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REEF ENCOUNTER

ICRS 13, Honolulu, Hawaii - Society Awards & Honors
COP21 - Global Coral Bleaching – Modelling – 3D Printing
Deep Reef Surveys – Coral Settlement Devices – *Sargassum*
Lophelia Sediment Removal- Caribbean Reefs at Risk

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International Society for Reef Studies

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REEF ENCOUNTER

Reef Encounter is the Newsletter and Magazine Style 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).

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.

CORAL REEFS - THE JOURNAL

The International Society for Reef Studies also publishes through Springer's 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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COVER PICTURE: Closed Circuit Rebreather (CCR) in use for scientific research. See article page 22 for which this is **Figure 1**. Note the small cylinder immediately behind the diver's head, and the two larger back up cylinders at the side of the diver. (Photo: Ally McDowell)

EDITORIAL

Apologies to members that this edition of Reef Encounter is appearing a little later than scheduled, but hopefully the content has been worth waiting for. My thanks to those who have come forward with such an interesting and unusually diverse range of articles, ranging from deep reef survey work to three-dimensional printing, to add to the continuing news of the near global effects of climate change and other impacts on our coral reefs.

Among the articles in this edition are also a diverse set of short communications in the REEF EDGE section. We have now clearly departed from the original policy of Reef Encounter, not to include papers based on original data. There were doubtless good reasons for this policy, but we agreed to trial this section, and to date I believe the innovation has been well received. The section not only offers researchers the opportunity to alert our community promptly to significant new findings, but also provides a service to members who may otherwise find it difficult to draw the attention of other members to potentially valuable observations.

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

RECORDING SECRETARY'S REPORT

In addition to approximately monthly conference calls of the Society's Officers, conference calls of Council Members were held on 8th/9th October 2015 and 14th/15th April 2016. To accommodate the now global distribution of Council Members, calls are held in two parts, at times suitable for members resident in eastern and western hemispheres respectively.

Significant items for discussion included: general organisation of (and arrangements for ICRS meetings at) ICRS13; selection of hosts for ICRS14 and a European coral reef meeting; Society finances; input to the Paris Climate Change Convention CoP; revision of the Society's constitution; Society journals and newsletters; the Society's website and facebook pages; design of and competition for a new Society logo; Society awards and honors; and establishment of new Education and Conservation Committees.

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

TREASURER'S REPORT

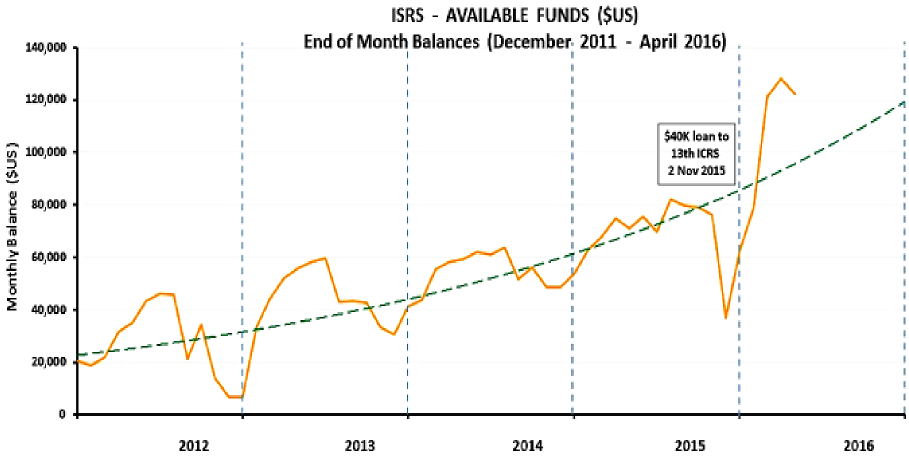

Figure 1. *Monthly uncommitted funds held by ISRS from 1 January 2012 to 30 April 2016.*

*The society's financial state and reserves have increased in every year since 2012. Figure 1 shows reserves of unliened funds at the end of each month since ISRS entered a contract with the Schneider Group to provide administrative support services (in mid 2012). On 30 April 2016, the society had an unliened balance of **$US122,300** with anticipated routine expenditures of about **$27,000** for the remainder of 2016.*

The initial strong annual cycle was caused by membership dues being paid mainly in the first half of each year. Dampening of the cycle in 2014 and 2015 probably stems from two policy changes in our dues structure: 1) increasing numbers of members are now paying dues 1-3 years ahead rather than annually, and 2) reduced dues seem to be increasing membership in developing countries. The sharp decline in late 2015 represents a $40,000 no-interest seed money loan to the organizers of the 13th ICRS, which we anticipate will be repaid by the end of 2016, while the huge 2016 increase is the direct result of more than doubling total membership in anticipation of the 13th ICRS.

ISRS income comes exclusively from membership dues, with one exception. In July 2015, Springer-Verlag made a gift €10,000 ($US11,189) as a bonus for the success and prestige of our journal "Coral Reefs." The increasing reserves has allowed ISRS to increase expenditures in support of the society's primary mission. Recent initiatives include $3,329 to ensure ISRS representation at COP21, the 2015 United Nations Climate Change Conference in Paris, and $10,000 to fund four Graduate Research Fellowships.

Donald Potts
ISRS Treasurer
Professor of Biology, University of California at Santa Cruz, California, USA

SOCIETY ANNOUNCEMENTS

Darwin Medal 2016

On 1st March the Society announced that the winner of the **2016 Darwin Medal** is **Dr. John E. (Jack) Randall, of the Bernice P Bishop Museum, Honolulu, Hawai'i**. The Medal is the Society's most prestigious honor, awarded only once every 4 years, to an eminent scientist based on their lifetime's achievements. The award will be presented at the upcoming International Coral Reef Symposium, coincidentally to be held in Honolulu, from 19th -24th June.

Society's Honors and Awards for 2016

The Society announced in February that its Annual Honors for 2016 have been awarded to the following members:
The ISRS Eminence Award (two awarded annually): Bette Willis and Katharina Fabricius
The ISRS World Reef Award: Sangeeta Mangubhai
The ISRS Mid-Career Award (2016): Andrea Grottoli

In addition the following members were elected to the status of ISRS Fellow: Katharina Fabricius, Andrea Grottoli, Mark Hixon, Ove Hoegh-Guldberg, Sangeeta Mangubhai, Rupert Ormond, Peter Sale, Bette Willis, and (in recognition of their past services to the Society) the following former ISRS Presidents: Ian Macintyre, Charles Birkeland, Bernard Salvat, John Ogden, Terry Done, Nick Polunin, Richard Aronson, and Bob Richmond. Congratulations to all recipients.

ISRS Graduate Fellowships

In March the Society announced the recipients of four new ISRS graduate fellowships (including two for students from developing countries). They and their project titles are as follows:
Archana Anand, Hong Kong University, Hong Kong: Linking sewage impacts to ecosystem decline in a human impacted marine environment.
Danielle Claar, University of Victoria, Victoria, Canada: Elucidating mechanisms of coral reef resilience to local stressors and El Niño on the world's largest atoll.
James Dimond, University of Washington, Seattle, USA: The role of DNA methylation in the response of tropical reef corals to environmental change.
Laura Marangoni, Federal University of Rio Grande, Rio Grande, Brazil: Interactive effects of acidification, increasing temperature and micronutrient enrichment on the physiology of *Mussismilia harttii* (Scleractinia, Mussidae) - implications of concurrent climate and non-climate stressors.
25 applications were received and assessed independently by a six-member selection committee. Congratulations to the successful candidates.

General Meeting of Members

The Society's next 4-yearly General Meeting of Members will take place on Wednesday 22nd June in the Hawaii Convention Center, Honolulu, Hawaii, during the course of the International Coral Reef Symposium being held there from 19th – 24th June. Members present at the Symposium are urged to attend.

Any member wishing to have an item placed on the Agenda should please notify the Corresponding Secretary, Rupert Ormond (rupert.ormond.mci@gamil.com**) or Recording Secretary**, Kiho Kim (kiho@american.edu) **by 31st May, 2016.**

Society's Constitutional Referendum

As members were advised by email, the Referendum to approve the proposed revisions to the Society's Constitution and Bylaws closed on 30th November 2015, with 49.3% of the membership having voted, all in favour of the revised Constitution. Proposed changes to the Bylaws were likewise approved. These votes having met the requirements of the old constitution, the revised Constitution and Bylaws became effective on December 1st.

New Conservation and Education Committees

At its meeting on 14th/15th April the ISRS Council agreed to establish two new committees which it is intend will become increasingly important and active - an Education Committee and a Conservation Committee. Chairs were appointed as follows: **Conservation Committee - Sue Wells** (email: suewells1212@gmail.com); **Education Committee - James Crabbe** (email: james.crabbe @wolfson.ox.ac.uk)

Each committee will be composed of three council members plus a minimum of three other society members, and include if possible at least two practitioners (e.g. teacher or coral reef manager) and two student members (graduate or undergraduate). Any member interested in being considered for either committee is asked to email the relevant chair with a copy of their CV.

The Terms of Reference for each committee can be downloaded from the home page of the Society's website (www.coralreefs.org).

Members' Directory

Members may wish to note that the Society's Directory of Members has, since last year, been available in the Members' area of the Society's website. The Directory can be searched for example to find members living in different countries, or working in a specific ocean region or researching a particular subject area. To access the Directory log in to your account using your email address and ISRS password at: http://coralreefs.org/membership/.

13th International Coral Reef Symposium, Hawaii

As members will know, the 13th International Coral Reef Symposium (ICRS) will be taking place in just over a month's time, from 19th – 24th June, at the Hawaii Convention Center, Honolulu, Hawaii. The ICRS, sanctioned by the International Society for Reef Studies (ISRS) and held every four years, is the primary international meeting focused on coral reef science and management.

It is now expected that the Symposium will be attended by over 2,100 coral reef scientists, policy makers and managers, from 97 different countries. 1507 talks are scheduled, along with 677 posters.

The full scientific programme is now available on line at:
https://www.sgmeet.com/icrs2016/sessionlist.asp.

Note that details of meetings and of workshops and townhalls are shown on separate web-pages as follows:
https://www.sgmeet.com/icrs2016/meetings.asp
https://www.sgmeet.com/icrs2016/workshops-townhalls.asp

Members and others can still register to attend, albeit at a higher rate than previously. For details see: https://www.sgmeet.com/icrs2016/registration-fees.asp

The Society's General Meeting of members (now to be held every 4 years) will take place during the course of the symposium on Wednesday 22nd June at 7.30 p.m. in Theatre 310

For queries concerning the scientific program, please contact:
Dr. Robert Richmond, Convener, 13th ICRS,
Kewalo Marine Laboratory
University of Hawaii at Manoa
41 Ahui Street
Honolulu, HI 96813 USA
email: richmond@hawaii.edu
Phone: (1) 808-539-7330

For practical and logistical queries contact:
Helen Schneider Lemay,
Conference Manager, 13th ICRS
SG Meeting and Marketing Services
5400 Bosque Boulevard, Suite 680
Waco, TX 76710 USA
email: helens@sgmeet.com
Phone: (1) 254-776-3550
Fax: (1) 254-776-3767

Honolulu, from Diamond Head

GENERAL ANNOUNCEMENTS

19th Reef Conservation United Kingdom (RCUK) Meeting

26th November 2016, Zoological Society of London, London, UK

Reef Conservation United Kingdom (RCUK) will again be organizing its annual one day meeting at London Zoo. The event will continue to highlight the need for multidisciplinary studies of coral reefs and adjacent environments, and the RCUK themes of conservation, management and education. RCUK meetings provide an excellent opportunity to meet fellow reef workers and enthusiasts in order to discuss ideas and activities on an informal basis. While the meetings are principally attended by UK reef scientists and conservationists, colleagues from elsewhere are very welcome to attend and present. The call for abstracts will open in early June and should be submitted online by Friday October 3rd. Registration is required (also online) by Friday November 21st, 2016.

More information will be posted shortly at: http://www.reefconservationuk.co.uk/rcuk-2016.html

European Coral Reef Symposium 2017

13-15th December 2017, Department of Zoology, University of Oxford, UK

The next European Coral Reef Symposium, sponsored by ISRS, will be held in association with the 20th Annual Reef Conservation UK Meeting, in the Department Zoology, at the University of Oxford, Oxford, UK, from 13th-15th December, 2017.

This three day conference is planned as the European Inter-congress scheduled to take place approximately midway between ICRS13 and ICRS14. The meeting will consist of talks, poster sessions, social events and workshops. More information will be posted online over the coming months at:
http://www.reefconservationuk.co.uk/ecrs-2017.html

WANTED: BARCODES OF NEOPOMACENTRUS CYANOMOS (REGAL DEMOISELLE)

The Indo-west Pacific reef damselfish *Neopomacentrus cyanomos*, aka the Regal demoiselle, is now well established in the southern Gulf of Mexico. We are trying to determine the ultimate source and mode of this introduction. Barcodes of this species from the Seychelles, Madagascar and the northern Great Barrier Reef do not resolve those issues. Hence we request that people in various other parts of its geographic range (e.g. the Red Sea, E Africa, India, Sri Lanka, Thailand, Indonesia, W Australia, the Philippines, Taiwan, and New Caledonia) provide barcodes of this species to help with this effort. Barcoded fish need to be field-caught (NOT supplied by the aquarium trade, which moves fish around a lot) and vouchered (a good photo will do if the fish can not be preserved and kept in a museum collection). Please send barcodes and collection and voucher information to: **D Ross Robertson** (Smithsonian Tropical Research Institute, Panama) at drr@stri.org. With many thanks for any assistance.

REEF PROFILE

A new section profiling members of note

Sangeeta Mangubhai

Sangeeta Mangubhai is the proud recipient of the Society's 2016 World Reef Award. She was born and grew up in Suva, Fiji. Following Fiji's first military coup in 1987, her family migrated to Toowoomba, Australia where she completed her last years of high school. She went on to graduate with a Bachelor of Science (Hons) majoring in marine biology from University of Queensland in Brisbane, Australia in 1995. Her first job was as a Conservation Officer with the Queensland Parks and Wildlife Service, where she gained her first experience in environmental management, and was heavily involved in the first zoning of Moreton Bay Marine Park. Three years later while on holiday in Fiji, she was offered the position of regional coordinator for the World Wide Fund for Nature's South Pacific Programme, providing technical guidance and strategic support to their country programs Fiji, Papua New Guinea, Solomon Islands and Cook Islands.

In 2001, she moved to Kenya as a research associate with CORDIO East Africa, and commenced her PhD in 2003 with Southern Cross University, Lismore, Australia as an external student. Her dissertation was on the *reproduction and recruitment of scleractinian corals on equatorial reefs in Mombasa, Kenya,* for which she received the Chancellor's Outstanding Thesis Medal. On completion of her PhD in 2007, Sangeeta moved to Indonesia where she spent a year as the Conservation Manager for Putri Naga Komodo helping to improve the management of Komodo National Park. A year later she took over as the Portfolio Manager for The Nature Conservancy's conservation program in West Papua. While in Indonesia, she provided technical advice to government on policy and legislation at the regency and national level, and designed and led strategies on spatial planning, Marine Protected Area (MPA) network design, climate change, fisheries, community resource management, governance, sustainable financing, and monitoring and evaluation. She helped lead efforts to formally declare Indonesia's first shark and manta ray sanctuary in Raja Ampat, the global center of marine biodiversity.

In 2013, Sangeeta decided to move back to Fiji permanently and currently is the Director for the Wildlife Conservation Society's Fiji Country Program. She oversees a diverse portfolio of work on national policy, MPAs, fisheries, gender, ridge to reef planning, forest protected areas, and payment for ecosystem services. She sits on numerous government committees providing policy, science and management advice, and co-chairs the Executive Committee for the Women in Fisheries Network-Fiji.

Since her PhD, Sangeeta has maintained her passion for science. Reflecting her diversity of research interests, she has published on coral reproduction, grouper spawning aggregations, coral bleaching, cetacean diversity, MPAs, sharks, and conservation planning. She specialises in designing monitoring programs to understand the impacts of disturbances on coral reef communities, and the return of investment of conservation strategies. She enjoys mentoring young scientists in developing countries to be stronger scientists, and has run multiple trainings and informal writing groups. She holds an adjunct scientist position with the New England Aquarium in Boston, and sits on the Kiribati Government's Scientific Advisory Committee for the Phoenix Islands, advising on monitoring and science in this Protected Area. She has participated in the long-term monitoring of Phoenix Islands since 2000, and helped lead the last two expeditions. She is currently an editor for the journal Pacific Conservation Biology.

CLIMATE CHANGE

Cardboard boxes, "consensus", COP21 and Climate change

Sue Wells, with contributions from Ove Hoegh-Guldberg and Mireille Guillaume

The climate change negotiations that took place in Paris in December 2015 now seem a long time ago, but it is useful to reflect on ISRS's effort for the UN Framework Convention on Climate Change (UNFCCC) COP21 and how this demonstrates the role that our Society can play globally. It is always difficult to judge the impact of campaigning and communications efforts, but we think that ISRS, along with the many others involved, played an important part in the historic outcome. The following is thus an overview of ISRS's contribution, a description of the event itself and some thoughts on what needs to happen next.

Cardboard boxes and consensus

In early December, Ove and I found ourselves in Paris with the potentially unmanageable cargo of some 15 cardboard boxes, each weighing over 10 kg. These contained 7000 English, 2500 French and 2000 Spanish copies of the ISRS Consensus Statement on climate change (http://coralreefs.org/Convention-on-Climate) which we had to get, in the right numbers and right languages, to the numerous event venues scattered across the city, including the COP21 itself at Le Bourget, some 15 km north-east of the city centre.

The boxes were not the first of our headaches. Reaching consensus on the content of the statement had been the first hurdle. ISRS had been calling for the 1.5°C target since at least 2009, as this has been recognised as essential by many, and notably by those countries most likely to be affected by climate change. For the UNFCCC COP15 in Copenhagen that year, we produced a very short flier (an initiative led by John Bruno, Sue Wells, Melanie McField and Caroline Rogers) that pushed for this. However, negotiations at COP15 proved particularly difficult and very little progress was made.

By 2015, there was a much greater understanding of the need for action, a larger body of irrefutable evidence on the causes of climate change and the impact it would have, and stronger political momentum to take action. ISRS Council felt that it was important that the Society used the research of its members and its scientific credibility to support the lobbying that was underway for the 1.5°C target. This time we had a slightly longer lead-in time and more capacity to produce a document. But things never go according to plan.

Producing a consensus statement is much like the proverbial herding of cats. Ove agreed to act as lead author and supporting co-authors were brought in (many thanks to Mark Eakin, Gregor Hodgson, Peter Sale and Charlie Veron), with Rupert Ormond as co-ordinator. The list of reviewers grew steadily longer as the Society worked towards a position that was acceptable to a majority. The meaning of "consensus" was nevertheless called into question. The Coral List and Jim Hendee's championing, as well as the ISRS membership network, allowed many people to air their views but inevitably not all members fully agreed with the final text. For future similar initiatives it would perhaps be best not to use the term "consensus". However, the statement was welcomed in many circles and, once approved by Council, the power of social media meant that it was circulated widely and almost instantaneously, which had not been possible in 2009.

Thanks to the efforts of Council and ISRS members, the leaflets were translated into French (Mireille MM Guillaume, Serge Planes, Nicolas Pascal, Francis Staub), Spanish (Juan P. Carricart-Ganivet, Anastazia Banaszak, Edwin Hernandez-Delgado), Arabic (Mohammed M. A. Kotb, Abdulmohsin Sofyani, Dirar Nasr) and Chinese (Dave Baker and students) – ISRS is very grateful to those who helped with this. We also had offers to translate it into German and Bangla (Bangladesh) but unfortunately did not have the time to take these up.

All language versions were posted on the ISRS website, and the ISRS network of members led to links being made very rapidly with numerous other sites. WWF International sent the statement to the 55 WWF national offices with marine teams within 24 hours of its completion, and ReefCheck similarly sent it to all its global contacts. Other organisations and discussion groups that took up the cause included: the International Coral Reef Initiative (printed copies were distributed at the annual ICRI meeting in Thailand in December); Australian Coral Reef Society; French Centre National de la Recherche Scientifique (CNRS); Coral-list and its French counterpart ACOR-list; Muséum National d'Histoire Naturelle (MNHN), Paris; Cambridge Conservation Forum; IUCN – Maldives network; Chagos Trust; "Healthy Reefs", Belize; Marine Conservation Society, UK; New Coral Reef Coalition; Reef Conservation, UK (RCUK) (printed copies distributed at its annual meeting); and marine science networks in Thailand, Singapore and many other countries. Rupert also organised a petition, based around the statement, and this rapidly gathered signatures, reaching over 1550 by the end of November 2015.

Meanwhile the COP21 itself was rapidly approaching and it became clear that we need printed versions of the 4 page statement to distribute to lobbyists and negotiators, and people there to distribute them. A friendly printer in Cambridge, UK, came to our aid as we had very few days to print and ship the leaflets, and the problems of travel to France had become acute, with the unhappy migrant situation in Calais and the shocking terrorist event in Paris. But the printer knew a driver willing to run the gamut of this and somewhat to our amazement the boxes arrived in time.

COP 21

The atmosphere in Paris was highly charged in every way – a deep sense of grief from the earlier terrorist tragedy combined with the heady excitement about finally making progress on the climate change issue. The logistics were impressive: the high level of security required was handled sensitively and there were helpful and friendly officials at every step. Paris was given over to promoting the message: the Christmas lights on the Champs Elysées were powered by solar and wind energy; there were numerous exhibitions on energy saving and the impact of climate change; and striking art installations, most notably the twelve 10-ton pieces of ice from Greenland that were placed outside the Pantheon by Danish-Icelandic artist Olafur Eliasson and geologist Minik Rosing in a clock formation and that progressively melted as the negotiations continued[1].

Solar and wind power take over the Champs Elysees powering the Christmas illuminations

The Le Bourget conference centre sprawls over 25 hectares (comfortable shoes were essential for walking between venues) and was divided into two: an area accessible to official delegates only where the negotiations took place, and an area open to the public (but under strict security arrangements). Here, 100s of side events, exhibitions and stands were located with presentations, displays and materials to support and influence the negotiators. Energy saving was paramount, with delegates in suits and ties pedalling furiously to charge their phones or laptops, or to have a freshly squeezed orange juice.

The oceans had a high profile and, in the context of the UNFCCC, a new and welcome visibility. Paris saw a fantastic mobilisation of groups of all types concerned about the future of the oceans, and the engagement and support from many political leaders. The Small Islands Developing States (SIDS) such as Seychelles, Palau, and Grenada played

[1] In case you were wondering, as I did, about the environmental impact of this, the ice chunks had already broken off from the ice sheet into Nuuk Fjord and the carbon footprint of the installation was estimated at equivalent to 30 return flights from Paris to Greenland.

prominent roles, along with the French overseas territories of New Caledonia and French Polynesia. The Ocean and Climate Platform (www.ocean-climate.org), established in 2014 to ensure that the UNFCCC negotiations took oceans into account, and the Global Ocean Forum (https://globaloceanforum.com), established in 2001 to provide support to the SIDS and now with a global agenda, were the two main co-ordinating bodies and brought together the evidence and science that needed to be relayed to the delegates. Tara Expeditions (www.oceans.taraexpeditions.org), a French non-profit organisation that uses the expeditions by the yacht *Tara* to campaign on ocean and climate-change related issues, set up a base in the city centre on the banks of the Seine for presentations, educational events and promotional activities

A regal aura accompanied the frequent appearances of the main ocean champions, not least because of their names: His Serene Highness Prince Albert of Monaco, Sérgolène Royal, Secretary of State John Kerry, and of course Sylvia Earle, well known as "Her Deepness". Ove and his colleagues organised and spoke at a number of high profile events including a pre-screening of David Attenborough's latest film ('Great Barrier Reef') at *La Maison des Oceans (Institut Oceanographique*). This included star appearances by Sir David, Sir Richard Branson and others. Australian Minister for the Environment, Greg Hunt, made regular appearances on behalf of Australia and survived (with good humour) heckling and disturbance from protesters drawing attention to the decline of corals on the Great Barrier Reef.

Ocean royalty at the GBR event

Equally important were the huge efforts put in by French marine and coral reef scientists and conservationists, and the ISRS members (notably Council member Serge Planes) who were present. A small band of unassuming heroes including Mireille Guillaume (MNHN), Léa Godiveau, André Abreu and Romain Troublé (Tara Expeditions), Claire Bertin (Ocean and Climate Platform), Miriam Balgos (Global Oceans Forum), Aurélie Boquet (IUCN French Committee) and many others stepped in to help with the significant logistical problems. We distributed the statement and promoted the coral reef message at numerous events and lobbied many official delegates. Concurrently, the French reef scientists urged the advisors to the French government at the Palais de l'Elysée and at various ministries to take the statement to the President of the COP21, Laurent Fabius.

