenbeil, Isaac Westfield, Phanor Montoya-Maya, Erik Meesters, Jill Harris, Kaho Tisthammer, Chris Perry, Renata Goodridge, Kate Philpot, Deborah Gochfeld, José Speroni, Bill Allison, Parth Tailor, Anne Theo, Barbara Kojis, Katie Peterson, Russell Kelley, Ken Nedimyer, Ray Buckley, Amilcar Magaña, James Engman, Craig Osenberg, Dennis Hubbard, and Ocean Leisure Cameras for the input and feedback that greatly assisted with the preparation of this article.*

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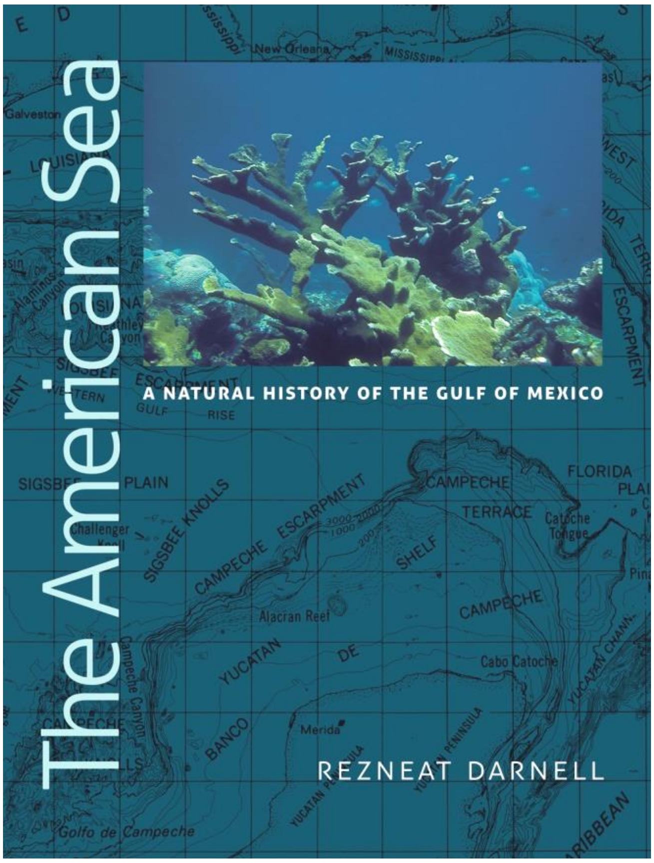
[4] To find out more about a particular camera and compare it to others I recommend looking at http://snapsort.com/

## The American Sea: A natural history of the Gulf of Mexico, R. Darnell.
## Texas A&M Press ISBN 978-62349-282-3

Reviewer: Robert S. Carney, Professor Emeritus, Department of Oceanography and Coastal Sciences, Louisiana State University, Baton Rouge, LA,



In the weeks that the Deepwater Horizon well spewed crude oil and the control crews dispersant into the Gulf of Mexico, many of the scientists who study that Large Marine Ecosystem had many unsettling experiences while attending the numerous public and private meetings. Typical of most gatherings, people from federal agencies and national-level NGO's would lament the lack of knowledge about the Gulf and characterize the region as being very poorly studied. As known by the "locals", the Gulf has been and continues to be relatively well studied using funds largely provided by those very same agencies and less often by industry. When pondering the causes of such a wide gap between what has been learned versus what is understood by the regulatory structure it can be concluded that Gulf research has not produced a concise and powerful synthesis readily accessible to scientists, the public and the regulators.

The late Rez Darnell who died in 2009 before the blowout had reached this very same conclusion about the need for a valid synthesis that could support a truly science-based management of the heavily exploited Gulf. Darnell spent most of his career as a traditionally-trained ecologist embedded in a department of oceanography with a strong offshore tradition. Retired from lecturing and doing his own inshore and coastal shelf research he began the more than a decade long task of making his major contribution to the needed synthesis in the form of a book published posthumously by Texas A&M Press as The American Sea: A Natural History of the Gulf of Mexico. The book is one of the publications provided by the Harte Institute of Texas A&M Corpus Christi. The large 554 page but modestly priced book belongs on the shelf of anyone interested in the Gulf whether their perspective is that of the regulator, researcher, conservator, or exploiter.

For the potential readers of the book it is important to recognize its limitations. Foremost, Darnell provides us with a massive compendium rather than a synthesis. I suspect that Rez would have enjoyed developing the synthesis along with his readers. What he does do is provide a perspective that demands the task of synthesis in chapters 15 through 18. That paradigm is preceded by a 14 chapter compendium of facts and informed-speculation about Gulf systems. It is the welcome task of readers to arrive at the needed new synthesis. Much of the information in the compendium will appear dated to specialists. While there is considerable use of studies from the 1980's and before, the findings of some of these pioneering papers remain valid.

The organization of the book is the same used by many of the introduction to oceanography textbooks intended for a one or two semester undergraduate curriculum. The greater breadth and scientific detail of The American Sea, however, make it most appropriate for graduate level students that have already completed an introductory course or sequence. Darnell's selection of topics is unusually broad. The chapters describing the physical environment (3 through 7) provide a quick introduction and good starting place for exploration of more recent work. The reader is informed or reminded that the Gulf basin and its waters are considerably more complex than, for example, the over-simplified versions of oceans, such as the Atlantic and Pacific, often taught in textbooks.

The American Sea is organized into four parts. The first contains a concise history and a rudimentary explanation of some of the major points of oceanography and marine biology collectively called marine science. The five chapters of the second part cover the physical environment, water, geology, air and chemistry. Readers of the book may find these chapters more informative if a general oceanography text is used to gain a better global context.

The seven chapters of the third part cover biology. Three chapters use the traditional biotic divisions of phytoplankton, zooplankton, and nekton. Treatment of the benthos is divided among soft bottoms and hard bottoms with reefs falling within the latter. All of these chapters on biota are strongly oriented towards knowing taxonomic inventories and provide numerous line drawings for familiarization. There are only two chapters devoted specifically to habitats. The longest and most familiar to Darnell is chapter 12, Plant Dominated Communities. This chapter can stand alone as an introduction to those systems. Chapter 14 addresses the deep Gulf. Perhaps here more than in other chapters the timing of the writing becomes unfortunate. More recent research has largely supplanted the older observations.

Part four consists of two chapters that serve to provide non-ecologists with a rudimentary understanding of ecological thought. The approach used by Darnell is very traditional 1960's-1980's and largely along the dual lines of synecology and autecology. The author's personal perspectives are most fully developed and appreciated in chapter 16 Ecological Processes II. This material moves between natural-history and a systems approach to explain integration of some of the Gulf's components.

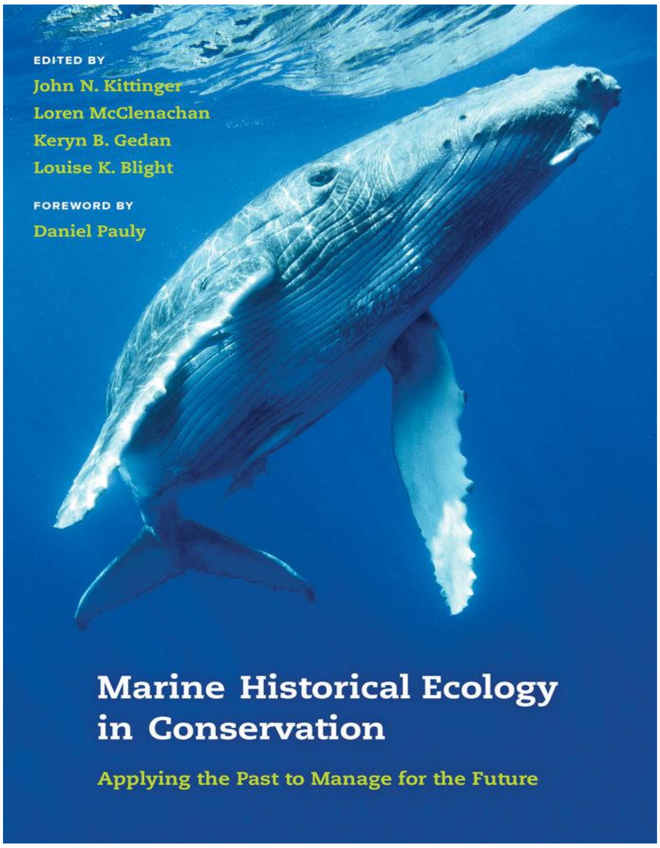
Readers from the regulatory and exploitation communities will find the fifth part, Human Relations, very informative. Darnell developed his assessment of impacting activities and the limitation of regulation long before the Deepwater Horizon disaster occurred. The prescience of his thought is shown by the fact that many of the same concerns have been echoed by the many post-spill working groups.

I think that most teaching scientists who write a career-end textbook are trying one more or one last time to better teach topics they are especially passionate about. When that writer decides which topics to include and how complex things can be simplified, it's common to think of how lectures will complement reading. Rez Darnell's failing health and eyesight made his task of researching and writing exceptionally difficult. It's easy to critique his inclusions, omissions and simplifications. Each writer has hisown opinion about what constitutes the most important facts. In the end he accomplished his intended purpose. The American Sea teaches about the Gulf. It conveys a wealth of information and challenges the readers to develop a better synthesis for the purpose of more effective management. It's unfortunate that we can't ever hear his accompanying lectures.

## Marine Historical Ecology in Conservation: Applying the Past to Manage for the Future, John N. Kittinger, Loren McClenachan, Keryn B. Gedan, and Louise K. Blight (eds). Foreword by Daniel Pauly.

**University of California Press, 312 p. (ISBN: 9780520276949) Hardcover $65.00.**

Reviewer: John W. Tunnell, Jr., Harte Research Institute for Gulf of Mexico Studies, Texas A&M University-Corpus Christi.



When Corpus Christi Bay and the Texas Coastal Bend were named “estuaries of national significance” by the United States Environmental Protection Agency, I first experienced the use of marine historical ecology and became a fan of its use as a tool for understanding both the present and past ecology of an area. Our research team at the Center for Coastal Studies at Texas A&M University-Corpus Christi received the Corpus Christi Bay National Estuary Program (now Coastal Bend Bays and Estuaries Program) contract to characterize all the living resources within the area in the mid-1990s. This gave us time to delve deeply into the status and trends of the species and habitats of the area. And although we documented 3,178 species, characterized 8 major habitats, and reviewed 49 protected species in 1,442 pages in 4 volumes, one of the most intriguing facts to me was the commercial harvest from 3 local counties in 1890 of 535,000 pounds of sea turtle meat. Wow! What was the size of the sea turtle populations back then? What was the extent of the sea grass beds that supported the probable most common species, the green sea turtle.

In the Foreword Daniel Pauly explains what is meant by marine historical ecology in conservation, “to inform us about what these populations have been in the past, and under which conditions these populations could flourish so that we can start helping them do so”.

John Kittinger, Loren McClenachan, Keryn Gedan, and Louise Blight have done a magnificent job as writers and editors of bringing together transdisciplinary teams to demonstrate how searching deeply into the past of various marine species and ecosystems can assist in their conservation and management for the future. The book is divided into 12 chapters with an introductory chapter followed by 4 parts. The 4 parts include: 1) Recovering Endangered Species (3 chapters); 2) Conserving Fisheries (3 chapters); 3) Restoring Ecosystems (3 chapters); and, 4) Engaging the Public (2 chapters). Each of the 4 book editors is a “lead section editor” for each of these 4 sections. In total, there are 36 authors from 6 countries that contribute to the 12 chapters. Although there are no specific chapters on coral reefs, the detective work described, the philosophy of approach, the use of disparate datasets to reconstruct baselines, the formation of historical ecosystem services, and many other topics can be applied to coral reef work. There is also a good index for quickly tracking down species, habitats, and geographic areas covered.

The editors define marine historical ecology broadly as “the study of past human-environmental interactions in coastal and marine ecosystems, and the ecological and social outcomes associated with these interactions”. They also have two overarching goals for the volume: 1) “First, we hope to provide impetus for a vibrant, transdisciplinary discussion on using insights from historical ecology to improve the management and conservation of marine ecosystems and species” and 2) “Second, it is our intention to showcase practical examples of how historical data can be used in the conservation of marine ecosystems”.

An added bonus is that each chapter is supplemented with “Viewpoint” boxes that contain reflections from policymakers, managers, and leading scientists about how the concepts in the book can be engaged in real world applications. Here coral reefers will see some familiar topics and names, like Peter Sale and Billy Causey.

Finally, in our summarization of all known literature for our book *Coral Reefs of the Southern Gulf of Mexico* (Tunnell et al. 2007, Texas A&M University Press), we were able to show that not only was the famous old Fort San Juan de Ulua built completely from coral reef materials but also to show that the primary building stone for old colonial Veracruz city, was not made from stone or brick, but from old coral heads from the adjacent reefs. Therefore, I encourage other coral reefers to dig deeper into the history of “your” coral reef by gaining new ideas and concepts for such study as presented in Kittinger et al. *Marine Historical Ecology in Conservation.*

# CONFERENCE REPORTS

*Informative overviews of recent conferences and meetings*

## The Second International Workshop on Mesophotic Coral Reef Ecosystems, Eilat, Israel

(26th-31st October, 2014)

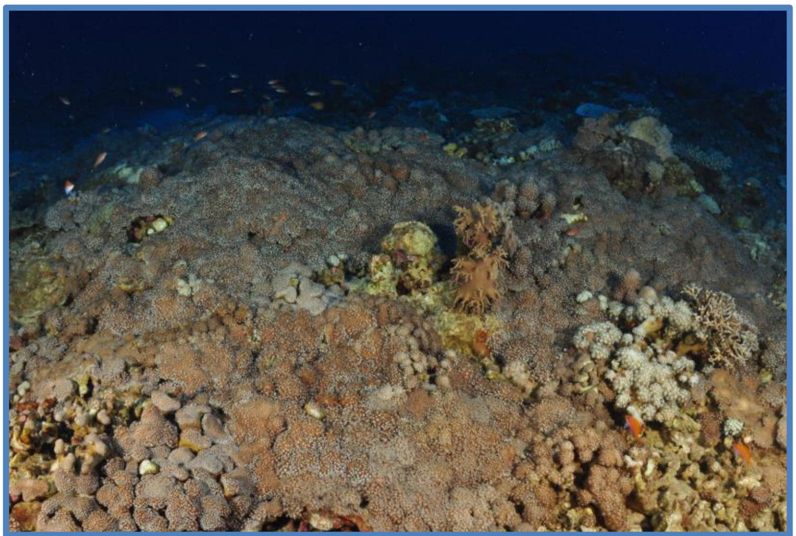


**Figure 1** (above). Mesophotic scenery offshore the IUI at 60m depth dominated by the hermatypic coral *Alveopora*.

**Figure 2** (below). The mesophotic coral *Euphyllia paradivisa* showing typical changes in fluorescence of color morphs (photo taken at 50m depth). This species listed as endangered under the US Endangered Species Act (ESA), is confined to 36-72 m depth in the Gulf of Eilat/Aqaba and surprisingly comprises 73% of the total coral cover.

Mesophotic coral ecosystems (MCEs) host thriving communities of light-dependent biota that have remained virtually unexplored, mainly due to technical limitations. There is sparse knowledge on the biology, ecology and biodiversity of coral reefs flora and fauna at these depths (30-150m), and still less on the effect of human activities on these ecosystems and their potential role in the context of world-wide coral reef degradation. An understanding the supportive role that these ecosystems play in the connectivity and maintenance of shallow-water reefs is essential for a full understanding of the health of coral reefs and is important for defining the key areas for protection and management(e.g. MPAs, fishery management areas, shore building regulations etc).

The Second International Mesophotic *Coral Ecosystems* (MCEs) *Workshop* was held at the Interuniversity Institute for Marine Sciences at Eilat (IUI), Israel, 26th-31st October, 2014. It followed the first MCEs workshop, which was held in 2008 in Jupiter, Florida, USA. Scientists and students from 11 countries gathered together for six days of lectures, field and laboratory projects and round table discussions. The workshop was devoted to the study of the MCEs and covered a variety of research areas, including biology, ecology and physiological properties of mesophotic species, conservation, connectivity between mesophotic and shallow reefs, biodiversity of mesophotic reefs, geology and innovations in underwater technology methodologies (see Program). 31 presentations and 17 posters were presented, as well as three days of active research projects (see Projects). The two-part workshop provided participants with fruitful interactive scientific discussions and hands-on experience. A report on results from one of the projects completed during the workshop has been published in PlosOne. A collection of papers resulting from the workshop, and devoted to MCEs, is expected to be published soon in *Coral Reefs*.