I spoke at a French symposium on "Coral Reefs and Climate Change" at the French National Assembly in the city centre, at the invitation of IFRECOR (the French Coral Reef Initiative), and the Maison de Nouvelle Calédonie (which kindly co-financed my trip to Paris) and again at a small side event organised by IUCN-France at the COP21 venue. Ove spoke at a breakfast on Oceans (that included an inspiring speech by John Kerry), and, as one of the co-ordinating lead authors of the 5th Assessment Report of the International Panel on Climate Change (IPPC), brought the conclusions that related to oceans to the main meeting. Both Ove and I presented the coral reef argument at an "Islands and Pacific Day" event that was organised by Tara Expeditions and attended by many leaders, official delegates and senior ministers of the SIDS. Overall, our precious coral reefs were front and centre – reminding everyone at COP21 how climate change is real, happening right now and has disastrous consequences if we don't begin to act now.

As is now common knowledge, the outcome was that 195 countries adopted the Paris Agreement (https://unfccc.int/resource/docs/2015/cop21/eng/l09.pdf), through which they intend to hold the increase in the global average temperature to "*well below 2 °C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5 °C above pre-industrial levels*" (Article 2 (1a)). This wording tallies closely with that of ISRS's statement: that countries should "commit to limiting atmospheric carbon dioxide (CO_2) concentrations to no more than 450 ppm in the short-term, and reducing them to 350ppm in the long-term. This should 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. This would prevent global collapse of coral reef ecosystems and allow coral reefs to survive in perpetuity." Naturally, we would like to believe that ICRS had a huge influence on the outcome!

The *Tara* and the Tara Pavilion used as a venue for many ocean events, on the banks of the Seine with the Eiffel Tower as backdrop

Climate change and coral reefs – the next steps?

There is a still a long way to go before the Paris Agreement comes into force. It opened for signature on 21 April 2016 and some 175 countries have now signed. Signature means only that a country **intends** to launch the domestic processes for ratification or acceptance of the Agreement. Subsequently, nations will formally deposits their instrument of ratification, approval, acceptance or accession with the UN Secretary-General, and this is the point at which they consent to be bound by the Agreement. The Agreement however does not come into force until the 30th day after the date on which at least 55 Parties that, between them, account for at least 55% of the total global greenhouse gas emissions, have deposited their instruments.

So there are many who are skeptical about whether any real progress has been made. As this issue of *Reef Encounter* appears, the current global bleaching event is continuing (see other articles), with a major event on the Great Barrier Reef in March[2] and the outlook for coral reefs continues to be dire. Current Intended Nationally Determined Contributions (INDCs) to reduce carbon dioxide emissions would probably only limit the rise to 3°C. But those with a more optimistic outlook feel that the Paris Agreement has set a path that is heading in the best direction feasible. To many, COP21 represented a watershed for the science of climate change, in that the Paris Agreement was accepted allowing future discussions to focus on implementation.

The 2°C target could be technologically feasible with the right investments, correct policies and appropriate political will, although even this target will require zero carbon economies by the end of the century. Hope lies in the fact that the agreement contains a "ratchet mechanism". Every 5 years, countries will have to say what they are doing to tackle climate change, in what will be called their Nationally Determined Contribution (NDC). Each successive NDC "will represent a progression beyond" a country's previous one. Vast changes will be necessary in the form of rapid de-carbonisation and adoption of new technologies but it potentially would be scientifically feasible to progressively lower temperature increase to 1.5°C by 2100[3]. ISRS will need to continue to take part in the global debate, perhaps going further than simply documenting the rate of decline of reefs, to championing some of the solutions that will be needed.

And the cardboard boxes: another lesson learnt. We printed far too many leaflets. We now live in an electronic world, and some of the boxes had to go for recycling. Printed leaflets were essential but in small numbers only. The value lay in being able to thrust the ISRS statement into the hands of a senior government officials and seeing their delight when they saw that ISRS's scientists supported their governments' negotiating position. And for the effect that had, we all feel that the slight indiscretion here was worth every gram of paper not consumed!

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[2] https://theconversation.com/great-barrier-reef-bleaching-would-%E2%80%A60would%20be%20almost%20impossible%20without%20climate%20change

[3] http://www.carbonbrief.org/piers-forster-1-5c-is-a-brave-new-world

REEF PERSPECTIVES

Personal comment on reef science, policy and management

WITH A LITTLE HELP FROM SOME MODELLING?

Peter J. Mumby

Marine Spatial Ecology Lab, School of Biological Sciences, University of Queensland, Brisbane, Australia;
email: p.j.mumby@uq.edu.au

First off, I'd like to express my sincere thanks to the ISRS for awarding me the inaugural "Mid-career Researcher Award" together with an ISRS Fellowship. Science tends to be a thankless business so recognition is gratefully received, and is especially humbling when from your peers. Thank you.

A boon of receiving the award is the opportunity to mount my soapbox and write a piece for Reef Encounter. I was reflecting on the paucity of modelling in reef science and the lost opportunities this presents. If that statement induces a feeling of nausea that makes you reach to turn the page, then **STOP** – this article is intended for you! Please read on.

Here, I attempt to answer four questions. 1) What are models used for in reef science? 2) Why should empiricists add some modelling to their research? 3) Are there any downsides to becoming "a bit of a modeller"? and, 4) How do we move forward?

1) What are models used for in coral reef science?
The most common uses of models are to support population and community ecology, though models are also used to integrate physiological mechanisms such as photosynthesis and bleaching (Gustafsson et al. 2013). There are many examples of models having been used to understand and predict the population dynamics of reef organisms including corals (Madin and Connolly 2006; Edmunds and Elahi 2007; Yakob and Mumby 2011; Bramanti and Edmunds 2013) and reef and commercial fish stocks (Ault et al. 2005; Ainsworth et al. 2008; Bozec et al. 2016). While most studies have focused on demography, others have explored population genetics (Kool 2009; Foster et al. 2012).

Most ecological modelling has been carried out on community-level processes. These include understanding community interactions and trajectories (McClanahan 1995; Van Woesik 2000; Connolly and Muko 2003; Mumby et al. 2006; Riegl and Purkis 2009; Zychaluk et al. 2012; Riegl et al. 2013; Sebastian and McClanahan 2013; Ortiz et al. 2014), community resilience (Mumby et al. 2007; Anthony et al. 2011; Blackwood et al. 2011,2012; Mumby et al. 2014b; Bozec and Mumby 2015), the function of ecosystem engineers (Bozec et al. 2013), reef carbonate budgets (Kennedy et al. 2013; Roff et al. 2015), and food web dynamics (Polovina 1984; Rogers et al. 2014). Several studies have also explored evolutionary mechanisms and the likelihood of coral adaptation to climate change (Baskett et al. 2009; Baskett et al. 2010; Ortiz et al. 2013).

In reality though, the list of reef scientists using models is pretty short; this probably stems from (1) empiricists being busy enough answering empirical questions, (2) a perception that the rewards of adding a modelling component are small, and, in some cases, (3) a fear of numerical methods. I wish there was a word for the expression most students wear when first asked if they'd like to include some modelling in their work; it's a cross between seasickness and the rictus grin you develop on the 100th wedding photo. Which brings us to item 2.

2) Why should reef scientists include some modelling in their work?
There are several reasons to consider incorporating modelling into what is often a field- or lab-oriented research programme.

Many of the key scientific questions require models. Almost every other paper I read talks about the effects of anthropogenic stress, including climate change, on coral reef dynamics. A typical discussion will argue that the study suggests that the effects of climate change are more complex or deleterious than previously thought. While this is usually true we should be cautious about implicitly scaling up to ecosystem-level impacts. This is particularly true when the study has only focused on one component of the system and one stressor (e.g., the effects of ocean acidification on acroporid calcification). When you actually embed that organism-stressor interaction into a wider ecosystem, you might find that the net effect is far less important than you expected (Mumby and Van Woesik 2014). This might be because the interaction is overwhelmed by another driver, or the result of the antagonistic influence of another stressor (Brown et al. 2013). For example, reducing levels of sedimentation might expose corals to greater levels of radiative stress and exacerbate bleaching. Including your results in even a simple qualitative model can help substantiate your conclusions and place your results in context. Moreover, the results of some empirical experiments are equivocal and require modelling to evaluate (Fig. 1).

One aspect of ecosystem-level dynamics that really benefits from modelling is resilience. The literature on coral reef resilience is diverse and, in some cases, confused (Mumby et al. 2014a). The core concept of resilience – the existence of alternative attractors (multiple stable states) – is quite challenging, but I have found that people find it much easier once they've had an opportunity to play with a model and understand it first hand.

Models point out what you don't know. This may be an obvious point, but there's nothing like trying to parameterise a model to help you uncover massive gaps in scientific knowledge. Alyssa Marshell's work is a good example. We discovered that no one seemed to have published the rate of algal biomass accumulation over time, yet this is fundamental to reef productivity!

Models challenge your understanding and pave the way for new research. I think it's fair to say that most reef scientists – myself included – chose this career because they love experiencing coral reefs. Not surprisingly, this tends to take us down an empirical path of field work and/or lab experiments. But it's worth bearing in mind that having an empirical familiarity with coral reefs can be a huge asset when developing models, since it helps you avoid making rash assumptions and sets you up to ask pertinent questions.

Models are great for challenging our understanding of a topic or process. Let me give you a couple of examples. We recently undertook a suite of experiments to deconstruct the process of coral recruitment into its component parts; settlement behaviour, competition, predation, the role of crevice refugia, and ontogeny. However, it's not clear whether the collective insights gained from multiple experiments are actually sufficient to explain the process as it occurs in nature. Could it be that we've missed a key process? Do the individual components actually integrate in non-intuitive ways that we were unable to measure? To test this, we used our experiments to construct a model of the system and then compared predictions to independent field data on the distribution of recruits across a reef. In this case we found that our insights were sufficient to explain what we observe in nature (Doropoulos et al. 2016).

But models don't always confirm that you understand things. Alyssa and I studied the processes governing algal turfs on reefs of the southern GBR and Palau. She used her field data and experimental results to parameterise a model of the bottom-up and top-down drivers of turfs and then attempted to predict the standing crop observed on the reef. In one habitat, the model fitted very well, implying that our understanding of these processes might be reasonable. But the model consistently failed in another habitat. This implies that something else is going on of which we are as yet unaware. Alyssa generated a series of hypotheses that might account for these discrepancies and these can be used to target new research. Similarly, models sometimes generate non-intuitive predictions which can generate new hypotheses for study (Ware 2015).

Models integrates science for managers. Coral reef managers are always telling me that they're willing to base decisions on the best science available, even though our knowledge is imperfect. So how do we provide the best science available? In some cases, the best science comprises one or two key papers on a topic, such as estimates of larval spillover from reserves. In others, there are literally hundreds of articles concerning an issue – particularly when looking

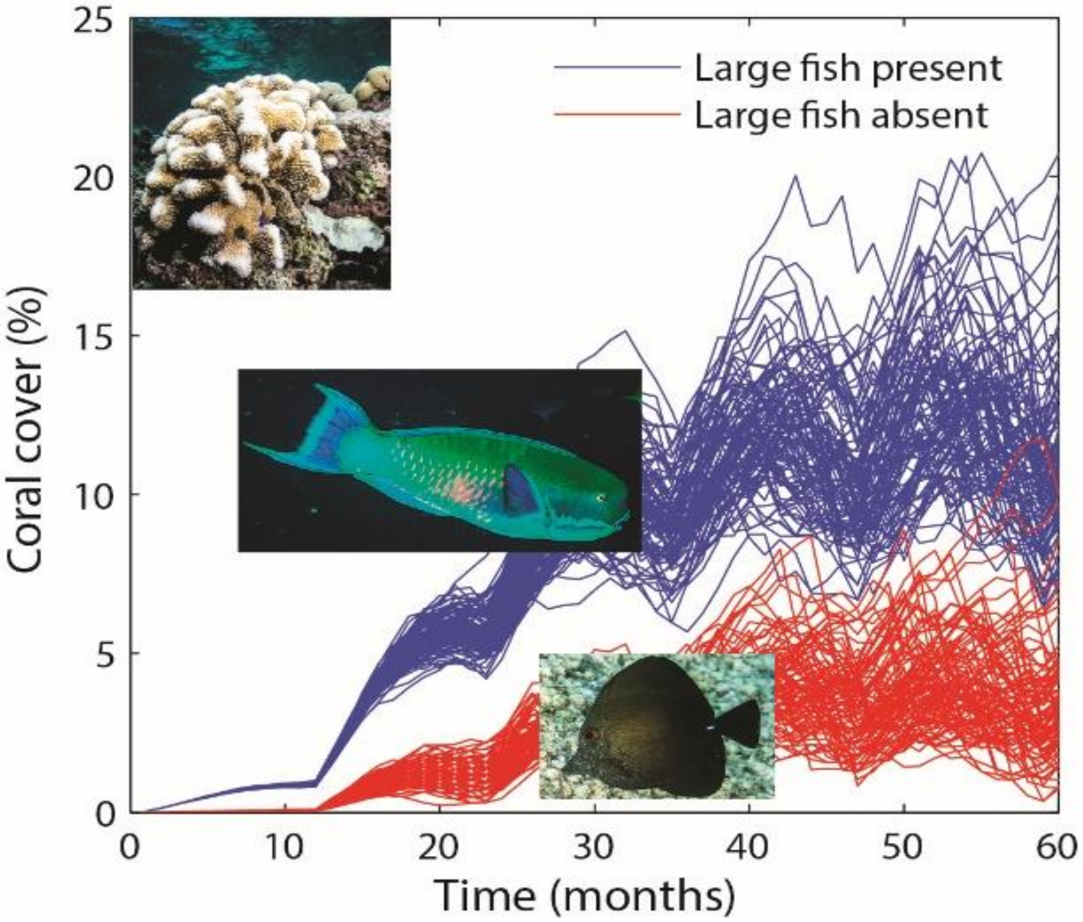

Figure 1. Use of an ecological model to evaluate the overall impact of large reef fish for coral recruitment in Moorea. Herbivory by large fishes benefits recruitment by reducing algal canopies but this comes at a cost of greater corallivory which increases mortality. Modified from Mumby et al (2015).

at questions like marine reserve impacts. Here, models are a great way to integrate information. For example, Emma Kennedy developed a model of the drivers of reef carbonate budgets – which underpin many ecosystem functions – and effectively integrated more than 300 individual studies (Kennedy et al. 2013). The results allowed us to compare the influence of management drivers (control of fishing and pollution) and greenhouse gas emission related stressors on the future carbonate budgets of reefs.

3) The downsides of becoming a bit of a modeller

I say a 'bit of a modeller' because while I hope that more empiricists will incorporate a little modelling into their work, I'm not advocating a wholesale shift in focus. In fact, I think the greatest advances in understanding coral reefs will happen when people with a sound empirical foundation integrate or challenge their work with models. So what, if any, are the downsides?

First, it requires some training, but this does not have to involve a return to the math(s) that terrorized you as a teenager. Some forms of modelling can be implemented using custom software programs that do not require any mathematical or programming skills (e.g., STELLA). And I think the most intuitive form of modelling for empiricists is to develop simulation models that explicitly capture the results of field studies into a virtual framework (e.g., coral recruits are placed on a 'reef' at the density observed in nature, the corals grow at observed rates, the competitive outcomes follow observed relationships, etc).

Perhaps the biggest downside I've experienced is during the publication process (surprise, surprise). Sometimes people forget that a model is – by definition and necessity – a simplification of reality, a situation which can easily result in some patronizing remarks. Most models evolve and increase in their complexity and representation of reality over time. For example, my first model did not attempt to discriminate the role of individual herbivore species, leading some referees to make dismissive comments asserting that I do not understand the complexity of the system. But this criticism is misplaced; it just wasn't possible to model it in greater detail at the time. A more appropriate criticism, and one made by Burkepile and Hay (2008), is to show that inter-specific differences in grazing are important and that models need to embrace this complexity. Absolutely right. Being aware of the deficiencies of the model I started a detailed campaign to "mind the gaps". Thus, we recently created a model of the bioerosion of *Orbicella annularis* by parrotfish that incorporated different species, body size, feeding rates, feeding preferences, and territory sizes; the results provided a compelling match to our observations (Roff et al. 2015).

In general, however, the interactions with referees are positive, and I can recall several occasions when a comment about the model formulation has advanced science by leading us to question some widely-held assumptions.

4) The way forward

I think the challenge of learning how to incorporate some modelling is getting easier all the time. Today, most graduate students are comfortable manipulating their data in R, and the skills needed to write basic programs are scarcely more sophisticated. My own experience was that Peter Sale asked me to write a book chapter on coral metapopulations. I figured that I really ought to develop some models to support this and took advantage of having a programming guru in the lab by the name of John Hedley. I asked him how he'd approach coding what I had in mind. He created a prototype following the rules of good programming, and this was enough for me to learn the basics and develop it further, albeit following far less efficient coding. Since then, most students and post-docs in the Marine Spatial Ecology Lab have picked up various bits of programming and used it to extend the scope and impact of their work. I don't think any of them regret it, or if they do, they haven't had the heart to tell me!.......Happy coding and good luck.

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REEF CURRENTS

General articles and overviews of reef science and management

Global Coral Bleaching 2014-2017

Status and an Appeal for Observations

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In 2014 we wrote in *Reef Encounter* about the prospect for a 2014-15 El Niño (Eakin et al. 2014). While that El Niño never fully formed, it helped set off the ongoing multi-year global coral bleaching event. A subsequent 2015-16 strong El Niño formed, spreading and worsening the bleaching, and has already caused bleaching in some areas two years in a row. As of April 2016, the current global coral bleaching event is the longest ever recorded. While it generally has not been as severe as the bleaching in 1998, it has affected more reefs than any previous global bleaching event and been worse in some locales (e.g., Great Barrier Reef, Kiribati), and thermal stress during this event has caused mass bleaching in several reefs that never bleached before.

Climatic History of the Global Bleaching Event

In June 2014 the US National Oceanic and Atmospheric Administration's (NOAA) National Centers for Environmental Prediction (NCEP) issued an El Niño Watch, indicating a greater than 70% chance that a weak-to-moderate El Niño would develop by late 2014. While the ocean warmed for several months, the atmosphere never fully engaged in formation of this event, and the warming dissipated without an El Niño being declared. However, warming resumed early in 2015 - this time with full engagement of the atmosphere. In March 2015, NOAA issued an El Niño Advisory, indicating that El Niño conditions had finally been observed and were expected to continue. Starting in 2013 and coincident with these events, an unusually warm patch of water appeared in the eastern North Pacific. Nicknamed "The Blob", it was most likely caused by a record-strength anomalously strong high-pressure ridge in the atmosphere over the region (Bond et al. 2015). This anomaly increased already warm ocean temperatures impacting marine life in much of the eastern North Pacific until late 2015 when the strengthening El Niño caused it to dissipate.

As of April 2016, NOAA's El Niño Advisory remains in effect, but the warming in the central to eastern tropical Pacific has begun to dissipate, following the usual chronology of an El Niño. Importantly for some reefs, such as in Micronesia and Palau, a La Niña Watch is in effect as the forecast estimates a >70% chance of a La Niña forming later this year.

2014: Initiation of the Global Bleaching Event

The current global coral bleaching event began in June 2014, with initial bleaching in Guam and the Commonwealth of the Northern Mariana Islands (CNMI, Heron et al. 2016a) – an area not normally linked to warming during an El Niño (Figure 1). Warming in Guam and the CNMI lasted until October 2014. Regions of anomalously warm water then expanded until they merged with the southwestward extension of "The Blob", encompassing parts of the Hawaiian archipelago, where the most severe bleaching was seen at Lisianski Atoll in the Papahānaumokuākea Marine National Monument. Thermal stress and bleaching extended into the Main Hawaiian Islands where major bleaching was seen along windward Oahu, especially Kāneʻohe Bay (Bahr et al. 2015). This was only the second widespread bleaching ever seen in the main islands of Hawaiʻi (Jokiel and Brown 2004). Also, in September 2014, severe bleaching was documented in both southeastern Florida and the Florida Keys. In November, sustained high water temperatures in the Republic of the Marshall Islands resulted in their most severe bleaching on record (Fellenius 2014). NOAA Coral Reef Watch's 5-km Degree Heating Week values (Liu et al. 2014) exceeded 8 °C-weeks (categorized as Alert Level 2 thermal stress, associated with widespread coral bleaching and significant mortality) in many of these areas.

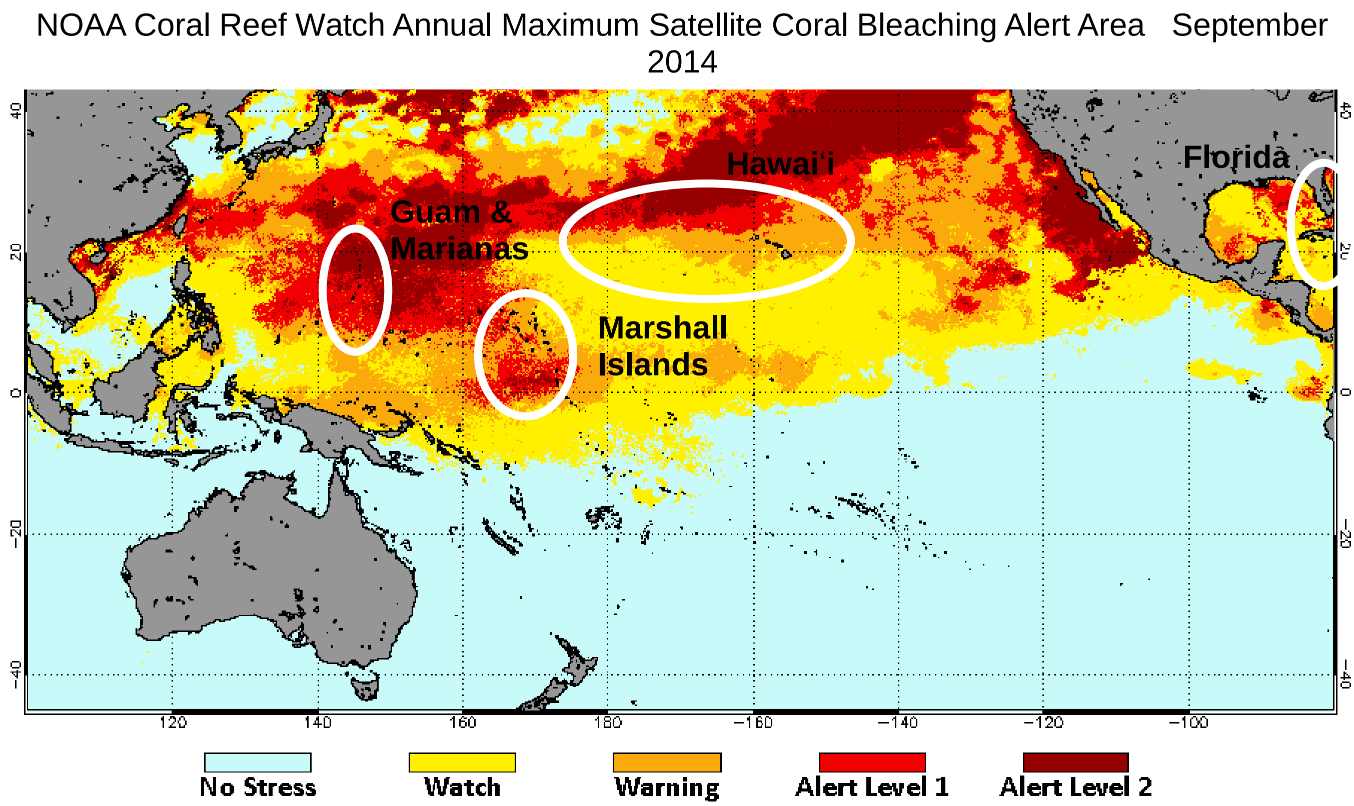


Figure 1. Coral Reef Watch Maximum Bleaching Alert Area map for September 2014. Marked are four areas exhibiting bleaching in the latter half of 2014. Alert Level 2 is associated with widespread coral bleaching and significant mortality.

January-June 2015: Bleaching Spreads

With the onset of austral summer, ocean temperatures started to rise and bleaching was reported in the Southern Hemisphere (Figure 2). Moderate levels of thermal stress and bleaching were reported in eastern Papua New Guinea and the Solomon Islands early in 2015, and subsequently in northern Fiji. The Samoas, especially American Samoa, reported the worst bleaching ever seen (Figure 3). Moderate levels of thermal stress were seen in the Indian Ocean in the first half of 2015 with reports of moderate bleaching in the Chagos Archipelago, the Maldives, western Indonesia, and the southern Red Sea. It is interesting to note that this pattern of bleaching in the South Pacific and Indian Ocean is most commonly observed during the second year of an El Niño, as in 1998 and 2010. However, most of the 2015 bleaching occurred before the 2015-16 El Niño conditions developed, raising the suspicion that this bleaching was associated with either the aborted 2014-15 El Niño or an oceanographic precursor of 2015-16 record-strength El Niño.