For more details please visit our website at: www.mceisrael.com or Israel Mesophotic Reefs on Facebook or @mceisrael on Twitter.

*Gal Eyal and Yossi Loya*
*emails: gal4596@gmail.com and yosiloya@gmail.com*


Attendees at 2nd International Mesophotic Coral Reef Ecosystems Workshop

## 8th Mexican Coral Reef Meeting, Puerto Vallarta, Mexico

**(May 19th – 22th, 2015)**

In May, the 8th meeting of the Mexican Coral Reef Society (SOMAC, Sociedad Mexicana de Arrecifes Coralinos) was held in Puerto Vallarta, Mexico, at the coastal campus of Universidad de Guadalajara. The first meeting of SOMAC was celebrated back in 2000 and to date meetings have been repeated every other year, alternating between institutions on the Pacific and Atlantic coasts. For the 2015 conference more than 200 researchers, students and government representatives participated, and a total of 130 poster and oral presentations were presented in joint venues, so as to encourage interaction between participants of all walks of science and management.

Attendees came from more than 70 Mexican institutions, and also from 25 international research centers and universities in the USA, Australia, Europe, and Central and South America. One of the most encouraging features of the conference was that some half of the presentations were authored by female scientists who between them received almost 70% of the student grants awarded by SOMAC to enable them to present their papers.


Attendees at the 8th Mexican Coral Reef Meeting

Conference scenes: broadcasting on Radio Arrecif, a poster session and the field trip.

The conference was organized into 10 different sessions covering a variety of topics, including biology and physiology of reef organisms, genetic diversity, ecology and conservation, symbiosis, climate change impacts, and coral reproduction. Each day started with a keynote lecture delivered by a leading coral reef scientist; these were in chronological order: Héctor Reyes-Bonilla, of Universidad Autónoma de Baja California Sur, La Paz (Historic review of the coral reef investigations in to Mexican coral reefs), Mónica Medina, of Pennsylvania State University, USA (Establishment and breakdown of symbiosis between cnidarians and microbiomes), Susana Enríquez, of Universidad Nacional Autónoma de México, Puerto Morelos (How can photobiology and functional allometry help us to study coral reefs?) and José Carriquiry of Universidad Autónoma de Baja California, Ensenada (Global change: climatic oscillations and the effects of ocean acidification on the calcification of the Mexican reefs during the Anthropocene).

For the first time in the history of these meetings, a team of reporters and media representatives covered the full event, producing press releases and a special radio program, “Radio Arrecife” (Reef Radio), broadcasted live every day from the meeting. On this program both keynote speakers and students had the opportunity to talk about their scientific work, and the general public was able to ask questions, and to refer to their own coral reef experiences.

The recently updated SOMAC website includes the abstracts and program of the conference, and links to the YouTube channel where recordings of all oral presentations of the meeting, including those by keynote speakers, are available, as well as podcasts of Radio Arrecife.

The next meeting will be in Chetumal, Quintana Roo, in 2017, hosted by El Colegio de la Frontera Sur, and as always will be open to anyone interested in or sharing their knowledge of the coral reefs of Mexico and Latin America.

*Pedro Medina Rosas*
*email: pedromedinarosas@gmail.com*

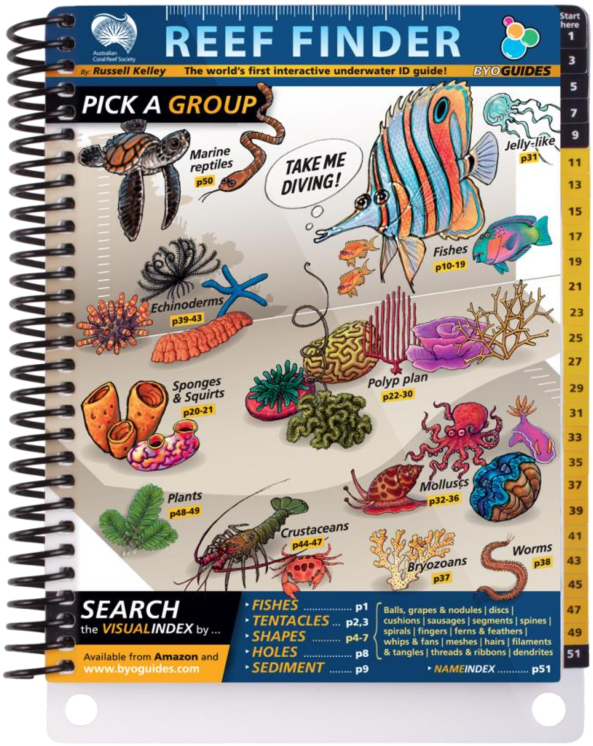
# REEF SHELF

*Details of new publications – manuals, reports and books*

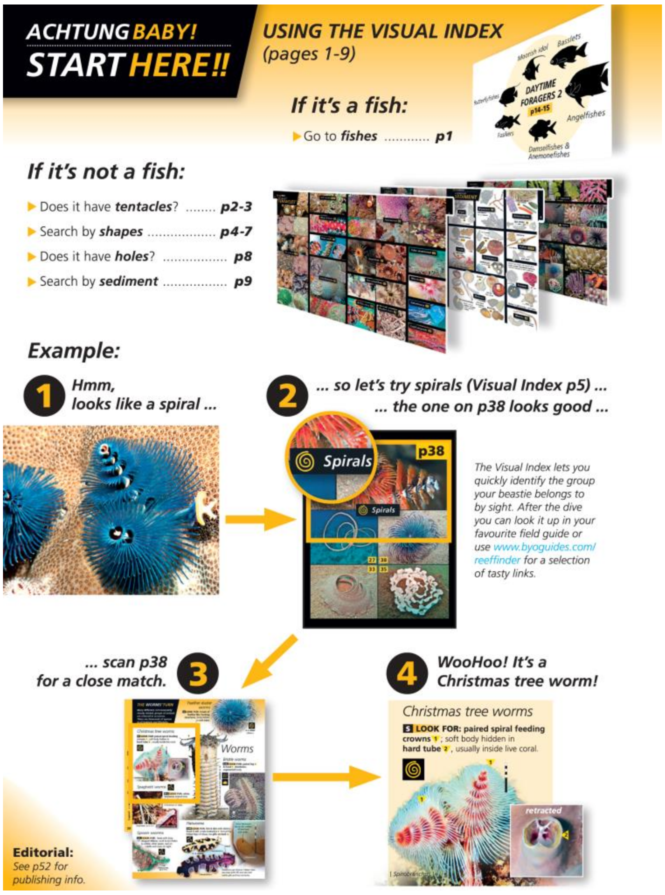
## The Reef Finder: A handbook for Caribbean coral reef managers

BYOGuides, designers of the increasingly popular underwater coral identification tool, The Coral Finder, have now published "The Reef Finder", intended as a visually driven, plain language guide that should enable anyone to identify reef fish or invertebrates, without any formal taxonomic knowledge or training. It is if anything even more sumptuously illustrated than the Coral Finder.

Both guides have been designed for students, researchers, recreational divers and citizen scientists and are likely to be an important resource for capacity building in coral reef research and management. According to BYOGuides, the Reef Finder, like its sister publication the Coral Finder, reverse engineers the *"What is that?"* question in favour of the user. It allows the interested person to put most fish or invertebrates into a "group". It then gives the user the most useful common name and visual characters to allow them to confirm an ID via a post dive look-up using traditional topside field guides / resources.



As the author and designer Russ Kelly explained in a recent article in Reef Encounter (Vol 29 (2), pp. 23-26) both publications are designed to achieve this by using visual logic instead of technical words and abstract concepts. The user can search a 9- page VISUAL INDEX that uses common shapes e.g. "spirals", "sausages", "threads", "ribbons", "fans" etc. as well as useful categories like "fish shapes", "holes", "tentacles", even "sediments". Anyone with a good eye for detail should find it easy and fun to use - "unburdened by the tyranny of assumed knowledge".



ACHTUNG BABY!
START HERE!!

USING THE VISUAL INDEX
(pages 1-9)

If it's a fish:

- Go to *fishes* ............ p1

If it's not a fish:

- Does it have *tentacles*? ........ p2-3
- Search by *shapes* .................. p4-7
- Does it have *holes*? ................. p8
- Search by *sediment* ................. p9

Example:

1 Hmm, looks like a spiral ...

2 ... so let's try spirals (Visual Index p5) ... ... the one on p38 looks good ...

The Visual Index lets you quickly identify the group your beastie belongs to by sight. After the dive you can look it up in your favourite field guide or use www.byoguides.com/reeffinder for a selection of tasty links.

... scan p38 for a close match. 3

4 WooHoo! It's a Christmas tree worm!

Christmas tree worms
LOOK FOR: paired spiral feeding crowns 1; soft body hidden in hard tube 2, usually inside live coral.

Editorial:
See p52 for publishing info.

A page from the Reef Finder, explaining the principles behind its design

More details can be found on the BYOGuides website at www.byoguides.com/reeffinder/, where a <u>**15% discount is available to members until November 30th**</u>, using the discount code "ISRS15".

NATURE NUMBER 5 ECHINODERMS

SEA URCHINS

**S-M** **LOOK FOR:** dome or disc-shaped with **5-fold symmetry**; **protective spines**; **tube feet**; external skeleton made of fused calcareous plates.

*5!*

*A close look at most sea urchins reveals the 5-fold symmetry (➡) found in all echinoderms (see p39).*

*Ouch!*

*The spines of this urchin are venomous and easily break off in the skin. Avoid!*

*Some urchins can burrow into solid reef rock for protection.*

*Going underground*

*Heart urchins and sand dollars have evolved reduced hair-like spines for streamlined burrowing.*

*Ouch!*

*Some urchins can deliver a nasty venomous bite from pincers 1 hidden among the tube feet and spines! Avoid!!*

**Legend:** ▬ 10mm; **S** 1-10cm; **M** 10-30cm; **L** 30-100cm; **XL** >1m

NATURE NUMBER 5 ECHINODERMS

SEA CUCUMBERS

**S-XL** **LOOK FOR: sausage or loaf-like**; some with **feeding tentacles**; many show **tube feet** 2 on body surface; most feed on organic debris from sediment.

*Don't touch!*

*Sea cucumbers are sensitive and may release sticky threads if handled. Leave them alone!*

*Going underground*

*Burrowing sea cucumbers filter particles from seawater with fine branching, feeding tentacles.*

Sea cucumbers

*5!*

*Sea cucumbers, like all echinoderms, have tube feet and 5-fold symmetry (➡), even if it is hard to see.*

***Echinoderms:*** see p39 for definition.

A sample page of the Reef Finder, and the Reef Finder in use.

# PROGRAMMES & PROJECTS

## Service d'Observation CORAIL

### A Long-Term Monitoring Program for the Coral Reefs of the South Pacific

http://observatoire.criobe.pf

**Context, Motivations and Scientific Objectives**
Since its inception more than 40 years ago, CRIOBE set out to establish a rigorous long-term scientific monitoring program to detect temporal fluctuations in the condition of the coral reefs of French Polynesia.  Today, this multi-faceted program, spanning many sites and island states, is known as Service d'Observatoire CORAIL (SO CORAIL).

The first data were collected in 1971 on Tiahura reef, in the north-western part of Moorea. However only in 1983 was a long-term monitoring program was truly established. Today we have more than three decades of scientific observations and data not only from around Moorea, and the archipelagos of French Polynesia, but also more recently from the small neighbouring island states and territories of the Global Coral Reef Monitoring Network (GCRMN) that form the Polynesia Mana network. The taxa that are monitored include all fish encountered (down to species level), corals (down to genus level), benthic algae and other benthic invertebrates. Physico-chemical parameters are also monitored. In 2007, France's Institut National des Sciences de l'Univers (INSU) recognized CRIOBE for their efforts and successes in the South Pacific and formally integrated their monitoring work into France's portfolio of Scientific Observatories (SO).

**SO CORAIL: CRIOBE's Long-Term Coral Reef Monitoring Program**
The main objective of the SO CORAIL monitoring program, as conceptualized by INSU, is to better understand how physical and biological systems change through time.  For biological systems, a focus is placed on exploring the drivers that regulate ecological processes over many generations.  It is only long-term data sets with a specific comprehensive set of variables which can reliably document the natural evolution of a system, discover changes within this system, and, more importantly, determine whether these changes can be attributed to seasonal variability or are a part of long-term processes of change. A successful monitoring program considers all aspects of an ecosystem and uses methods that allow variability over time and space to be ascertained. A long-term approach is of particular importance for the study of marine ecosystems, where change typically happens slowly, but where the impacts of this change can have significant consequences for coastal communities and environments.

SO CORAIL has adopted this long-term view in its monitoring of the coral reef communities of French Polynesia and the South Pacific. The overall objective of SO CORAIL is the systematic and coordinated acquisition of a common set of **hydrological, climatic, chemical** and **biological** parameters across sites spanning more than 10 million km$^2$ throughout French Polynesia and the South Pacific. Through a systematic and coordinated approach across all sites, meaningful conclusions about how systems change over time and space can be drawn.

Results from long-term monitoring efforts are being used to:
1. Define a baseline at each site such that any deviations from this state can be investigated.
2. Identify inter-annual fluctuations, within and across sites.
3. Identify common fluctuations across sites to study how coral reef ecosystems respond to disturbance, of natural and anthropogenic origin, and to distinguish between these two sources of variability.

An important point especially worth mentioning now, when the world is deeply concerned about global warming and climate change, is that if we are to effectively monitor changes in an ecosystem, we cannot restrict ourselves to biological parameters. Rather it is important to couple biological observations with the collection of physical and chemical parameters, so as to acquire the data necessary for modelling scenarios used to study environmental change. Thus SO CRIOBE collects the following comprehensive set of data:

- Biological data (diversity, abundance, biomass for each of the different biological components of the ecosystem)
- Physical data (temperature, salinity, currents, swell, and climatology)
- Chemical data (concentration measurements and the flow of inorganic materials, nutrients, sedimentation, pollution, etc.)

**Geographic Coverage**

The SO CORAIL is the first monitoring network of its size, spanning an area of more than 10 million km$^2$ and extending across nearly 4700 km between Pitcairn Island and Tonga. There are currently 15 island sites within the SO CORAIL network (Figure 1). In French Polynesia itself, monitoring sites are spread across 10 islands belonging to four of the territory's archipelagos:

1. Society Islands: Moorea (3 sites), Tahiti (3 sites), Tetiaroa, Raiatea
2. Tuamotu Archipelago Gambier: Nengo Nengo, Marutea south, Rangiroa, Tikehau
3. Marquesas Islands: Nuku Hiva
4. Archipelago Austral: Tubuai

In 1999, SO CORAIL was transformed into a wider regional network, with one new site added in each of the following 5 countries: the Cook Islands (Rarotonga), Kiribati (Christmas Island), Pitcairn Island (UK), Samoa (Apia) and Tonga (Tongatapu).

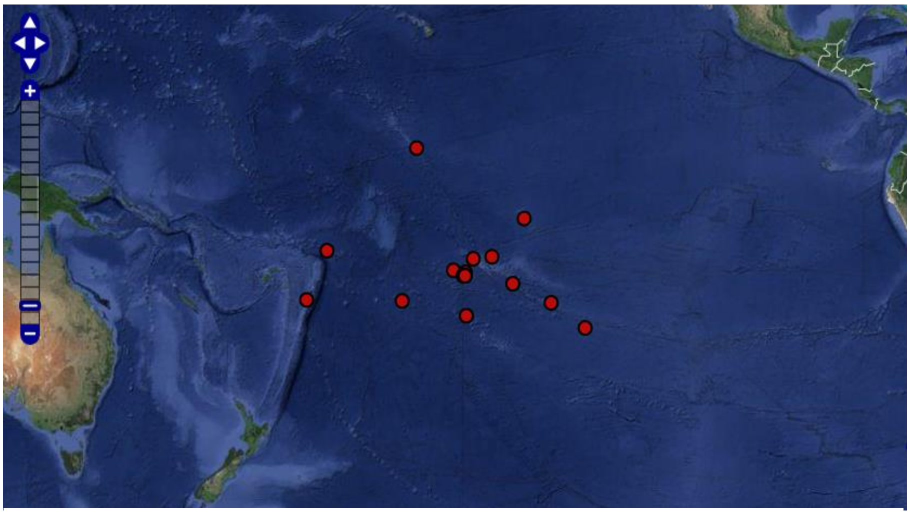


**Figure 1.** Location of the 19 monitoring sites (red dots) within the current CORAIL LTMP Network

What began over 40 years ago as the work of one researcher, focused on the biology of corals and fish at a single site on the island of Moorea, has now expanded by many orders of magnitude, to create a network that now spans multiple countries and is integrated within the Global Coral Reef Monitoring Network (ICRI-GCRMN). The details of this expansion are documented in the table 1. Notably, in 1992, Clive Wilkinson (GCRMN) and Bernard Salvat (EPHE) established 'Polynesia Mana', a coral reef monitoring network spanning French Polynesia and the small neighbouring island states and territories of the Cook Islands, Kiribati, Tokelau, Tonga, Pitcairn, Niue, Wallis and Futuna. Polynesia Mana is managed by CRIOBE in partnership with CRISP, SPREP and AFD.