Initiation of the 2015-16 El Niño resulted in high thermal stress in the eastern tropical Pacific, with observations of bleaching in Panamá, and expected but unconfirmed bleaching in the northern Galápagos Islands. Mid-2015 also brought thermal stress to Kiribati, especially the Line Islands, where thermal stress reached the highest levels ever recorded, and killed at least 80% of the corals there (K. Cobb, pers. comm).

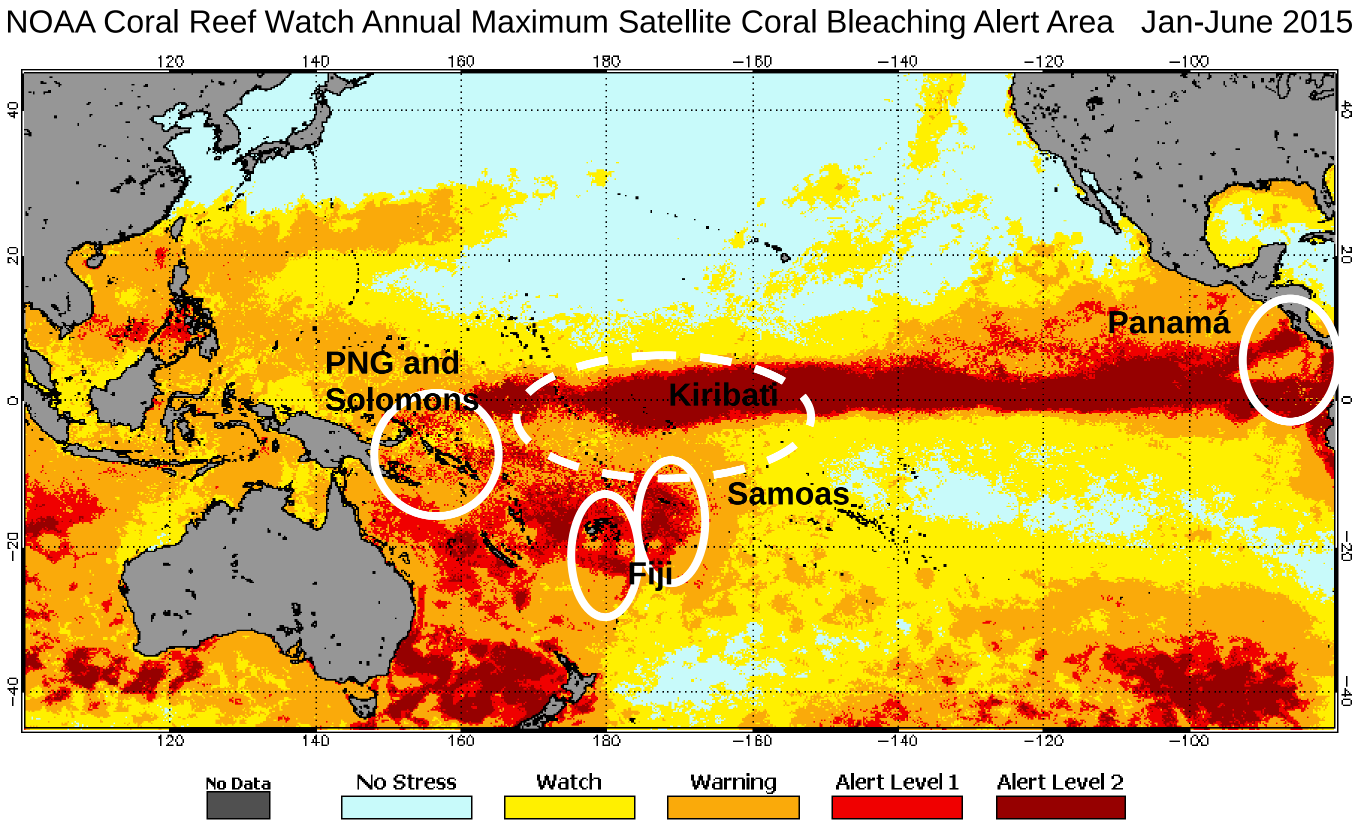


Figure 2. Coral Reef Watch Maximum Bleaching Alert Area map for January-June 2015. Marked are six areas exhibiting bleaching in the first half of 2015.

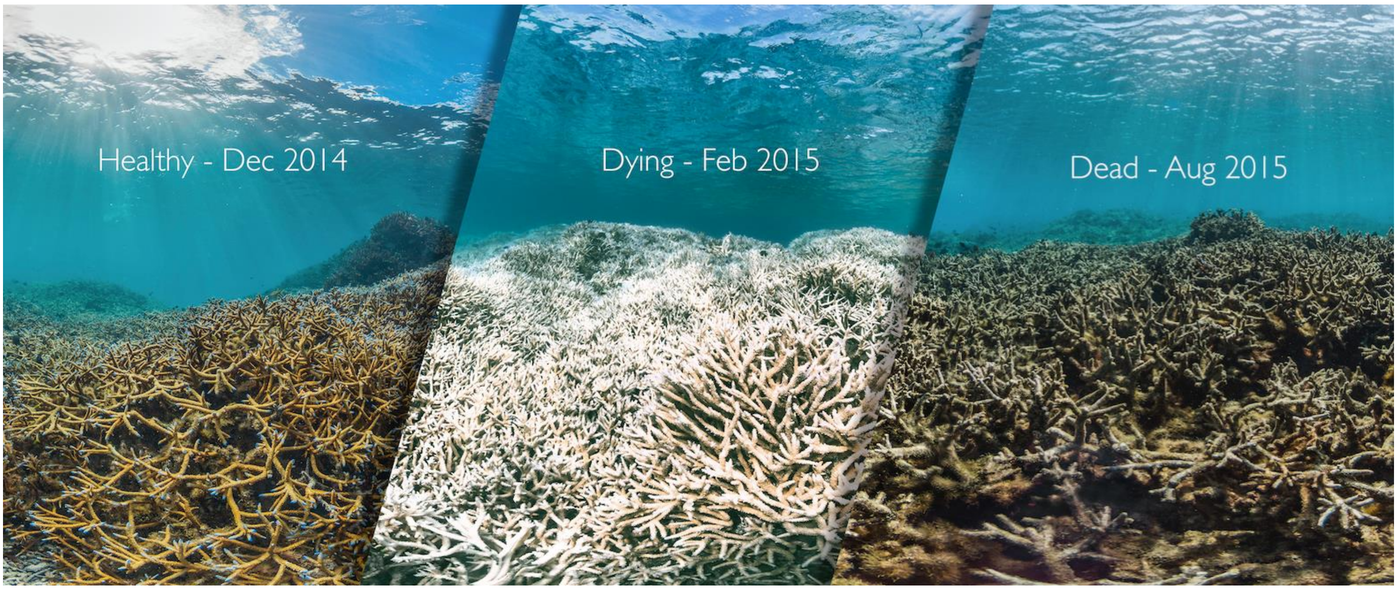


Figure 3. Photo composite of before, during, and after bleaching at Airport Reef, Tutuila, American Samoa (image courtesy of R. Vevers, XL Catlin Seaview Survey).

July-December 2015: Global Bleaching

With the 2015-16 El Niño in full swing, thermal stress intensified in the central to eastern Pacific (Figure 4). Reports from the Phoenix and Line Islands of Kiribati indicated bleaching and mortality of corals were well underway. A warm water mass, most likely related to warm El Niño waters off the Americas, spread to the Hawaiian archipelago from the southeast, resulting in widespread bleaching in the main islands of Hawai'i, with the most severe bleaching seen along shores of Hawai'i Island and Maui Nui. This was the worst bleaching ever seen in the main Hawaiian Islands and their first documented instance of back-to-back bleaching.

Unlike 2014, thermal stress and bleaching were widespread in the northern Caribbean, along with some bleaching in other parts of the basin. Bleaching of varying severity was reported in Florida, Cuba (northern and southern coasts), the Bahamas, Turks & Caicos, the Cayman Islands, parts of the Dominican Republic, Haiti, and Bonaire. Southeastern Florida and the Florida Keys not only saw a second year of bleaching, but southeastern Florida saw a severe outbreak of a white disease resulting in high levels of mortality. As of October 2015, with widespread bleaching in each of the Indian, Pacific, and Atlantic basins, NOAA declared that the third documented global coral bleaching event was underway. This followed confirmed global bleaching in 1998 (Wilkinson 2000) and 2010 (Heron et al. 2016b). Of note, this actually may have been the fourth global event, as widespread, possibly global bleaching was seen in 1983 in association with the 1982-83 El Niño (Coffroth et al. 1990).

By the end of 2015 32% of coral reefs worldwide had been exposed to thermal stress of 4 °C-weeks or more and almost all of the world's reefs had exceeded their normal warm-season temperatures.

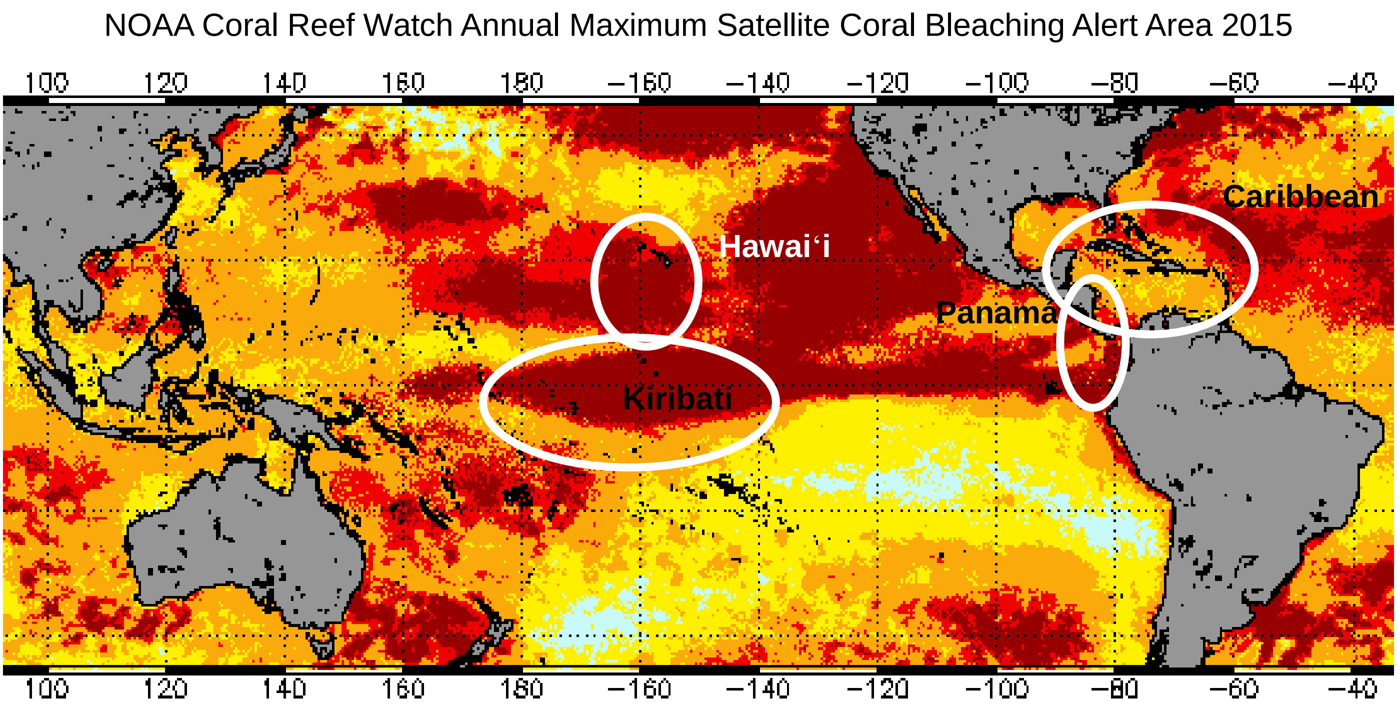
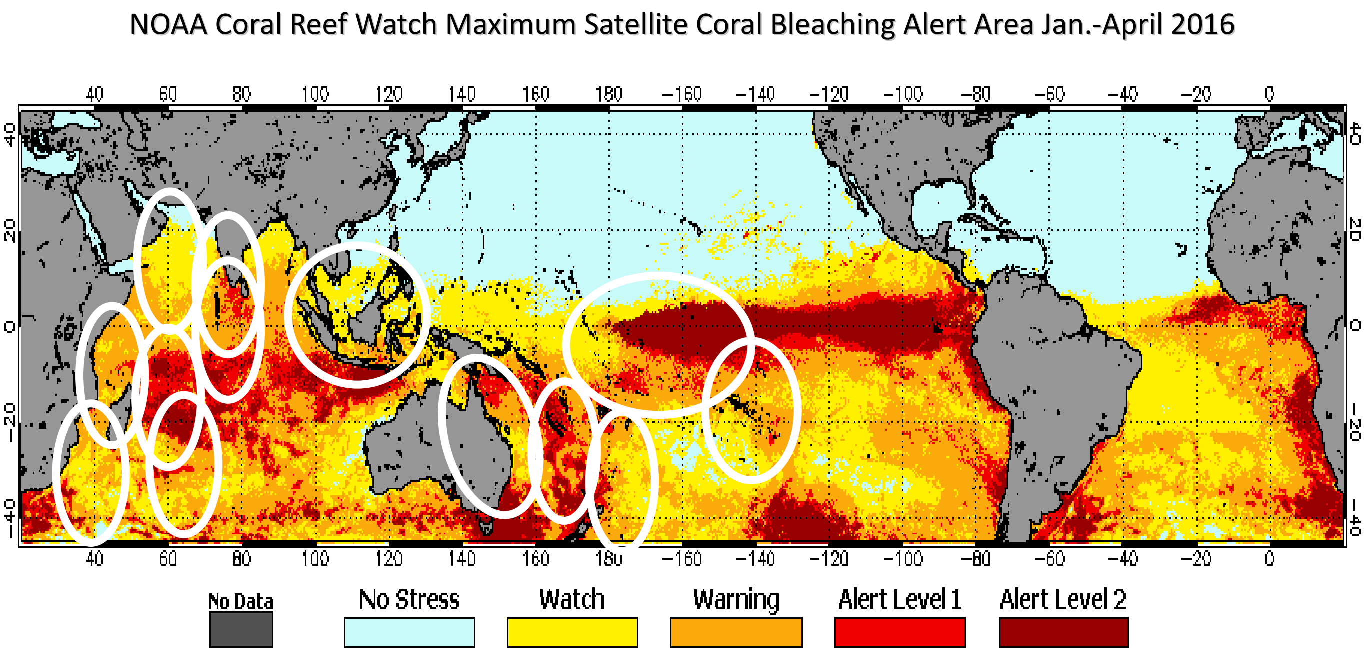


Figure 4. Coral Reef Watch Maximum Bleaching Alert Area map for 2015. Marked are five areas exhibiting bleaching in the latter half of 2015.

2016: Global Bleaching Continues

The El Niño continued to strengthen, becoming one of the strongest ever witnessed by the end of 2015. With the return of the austral summer, thermal stress and bleaching returned to the Southern Hemisphere. As of this writing, bleaching has been reported from as far west as Tanzania to as far east as French Polynesia, with severe bleaching in the Far Northern Great Barrier Reef, New Caledonia, and Fiji. Bleaching in the GBR has been the worst ever



Oman	**Western India**	**Thailand**	**Kiribati**
Kenya	**Maldives**	**Indonesia**	**French Polynesia**
Seychelles	**Réunion**	**Great Barrier Reef**	
Tanzania	**Mauritius**	**New Caledonia**	
Mozambique	**Madagascar**	**Fiji**	

Figure 5. Coral Reef Watch Maximum Bleaching Alert Area map for January-April 2016. List of marked areas with reports of severe bleaching.

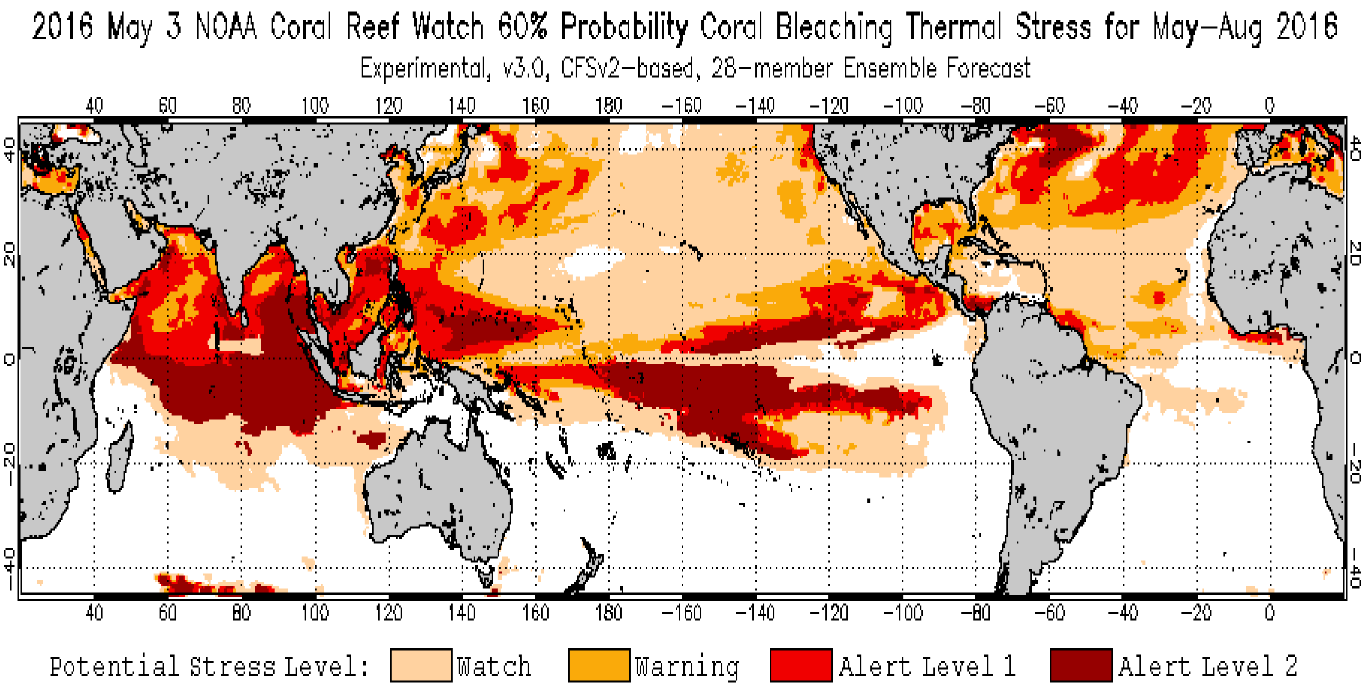


Figure 6. Map of areas where 60% or more of the model ensemble members are predicting thermal stress at each of NOAA Coral Reef Watch's bleaching thermal stress alert levels through August 2016 (as of 3 May 2016).

documented, affecting over 93% of the reefs with severe bleaching in 95% of the reefs in the northern 1/3 of the GBR, formerly the healthiest part of the GBR (De'ath et al 2012). Far worse is the bleaching in Kiribati. Surveys in March and April revealed over 80% of corals dead and 15% bleached, leaving few untouched (J. Baum, pers. comm. and in Harvey 2015).

An important question for Micronesia, Palau, and some other parts of the western Pacific Ocean, is whether a strong La Niña will follow this El Niño, as occurred in 1998. It is unfortunately too soon to tell. NOAA has issued a 70% chance of a moderate La Niña, but predictions of El Niño and La Niña issued before June are not highly reliable. NOAA Coral Reef Watch's Four Month Outlook indicates that more bleaching is likely in the northern Indian Ocean, parts of the Coral Triangle and Southeast Asia, and the central to eastern tropical Pacific during April-July (Figure 6). Also, the extended-range outlook and past El Niño patterns indicate bleaching will likely return to the Caribbean again this year. While still beyond the range of the seasonal models, bleaching has been seen in the Southern Hemisphere in the year after an El Niño, leaving open the possibility of this event continuing into 2017.

Documenting the 2014-(2017?) Global Bleaching Event

Unfortunately, two international programs that previously documented coral bleaching events are no longer serving this purpose. ReefBase has not added new bleaching observations since 2012 and few records in the database document the 2010 global bleaching. Also, since the retirement of its former coordinator, Clive Wilkinson, the Global Coral Reef Monitoring Network (GCRMN) has not actively maintained observations and reporting of bleaching worldwide. Fortunately, some regional GCRMN networks are still in place or are rebuilding, while other regional and global programs, like Reef Check, continue to coordinate coral reef monitoring.

To ensure that documentation of the ongoing bleaching event is as complete as possible, Coral Reef Watch plans to collate and report on the global extent of this event and we would be happy to work with any local or regional partners. Please continue any monitoring you are conducting and either report to your existing regional efforts or send them directly to us at Coral Reef Watch. Of note, we need both bleaching and non-bleaching observations to document the spatial extent and timing of the event, and to validate our satellite- and climate model-based products. Contributing data ensures that your site data are considered in global analyses; helps to understand how to better use the tools for your reefs; gives context to how bleaching patterns at your sites compare with global patterns; and provides access to the latest global bleaching data analyses to communicate climate impacts to decision makers. All contributors will have the opportunity to co-author peer-reviewed publication(s) on global and/or regional bleaching.

Additionally, film-makers at Exposure Labs are developing a documentary on this bleaching event. They are in need of assistance capturing pictures and video of the bleaching in as many places as possible. They have issued an appeal for underwater photographers and videographers to help them in this project.

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Challenges and opportunities in conducting mesophotic reef research

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Introduction

Mesophotic coral ecosystems (MCEs) are of growing interest because of the degradation of shallow coral ecosystems as a result of regional and global stressors, and the possibility that MCEs may be more protected by virtue of their depth. MCEs occur between depths of 30 to 150m, and are characterized by light-dependent zooxanthellate coral, octocorals, macroalgae and sponge communities (Hinderstein et al. 2010). Historically, MCEs have been poorly studied because of the logistical challenges associated with surveying this depth range (Pyle 2000; Hinderstein et al. 2010). Recent advances in technology are now making it possible to conduct research at these depths.

Much interest in MCEs has been driven by the deep-reef refugia hypothesis, first proposed by Glynn (1996) and based on decreased thermal stress with depth, but now expanded to other reef stressors. In short this states: many of the stressors causing damage to shallow reefs decline with depth, therefore allowing species threatened on shallow reefs to survive in deeper waters. These deep populations can then recolonize shallow reefs following disturbance, forming a local source of recruits (Bongaerts et al. 2010). There is evidence that MCEs are buffered from the impacts of storm damage, chronic pollution, sedimentation and overfishing with increased depth (Bridge et al. 2013). For example, in a 30 year time series of permanent photo quadrats in Curaçao and Bonaire, shallow reefs (<20m), appear to have experienced the greatest change, while MCEs appear to have maintained their coral communities (Bak et al. 2005).

It is increasingly being recognized, however, that MCEs themselves are under threat (Andradi-Brown et al. in press). For example, fishing has caused declines in fish biomass on MCEs (Lindfield et al. 2014). Damage from invasive species has also been recorded on MCEs, with high densities of lionfish (*Pterois volitans* and *P. miles*) in the western Atlantic, and Snowflake coral (*Carijoa riisei*) in Hawaii, leading to changes in the benthic community (Andradi-Brown et al. in press). Research to understand the refuge potential of MCEs and their resilience to stressors is therefore a high priority. Here we discuss how the University of Oxford Thinking Deep expedition overcame some of the logistical challenges associated with diver surveying of MCEs and conducted ecological research to 85m in Utila, Honduras, in September 2015.

1. Use of Closed Circuit Rebreathers (CCR)

We used closed circuit rebreathers (CCR) to conduct decompression dives on MCEs. CCRs re-cycle the expired gas from the diver by absorbing the exhaled carbon dioxide, allowing the diver to breathe this gas again, giving much greater efficiency than traditional open circuit (OC) scuba diving, as no gas is released (Sieber and Pyle 2010). Therefore with each breath the only gas addition required is a small amount of oxygen to maintain the oxygen partial pressure in the breathing gas, or a small amount of diluent gas with a lower percentage of oxygen - typically air or a helium-based gas mix, to dilute the breathing gas if it contains too much oxygen given the depth. The CCR unit contains multiple independent oxygen detectors (cells) to measure the partial pressure of oxygen being breathed. A specialized dive computer can then adjust the partial pressure of oxygen automatically or the diver can manually adjust, through adding oxygen or diluent to maintain the breathing gas at the desired oxygen level. This gas recycling allows divers to use far smaller cylinders than traditional open circuit diving, while substantially extending dive times by maintaining optimal breathing mixes. As a back-up measure, divers always carry extra cylinders to provide sufficient breathing gas to end the dive should their rebreather fail. Despite the need for back up cylinders, using a rebreather substantially reduces the number of cylinders required compared to traditional OC mesophotic reef dives of similar depth and duration (Figure 1 – on cover). For example, carrying out 30 minutes of research at 60m depth using trimix breathing gas (mix of oxygen, helium and nitrogen) followed by required decompression results in similar total dive times for OC and CCR, of 100 minutes and 102 minutes respectively, yet vastly different cylinder requirements. A CCR diver conducting this work would need to carry two back up cylinders in addition to their rebreather, whereas an OC diver requires seven cylinders to make the dive safely (Table 1). This difference is crucial, as it gives CCR divers the space to carry camera systems, photo-quadrat frames, transect tapes and other required scientific survey equipment to mesophotic depths. In addition the available gas resources to the diver allow a much more conservative reserve than could possibly be carried by a diver using OC.

Gas mix	**Open Circuit cylinders**	**Rebreather back up cylinders**
18/45 trimix (18% oxygen, 45% helium, 37% nitrogen)	4	1
50% nitrox *(50% oxygen, 50% nitrogen)*	2	1
100% oxygen	1	0
Total cylinders	7	2

Table 1. Number of cylinders a diver must carry to conduct 30 minutes of reef survey work at 60m depth followed by required decompression. Calculated assuming a cylinder size of 11.1L filled to 200bar, breathing rate of 20 L/min, rule of thirds for gas management, gradient factor conservatism of 30/70, CCR set point of 1.3, CCR diluent of 16/45.

When diving in relatively remote locations, helium and oxygen can often be in limited supply and expensive. CCR maximizes gas efficiency; for example on our reef survey dives to 85m, each diver consumed less than 600L of oxygen and 600L of trimix diluent per dive. This reduced breathing gas consumption meant we could conduct approximately eight mesophotic CCR dives using the same amount of trimix that a mesophotic OC diver would use on a similar single dive, allowing helium and oxygen usage and costs to be minimized while maximizing survey dive time.

In addition, we also used CCRs for shallow survey dives. While these dives were within the range of recreational OC scuba diving (<30m), the use of CCRs allowed us to markedly increase efficiency. Our team was able to execute single dives up to four-hours long, far beyond the gas and obligatory decompression limits of recreational OC diving. Table 2 shows the potential for CCR diving at 15m depth, dramatically increasing survey time without the bulk of additional cylinders and the build-up of decompression debt. After three hours of diving at 15m using an air diluent on CCR only one minute of mandatory decompression is required before surfacing, whereas over one hour of mandatory decompression is required using OC air. Switching to OC nitrox (mix of oxygen and nitrogen) reduces the decompression obligation but still leaves divers overburdened by a large number of cylinders. Application of rebreather technology enables researchers to substantially increase data collection time over the course of a fieldwork trip, especially in the recreational dive range, making it a tool that should be considered by reef scientists who conduct fieldwork even in the depth ranges of recreational scuba diving.

Depth	**Air OC diver** ***(21% oxygen, 79% nitrogen)***	**40% nitrox OC diver** ***(40% oxygen, 60% nitrogen)***	**CCR diver**
Survey time at 15m (min)	180	180	180
Decompression time at 9m (min)	1	0	0
Decompression time at 6m (min)	13	0	1
Decompression time at 3m (min)	45	1	0
Total dive time (min)	240	183	182
	7	6	1 *(back up cylinder)*

Table 2. Dive plan for 180 minutes survey work at 15m depth, showing time required to complete the survey work followed by required decompression. Comparisons are made for open circuit (OC) air, open circuit recreational nitrox (40% oxygen and 60% nitrogen) and closed circuit rebreather (CCR). The total number of cylinders of the required open circuit gas is indicated. Total dive time includes time to ascend between indicated depths. Calculated assuming a cylinder size of 11.1L filled to 200bar, breathing rate of 20 L/min, rule of thirds for gas management, gradient factor conservatism of 30/70, CCR set point of 1.3, air CCR diluent.

While earlier CCR technology gained a reputation of being dangerous, to the point of not being worth the risk, the main causes of these issues have been overcome with more modern systems, testing, and rigorous diver training. Although there are higher inherent risks when using CCR rather than OC (Fock 2013), the accident analysis research related to both training and manufacturing has led to a greatly improved safety record. Rebreather training courses regularly emphasize constant monitoring of the CCR unit, and involve extensively practicing drills to simulate possible unit failures. For example, following each day's diving during the Thinking Deep expedition, the Dive Safety Officer downloaded dive profile data for each rebreather. From this it was possible to check the oxygen cell readings for the unit for any inconsistencies indicating possible degradation or faulty connections, with the aim of identifying and solving problems before they occur. Should the diver encounter a problem, CCRs provide far more failure management options and available gas resources than OC systems, and divers always have a fully isolated back up option. With proper maintenance, diving practices, and training, CCRs can be used safely for research.

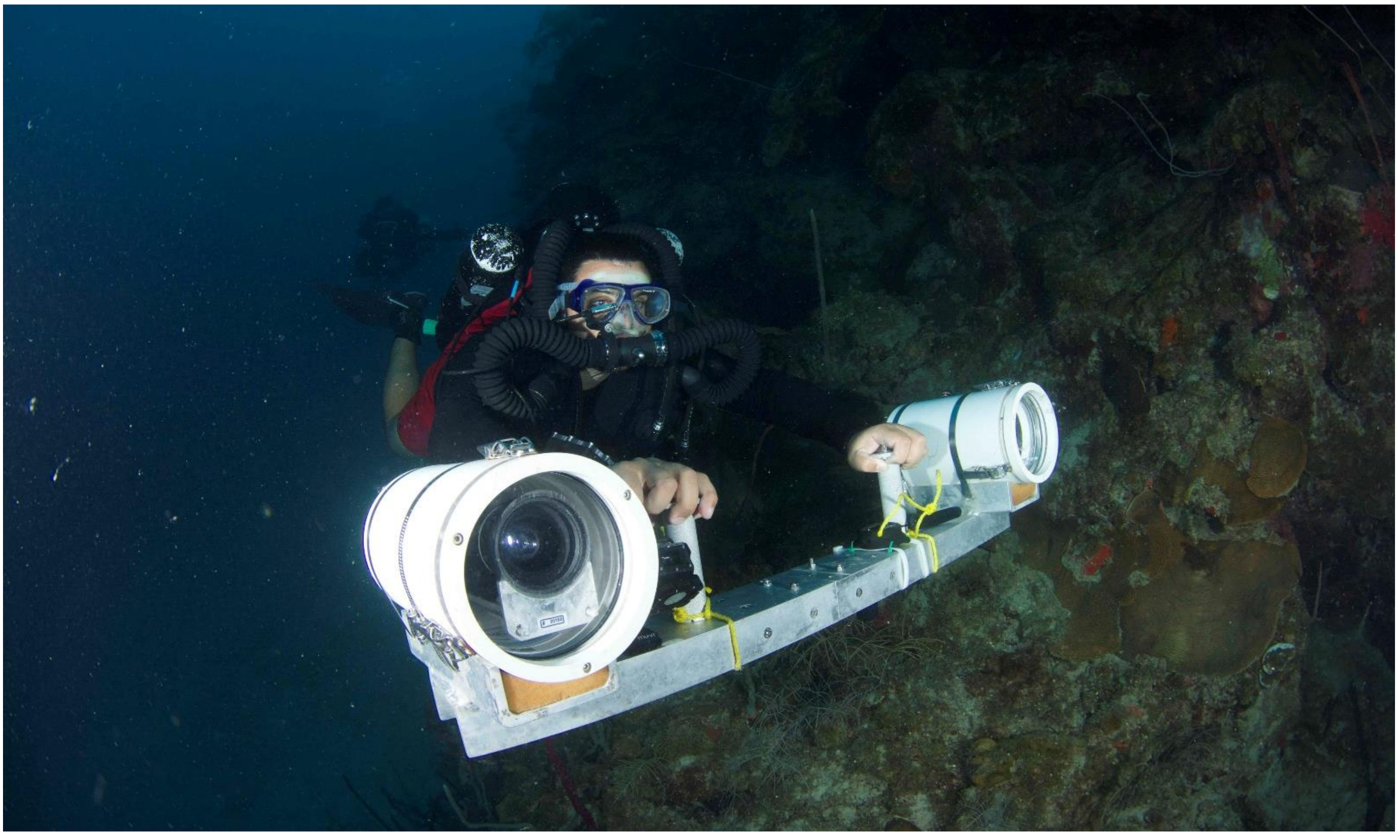

Figure 2. A CCR diver using a stereo-video system to conduct fish biomass surveys along reef transects. Post dive the footage from the two cameras are synchronized, allowing fish lengths to be accurately estimated. (Photo: Ally McDowell)

2. Use of photogrammetry

Even with the use of rebreathers, there are limits on how much the time for data collection can be extended, making it crucial to maximize efficiency. In coral reef ecological research and monitoring, most data are collected by divers in the water recording visual observations. While this process allows direct observations of reef organisms in situ, it is time consuming, resulting in long field trips to collect even small datasets. Yet the careful use of photogrammetric methods (photo/video) can enable vast amounts of data to be collected with minimal time in the water.

With improvements in camera quality and reliability it is now possible for many studies to get data of similar, and in some cases superior quality, from photogrammetric methods. For example, we used stereo-video systems for accurate fish community biomass assessments (Figure 2). This method allows more accurate fish length measurements than traditional diver visual length estimations (Harvey et al. 2001). A typical 50m fish visual transect takes 20 minutes to complete in a high-fish diversity reef environment, whereas a stereo-video transect can be filmed in less than 4 minutes. This shifts the bulk of the workload to post field trip analysis of video footage, but enables vast quantities of data to be collected in short, highly efficient field trips. Photogrammetric methods also have the advantage of creating images and videos that can be archived as permanent records, allowing examination at a later date for additional information. Archived photos and videos may also be used in future studies that are not yet envisioned. In addition, the use of photogrammetry with blinding of survey location during image/video analysis is particularly useful for eliminating unconscious bias (e.g. comparing MPAs to fished areas). Specifically for mesophotic reef surveys, the use of photogrammetry overcomes the restricted dive times at greater depths, while simultaneously allowing the insights from in-water observation and first-hand experience that is not possible using remote survey techniques.

Figure 3. Support diver receiving unused deep back up cylinders from the deep dive team during their decompression stops. Good teamwork is necessary to efficiently conduct mesophotic dive surveys. (Photo: Jack Laverick)

3. Use of team-oriented diving

Teams of technical and recreational support divers working together improved the overall safety for deep dives, while increasing data collection ability. Support divers were able to collect bulky equipment (e.g. stereo-video systems, photo quadrats), delicate samples (e.g. water samples, sediment traps) and spare back-up gas cylinders from the deep dive team early during their decompression schedule (Figure 3). Divers completing long decompression schedules (>2 hours) were therefore not overladen with equipment, reducing physical exertion and increasing comfort, and so reducing a risk factor contributing to decompression complications. It was important for each team to have a clear dive plan with accurate time estimates to allow teams to stagger their water entry and meet underwater. In addition, by taking research equipment (e.g. a stereo-video system) from the deep divers early in their decompression schedule, it was possible for an additional dive team to use this equipment while the deeper team was decompressing. In some cases, this allowed several hours of additional data collection on shallow reefs that would otherwise have been wasted.

Support divers also acted as a standby response team that could assist the deep divers in an emergency situation. We used pre-arranged color coded delayed surface marker buoys (DSMB) to signal to the boat and support divers on the surface, allowing support divers to quickly descend down the DSMB line to meet the deep divers. A single orange DSMB indicated the deep dive team had begun decompression, that all was well, and for the support divers to carry out the pre-planned equipment or scientific samples collection from the deep dive team. A single yellow DSMB indicated an emergency situation requiring immediate assistance. In this situation the support divers would immediately descend while the boat radioed the dive center informing them an emergency situation was underway and to standby for more information. Both an orange and a yellow DSMB on the same line indicated the deep divers required additional back up decompression gas, which the support divers were able to descend with.

Preliminary mesophotic observations

Utila is located on the edge of the continental drop-off, with steep coral covered walls off the north shore and gentler reef slopes on the south. Several ledges broke the steep north shore walls at approximately 30m, 55m and 70m depths. These ledges were approximately 20m wide and covered with established reef communities, providing a source of structural complexity that was associated with higher fish densities. Common fish observed in the 70-85m depth range included the Sunshine fish (*Chromis insolata*) and Blackfin snapper (*Lutjanus buccanella*). In addition, on several occasions we observed Caribbean reef sharks (*Carcharhinus perezii*) at depths >50m. Because of the historic shark fishing around Utila, divers on shallow reefs very rarely report seeing Caribbean reef sharks. Despite over 350 shallow reef dives conducted on Utila during the past three years we had never previously observed these sharks. Utila has an intensive shallow reef lionfish culling program, and we saw few lionfish on the fringing reefs shallower than 30m. However, large aggregations of lionfish were seen at mesophotic depths, with multiple occasions where >10 individuals were observed aggregated around single coral bommies. Full benthic and fish video analysis is currently underway, and we plan to shortly publish full research findings from this expedition.

Conclusion

When planning mesophotic research it is important to carefully consider which survey techniques to use based on the specific research objectives. Many established shallow reef techniques can be adapted to mesophotic depths depending on the resources available and logistics of the study site. For our research questions, many of the changes required to adapt shallow reef techniques for mesophotic depths were technological, such as using closed circuit rebreathers rather than open circuit scuba and using photo and video methods. It is important to remember that shifting research diving to greater depths requires a step-up in team awareness, training and orientation to ensure all divers remain safe and surveys can be conducted efficiently.

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A New Approach to Coral Reef Restoration: The Coral Settlement Device

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オニヒトデ食害やサンゴ白化現象により衰退し、回復の進まない琉球列島石西礁湖サンゴ群集再生のため、有性生殖を利用した連結式サンゴ幼生着床具によるサンゴ礁再生が 2002 年から環境省により行われてきた。着床具は、毎年、サンゴ産卵 1 ヶ月程度前の 4 月下旬、高いサンゴ着床が期待できる礁湖北側海底等に約 4.8 万個が設置された。約 2 年間、海底で育成された後、移植種苗としての選別が行われた。2015 年 3 月の採苗率（＝着床のあった着床具数／設置した着床具数×100）は約 30%であった。移植種苗は、生息環境が良好であるにもかかわらず、加入が貧弱なため、回復の進まない礁湖南部海域に運搬され、移植された。移植は、主として海底地形が尾根状の頂部岩礁で、エアドリルにより穿孔した穴に接着剤とともに、着床具脚部を挿入し、固着した。2005 年度 - 2014 年度に、累計約 39,000 個の種苗が移植された。種苗の多様性は高く、90%以上は多種の *Acropora* 属であるが、20 属以上が生産された。最も成長の早いユニット（2008 年 1 月移植開始）では、2016 年 2 月に被度は約 60%に達した。2010 年 5 月、2006 年 2 月に移植したハナガサミドリイシ *Acropora nasuta* の産卵を始めて確認し、以後 2014 年まで、多くの移植ユニットで毎年産卵確認を行っており、石西礁湖への幼生供給を果たした。

In this article we would like to describe our experience of testing and using over about 10 years a design of coral settlement plate that we developed to aid coral community restoration in the Ryukyu Islands of Southern Japan. Coral reefs in the Ryukyu Islands have been deteriorating ever since a serious outbreak of crown-of thorns starfish, *Acanthaster planci,* occurred in the 1970s (Omori 2011). To restore degraded reefs, various reef recovery projects involving transplantation of coral fragments were undertaken beginning in the 1990s. However, strong opposition was expressed by numbers of local scientists to the use of this method without scientific support on several grounds (Japanese Coral Reef Society 2004). Firstly, concern was expressed at the damage being caused to surviving coral colonies and habitat by collection of the coral fragments or branches to be used for planting out. Secondly, concern was raised that repeated collection from corals at a few favored locations would likely result in both a reduction in biodiversity and a decreasing genetic diversity within species (see Rinkevich 2005). Therefore it seemed worth considering whether an alternative restoration technique could be developed that would avoid these undesirable side-effects.

Sexually Reproduced Coral Spat

The alternative to employing artificial asexual reproduction to create new coral colonies must be to take advantage in some way of normal sexual reproduction. Over recent decades much has been learnt about reproduction in corals. Among the most important facts are that while in some genera fertilization takes place internally with the larvae being brooded within the coelenteron prior to release, in most corals both female and male gametes are discharged to the water column with fertilization taking place externally. In some regions spawning involving many species appears to take place synchronously over the same night (or few nights) of the year. Such mass spawning was first recorded on the Great Barrier Reef (Harrison et al. 1984), but also occurs in the Ryukyu Islands, where the dominant genus, *Acropora*, mostly spawn around full moon in either May or June (Hayashibara et al. 1993; Misaki 1994). It was naturally tempting to make use of this fact in searching for a method for restoring reefs there via sexual reproduction.

Broadly speaking two approaches have been used to propagate corals sexually. The tank method uses larvae and embryos collected from spawn slicks or larvae produced from gametes collected from coral colonies, with the resulting larvae then being reared in culture tanks at the laboratory. The seabed method, by contrast, involves deploying on or above the seabed portions of suitable substrate on which larvae will settle naturally post-spawning. While this latter method may seem haphazard and likely to require huge areas of settlement substrate if sufficient larvae are to be acquired, if successful it would have the advantage that no laboratory facilities would be required. Rather, trained workers could deploy the settlement units on suitable areas of seabed, and given sufficient recruitment corals could be economically produced or raised. Researchers at the Akajima Marine Science Laboratory have taken the first approach and trialed the transplantation of juvenile corals produced after fertilization of coral eggs in culture tanks or rearing of the larvae collected *in situ* (Omori 2011). By contrast Okamoto et al. (2005) evaluated artificial substrates for coral settlement using test panels, and subsequently developed the Coral Settlement Device (CSD) (Okamoto et al. 2008), use of which we describe here.

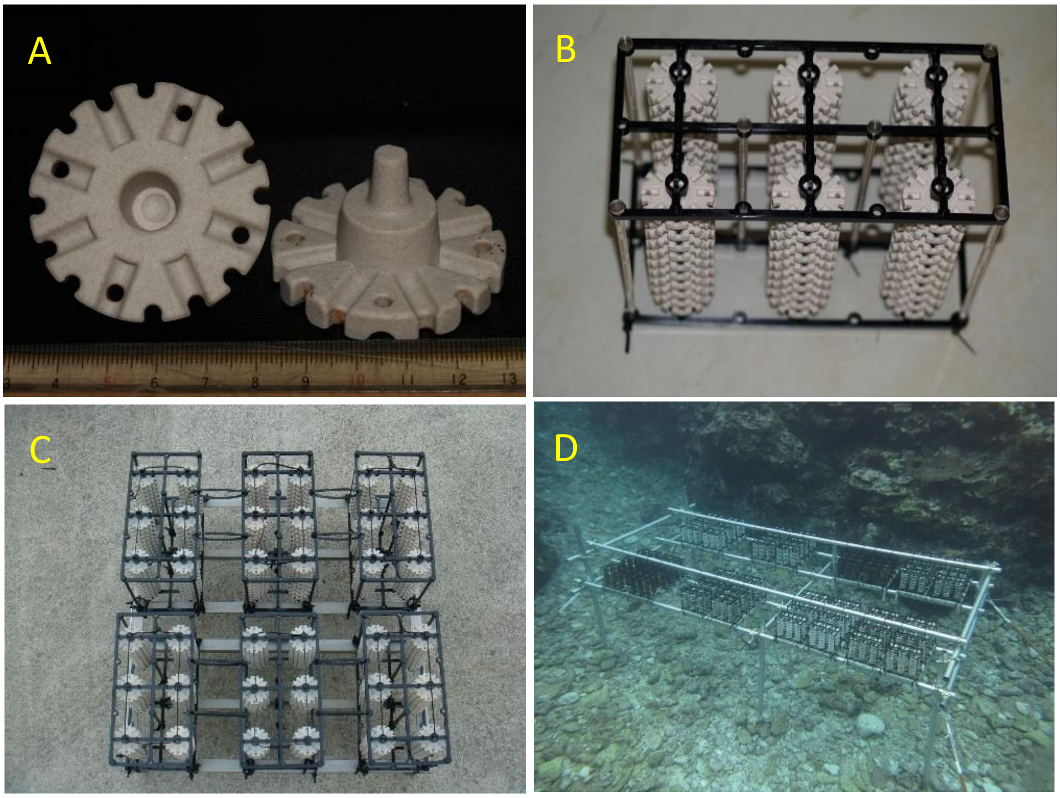

Figure 1. Coral Settlement Device. Ten devices were stacked into one batch. Six batches were arranged in a plastic frame. Six frames were set on a stainless steel platform. Eight platforms were deployed on a steel pipe stand placed on the sea bottom. A: coral settlement device, B: plastic frame, C: stainless platform, D: steel frame.

The Coral Settlement Device

The CSDs described here were designed to provide an optimal surface for coral recruitment on a structure that could then be placed directly on to the reef once the coral larvae had established themselves and metamorphosed into juvenile corals. Each CSD consists of a ceramic vase-shaped component, 5 cm in diameter, and 3 cm in height (Fig. 1). They are designed so that individual CSDs can be stacked together by inserting the peg-like base of the lower side of one into a depression in the upper side of another below it. Several CSDs can be stacked together, and the stacks of CSDs are then installed into a robust plastic frame which is set out on the reef to await recruitment.

We have found that the final design of the CSDs has the following advantages:

(a) The ceramic material used provides a substrate similar to natural reef rock.
(b) Grooves formed on both upper and lower surfaces of each CSD attract and promote the settlement of larvae.
(c) The spaces between the CSDs in each stack are sufficiently small to prevent entry and attack by most predators, or accidental damage by grazing herbivores.
(d) The peg-like design assists transplantation of each CSD out on to the reef, in addition to assisting with stacking.

(e) The stacked units can be set out on the reef in large quantities.
(f) The strong plastic frames used to hold the stacks of CSDs are convenient to carry and resistant to wave action.
(g) Holes formed on the upper side of each CSD also encourage further coral recruitment after the CSDs have been out-planted on to the reef.
(h) Both mass production of the CSDs and their deployment in reef areas has been found to be cost effective and the method economic.