| Context | Target | Location | Start | Duration |
|---|---|---|---|---|
| Galzin Research | Fish, Benthic Communities | Tiahura/Moorea | 1983 | 28 years |
| CRIOBE Research (ATPP) | Fish, Benthic Communities | Tiahura/Moorea | 1990 | 25 years |
| GCRMN, Polynesia Mana | Corals, Fish | French Polynesia, 10 Islands | 1992 | 23 years |
| GCRMN, Polynesia Mana | Corals, Fish | Cook, Kiribati, Niue, Tokelau, Tonga, Wallis and Futuna, Pitcairn, Samoa | 1999 | 16 years |
| PGEM Moorea | Fish, Benthic Communities | Moorea, Marine Protected Areas | 2004 | 11 years |

**Table 1.** A summary of the history of CRIOBE's long-term biological monitoring efforts

### Biological Data

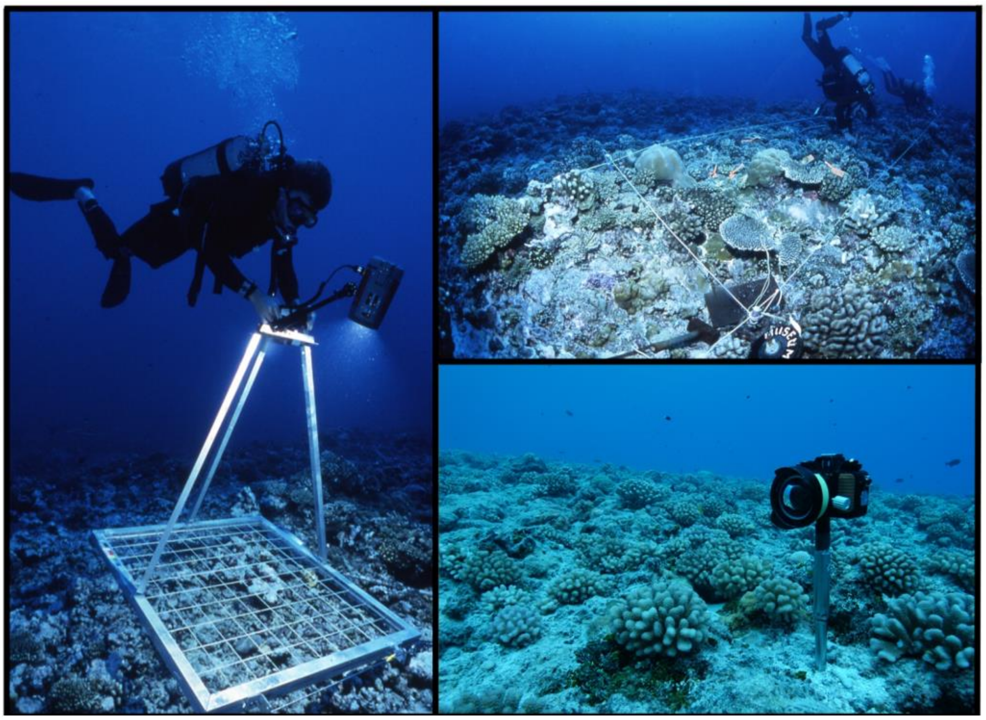


**Figure 2.** Some of the different techniques used to collect benthic biodiversity data.

Polynesia Mana has adopted the methods and objectives developed by the GCRMN. It aims to monitor and to understand how populations of corals and fish change through time, particularly in response to natural and climate-change related disturbances (Fig. 2). Each site is surveyed, at a minimum, on a biennial basis. Biological measurements are made at a depth of 7 to 12 m, and carried out according to several techniques and at differing spatial scales:

- Coral populations are studied in great detail over an area of 20 $m^2$ using a photographic technique (20 permanent quadrats).
- Broadscale Manta tows are conducted along the outer reef slope for semi-quantitative assessment of coral cover.
- Landscapes are monitored using photographic surveys along on a fixed transect.
- Fish are censused along transects on which the species and size of each individual is recorded.

Further information on sampling methods can be found at http://observatoire.criobe.pf.

### Physicochemical Parameters

The need for physical and chemical data to be collected in parallel with biological surveys has led to the deployment of permanent measuring devices across the network of study sites. Table 2 provides details on the equipment deployed at each site. The physical and chemical parameters selected for inclusion into the SO CORAIL monitoring protocol (temperature of the sea water, hydrodynamics of mineral salts and dissolved gases) yield valuable data with respect to direct and indirect impacts of natural disturbances or global climate change, as well as local anthropogenic pressures (waste water, urbanization, changes in the coastline, exploitation of resources).

There are 3 types of automated instruments currently used to measure physicochemical parameters (see Fig. 3). These are:

**SBE56 Sea-Bird Thermographs.** Today, SBE56 Sea-Bird thermographs are installed at all SO CORAIL sites. Prior to the Sea-Bird, several other models of thermographs were used, including the Stowaway and Pro V2 models by ONSET (accuracy: 0.2 ° C resolution 0.02 ° C to 25 ° C). Through trial and error, the Sea-Bird model has proven to be more efficient and stable than other models, so starting in 2010 older models were phased out and replaced with the Sea-Bird. They have proven

**Figure 3.** View of the data logger as set out on the reef to collect environmental parameters.

reliable at significant depths from 1-55m at the SO CORAIL site in Moorea-Tiahura, and across vast geographies in the GCRMN Polynesia Mana Network. Data is automatically recorded at hourly intervals for all sites, and data reports are generated twice a year.

**Sea-Bird SB26plus Probes**. The Sea-Bird probe precisely measures conductivity (precision 0.0005, resolution 0.00005), temperature (precision 0005, resolution 0.0001) and pressure associated with depth and swell (precision 0.02%, resolution 0.002%). Probes are strategically placed on each archipelago of French Polynesia, and one in each additional territory or state within the GCRMN Polynesia Mana network. Tide is automatically measured every 15 minutes, waves are measured every hour, and data reports are generated twice a year.

**Sea-Bird SB16plusV2 / SBE18 / SBE43 Probes / WET Labs ECO FLNTU.** These probes can measure not only temperature and conductivity (like the Sea-Bird SB26plus), but also dissolved oxygen (precision 2%) and pH (precision 0.1 pH). These probes are also equipped with turbidity and chlorophyll sensors. However, the lifespan of these probes is limited, generally from 6-9 months, and, because of the need to replace them frequently, they are installed at locations close to the CRIOBE laboratory (within 60km) and at sites where they can be easily accessed. Two sites in Moorea and Tahiti are currently equipped with these probes. Data is collected automatically every 3 hours and data reports are generated twice a year.