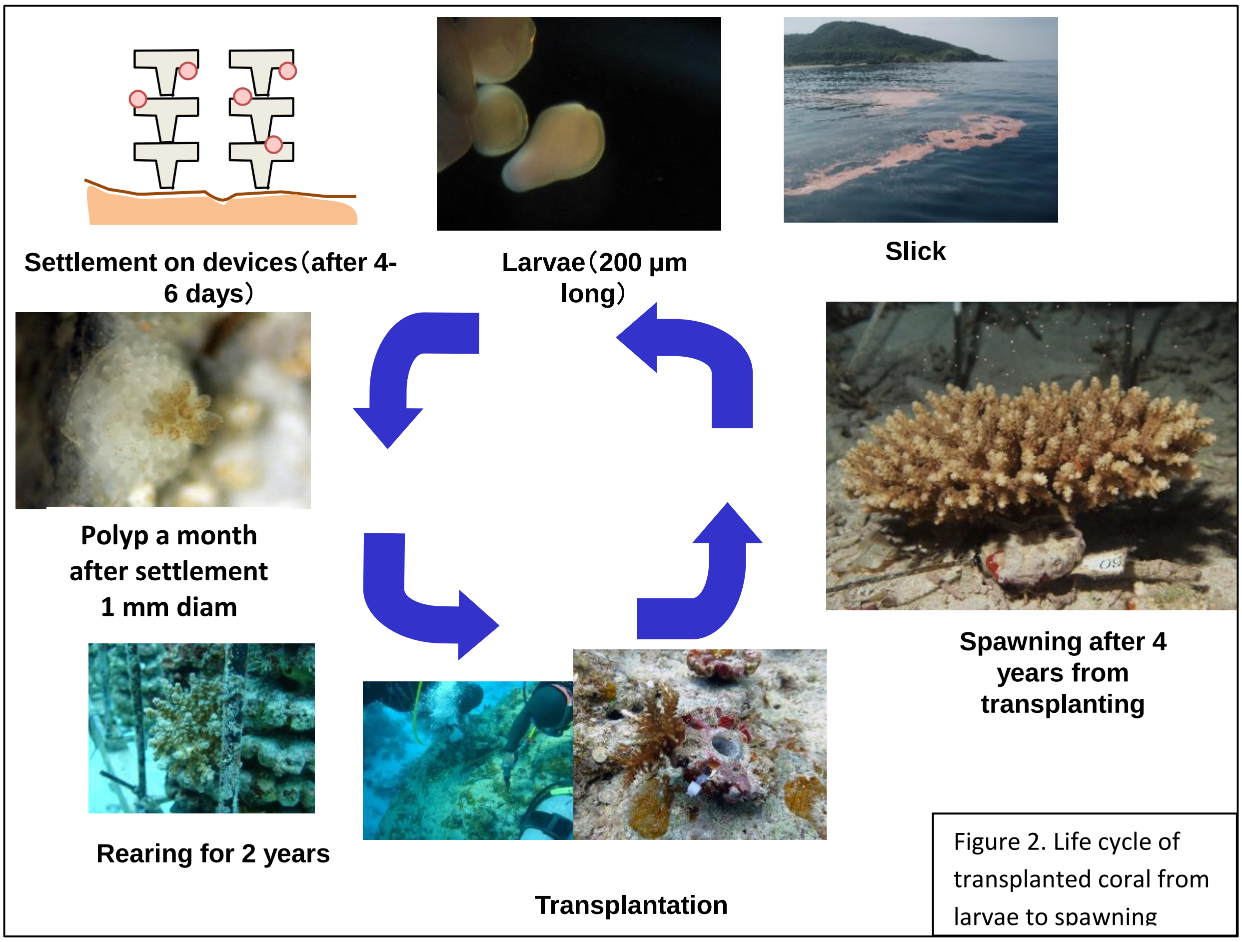

Figure 2. Life cycle of transplanted coral from larvae to spawning

The Sekisei Lagoon

The site where we tested and then employed the CSDs on a coral rehabilitation project was Sekisei Lagoon, which is positioned between Iriomote and Ishigaki Islands in the south Ryukyu archipelago. It is part of the largest coral reef complex in Japan, which extends 20 km from east to west and 15km from south to north and has been designated as the Iriomote - Ishigaki National Park. The broad lagoon is enclosed between the two large islands by various smaller islands and their fringing reefs, in addition to which there are patch reefs scattered around the lagoon. Together these features create a varied environment that supports a diverse coral community. However, the coral communities in the Sekisei Lagoon were devastated by an outbreak of *A. planci* that began in the 1980s and to some extent continues (Fujiwara & Omori 2004). More recently in 1998 and 2001 extensive mortality followed coral bleaching due to thermal stress (Shimoike 2004). Since these events coral community recovery has been slow and very variable depending on location, likely reflecting the fact that coral recruitment can vary both temporally and spatially (Harrison & Wallace, 1990). Because of this patchy recovery a coral reef restoration project using CSDs was launched in 2002 by the Ministry of the Environment. The project aimed in particular to assist rehabilitation of those reef areas which otherwise showed very poor recruitment. It was hoped that once their coral communities had been rehabilitated, these sites might in turn act as source areas for coral larvae that would assist other sites to recover (Fujiwara, 2010).

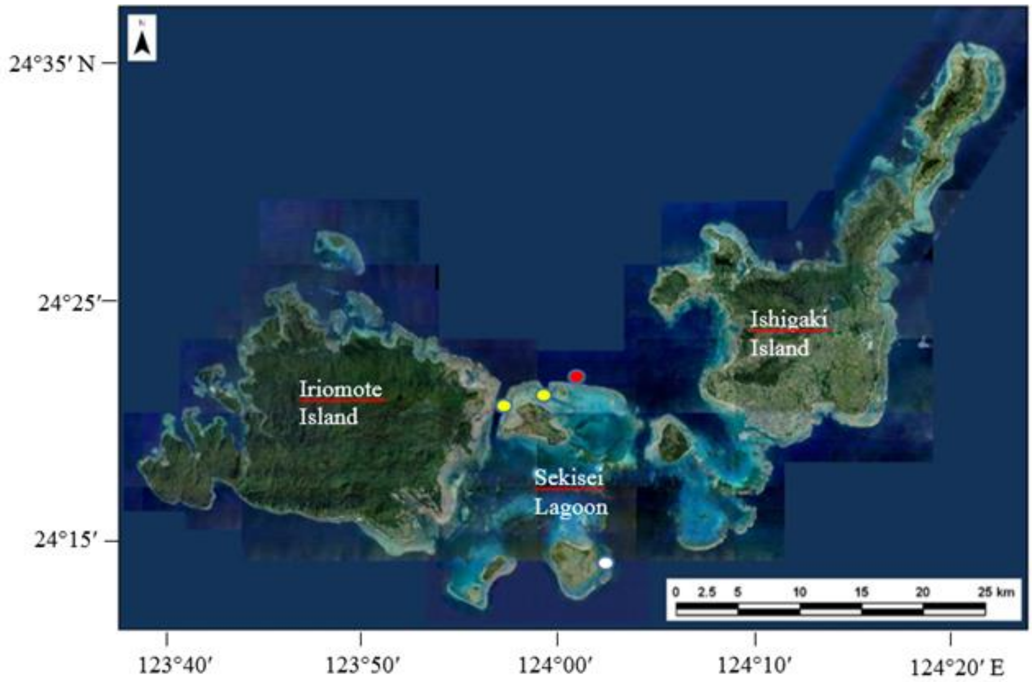

Figure 3. Left, location of the Project Sites in the Ryukyu Islands: White solid circle = transplantation area; Red solid circle = larvae settlement area; Yellow solid circles = rearing areas. Above, location of Ryukyu Islands in the south of Japan.

As on the Great Barrier Reef, in Sekisei Lagoon many corals, especially *Acropora* species, which dominate there, spawn synchronously once a year, usually at midnight around the May full moon when daily mean temperature reach about 26°C (Hayashibara et al., 2004; Fujiwara et al., 2015). Therefore, with this timing in mind, every year, from the start of the project in 2005 until 2015, we deployed approximately 48,000 CSDs in frames on to the reef in late April, up to one month before coral spawning was due (Fig. 2). The main deployment site chosen was in water 5 to 6 m deep towards the northern reef margin in an area where coral recruits were naturally relatively abundant, suggesting a good supply of coral larvae. Here in 2015, for example, settlement rates of 16.2 recruits per 100 cm^2 were recorded on the artificial plates, even though the mean settlement rate across 35 sites in Sekisei Lagoon was only 1.88 colonies per 100 cm^2 (Naha Nature Environment Office, 2016). The dominant coral species *Acropora nasuta* and *A. cytherea* appeared to settle especially at this depth. However, although the reef margin was a good deployment site from the point of view of larval settlement, it is also subject to severe wave action if a typhoon occurs; therefore after a month or two the frames were moved to calmer areas before the beginning of peak typhoon season in July. Besides this move, the frames and CSDs were maintained by regularly removal of fouling algae that might otherwise overgrow any coral spat.

The area selected for transplantation was in the southern part of the lagoon. It was chosen because, while water quality was considered favorable and conditions looked suitable for coral growth, coral community recovery had been impeded there due to poor recruitment (Fig. 3). Most likely this was because with the residual tidal currents moving from south to north, the area received relatively few coral larvae from elsewhere. In addition the area was preferred because generally it did not experience severe waves generated there by typhoons, because it was well away from any sandy bottom areas, which can be stirred up by typhoon waves resulting in sediment being deposited on and smothering the juvenile corals, and because the presence of a ridge topography also protected the area from gravel drift which can be caused by typhoon waves.

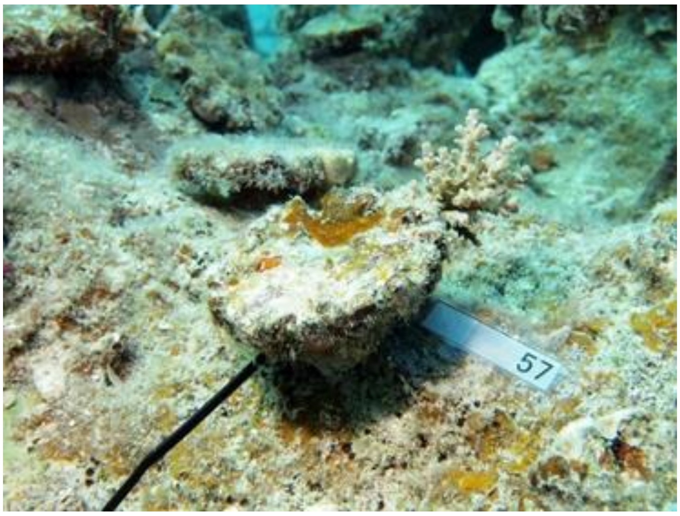

Figure 4 A transplanted juvenile coral (growing from the upper right of an encrusted CSD) which is being monitored.

Figure 5 The camera arrangement used to monitor corals for spawning, taking a picture every 30 minutes.

Transplantation of the CSDs

For transplantation the stacks of CSDs were removed from their frames approximately 2 years after their original deployment, and each stack disassembled so that the CSDs could be planted out individually. The peg of each individual CSD unit was then inserted in to a suitably sized hole drilled in to the rocky reef substrate with an pneumatic (air-powered) drill and the peg fixed in place with a suitable glue. In general about ten juvenile corals were transplanted to every square metre of substrate, with a total of about 39,000 juvenile corals being transplanted between fiscal years 2005 and 2014 over an approximately 1 km^2 area. Unsettled CSDs were removed and reused in subsequent years.

About 10 % of these corals were tagged for monitoring purposes (Fig. 4) and then checked at 1, 6 and 12 months after transplantation and subsequently once a year. The following parameters were recorded: survivorship, coral length, bleaching, destruction, predation, algal smothering, sedimentation, and whether any habitat was being provided for animals. Temperature and turbidity were measured every hour by data loggers. Once they were four-years old a proportion of transplanted corals were observed to see if spawning occurred. Because most *Acropora* corals synchronously release bundles of gametes at around midnight, we set automatic cameras near the transplanted corals and took photos every 30 minutes over four consecutive nights to see whether spawning occurred (Fig. 5).

Recruitment, Growth and Spawning

The production ratio of the CSDs, i.e. the proportion of CSDs with juvenile corals, was monitored. In 2015 for example the ratio was 30 %. The use of the CSDs resulted in a much higher mean density of recruits than elsewhere in the lagoon, much of which suffered from very poor recruitment. Besides producing high densities of juvenile corals, the use of CSDs also resulted in a high diversity of recruits - although over 90 % of recruits were different species of *Acropora*, corals from more than 20 other genera were recorded (Fig. 6). The batch giving rise to the fastest growing corals was planted out in 2008 and by 2016 had generated a mean coral cover of approximately 60% (Fig. 7). At this density the corals were increasingly providing habitat for a range of fish and invertebrates, most noticeably various damselfishes and crustaceans. By creating sufficient coral habitat to provide food and shelter for other reef fauna the rehabilitation project was thus fulfilling one of the important functions of coral community rehabilitation.

The first spawning of a transplanted coral, by an *A. nasuta* that was transplanted in February, 2006, was recorded by our automatic camera in May, 2010. Subsequently we also observed, in 2011, spawning by colonies of *A. nasuta* and *A. selago*. By 2014, when observations ceased, spawning was occurring annually in many of the blocks of transplanted corals. The extent of spawning suggested that the areas of transplanted corals were also beginning to function as a source of coral larvae for other parts of the lagoon.

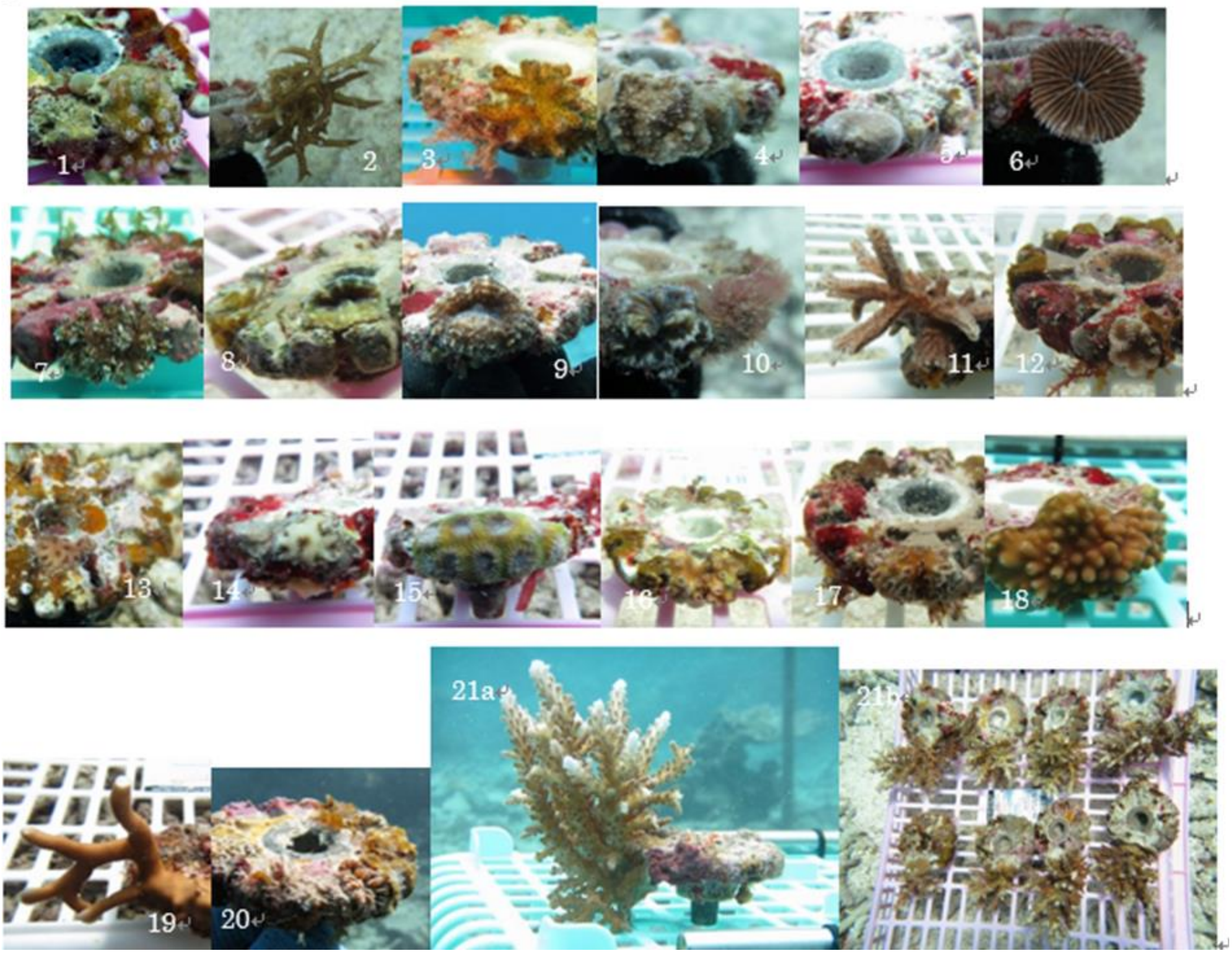

Figure 6. A variety of juvenile colonies recruited on to the CSDs 1: *Pocillopora*, 2: *Seriatopora*, 3: *Stylophora*, 4: *Montipora*, 5: *Porites*, 6: Fungiidae, 7: *Galaxea*, 8: *Echinophyllia*, 9: Mussidae, 10: *Symphyllia*, 11: *Hydnophora*, 12: *Merulina*,, 13: *Favites*, 14: *Goniastrea*, 15: *Montastrea*, 16: *Cyphastrea*, 17: Faviidae 1, 18: *Turbinaria*, 19: *Millepora*, 20: Faviidae 2, 21a,b: *Acropora* (the most abundant coral)

Concluding Remarks

Rinkevich (2005) has suggested that the extent of degradation on coral reefs globally is now so high that many reef areas are already beyond the possibility of natural recovery and that transplantation must become an important method for restoration. It seems unlikely that cultured coral fragments or laboratory reared juveniles could be produced on the scale required to restore very large areas. Our experience suggests that, in contrast, CSDs such as those described here can be an invaluable tool in reef restoration. The design of the CSDs appears very effective in encouraging natural settlement of coral spat and in preventing predation by fish and invertebrates. A high proportion of the CSDs are settled by larvae that grow to reproduce. The method avoids damage to existing corals caused by the collection of coral fragments, which may be critical in areas where coral abundance is already very low. The methods also avoids artificial colonisation of an area with only a limited number of coral genotypes, such as might happen if coral fragments are collected from only a few sites. And the method automatically results in the planting out of a wide variety of genera and species in approaching natural relative abundances. We believe that the method deserves further study.

Figure 7. The site showing the fastest recovery of corals following transplantation. Left, the site as it was in January 2008 with few living corals. Right, the site in February 2016, with coral cover increased to approximately 60 %.

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3D Printing Solutions for Coral Studies, Education and Monitoring

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Introduction
Since the development of the first rapid three-dimensional printing (3DP) prototyping method in the 80's by Hideo Kodama, of the Nagoya Municipal Industrial Research Institute, the technology has matured and seen an explosion in popularity. 3D Printing (3DP) is a term used to collectively describe an additive manufacturing method where a layering process is used to generate 3D components. 3DP has seen astonishing results in medicine, engineering, product design, paleontology, archaeology, biomolecular sciences, and even fashion with rapid integration into the mainstream of all science and engineering sectors. Since the first system in the 80's, the accuracy, hardware, software and accessibility of many 3DP systems has greatly improved, and the time and cost of manufacturing has decreased considerably (Fredieu et al., 2015).

Numerous 3DP methods exist, and the major difference is how these individual layers are generated to form the building blocks of the construct. Stereolithography (SLA) and Fused Deposition Modelling (FDM) will be considered in this perspective due to their individual advantages. SLA is based on the polymerization of a single molecule plastic (Monomer) into a multi molecule plastic (polymer) through the projection of a specific light onto the individual layers. FDM uses the extrusion of a thermoplastic through a hot aperture to create adjacent lines/patterns of extruded polymers to form the individual layers of the construct. SLA can generate extremely fine features with high surface finishes. The SLA process however isn't as user accessible as FDM with limited polymer material types available and no easy method of multilateral printing within a single layer. The SLA process also requires a high level of process control from the user and thus the system wouldn't be as robust as the simple construction of an FDM printer. There are also more complex handling issues and costs associated with the liquid resins for SLA thus resulting in lower user accessibility than the solid polymer wire material used by FDM processes. FMD is a simple, low cost, robust process with very easy handling issues and high availability. Its major advantage is disponibility of materials. FDM has the capability to handle almost any thermoplastic, as well as the ability to handle compound materials, thermoplastics with various additives and mixtures of thermoplastics and fibers or particles. With this method you can easily combine various materials within a single component and tune areas of the component to perform as desired. This multi-material printing can be done within a single layer, offering great advantages. FDM's major disadvantages over SLA are surface roughness and feature resolution.

As 3DP reaches a peak of versatility, flexibility, and ease of online collaboration, not only in engineering sciences, it is also being used in item replication for museum collections and generation of exhibits (Allard et al., 2005; Tomaka et al., 2009; Wachowiak and Karas, 2009; Chapman et al., 2010). The most conspicuous use of this technique has been in medicinal science, especially for prototyping parts for the human body (Gerstle et al., 2014) and planning surgery using CT and MRI scans by 3D reconstruction of internal structures (McGurk et al. 1997; Rengier et al., 2010; Klein et al., 2013). Applications in biomolecular sciences have also provided accurate physical representations of molecules (Jones, 2012) of paleontological and archaeological models used for documentation and restoration of artifacts and for the study biomolecular materials (Kuzminsky and Gardiner, 2012). There are also applications in education (Eisenberg and Buechley, 2008; Eisenberg, 2013; Fredieu et al., 2015), science visualisation (Partridge et al., 2012; Segerman, 2012) and science outreach.

3DP and coral reefs
3DP has been recently used to produce cement and sandstone blocks for artificial coral reef restoration (Pardo, 2013). Furthermore, these 3D prints could be used in hydrodynamic simulations in flow chambers as described in Chindapol et al. (2013). These 3D prints can be used for taxonomic and ecosystem instruction. High resultion 3D imaging of coral colonies, skeletons and corallites has been High resolution 3D prints produced from 3D imaging

from underwater coral colonies, fresh corallite samples and skeletons (Gutierrez-Heredia et al., 2015, Gutierrez-Heredia et al., 2016), with embedded taxonomic features can be used to demonstrate these structures to students. Multi-scale printing can show how different characteristics are related at distinct organizational levels (Fig. 1). Multispectral (visual light, fluorescence, infrared) samples can be created to indicate relationships in coral communities at different electromagnetic spectra and demonstrate the relationship to biological attributes (Fig. 2).

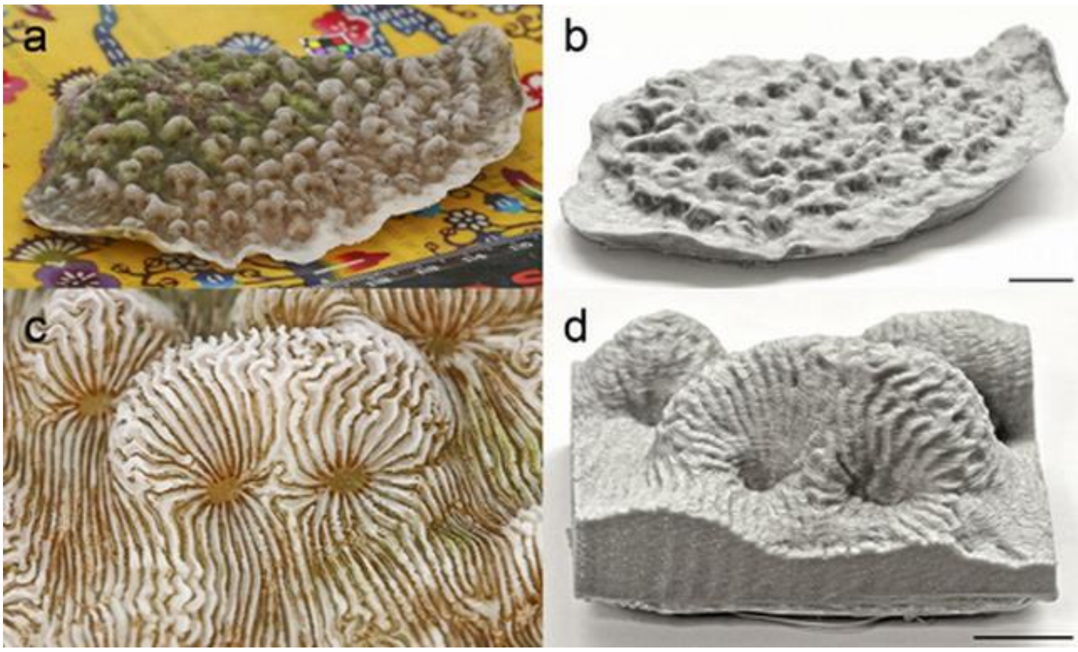

Figure 1. Multiscale imaging and 3DP of *Leptoseris incrustans* colony and corallites. a) Image used for 3D digitisation of colony sample. b) Silver PLA print of colony sample. c) Image used for 3D digitisation of corallites. d) Silver PLA print of corallites. Scale bars represent 1 cm.

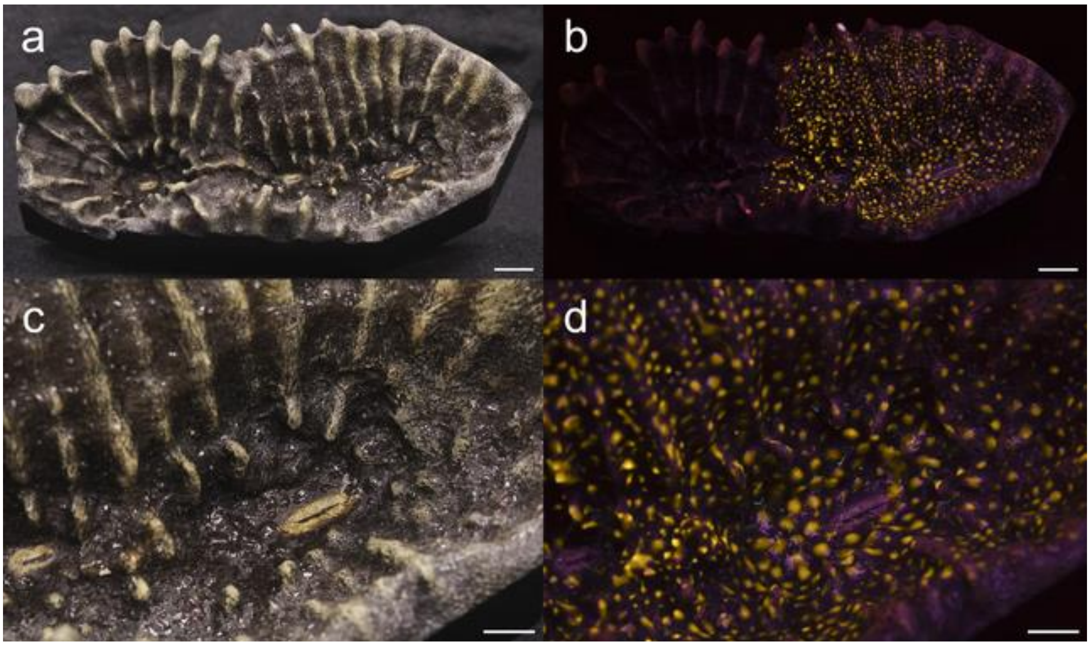

Figure 2. Multispectral imaging and 3DP of *Oulophillya crispa* corallites.a) 3DP sandstone construct of *O. crispa* with model paint. b) 3DP sandstone construct of *O. crispa* with fluorescent paint under UV lighting Scale bars represent 1 cm. c) Detail of *O. crispa* sandstone corallite. d) Detail of *O. crispa* sandstone corallite under UV lighting. Scale bars represent 5 mm.

DYI coral reef research tools

3DP can also be used for quick construction of custom designed laboratories and workshops tools for (Baden et al., 2015) fix placement speeding up research progress and improving research quality. Tools and mechanisms used for coral research and monitoring (Fig. 3), such as underwater calibration stands, and frames for imaging and lighting equipment ,can be swiftly customized, and subsequently uploaded online for open source communities to share.

Figure 3. Customised tools for coral research. 3D printed UV torch container and camera stabiliser used for field coral imaging.

So many options at our fingertips

The extensive development of 3DP since the beginning of the RepRap Movement focused on FDM has resulted in the addition of a very wide spectrum of polymers compatible with low cost FDM systems. These include PLA imbedded with metal particles such as copper, bronze, stainless steel, wood, ceramics etc., and other alternative materials made from wood linen or algae (Fig.4). These filaments offer different degrees of texture, strength, flexibility, elasticity, and colours, including fluorescent, phosphorescent and translucent. An interesting approach to coral reef research, and general marine benthic community research, would be the use of sensory materials, or temperature or UV reactive plastics for the production of marine condition indicators, showing changes in water temperature, salinity or pollution levels. Recent developments have made available polymer for FDM which are color responsive to a range of changes in physicochemical parameters in the contact environment. (Fig.5). Commercial sensory products with similar qualities have been used in aquariums to assist in keeping environmental parameters optimal (temperature, pH and UV light decals attached to the walls).

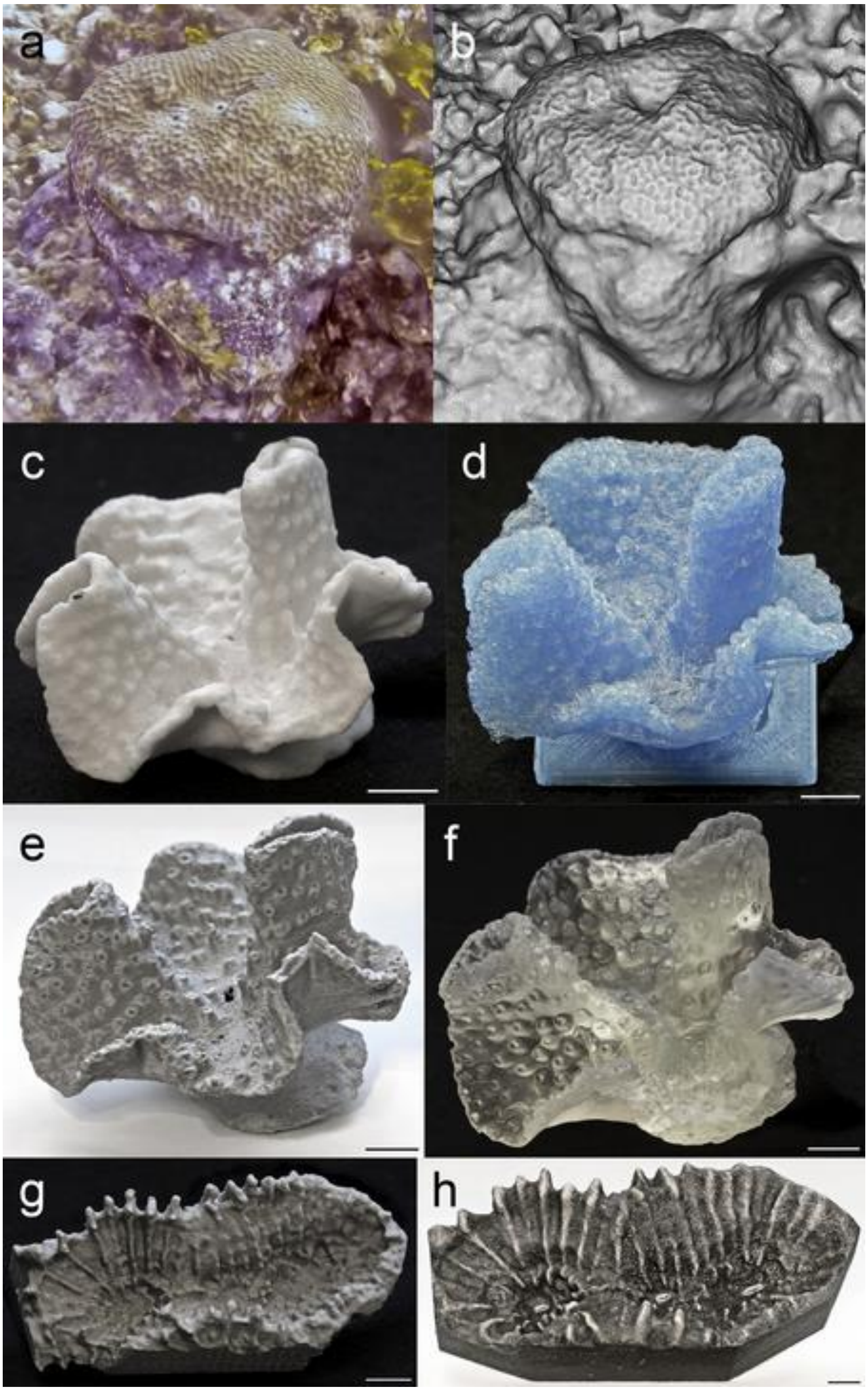

Figure 4 Multi-material coral sample production imaged with photogrammetry. a) Textured 3D model of underwater colony of *Platygyra daedalea*. b) Untextured 3D model of underwater colony of *Platygyra daedalea*. c) White sandstone 3D print of *Turbinaria* sp. skeleton. d) Blue PLA 3D print of *Turbinaria* sp. skeleton. e) Silver PLA 3D print of *Turbinaria* sp. skeleton. f) Translucid resin 3D print of *Turbinaria* sp. skeleton. g) Silver PLA 3D print of *Oulophyllia crispa* corallites. h) Sandstone 3D print of *Oulophyllia crispa* corallite coloured with modelling paint. Scale bars represent 1 cm.

Structures manufactured with these reactive plastics could be used on a larger scale in underwater environments. Thermochrome rings can be readily used to indicate abrupt changes in water temperature (e.g. El Nino climate incidents), photochrome rings could signal UV bleaching, and even halochromic rings could reveal changes in water acidity. These accessories are potential tools to passively monitor ocean changes via attachment to boats or as permanently placed objects, such as coral structures, in marine environments.

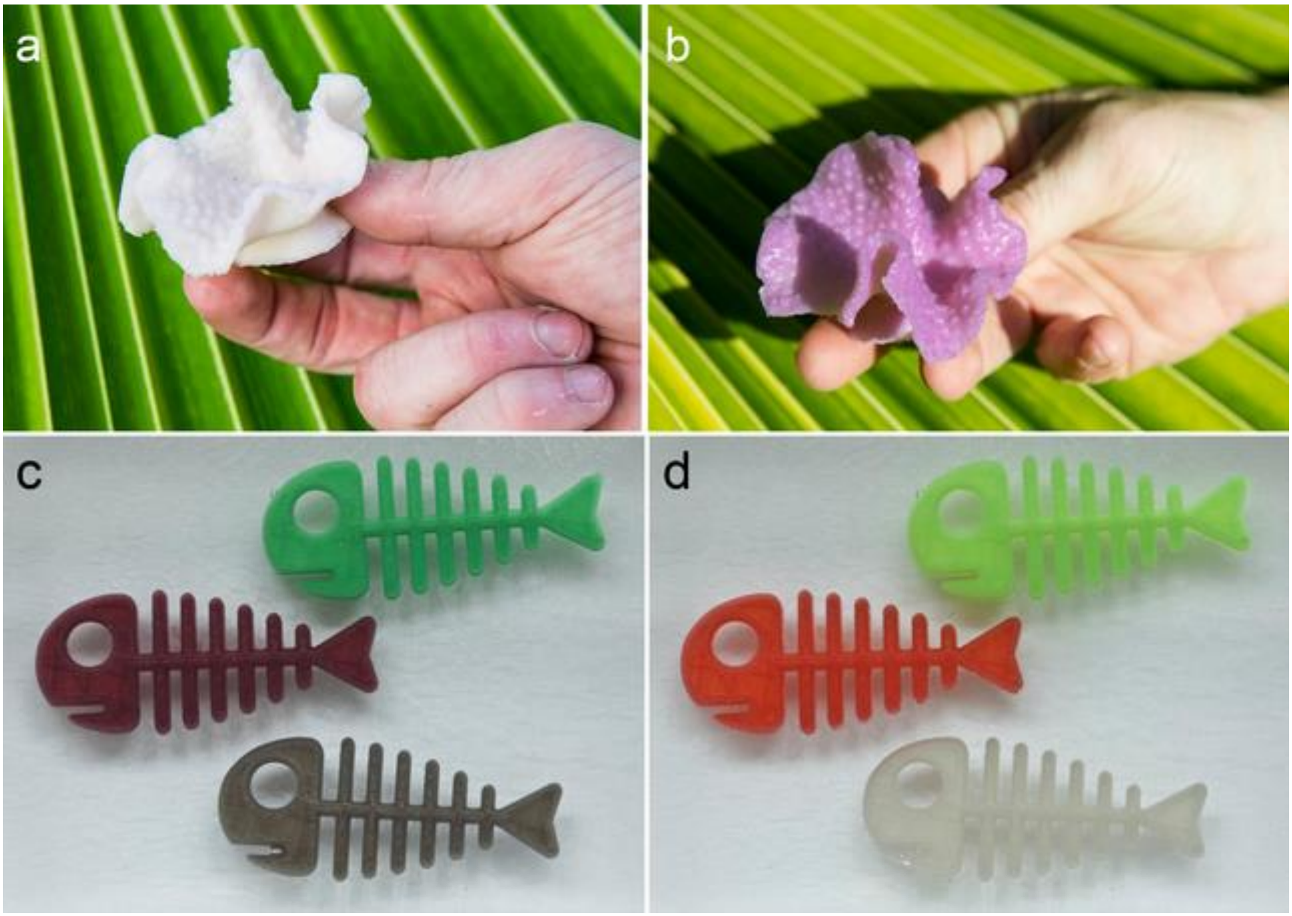

Figure 5. Sensing materials for coral research. a) Photochromic PLA 3D print of *Turbinaria* sp. skeleton. b) Photochromic PLA 3D print of *Turbinaria* sp. skeleton under direct sunlight. c) Thermochromic PLA 3D prints of fish skeletons below 23° C. b) Thermochromic PLA 3D prints of fish skeletons above 23° C.

Prospects for these technologies rely on the use of online resources to display, collaborate, and even add aesthetic and monetary value to these constructs. One website, Sketfchfab (https://sketchfab.com/), allows the researcher to upload 3D content to a free account, where it can be displayed for education and science outreach, shared amongst collaborators, and even animated. Two websites, Thingiverse (https://www.thingiverse.com/) and Shapeways (http://www.shapeways.com/) can potentially be the marketplace where the users of 3D digitisation and 3D printing can promote a global community of design and manufacturing. Thingiverse is a free website engaged with the sharing of user created 3D design files, and Shapeways is a 3D printing forum and service startup company. Used in conjunction, they provide a place where researchers can upload and share 3D printable files that can be printed in a wide range of materials and colours, and shipped across the globe. This allows a multi-user community where valid 3D prints can be interchanged, and practical solutions and customised tools for research and monitoring can be generated. Additionally, 3D forms can be sculpted into artistic artifacts. This will certainly promote the already rapid expansion of 3D printing in coral and other biological endeavours (Marine Life Modeling, Cataloging and Education, and improve general public awareness of coral reef health and value.

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REEF EDGE

Scientific letters or notes describing observations or data

What is the Source of Massive Amounts of *Sargassum* Seaweed on Caribbean Beaches?

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On usually pristine beaches from Barbados to Cancun huge drifts of *Sargassum* weed have showed up intermittently since 2011, causing great concern to tourists and those in the tourist industry. Our literature review of possible sources of this usually dispersed floating brown alga suggests that nutrients from Amazon floodwaters may be the culprit.

Sargassum seaweed is a brown macroalga that forms floating mats in the tropical and subtropical Atlantic mainly composed of two species: *Sargassum natans* and *Sargassum fluitans* (Doyle and Franks 2015, Fig. 1). Of the 7-10 x 10^6 tons of pelagic *Sargassum* in the Sargasso Sea, ~90% is *S. natans* with the remainder consisting of *S. fluitans* and other benthic *Sargassum* species (Lapointe 1995). Small bladders or pneumatocysts filled with gas enable the algae to float until the mat becomes so encrusted with other organisms that the mat eventually sinks. The dominant alga, *S. natans,* floats for its entire life cycle of about one year supporting a variety of fish, shrimp and other crustaceans specially adapted to the weed. These two *Sargassum* species reproduce asexually and fragments can regenerate the entire plant. Many species like the *Sargassum* frogfish, *Histrio histrio,* perfectly camouflage themselves in the seaweed, as do other vertebrate and invertebrate species, suggesting a long evolutionary relationship between species living in the *Sargassum* and the *Sargassum* itself (Fig. 2). The floating mats form a refuge and

Figure 1. *Sargassum* weed a) floating and b) on the beach (commons.wikimedia.org).

provide food for turtles and several species of fish like tuna.

Figure 2. Sargassum Frogfish, *Histrio histrio* (photo by Caroline Rogers).

Figure 4. *Sargassum* weed accumulations on Gaviota Azul Beach in Cancun, Mexico July 2015 (voanews.com 2015).

Sargassum has been farmed and used as fodder and fertilizer in many countries and comprises about 10% of the average Japanese diet where it is eaten as salad or cooked with coconut milk (Oyesiku and Egunyomi 2014). *Sargassum* wrack is not toxic although it may emit hydrogen sulfide as it rots on beaches, and it has disrupted the nesting activities of turtles. In Bermuda salt free *Sargassum* is used to fertilize banana plants. Algin an extract of this seaweed has been used in textile, paper and pharmaceutical industries. In addition, *Sargassum*, is a rich source of flavonoids (with antiviral properties), tannins (used for healing wounds) and terpenoids (with antimicrobial and antiamoebic properties), and has been used as herbal medicine in China (Oyesiku and Egunyomi 2014). Proposals have been made to grow or harvest *Sargassum* spp. as food, fodder, fertilizer, pharmaceuticals or biofuel in the United States (Redmond et al. 2014). The National Marine Fisheries Service banned the harvesting of *Sargassum* in 2003 anywhere within the U. S. jurisdictional waters to 200 miles offshore (except off the coast of North Carolina where the limit is 100 miles), to protect it as a keystone species and for its ecosystem services (McGrath 2003). In North Carolina, Aqua 10 Laboratories harvested *Sargassum* commercially for livestock and agricultural supplements and as a waste-water additive to reduce sewage sludge. In recognition of the unique ecosystem that is the Sargasso Sea, in 2014 a Sargasso Sea Alliance was established as a conservation effort led by the Bermuda government and partners (@sargseacommission.org).

Sargassum seaweed floats with the great currents of the subtropical Atlantic gyre (latitude 20°-40° N and longitude 40°-80° W). It is generally widely dispersed and often follows long lines of Langmuir circulation which are shallow, slow, counter-rotating vortices at the ocean’s surface aligned with the wind (Wikipedia). Sailors have long noted the distribution of the floating mats in the Sargasso Sea (Fig. 3). A recent analysis of satellite images from 2002 to 2008 revealed that the floating *Sargassum* mats originated in the northwestern Gulf of Mexico each spring fueled by nutrients from the Mississippi River plume and were exported to the Sargasso Sea during the summer months (Gower and King 2011). An estimated one million tons wet weight of *Sargassum* is exported to the Atlantic each year. Since the 1980s and 1990s an increased drift accumulation of the *Sargassum* mats have littered the tourist beaches of the Gulf of Mexico (Smetacek and Zingone 2013). These beach accumulations of piles of seaweed were linked to nutrients from the Mississippi River (Lapointe 1995).

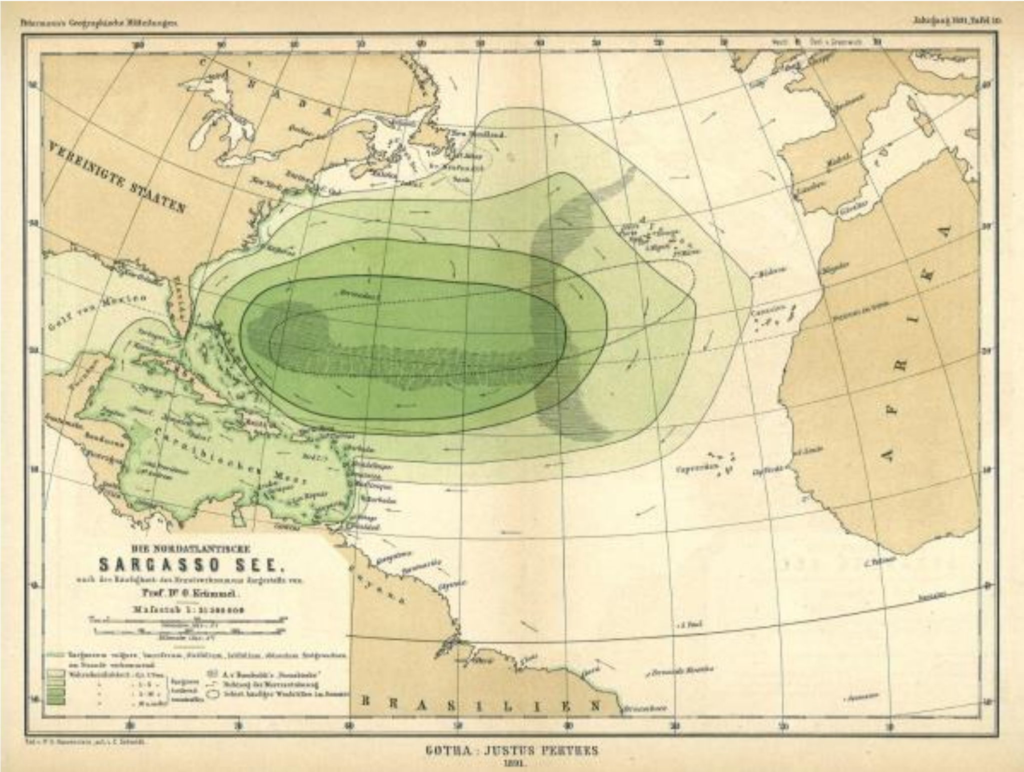

Figure 3. 1891 Map of the Distribution of Sargassum weed In the Sargasso Sea. Image source: NOAA –Teachers at Sea.

During 2011 nuisance accumulations accelerated to a new level with huge drifts of *Sargassum* weed (up to 3 m high) building up on beaches from Granada, to St Vincent, to Barbados to Mexico, causing the tourist industry serious consternation and millions of dollars in clean-up costs (Fig. 4). At the same time, coastal areas and beaches along the African coasts of Sierra Leone, Nigeria and Ghana were similarly blanketed for the first time, disrupting fishing activities and small boat navigation (Smetacek and Zingone 2013). Gower et al. (2013) present satellite images suggesting a huge new source of *Sargassum* in 2011 from the north coast of Brazil (7^o N, 45^o W) and presumably the plume of the Amazon River (Fig. 5). Increased *Sargassum* seaweed detections occurred in April 2011 and reached a peak in July, returning to normal levels by October. The authors estimate the 2011 peak amount was 3x higher than the previous maximum *Sargassum* year in the Gulf of Mexico (June 2005). Prior to these satellite observations *Sargassum* was thought to be limited to the Gulf of Mexico and the North Atlantic Sargasso Sea (Fig. 3). Since 2011 *Sargassum* seaweed has, according to news reports, covered beaches in the Caribbean during 2012, 2014, and 2015. No reports of problem *Sargassum* were found in 2013.

A circulation study of the Amazon River provides evidence of a transport mechanism for carrying *Sargassum* to the beaches of the Caribbean. During the flood year of 1998, the Amazon River plume, from its mouth at the equator, moved north along the Brazil coast and into the eastern Caribbean (Hu et al. 2004). A colored dissolved organic matter (CDOM) used as a tracer for river waters, showed high concentrations moving north from the Amazon River mouth into the Caribbean, and also being transported in equatorial currents toward the coast of Africa (Fig. 6). During the first half of the year Amazon water dispersed to the northwest toward the Caribbean Sea and during the second half of the year the plume flowed around the North Brazil Current retroflection near 5-10^o N and eastward to the North Equatorial Counter Current. The average depth of the plume having a sea surface salinity of 32 to 35 was 20 to 30 m. The total volume of river water discharged between mid-April and July (1998 – 2001 average) was estimated to be 2 x 10^{12} m^3 (Hu et al. 2004). This is 7 times larger than a conservative estimate for the Orinoco River plume to the north of the Amazon River mouth. No news reports indicate Orinoco River flooding during the period of Amazon floods. And no news reports indicate a *Sargassum* problem during these years.

The question arises: Could the Amazon River flow of 2011 and later, be responsible for the sudden increase in *Sargassum* in the Caribbean? During 2011, 2012, 2014 and 2015 the largest floods in Amazon history occurred according to news reports of river levels; reports for 2013 indicated the flood was not so bad during that year (Bowater 2014). Some 500 villages, towns and cities were submerged with loss of life for dozens and with river levels of 119 m above normal in 2012 at Iquitos, Brazil. This flood was 90 cm higher than the previous floods of 1998 and 1938 at Iquitos (Otoronogo Expeditions 2012). Studies report that the Amazon basin has been experiencing significantly greater precipitation since the 1990s (Gloor et al. 2013). The rainfall trend can be correlated with increasing tropical Atlantic sea surface temperatures (Fig. 7). The increase in sea surface temperature would cause an increase in water vapor input from the Northeast Equatorial Trade Winds to the northern Amazon Basin. The period of increased sea surface temperature is consistent with the warming period from the 1990s to present of the Atlantic Multidecadal Oscillation (The AMO warming occurs during a roughly 75 year oscillation cycle when wind and current systems alternate with warming and cooling of the surface North Atlantic (Knight et al. 2006)). A previous flood in 1938 may have occurred during the previous warming period of the AMO from the 1930s to the 1950s (Fig. 7). A person in St John, US Virgin Islands recalls a previous *Sargassum* beach stranding episode in the 1930s. Cool periods during the oscillation cycle have occurred in the 1900s to 1920s and 1960s to 1980s (Knight et al. 2006). Note the step increase of almost 1^{o} C global warming from the 1930s period to the current period (Fig. 7), an increase consistent with the greater flooding during the current period.

We can make a crude estimation of whether the nitrogen in an Amazon flood could support the massive amounts of *Sargassum* reported on beaches. Devol et al. (1994) report over a multiyear study that during Amazon flood months nitrate reaches 8 -16 µM concentration. Ogesiku and Egungomi (2014) report a nitrogen weight percent of *Sargassum natans* of 0.063%. Hu et al. (2004) report a river discharge through April to July of 2 x 10^{12} m^3, which we have doubled for the extreme 2011 flood year. Using these numbers, trillions of metric tons of *Sargassum* could be supported by the nitrogen concentration during extreme flood events, which contrasts with the 10 million tons in the Sargasso Sea previously reported (Lapointe 1995) and seems more than sufficient for the observed amounts reported.

Our brief review does not solve all of the mystery of the explosive growth of *Sargassum* and the massive drifts of seaweed on the Caribbean beaches first observed in 2011. The Amazon River also flooded to a lesser extent in 2009, 1999, 1989 and 1954 but failed to result in large growths of *Sargassum* so far as we know (Marengo et al. 2013).