The collection of nutrient data is not currently automated and is performed on a monthly basis through the collection of sea water samples for analysis of phosphate, nitrate, nitrite, carbonate, silicate and ammonium. This sampling is done solely for the Moorea/Tiahura site, with samples taken from each of the three primary geomorphologic reef structures: fringing reef, barrier reef and outer reef slope.

| Island | Prof (m) | Position (°, mn, 100° mn), WGS 84 | Fre-quency | Instrument | Parameters | First Record | Frequency of Sampling |
|---|---|---|---|---|---|---|---|
| Apia (Samoa) | 35 | 13°48,354S/172°01,915W | 15 mn | Sonde SB26 | T°, waves, sea level | 15/05/13 | F sampling routine, 2 years |
| Apia (Samoa) | 10 | 13°48,354S/172°01,915W | 1 heure | Thermographe SB56 | T° | 15/05/13 | F sampling routine, 2 years |
| Christmas Island (Kiribati) | 10 | 01°57.398N/157°29.368W | 1 heure | Thermographe SB56 | T° | 10/11/10 | F sampling routine, 2 years |
| Christmas Island (Kiribati) | 26 | 01°57.418N/157°29.459W | 15 mn | Sonde SB26 | T°, waves, sea level | 09/11/10 | F sampling routine, 2 years |
| Marutea sud | 10 | 21°29.628S/135°38.489 | 1 heure | Thermographe SB56 | T° | 15/09/99 | F sampling routine, 2 years |
| Moorea Moorea Tiahura Bouée Jaune | 25 | 17°28.940S/149°53.985W | 1 heure | Sonde SB16 | T°, S°/°°, O2, pH, nephelo, chl a | 03/07/08 | F sampling routine, 6 month |
| Moorea Moorea Tiahura P14 | 14 | 17°28.980S/149°53.985W | 1 heure | Thermographe SB56 | T° | 29/01/98 | F sampling routine, 2 years |
| Moorea Moorea Tiahura P25 | 25 | 17°28.960S/149°53.985W | 1 heure | Thermographe SB56 | T° | 29/01/98 | F sampling routine, 2 years |
| Moorea Moorea Tiahura P3 | 3 | 17°29S/149°53.985W | 1 heure | Thermographe SB56 | T° | 03/04/98 | F sampling routine, 2 years |
| Moorea Moorea Tiahura P35 | 35 | 17°28.940S/149°53.985W | 1 heure | Thermographe SB56 | T° | 25/03/98 | F sampling routine, 2 years |
| Moorea Moorea Tiahura P35 | 35 | 17°28.940S/149°53.985W | 1 heure | Sonde SB16 | T°, S°/°°, O2, pH, nephelo, chl a | 01/12/08 | F sampling routine, 6 month |
| Moorea Moorea Tiahura P35 | 35 | 17°28.940S/149°53.985W | 15 mn | Sonde SB26 | T°, waves, sea level | 02/01/09 | F sampling routine, 2 years |
| Moorea Moorea Tiahura P55 | 55 | 17°28.890S/149°53.985W | 1 heure | Thermographe SB56 | T° | 15/05/99 | F sampling routine, 2 years |
| Moorea Moorea Tiahura P8 | 8 | 17°28.996S/149°53.985W | 1 heure | Thermographe SB56 | T° | 29/01/98 | F sampling routine, 2 years |
| Moorea Taotaha | 65 | 17°32.614S/149°54.720W | 1 heure | Sonde SB16 | T°, S°/°°, O2, pH, nephelo, chl a | 01/04/09 | F sampling routine, 6 month |
| Nengo | 10 | 18°42.420S/14152.020W | 1 heure | Thermographe SB56 | T° | 31/08/02 | F sampling routine, 2 years |
| Nuku Hiva | 10 | 08°54.930S/140°00.982W | 1 heure | Thermographe SB56 | T° | 02/10/08 | F sampling routine, 2 years |
| Nuku Hiva | 40 | 08°55.367S/140°01.197W | 15 mn | Sonde Sea Bird SB26 | T°, waves, sea level | 02/10/08 | F sampling routine, 2 years |
| Pitcairn | 10 | 25°03.821S/130°07.254W | 1 heure | Thermographe SB56 | T° | 03/10/09 | F sampling routine, 2 years |
| Pitcairn | 36 | 25°03.361S/130°07.596W | 15 mn | Sonde SB26 | T°, waves, sea level | 03/10/09 | F sampling routine, 2 years |
| Raiatea | 12 | 16°44.230S/151°30.240W | 1 heure | Thermographe SB56 | T° | 06/01/98 | F sampling routine, 2 years |
| Rarotonga (Cook Islands) | 12 | 21°12.920S/159°49.976W | 1 heure | Thermographe SB56 | T° | 01/02/09 | F sampling routine, 2 years |
| Rarotonga (Cook Islands) | 35 | 21°12.906S/159°50.067W | 15 mn | Sonde SB26 | T°, waves, sea level | 01/10/08 | F sampling routine, 2 years |
| Tahiti Motu Uta | 52 | 17°31.334S/149°34.354W | 1 heure | Sonde SB16 | T°, S°/°°, O2, pH, nephelo, chl a | 01/01/10 | F sampling routine, 6 month |
| Tahiti Taapuna | 55 | 17°36.111S/149°37.548W | 1 heure | Sonde SB16 | T°, S°/°°, O2, pH, nephelo, chl a | 01/04/09 | F sampling routine, 6 month |
| Takapoto | 9 | 14°42.24S/145°15.20W | 1 heure | Thermographe SB56 | T° | 24/06/09 | F sampling routine, 2 years |
| Tetiaroa | 12 | 17°01.787S/149°33.322W | 1 heure | Thermographe SB56 | T° | 13/02/03 | F sampling routine, 2 years |
| Tikehau | 13 | 15°00.860S/140°17.290W | 1 heure | Thermographe SB56 | T° | 11/06/02 | F sampling routine, 2 years |
| Tikehau | 35 | 15°00.860S/140°17.290W | 15 mn | Sonde SB26 | T°, waves, sea level | 03/07/09 | F sampling routine, 2 years |
| Tongatapu (Tonga) | 12 | 21°04.046S/175°20.256W | 1 heure | Thermographe SB56 | T° | 20/10/09 | F sampling routine, 2 years |
| Tongatapu (Tonga) | 35 | 21°04.046S/175°20.256W | 15 mn | Sonde SB26 | T°, waves, sea level | 19/10/09 | F sampling routine, 2 years |
| Tubuai | 14 | 23°20.66S/149°24.22W | 1 heure | Thermographe SB56 | T° | 24/01/02 | F sampling routine, 2 years |
| Tubuai | 35 | 23°20.66S/149°24.22W | 15 mn | Sonde SB26 | T°, waves, sea level | 01/12/09 | F sampling routine, 2 years |

**Table 2.** Location and measurement details for probes and thermographs deployed throughout SO CORAIL network (* = sites located outside of French Polynesia)

### Sampling Duration

Collection of physico-chemical data began officially in 2007, but it was not until 2010 that the network had the full suite of equipment and processes in place. It is considered that two decades (2010-2030) of physicochemical and biological data will be required to run an analysis powerful enough to deliver results providing insight into the impacts of global climate change on reefs. Twenty years is considered a 'magic number' in the context of coral reefs, where biological cycles are typically of this order of magnitude.

### Data Storage and Security

Two types of data are archived as part of SO CORAIL. First, there is the metadata. Metadata provides a detailed description of the study sites, the methodology for collecting data on corals and fish, details pertaining to the instrumentation used (deployment and technical specifications), the structure of the data collected, and details of the observers or individuals responsible for data collection. Second, there is the data itself. Data are stored in raw Excel file format. Metadata and data are stored in duplicate on computers that are physically located at CRIOBE in Moorea, French Polynesia and Perpignan, France (CRIOBE). In addition, all data is stored online in a virtual Cloud storage setting. Metadata is currently accessible on the Internet at http://observatoire.criobe.pf. Access is unrestricted and the metadata is downloadable in PDF format.

### Use of Data by Interested Scientists

All raw data is available through an online infographic available at http://observatoire.criobe.pf. Interested parties must submit a signed application form (located on the website) to gain access to the data. The form simply asks for the name of the person making the request, the data they are interested in and a brief description on how the data will be used. To date, there have been no restrictions on the use of data. By signing the form, users also agree to acknowledge SO CORAIL in any publications resulting from the use of the data. All these projects fall under the auspices of the INSU (Institut National des Sciences de l'Univers) of the CNRS.

*Planes S, Chancerelle Y, Siu G, Claudet J*
*CRIOBE, USR 3278 CNRS-EPHE-UPVD, Laboratoire d'excellence CORAIL, Perpignan, France and Moorea, French Polynesia.*

## GREEN BUBBLES

The European Project on Sustainable Diving

www.greenbubbles.eu

Recreational SCUBA diving has become a mass leisure activity engaging millions of divers worldwide. The diving industry generates large direct and indirect revenues for local communities and Marine Protected Areas (MPAs). Other benefits linked to diving include the promotion of environmental and ocean stewardship, contribution to scientific research, fostering social inclusion and personal development. Yet, diving has also negative impacts, due to damage or disturbance of habitats and organisms and to conflicts with local communities for the access to/use of the same resources, equity issues, or cultural clashes. These aspects clearly relate to the three pillars of sustainability, covering environmental, economic and social dimensions and can only be addressed by a systemic approach.

The central objective of Green Bubbles is to maximise the benefits associated with diving, whilst minimising its negative impacts, thus achieving the environmental, economic and social sustainability of the system. This will be done by:

- Carefully assessing and modelling the system itself;
- Developing innovative products based on the issues and needs highlighted by assessment and modelling;

Promoting the uptake of such products by the system designing tailored business models and marketing plans.

Direct engagement with selected stakeholders (divers, professionals, operators, certification agencies - CAs, MPAs, NGOs) will ensure relevant feedback throughout the project's lifetime, as well as effective uptake of results at the end of the project.

Green Bubbles is a project about diving and its positive as well as negative potential impacts. It was conceived to support the evolution of the diving system towards sustainability and to be implemented together with stakeholders. The project puts emphasis on the European diving industry, taking advantage of parallel comparative work on the coral reef one. Some activities will also be carried out on a larger scale (European or global). Indeed, while keeping a global or European perspective in most of its assessment tasks, Green Bubbles focuses on two case study locations for most of product development, testing and for designing strategies for uptake. This double scale is crucial in ensuring that the whole system is assessed and appropriately segmented, while products are effectively developed and tested in real-case scenarios. The two case studies are highly representative of diving systems in an European and in a coral-reefs context, paving the way for future translation to other locations.

**Ponta do Ouro.** Located in Mozambique, the Ponta do Ouro Partial Marine Reserve (PPMR), established in 2009, stretches for 86 km and links with the iSimangaliso Wetland Park on the South African side of the Mozambique border. It has an all-year round warm climate with an average of 28 degrees Celsius. Currently ranking top 86th diving place in the world, Ponta do Ouro hosts a number of vulnerable species including turtles, birds, and sharks. Further, the reefs there receive as many as 60 thousand dives yearly.

**Portofino MPA.** Established in 1999, Portofino MPA is a major diving destination in the NW Mediterranean Sea (45-60 thousand divers/year). The Mediterranean represents about 50% of the Gross Added Value for coastal and marine tourism in Europe. Portofino MPA has been the focus of much research on marine habitats and, more recently, on socio-economic aspects. Green Bubbles was launched in January 2015 and will last until December 2018. It is carried out by a multidisciplinary consortium of 9 members from 6 countries and 3 continents encompassing universities, research centers and private companies. Covered expertise includes environmental, marine and biological sciences; engineering, IT and gamification; pedagogy, education and communication; safety, medical science and risk prevention; tourism and leisure sciences;
marketing and business planning.

All outcomes from the project will be made publicly available both via reports/press releases (already being posted on the project's website) and via Open Access scientific papers. The latter not only to abide the EU Horizon 2020 legal requirements on dissemination and communication, but also to facilitate the creation of a multi-sectoral and multidisciplinary community of informed stakeholders, beyond the narrow academic context.

For further information please see:

| | |
|---|---|
| www.greenbubbles.eu | FB: https://goo.gl/IPv0Jx |
| join@greenbubbles.eu | #GreenBubblesRISE |
| Twitter: GB_RISE | #sustainable #scuba |

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*The Green Bubbles project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Sklodowska-Curie grant agreement No 643712. The piece of writing reflects only the authors' view - the Research Executive Agency is not responsible for any use that may be made of the information it contains.*

# REEF DEPARTURES

*Memories of recently departed members and reef scientists*

## Loïc Charpy (1950-2013)

Loïc Charpy, who died on 7 February 2013, was born on February 26, 1950 in Phnom Penh (Cambodia) and spent his childhood on the Tilapia fish farm founded by his father in Congo Brazzaville. Even when young, he was an adventurer and very interested in nature.

He graduated with honors in biological oceanography from the University of Aix-Marseille. From 1975-1977 he spent his military service as a volunteer at the National Active Service (VSNA) in Argentine Patagonia, based at the "Centro Nacional Patagonico", where he worked on phytoplankton population dynamics in Gulf Nuevo and Gulf San Jose. This became the subject of his thesis, and the related publications are still important reference literature for understanding plankton dynamics in this area. From 1978 to 1981, he worked in Brazil at the University of Rio Grande where he set up a phytoplankton laboratory and was appointed head of all the laboratories of the "Base oceanográfica". From Brazil, he moved back to the Congo to work on a Tilapia aquaculture project and walk in the footsteps of his childhood at “Djoumouna Farm”! Shortly afterwards he joined ORSTOM (now Institut de Recherche pour le Développement - IRD) and was posted to French Polynesia where he developed research on phytoplankton and primary production in the atolls.

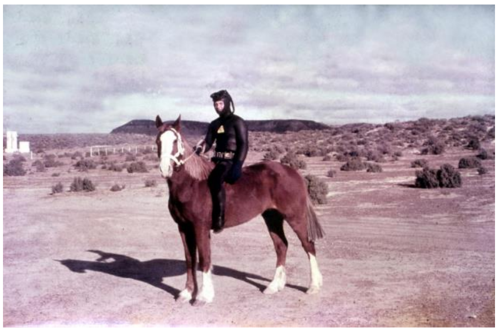
Apart from his three long stays in French Polynesia (1982-1988, 1991-1995, 2010-2012), he was based at the Marseille Oceanology Center from where he undertook missions to the Indian Ocean (Mauritius, La Reunion, Mayotte, Iles Eparses, Madagascar) and the Pacific (Okinawa-Japan, New Caledonia, Fiji, Cook Islands, French Polynesia, Clipperton Island). His work resulted in a long publications list, including over 50 peer-reviewed articles, 20 papers in conference proceedings, and 8 scientific book chapters. He edited six books and gave over 60 presentations at international conferences including four as invited speaker (Mexico 1998, Japan in 2004, Argentina 2004 and Spain 2005). This body of work is a key reference on productivity of lagoon waters. He was a talented storyteller, captivating his audiences by presenting his work as an exciting story and giving life to the organisms he studied.

He was involved in the TYPATOLL programme to investigate 16 atolls, noting that latitude as well as the extent to which the lagoons are open appears to influence their diversity. He also worked on benthic cyanobacteria in the Indian and Pacific Oceans and took part in several coral reef ecosystem programmes.

*Working on board during a cruise around the Iles Eparses in the Indian Ocean*

Loïc had wide experience in the field, was hugely inventive, and encouraged local people to set up laboratories in the most remote places (including, in French Polynesia, the laboratories on Tikehau Atoll which ran from 1983 to 1995, and Ahe Atoll, where he ran a programme on "Professionalization and sustainability of pearl farming" from 2007 to 2010, financed by the European Development Fund). He also led pearl culture, aquaculture and environmental programmes in Cuba, the Cook Islands, the Mekong Delta in Vietnam, and in the Indian Ocean. Combining his enthusiasm for both exploration and scientific inquiry, he helped to organize the Clipperton Island expedition mounted by Jean Louis Etienne in 2005. Under the PRE-COI program (1998-2000), he helped to set up a coral reef health monitoring network. Loic boosted the development of many international research cooperation programmes, including the Franco-Japanese cooperation initiative (2001-2008) with the University of Shizuoka and in 2007 established a partnership between Boston University, the University of Oldenburg and the Sultan Qaboos University for the study of benthic cyanobacteria mats.

He was a good communicator, diffusing his knowledge through internet sites (notably IRD's bilingual site which describes 20 years work in French Polynesia), conferences (e.g at Océanopolis, Brest and in Marseille), videos, and interviews for newspapers and radio stations. Loïc communicated his scientific passion with joyful enthusiasm, and numerous students and young researchers considered him as a role model. His sense of humor, his ability to find solutions to problems, and his excitement about life, made field missions a joy. His vision and analytical mind made him a valuable collaborator in developing programs and research initiatives.



Loic in the Argentine Patagonia, on his favorite horse

Loïc loved the great outdoors and remote countries, and was an excellent diver, remarkable horseman, and passionate hand glider (he participated in several championships in France).