Another mystery is where did the algae sink to the bottom and what impacts have occurred to those bottom communities? Where will those regenerated nutrients be upwelled and what impacts may result? Along the same lines what is the longer-term impacts on beaches where the tons of seaweed stranded and what has been the impact of that unforeseen nutrient input.

Perhaps the most important question is how long will these Amazon floods persist? Knight et al. (2006) have performed a 1400 year simulation of the AMO using a global climate model to improve predictions of climate trends when the observation record is so limited.

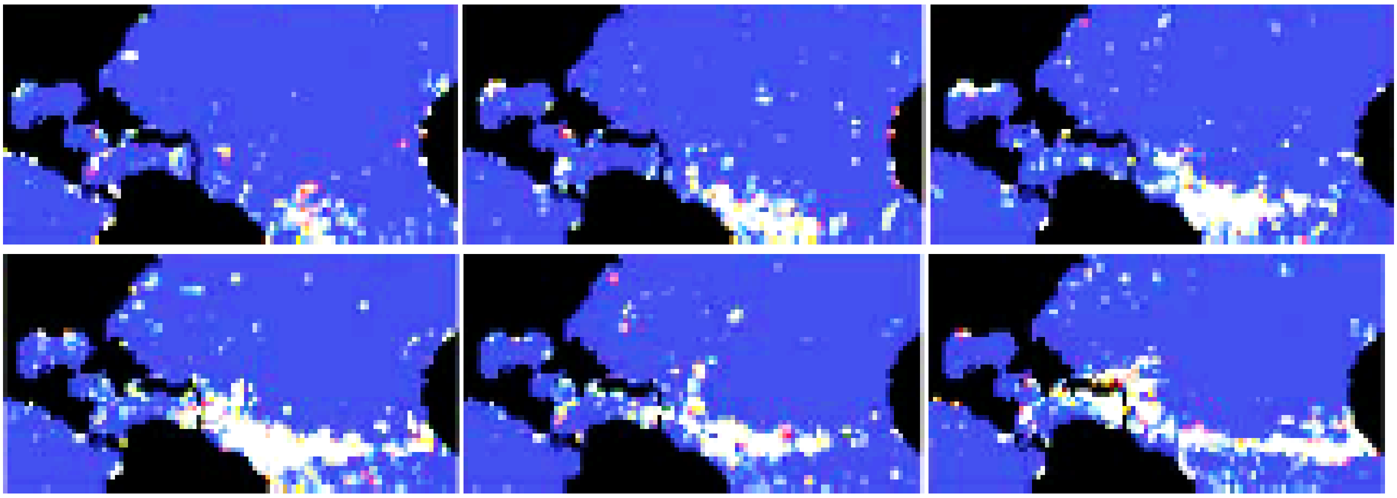

Figure 5. 2011 April to June (above) and July to September (below) Satellite images of the Caribbean showing in white the accumulation of Sargassum weed from the north coast of Brazil to the Caribbean and to the north coast of Africa (from Gower 2013).

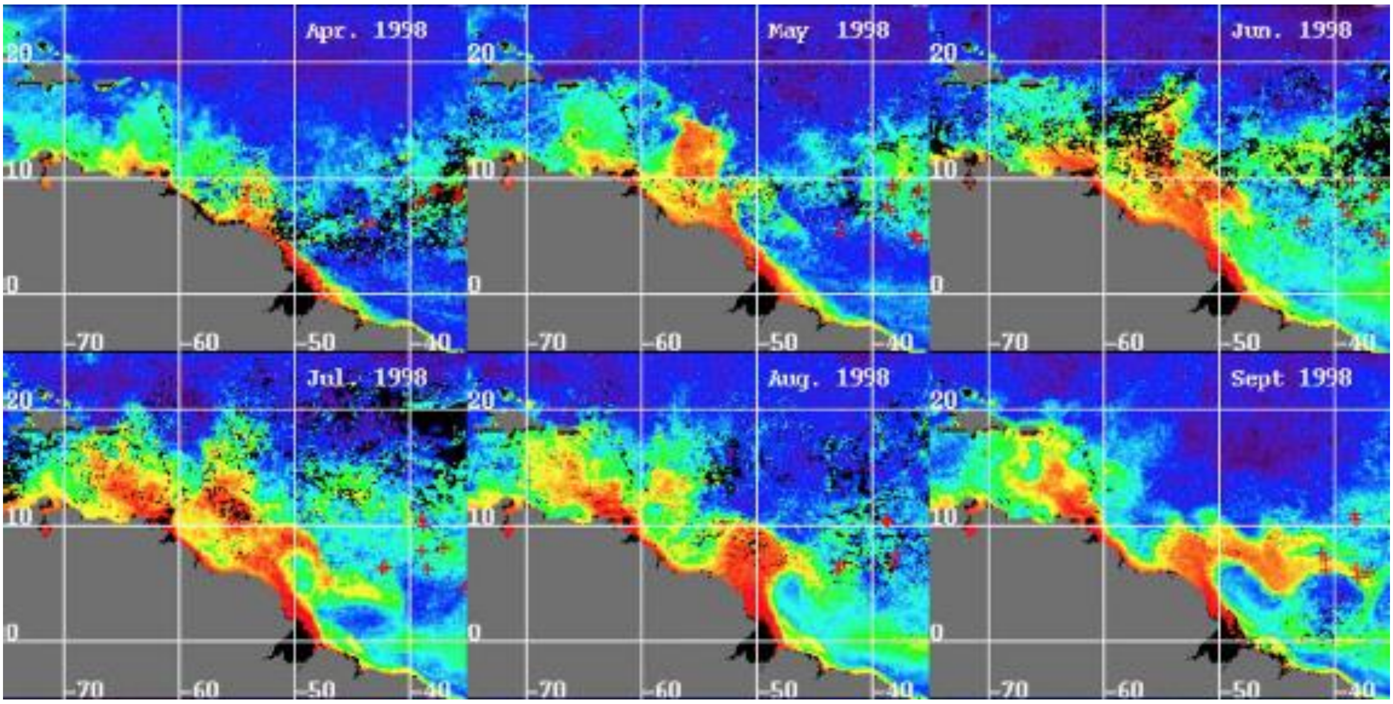

Figure 6. "Yellow-stuff" from the Amazon River plume being transported north along the Brazil Coast, into the Caribbean and into the north equatorial counter current toward Africa during the Amazon Flood of 1998 (From Hu et al 2004).

Their simulation results for the warm phase indicate a northward displacement of rainfall over the tropical Atlantic and a shift of the Inter-tropical Convergence Zone to the north of its climatological March-April-May position leading to a reduction in northeast Brazil rainfall. Their Figure 1 E for this period suggests that during this warm phase a greater amount of rain falls over the northern Amazon basin, although the amount is a lot less than has actually been observed. The simplified model also indicates this rainfall farther north in the Amazon Basin than has been observed. More pertinently the rainfall pattern seems to switch in about 10-20 year increments over stages of the 70-75 year AMO cycle (Knight et al. 2006). So if the current warm cycle began in the 1990s the end of the warm phase may be soon and before 2020. Alternatively, the northeast trades could fail to freshen and to mix and cool surface water temperatures allowing floods to continue in the Amazon, but that stage of global warming has probably not yet arrived.

El Niño also influences rainfall in the Amazon Basin. During La Niña floods of the Amazon intensify, and, conversely during El Niño droughts may occur as happened in 2010 (Gloor et al. 2013). Thus the 2015-2016 El Niño year may be a test of the hypothesis that AMO induced Amazon flooding serves as a source of nutrients for *Sargassum* growth in the Atlantic Ocean. The prediction would be no flooding and a lack of large *Sargassum* drifts on beaches during the El Niño 2016 year in the Caribbean. It is likely, that if the coast of Northern Brazil continues to be a source of *Sargassum*, some mats will flow with Amazon water to Caribbean beaches but the seaweed should be only a minor contribution during a non-flood year. Scientists at Texas A&M University in Galveston have been investigating the use of satellite images to forecast landings with an Advisory System (SEAS) (Webster and Linton 2013). For information on future landings check their forecasts (http://seas-forecast.com).

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Coral Bleaching in Saudi Arabia Affecting both the Red Sea and Arabian Gulf

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We are currently experiencing a third global bleaching event, officially recognised as such last October by the US National Oceanic & Atmospheric Administration (NOAA, 2015). NOAA has attributed this global bleaching to the combined effects of global warming and a very strong El Niño event, and predicted that it may impact over a third of the world's coral reefs. In this context it is of particular interest that bleaching has recently occurred on both coasts of the Kingdom of Saudi Arabia, since both the Arabian Gulf and Red Sea coasts have historically experienced summer peak temperatures that would normally be expected to cause bleaching of corals elsewhere, but have not typically done so in these extreme environments.

In the Arabian Gulf surveys undertaken in September (2015) by the King Fahd University of Petroleum and Minerals (KFUPM) as part of research lead by the Environmental Protection Department of Saudi Aramco (Sustaining Project Phase VI) found coral bleaching at Manifa, Safaniya, and on Jana Island. Surface water temperatures at the time were as high as 32.5°C. Coral bleaching was noted in both nearshore and offshore locations, and observed to be affecting both massive and branching corals (Fig. 1), with *Porites* being the genus most affected. Mass bleaching events were previously recorded in the Arabian Gulf during 1996 and 1998, when seawater temperature reached 37.7°C, resulting in the almost total extirpation of the most abundant coral genus, *Acropora* (Sheppard and Loughland 2002, Burt et al. 2011). *Acropora* colonies remain relatively uncommon on reefs in the Arabian Gulf to this day.

In the Red Sea, scientists of the Reef Ecology Lab at King Abdullah University of Science and Technology (KAUST) observed the occurrence of bleaching in both South-Central and North-Central regions. In the South-Central region bleaching was first reported from reefs near Al-Lith during the northern hemisphere summer, and persisted even through December. At least some offshore reefs (~50km from the coast) were heavily impacted, as were corals down to depths of 20-30m. In the North-Central region (near Thuwal), preliminary analyses suggest that the bleaching pattern was more similar to that observed in 2010 (Furby et al. 2013) when deeper and offshore sites appeared much less affected. Many different species of hard corals were affected as were some soft corals and sea anemones (Fig. 2). The data are being further analysed and a full report will be published in due course.

The fact that corals in the Kingdom´s waters have been affected by bleaching despite their known greater tolerance of high sea temperatures (Coles & Riegl 2013, Voolstra et al. 2015) suggests that if global warming continues these corals may not be able to adapt further (Baker et al. 2004, 2008, Cantin et al. 2010). It may also suggest that there is less scope than had been hoped for transferring any genetic tolerance to bleaching shown by the Kingdom's corals to corals elsewhere.

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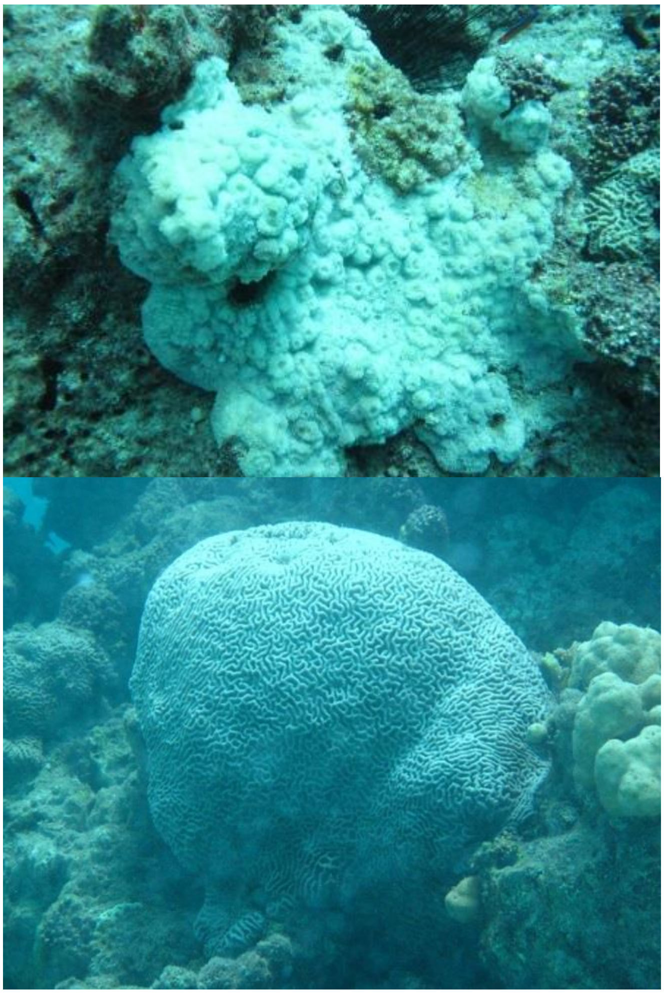

Figure 1. Contrasting coral growth forms affected by bleaching on Jana Island, in the Saudi Arabian Gulf. Photographs courtesy of Sustaining Project Phase VI, Marine Department, KFUPM.

Figure 2. Bleached branching corals and sea anemone at Al Lith, Central Saudi Red Sea. Photographs by Vanessa Robitzch.

Ciliary removal of particles by the cold-water coral *Lophelia pertusa*

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Introduction

Lophelia pertusa is a species that often dominates cold-water coral ecosystems and is mostly found on banks, ridges and seamounts at a depth range of 300 to 800 m (Freiwald et al. 2004). Here, *L. pertusa* can be exposed to high sediment concentrations occurring as a result of both strong local seabed currents, and also offshore drilling operations or bottom fish trawling (Freiwald et al. 2004). Although not yet well studied, several recent studies have addressed the impact of sedimentation on *L. pertusa* (e.g. Brooke et al. 2009; Allers et al. 2013; Larsson et al. 2013). A general conclusion is the high resilience of the species to relatively high sedimentation loads. While these studies emphasise the physiological impacts of sedimentation, an understanding of the removal mechanisms is lacking. Shelton (1980) used graphite particles to observe two types of ciliary currents in *L. pertusa*: (1) a ciliary current that moved particles from the base to the tips of tentacles, and (2) pharyngeal cilia, which maintained a current directed inward to the gastrovascular cavity. These types of ciliary currents are well known for many Atlantic and Pacific scleractinians (Lewis and Price 1976; Stafford-Smith and Ormond 1992; Stafford-Smith 1993). More recently, vortical flows induced by epidermal motile cilia were also implicated in actively enhancing mass transport of nutrients and oxygen (Shapiro et al. 2014).

Particle removal mechanisms in warm-water corals frequently involve tissue expansion and ciliary movement as well as mucus release (Stafford-Smith and Ormond 1992; Stafford-Smith 1993; Gass 2006). Tissue expansion has so far not been observed in *L. pertusa*, however, mucus release has been observed and quantified (Shelton 1980; Allers et al. 2013; Larsson et al. 2013; T. Baussant, unpub.). A recent study has now further confirmed the involvement of mucus in particle removal using a novel technique, so-called digital holographic microscopy (DHM) (Zetsche et al. 2016). This technique enables observations of the behaviour and physiology of *L. pertusa* in vivo at the µm- to cm-scale, and allows the imaging of otherwise transparent substances such as coral mucus. As a result of the high magnification of DHM, it is also possible to observe the tentacle surface of the individual coral polyps. We hereby present the results of these new observations and discuss their potential implications for our understanding of sediment removal and the resilience to sedimentation effects of the cold-water coral *L. pertusa*.

Materials and methods

Details of specimen collection, the treatment with particle suspensions, and the imaging set-up and technique are given in Zetsche et al. (2016). Briefly, individual fragments of *L. pertusa*, which were maintained at the IRIS laboratory facilities, were used for this study. The corals were kept in the dark in flow-through seawater conditions (7.5 ± 0.2°C, salinity 33 ± 0.5) and fed 2-3 times a week with a solution of live *Artemia salina* nauplii. The fragments were used as part of a larger study (Project HAVKYST-ES460364) investigating the sensitivity of cold-water communities, in particular *L. pertusa*, to drilling mud. This study was conducted in Dec 2013 when fragments were in the recovery phase of an experiment, after an exposure period of 2.5 weeks to different levels of drilling muds (Provan *et al*. in press). This study used polyps from the control treatment and two treatments with drilling mud, 4 and 14 mg L-1 respectively.

L. pertusa fragments were imaged with a digital holographic microscope (oLine D3HM, Ovizio Imaging Systems, Belgium) in DHM-adapted, flow-through chambers, holding approx. 615 mL of seawater. The water in the chambers was maintained at a temperature of 7.5 ± 0.2 °C with a flow rate of approx. 10 mL min-1. Fragments consisted of 9–15 polyps, which were gently positioned in the chambers avoiding contact with the chamber walls. Fragments were subjected to solutions of suspended particles, either charcoal (average grain size ~30 µm), or water-based drill cuttings (fine silt particles <63 µm, predominantly ~20 µm; final solution 26 ± 11 mg L-1).

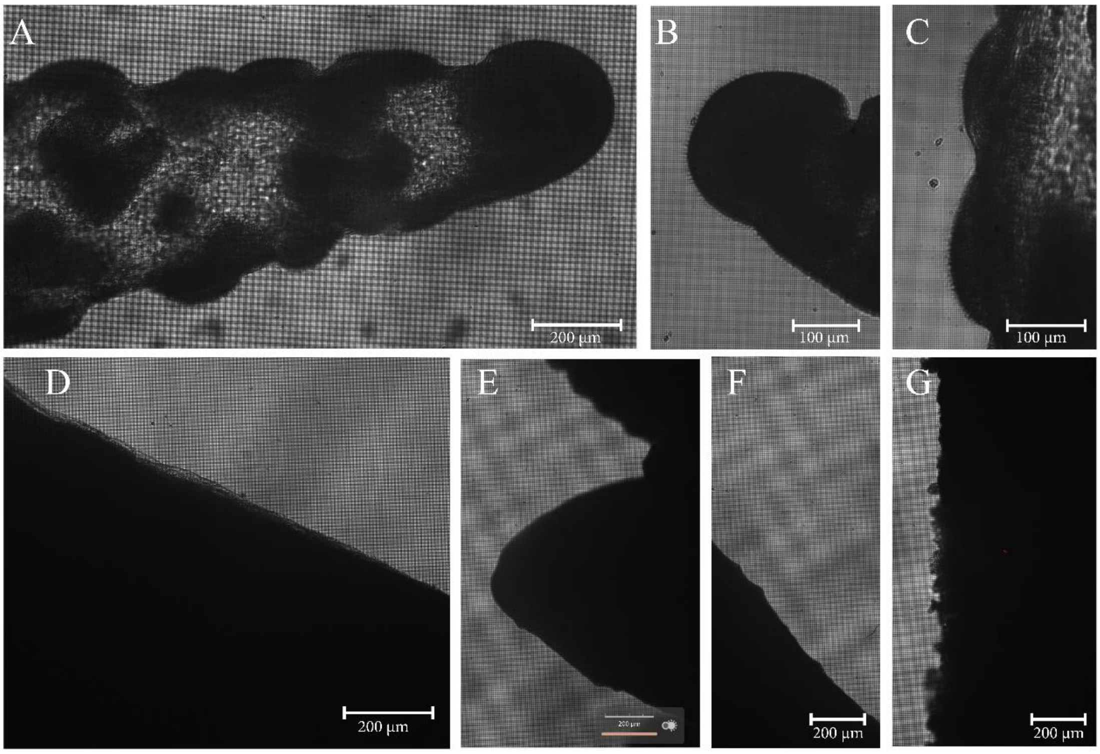

Figure 1. Images are taken from different polyps. A-C: On close inspection cilia are visible along the length of each tentacle. What appears to be a halo in the cilia array (B-C) is an optical artefact caused by the density and 3-D structure of the tentacles and does not indicate the presence of a mucus layer. D-G: No cilia are visible along the theca of the polyps, neither at their base (G) nor close to the oral disc (E).

L-1). Solutions with particles were gently added close to the polyps with a Pasteur pipette, before images and videos were captured with the oLine D3HM.

Compared to bright field microscopy, DHM has the ability to obtain not only light intensity information, but also quantitative phase information (Zetsche et al. 2014). A key advantage is its ability to detect and image transparent substances if the refractive index between two objects is different enough, for example between coral mucus and its surrounding seawater (Zetsche et al. 2016). The D3HM was used with a red LED light (630 nm) and a Leica 4x objective, providing a field-of-view of approx. 1.6 x 1.6 mm, which allowed us to image *L. pertusa*'s polyps at high resolution in vivo and in real-time.

Results

Cilia were observed on all image records of tentacles, were approx. 4-7 µm in length, and extended in a continuous layer from the tips to the bases of the tentacles (Fig. 1A-C). No cilia were observed on the theca of the polyps, in theca covered with coenosarc or in areas without coral tissue (Fig. 1D-G). Charcoal particles and drill cuttings only attached to the cilia surface layer of the tentacles as individual particles or small aggregates (Fig. 2). These particles also never reached the actual surface of the tentacles; they always remained at a distance of several µm above or within the layer of cilia. Whether mucus was involved in this entrapment or individual particles themselves were of a sticky nature was not clearly determined. In contrast, particles elsewhere on the polyp with no cilia were indeed trapped in mucus strings and sheaths (Zetsche et al. 2016).

Most of the individual particles observed along the cilia of the tentacles were also moved along the tentacles, generally towards the tips of the tentacles. On one tentacle, where detailed observations with the DHM were made, sediment rejection of several individual particles and of small aggregates to the surrounding seawater followed the same trajectory, moving along the tentacle's cilia towards the tentacle tip where the final removal took place (Fig. 3).

Discussion

A common feature among scleractinians is the presence of cilia on the epidermis (Lewis and Price 1976; Stafford-Smith and Ormond 1992; Stafford-Smith 1993). Cilia were clearly visible on the D3HM images in a continuous layer (several µm wide) extending from the base to the tip of the tentacles. Shelton (1980) described the presence of motile cilia on the oral disc and tentacles of *L. pertusa*. In this present study, as in others, ciliary movement was suggested, based on movements observed after the addition of particles. Unprecedented imag - es were obtained with the DHM and visual confirmation of the presence of cilia in *L. pertusa* and of their involvement in the rejection of individual particles clearly ob- tained.

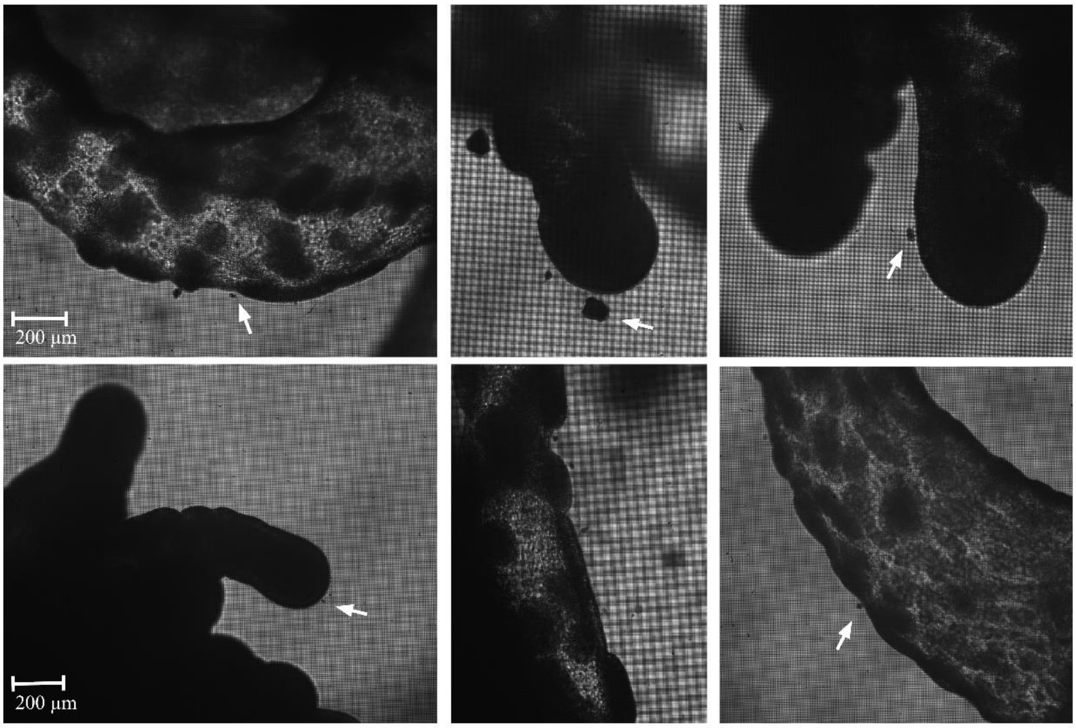

Figure 2. Single particles or small aggregates of particles were observed only at isolated sites along the tentacles of the various polyps. The particles never touched the tentacle surface itself, but remained at a distance above or within the cilia layer. The given scale bars apply to all images.