Loïc's friends and admirers all feel that the planet was not big enough for him.

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## Glenn Richard Almany (1967–2015)

It is with great sadness that we write this tribute to a very special colleague. Glenn Almany, well known and greatly appreciated in the coral reef research world, passed away on March 24th 2015. Glenn had recently been hired by the Centre National de la Recherche Scientifique (CNRS), through a highly competitive recruitment process, to work at the Centre de Recherches Insulaires et Observatoire de l'Environnement (CRIOBE) in Perpignan (France) and Moorea (French Polynesia).

Glenn's life was one of discovery, albeit with a strange start. Having enrolled in the US Navy at the age of 17 with the aim of seeing the world, he ended up traveling around it several times in a nuclear submarine and thus seeing very little of it. Nevertheless, these six years had a major impact on him, and changed his expectation of life, giving him a better idea of what was and what was not important

to him. While in the navy, Glenn spent several weeks in Guam and, as his boat underwent repairs, he experienced coral reefs for the first time. This changed everything for him, with coral reefs becoming the driving force for the rest of his life.

After leaving the US Navy, Glenn completed a BSc at San Francisco State University in 1966, and a PhD at Oregon State University in 2002. His postgraduate research was on coral reef fish ecology, with much of his fieldwork undertaken in the Caribbean. He received a Fulbright Postgraduate Scholarship in 2003 and moved to Australia to work with Geoffrey Jones and other colleagues from James Cook University.

Glenn's career has been very rich and varied. He was a particularly good "connector" and enjoyed putting together people with different expertise to create projects and building on the interactions between the individuals to create something greater. He will be remembered as a marine scientist who was becoming increasingly recognised for his groundbreaking work on the dispersal patterns of coral reef fish larvae.

Glenn also enjoyed spending time with local communities, and worked intensively with some of the Pacific islanders to tackle issues around fisheries management. He became very involved in these communities, helping to improve their lives and enabling him to understand the role that individuals have in managing their environment. We all remember him telling us how much he enjoyed being embedded in these local communities, living with them, and learning about their lives. He would get very excited telling stories of what had happened to him, for example, when he got caught up in a war between clans on Manus Island, Papua New Guinea, over use of fishing grounds.

Gone far too soon, these pictures show Glenn indulging some of his favorite activities: playing with local children and playing with reptiles (he often said that reptiles would be his main interest if it were not for fish). A brilliant scientist with a deep green core, Glenn was deeply concerned about making a meaningful difference to the world.

We will remember fondly all the work we carried out together in Kimbe Bay, the ideas we discussed all night long, while drinking gin, arguing of course, because science is the result of friends arguing and sharing ideas; we will miss your ideas, and your optimism, even when you were told "*oh my friend, this will never work…* "

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**Geoffrey Jones**, James Cook University, Townsville, Queensland, Australia
**Michael Berumen**, King Abdullah University for Science and Technology, Thuwal, Saudi Arabia
**Simon Thorrold**, Woods Hole Oceanographic Institute, MA, USA.

# ISRS MEMBERSHIP

ISRS membership is open to all persons interested in any aspect of the science of coral reefs. While the society's membership consists principally of researchers, managers and students with interests in coral reefs and associated ecosystems, other people with genuine interests in or concern for reefs, of any type, are welcome.

The benefits of membership include:

- Receipt of the Society's scientific journal *Coral Reefs* (either on-line or hard copy)
- Receipt of the Society's newsletter/magazine *Reef Encounter* (by email or on-line)
- 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 whether a hard-copy subscription or on-line access to the Society's Journal Coral Reefs is preferred, and according to the mean income level of the member's country.

**Student Membership**

The benefits are the same as for a Full / Individual Member, and include hard copy or 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 journal that is paid for.

**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:

**ISRS Member Services**
**5400 Bosque Blvd, Suite 680**
**Waco, Texas 76710-4446 USA**
Phone: 254-399-9636
Fax: 254-776-3767
email: isrs@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 services page at: https://www.sgmeet.com/isrs/membership/memberlogin.asp

# NOTES FOR CONTRIBUTORS

**Reef Encounter** welcomes the submission of Scientific Articles, News Items, Announcements, Conference Reports and Book and Product Reviews, relevant to the coral reef researchers and managers. We especially welcome contributions by young researchers with a fresh perspective and seasoned reef scientists able to integrate a lifetime of experience.

Colour pictures or other illustrations (normally 1 -3 according to article length) are welcome to accompany an item. Cartoons and stand alone pictures of special note may also be submitted.

Different types of item should be sent directly (preferably by email) to the relevant section editors (see inside front cover - page 2 – for details).

# Notes for Contributors

## Types of Article

Reef Encounter accepts three distinct type of "Scientific Article". Note that, for any of these types of article, priority will normally be given to authors who are members of ISRS.

The **REEF PERSPECTIVES** section takes 2-4 page articles which express a fact-based opinion about a scientific or management issue. Our goal is to encourage thoughtful and stimulating discussion within and across disciplines and generations. Authors thinking of offering an opinion-type item are encouraged to consult the editor. Readers are encouraged to respond by writing letters to the **CORRESPONDENCE** section, but such responses should be well reasoned and respectful (in contrast to the faster-paced open discussion characteristic of coral-list).

**REEF CURRENTS** takes 1-5 page articles which overview a topic or a programme with which the author is familiar or has become acquainted. Priority will be given to articles focusing on subjects which are relatively new or poorly known or often misunderstood.

**REEF EDGE** takes short scientific notes or papers (scientific letters) of three-quarters of a page to two and a half pages in length. The intention is to provide a forum for recording observations of scientific or management value that may be too limited in scope to form the basis of a full scientific paper in a quality journal (such as Coral Reefs). It is especially intended that this section provide a useful vehicle for young scientists or those whose first language is not English. Nevertheless submissions must be based on adequate data and appropriate analysis.

For any of the above types of article no standardised division into sections is required; rather authors can propose section headings as best suited to their material. Similarly abstracts will not be used. However articles should be properly referenced, with typically 3 -12 publications cited in a reference section at the end. All types of article will be subject to refereeing by one or more suitably experienced referees.

## Style and Format

Contributions should be clearly written and divided into paragraphs in a logical manner. They should normally be in English, but editorial policy is to accept one article per issue written in French or Spanish, but with an abstract in English.

Pages are set with margins as follows: Top 1 cm; Bottom 1.5 cm; Sides 1.3 cm
Reef Currents articles are set as a single column across the page. Reef Perspectives and Reef Edge (and also Reef News) items are set as double columns with the gap between columns = 1 cm
The standard font is: Calibri size 11, with section headings in Calibri 11 Bold. Sub-headings are also in Calibri 11 bold, but set into the beginning of the paragraph.
References are in Calibri font size 10, and footnotes in Calibri font size 8.

Paragraph settings are: line spacing = single with a 10 pt line space after a return or at the end of a paragraph, but no additional line spacing before. There is no indentation on either side, except when lists or bullet points are inserted.

Figures & Pictures should have a resolution of at least 350 dpi and be of a size suitable to the format. Each should have an explanatory caption either below or alongside it. Captions should be reasonably full, but not too long. Leave a single line between a figure and a caption below it. Use “Fig.” (i.e. abbreviated) in the text, but “Figure” (e.g. Figure 1) to start a caption

Tables may be single column or page width, but large tables are not normally suitable for publication in Reef Encounter. Each should have an explanatory caption either below or alongside it. Leave a single line between a table and a caption below it.

## References

The style of References follows that used by Coral Reefs with no points or stops after initials or abbreviations, but with parentheses / brackets around dates, e.g. for journal papers and books:

Matsuura H, Sugimoto T, Nakai M, Tsuji S (1997) Oceanographic conditions near the spawning ground of southern bluefin tuna; northeastern Indian Ocean. J Oceanogr 53: 421-433

Klimley AP, Anderson SD (1996) Residency patterns of white sharks at the South Farallon Islands, California. In: Klimley AP & Ainley DG (eds) Great white sharks: ecology and behaviour. Academic Press, San Diego, pp. 365–374

Each reference should have a hanging first line with subsequent lines indented by 0.5 cm. A full list of abbreviations can be found and downloaded from the Springer website at http://www.springer.com/life+sciences/ecology/journal/338