Particle movement towards and away from the tentacle tip was recorded during several time-lapse observations. The time of particle removal in Fig. 3, for example, varied between 3 sec (Fig. 3 C - E) and ~16 sec (Fig. 3 G - J). It remains unclear whether any mucus was involved in this ciliary movement as mucus was not detectable here with DHM. Movement of mucus-trapped particles along the thecal regions was not mediated by ciliary movement (Zetsche et al. 2016).

Particles do not appear to settle easily onto the tentacles of *L. pertusa*; only few individual particles or small clumps of particles were moved along the tentacles directly (Fig. 2, 3). Shapiro et al. (2014) recently showed that strong vortical flows driven by epidermal motile cilia increased the overall mass transport of solutes in several tropical corals. We speculate that such vortices may also hinder the settling of particles onto the coral's surface. Zetsche et al. (2016) described the occurrence of circular motions of mucus strings and mucus balls containing particles, which suggests that flow patterns with vortices were not only driving mucus transport in *L. pertusa*, but may also influence the settling of particles. Although the magnification used in this study does not allow us to determine whether the cilia were moving passively or actively, it is known that even passive cilia can be used to create self-cleaning surfaces provided there is ambient water flow (Tripathi et al. 2014), as is often the case in *L. pertusa's* habitat. Future studies using higher magnification may help elucidate this point further.

Conclusions

The presence of cilia on the tentacles of *L. pertusa* was confirmed, and their involvement in sediment removal observed, by using a novel microscopy technique that maintained polyps in vivo and allowed observations at the µm- to cm-scale in real-time. Recent interest in cilia as a natural defence against biofouling has sparked several studies modelling the behaviour of cilia in terms of (ambient) flows as well as actively or passively settling particles (Shum et al.2013; Tripathi et al. 2014). These have shed light on the importance of cilia as a protective layer and may explain their role in *L. pertusa* and other coral species as a sediment removal mechanism. These observations may also explain why motile epidermal cilia have been retained by scleractinian corals in their evolutionary history (Shapiro et al. 2014). The movement of cilia requires little energy (<0.1% of the coral's total energy budget; Shapiro et al. 2014) and may partly explain the ability of *L. pertusa* to cope efficiently with sedimentation exposure (Allers et al. 2013; Larsson and Purser 2011; Larsson et al. 2013; T. Baussant, unpub.), at least in the short-term and below a certain sediment load. Above a given thresh - old, cilia exhaustion may potentially occur (Stafford-Smith 1993), and their function in cleaning can be disrupted, leading to sedimentation, and in the worst cases death of the coral (Brooke et al. 2009). Further studies are needed to elucidate more explic-itly the active role of cilia and their inter-action with other sediment removal mechanisms, such as mucus release.

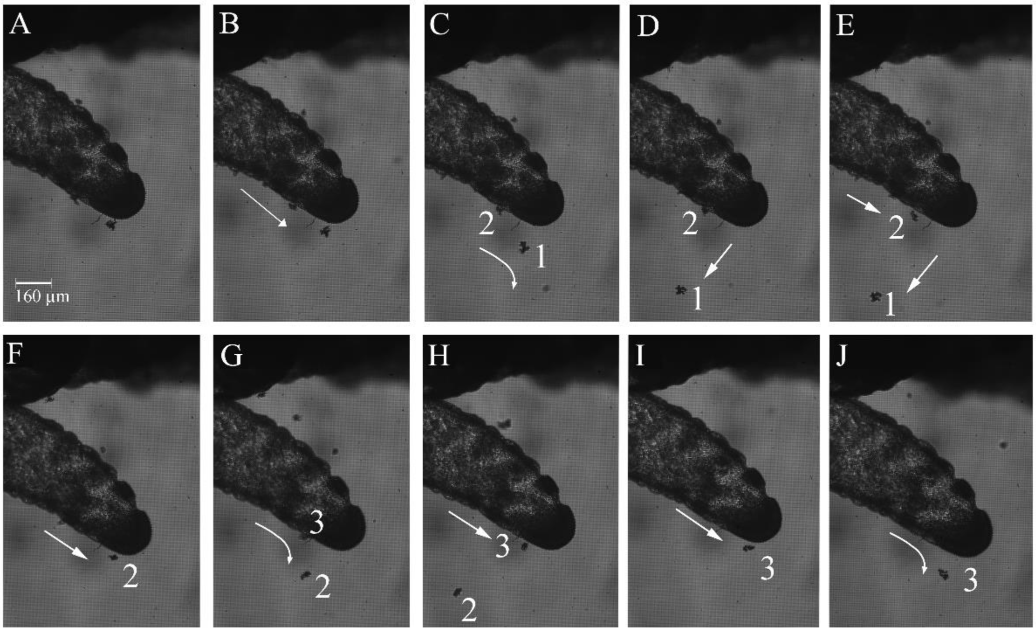

Figure 3. The image sequence shows the movement of particles along the cilia of one tentacle and their expulsion at almost the same position each time. Arrows indicate approximate directions and numbers track specific activated charcoal particles. The scale bar shown in A applies to the entire image sequence.

Acknowledgements

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BOOK & PRODUCT REVIEWS

Reviews of books, software, hardware and other products

Coral – Master builder of the Seafloor
Helmut Schuhmacher

BLV Verlag, September 2010
ISBN: 9783835406049
€ 39.95

Review by Bernhard Riegl
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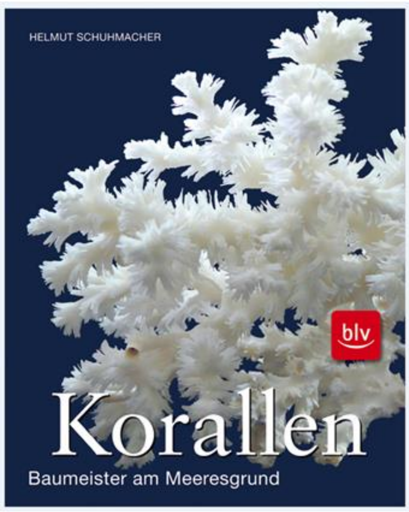


Helmut Schuhmacher's latest book, which escaped review during Reef Encounter's break in publication, is a visually stunning, and scientifically accurate celebration of the wonderworld found in coral reefs. Intended for the non-specialist, it nonetheless offers a fascinating and informative read for both specialist and amateur alike – it makes for a great undergraduate textbook. Not many have researched so many different aspects of reef biology and geology to allow them to give such a broad, even-handed, and engaging overview. But one need not be surprised.

Prof. Schuhmacher is an old hand at reef science. He is one of the founding fathers of the International Society for Reef Studies and certainly one of the fathers of German reef science. His seminal studies of long-term reef dynamics began in the Red Sea in the early 1970s. Unlike today, where big cities and well-organized marine labs exist along its shoreline, then the Red Sea was pretty empty and its cities had just begun developing or were still being planned. After his dissertation on a freshwater theme in 1969 Schuhmacher immediately turned to the coral world of the Gulf of Aqaba (Red Sea). The result of this dedication was a long stream of meticulously accurate publications that are still of great value today as some of the most solid baseline studies available. Given the difficulties, there must have been an abundance of affection for his study object.

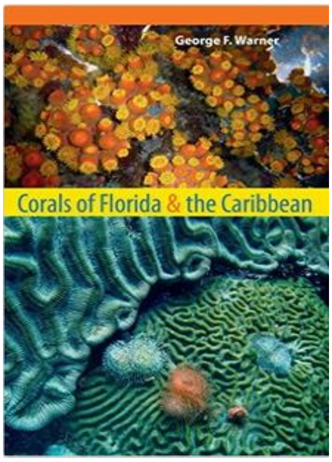
The book does a great job of passing on the affection for and fascination with coral reefs. It is abundantly and beautifully illustrated in the finest tradition of scientific photography. No image is surplus, all serve to illustrate points made in the text – but they are all stunning. Leafing through the book is a bit like a field trip, with instructor Schuhmacher taking one first diving and then to the lab to have a closer look at this or that fascinating item. The text begins by introducing corals from a zoo-systematic viewpoint and also tells us why they are so pretty – where the colors come from, what the shapes are good for. Then the scleractinian coral is discussed in detail – life history details, skeletogenesis, various types of corals. In a subtle and captivating way, many of the results of Prof. Schuhmacher's own work now serve to make us understand the coral better. An example is how the skeletons of different taxa variably resist abrasion and thus help determine ecological zonation – ingeniously captured in one beautiful figure. Also non-coral framebuilders and –fillers are discussed in detail. Forams, bryozoans, red algae, etc. all are introduced, again beautifully illustrated, and discussed in their importance. This organically leads to the discussion of reef growth as the balance of construction and erosion. The principles of stressors and their interplay with bioerosion are introduced here – hydrodynamic stresses, sedimentation but also diseases and predator outbreaks. Sea level – as a key determinant of where a reef can grow, is of course also discussed. The various biocoenoses of the reef are then discussed using the famous analogy of cities under water – and again the inhabitants and their dwellings are beautifully illustrated.

"Man and Reef" is the final chapter of the book – and makes us appreciate that not only in the book we may be nearing the final chapter of reefs unless management practices become dramatically more successful in the near future. All important anthropogenic stressors are described in a fair, non-polemic way. We appreciate here that Prof. Schuhmacher has a unique vantage point – the systems he studied in the 1970's were almost untouched, growing along coastlines unaltered since before biblical times. His descriptions here help to avoid "shifting baseline syndrome". Finally we are led into conservation and reconstruction issues and a brief overview of techniques and possibilities is given.

In summary, this book is a very worthwhile read. It would make a perfect undergraduate textbook – and one would hope that German universities use it abundantly. Unfortunately, the book so far only exists in German but even if you do not speak the language, it is still worth having, be it only for the illustrations. This book should have a place of honor on anybody's bookshelf who is interested in coral reefs.

Corals of Florida and the Caribbean
George F. Warner

University Press of Florida, September 2012
ISBN-10: 0813041651
ISBN-13: 978-081304165
$ 21.68



Review by Rupert Ormond
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This delightful little book, which also escaped review during Reef Encounter's break in publication, deserves to be much better known. In just 200 pages George Warner provides clear and interesting accounts of all the species of hard coral one is likely to encounter in the Caribbean, and given the book's title it is perhaps worth emphasising that it will likely be even more useful through the islands than in Florida, where I imagine not all the species described are present. The text is supported by more than 150 often superb colour photographs, reflecting the author's long experience of research in Jamaica and elsewhere, and by short supplementary chapters (on coral biology, reef ecology and the threats to Caribbean reefs) that clearly benefit from his University teaching experience. Given its portability, and availability on Kindle, I would certainly regard this as my preferred tool for Caribbean coral identification. As John Ogden comments on the book's back cover "this informative guide...should be in the dive bag of every novice and snorkeller," to which I would add, "and in the kit of every undergraduate and graduate biologist seeking to get to grips with Caribbean coral reefs".

I do however have a couple of minor quibbles. Having myself first tried to master Caribbean corals over 40 years ago from a guide that contained nothing save black-and-white photos of museum specimens, it is a relief to see so many gorgeous underwater pictures; but it would have been instructive to have included more close-up images of underlying corallite structure, for example for the iconic Pillar Coral, *Dendrogyra*. My other disappointment is that the book felt obliged to make use of the so-called common names invented by some of the earliest Florida and Caribbean reef guides. The result is a confusing proliferation of "starry", "star" and "starlet" corals, often quite unrelated to each other. Surely recreational divers as well as students could easily cope with hybrid popular-scientific names (such as "Stagshorn Acropora") that more helpfully reflect the taxonomic position of the species and families concerned.

Ecology of Fishes on Coral Reefs
Edited by Camilo Mora

Cambridge University Press, April 2015
ISBN 9781107089181
Hardback £75, US $120

Review by Callum Roberts
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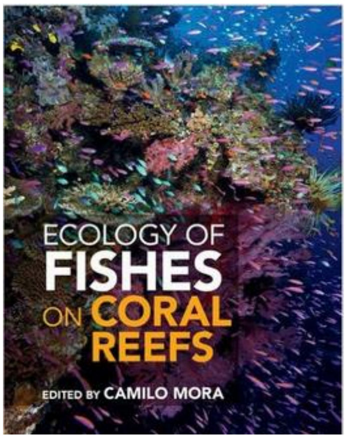


For those of us who have knocked about on coral reefs for more than a couple of decades, *Ecology of Fishes on Coral Reefs* has a special place in the lexicon of research and teaching. A bit like Dr Who in the BBC television series, the book has been periodically reborn completely afresh. Peter Sale edited the first edition in 1991, and then in 2002 edited an entirely new book with a similar name *Coral Reef Fishes: Dynamics and Diversity in a Complex Ecosystem*. In this latest edition, Peter Sale has been reborn as Camilo Mora, who takes up the editing role, but still contributes a Foreword, and the penultimate chapter on what the future has in store for reef fishes. Viewers of Dr Who easily forgive the *timelord* for changing his form because the calibre of replacements has always been outstanding. In this respect, *Ecology of Fishes on Coral Reefs* is much like Dr Who: an outstanding reinvention.

Many academic texts are here today, gone tomorrow affairs that leave few ripples in the research pond. They often take years to produce, held back by a handful of laggard authors whose contributions are, ironically and unfairly, the most up to date pieces included when the book finally emerges. But one is left wondering, leafing through their pages and finding them superseded by more recent reviews, why did anyone bother? This book is not like this and never has been. *Ecology of Coral Reef Fishes* has always been timely, authoritative, expansive in scope, challenging and relevant. It is everything an academic book should be, offering an accessible view of a broad subject that will stimulate fresh-faced novices and the most leather-hided field scientists alike.

I well remember Peter Sale's first journal-published overview of what was then a young field in the early 1980s, leafing through my dog-eared copy by the hissing light of a paraffin lamp on the Red Sea coast. It was wonderful to be able to jump in the water the next day and look for the things I had just read about. At 374 pages long and 1.3 kilos, this is altogether heftier, but still essential field reading. The price is a bit steep and will burn a large hole in most student budgets. But it is worth having. With 36 mostly short and pithy chapters, the book covers a spectacular range of topics, from deep history and the evolution of reef fish, the emergence of coral reefs as diverse and complex systems, to their role sustaining the livelihoods of hundreds of millions of people across the tropics. Dipping into these chapters, I could feel my excitement building as dearly held ideas were challenged by new data and fresh eyes. Some of those who were young Turks at the time of Sale's first edition are authors here, but Mora has recruited a bevy of young talent for this edition.

These days I look at academic books with teacher's eyes as well researcher's. The first thing you look for as a teacher is the quality of illustrations, in conception, content and production standard. Will this image reproduce well in a powerpoint slide, the perennial thought. While some chapters contain few or no illustrations, most have excellent figures that will transfer easily to lecture slides. My coral reef course will be all the better for them.

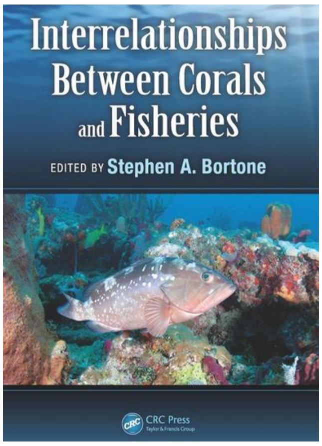
In his Foreword, Peter Sale points out that there is still much energy in the field of reef fish research with recent injections of new technology, especially molecular tools, revolutionising our understanding. But he also laments that the ease with which lab tools can be applied to quickly gathered samples, means that researchers often spend too little time on the reef itself. I can't agree more. There is nothing better than time served in the water to really understand how coral reefs work, and what happens when things go wrong. You can't learn about reefs from books alone or from bottled fragments of flesh.

None of us know what the future holds for coral reefs but it doesn't look rosy. There has never been a more important time to study them and to speak loudly and widely about the implications of that science for their better management. As Peter Sale puts it beautifully in his chapter, "That these apes [i.e. us] have the intellectual acumen to understand what they are doing, and how, but apparently do not have the capacity to recognize the self-interest in working together to reverse their deleterious impacts is both ironic and deeply disappointing. I hope I undervalue the capacity of *Homo sapiens* to actually be wise, because the future of coral reefs will be far brighter, and the quality of life of coastal peoples will be far greater if we can pick up the tools we have at hand to remedy past mistakes."

Interrelationships between corals and fisheries

Bortone SA (editor)

Publisher: CRC Press, July 2014
ISBN 978-750-8400
US$ 45.00 to 99.95 hard cover and digital.



Review by Rupert Ormond
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This volume is the result of a workshop of the same name held in Florida in May 2013. It contains 15 chapters that consider "Current and emerging threats as well as challenges and opportunities for managing corals and associated fisheries." In fact the title of the book is potentially a little misleading in that it is largely concerned with fish and fisheries of the Gulf of Mexico and to a lesser extent the southeast seaboard of the US. Only a useful overview chapter by Peter Sale and Mark Hixon is fully concerned with coral reef fishes and their habitat. Nevertheless, the volume covers a wide and interesting range of topics, including the impact of coral reef decline on fishery yields, deep-water coral and sponge habitats, the coral populations of offshore oil platforms, the role of mangrove connectivity in sustaining adjacent reef fisheries, and issues relating to the restoration of deep-water coral ecosystems and fisheries subsequent to the "Deepwater Horizon" oil spill. Taken together the chapters provide a volume that no marine science library should be without, but likely only a few coral reef researchers will need to possess personally.

As a scientist from the other side of the pond, I at first found the style of reference to geographic features a touch confusing, until I realised that "The Gulf" was not the one referred to internationally in this style, and that the "South Atlantic Council" only deals with the east coasts of Florida and neighbouring states, and not say, the actual South Atlantic. Such usage may constitute a small entry barrier to international readers, but will not bother locals.

Such niggles apart, the volume is well worth dipping into for the many interesting technical details. For example the chapter by Anna Martin provides useful background on the US legal framework for marine habitat management established by the Magnuson-Stevens Fishery Conservation and Management Act (2007), introducing HAPCs (Habitat Areas of Particular Concern) and CHAPCs (Coral Habitat Areas of Particular Concern), areas through which bottom longlines and fish-pots and traps, as well as bottom trawling and dredging, may be prohibited.

Likewise Simon Pittman and Anders Knudby provide a handy overview of the methods now used in predictive mapping of fish habitats and abundances for management purposes. Tools including high resolution bathymetry, multiscale modelling and machine learning algorithms are considerably more sophisticated than I had supposed. Their chapter is supported by some useful case studies.

And the chapter by Carrie Simmons, Angela Collins and Rob Ruzicka, on the distribution and diversity of Gulf of Mexico coral habitats and fishes, provides a nice introduction the region's most interesting areas and their fisheries resources. I had incorrectly assumed that features with names like "Steamboat Lumps" must lack biological interest, but it was designated a Reserve as long ago as 2000; while despite their fanciful name and wide separation from other coral reef areas, the Flower Garden Banks are accreting reefs that support 21 species of scleractian coral.

CONFERENCES & WORKSHOPS

Informative overviews of recent conferences and meetings

Caribbean Coral Reefs at Risk

Improved Decision Making Through Better Science and Communication

Group Statement from the Workshop held at the Teresa Lozano Long Institute of Latin American Studies, The University of Texas at Austin, September 2015

The degradation of Earth's coral reef ecosystems has environmental and socio-economic consequences of importance to fisheries, food security, shoreline stability, tourism, and economic development options. Since our planet's history suggests that thousands to millions of years have been necessary for coral reefs to recover from similar past collapses, a key question that deserves an immediate response is '*Can we afford further degradation*?'

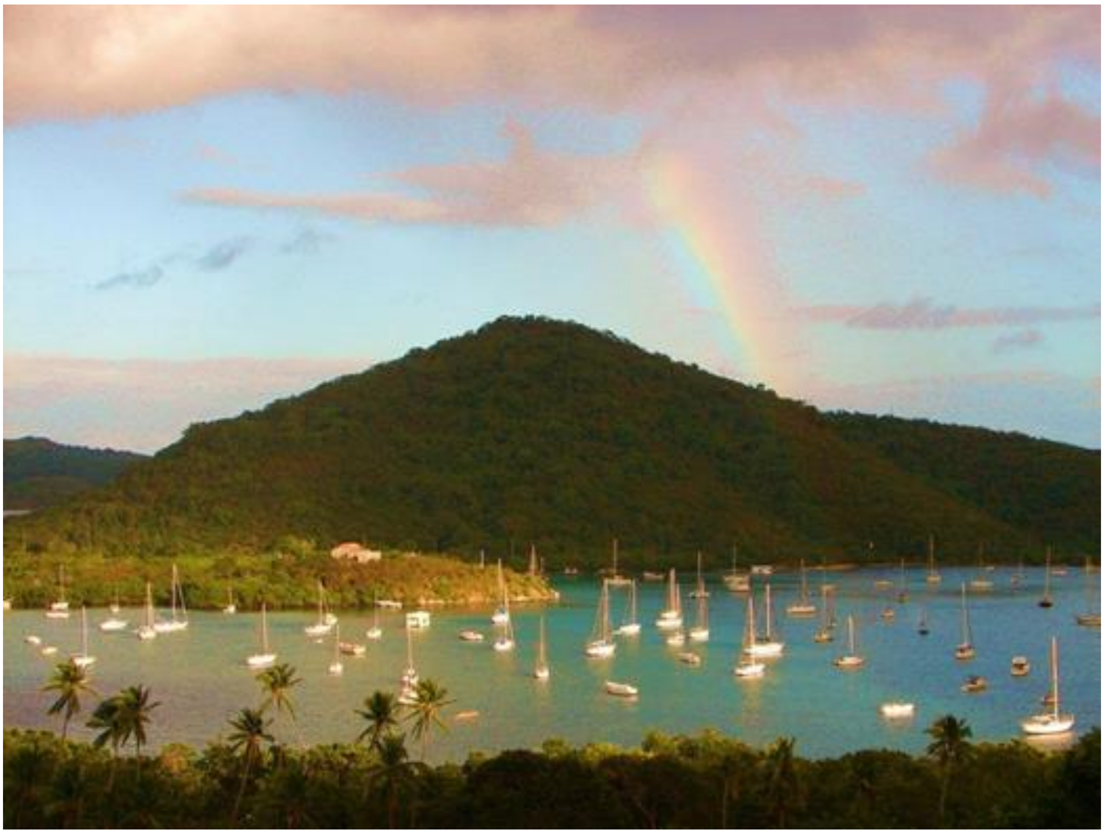
Coral reef ecosystems in the Caribbean are particularly at risk. The well-documented loss of coral cover throughout the region, and the increased abundance of macroalgae in many locations provide strong evidence of systems undergoing major changes in species composition, physical structure, and function. The causes of modern coral reef degradation are numerous and can differ from one location to the next, but experts agree that humans have played and continue to play a major role in this decline.

As concerned citizens representing a variety of geographical locales from both the private and public sectors, the participants of The University of Texas workshop held in September 2015 wish to voice our concerns and recommendations for how to proceed with the conservation of coral reefs and other associated coastal environments. Although we acknowledge the alignment of our views with statements and resolutions of the US Coral Reef Task Force, we still wish to reformulate and emphasize some important points. As a group we concluded that the main challenge we face is determining how to bring the best science and management actions together to assist in ecosystem recovery. We believe this would be best achieved through the regional replication of locally implemented management measures that take advantage of the natural resilient capabilities of coral reefs. Workshop participants from Colombia, México, Puerto Rico, and the U.S. Virgin Islands concluded that warmer seawater temperatures, particularly by rendering susceptibility to disease outbreaks, and land-based sources of pollution represent two of the most pressing causes for coral reef degradation in each of these areas. Participants agreed that Caribbean-wide reductions of some key coral reef stressors can be achieved through local actions and watershed-scale management efforts.

Degraded reef in Akumal-MX (Photo by JR Garza-Pérez)

What are the causes of coral reef degradation?

- ***Regional or global causes*** – While climate change can induce severe stress to coral reef systems through warming seawater temperatures and acidification, little can be achieved at a local level to directly attenuate those sources of stress. However, it is still possible and worthwhile to control and manage local stressors. Climate change must not be used as an excuse to stall local actions.



Coral Bay, St. John, US Virgin Islands (Photo by Judy Scott, CBCC)

- ***Local causes*** –Intensive fishing and water quality deterioration associated with land development are two very important and potentially controllable local sources of stress [*See Akumal-México inset*]. By mitigating these effects, we may allow corals enough time to adapt to a changing climate and resist other sources of stress such as those related to disease. The recently published Caribbean-wide coral reef synthesis by Jackson et al. (2014)[1] focuses on overfishing of parrotfish (*Scaridae*) as a major cause of reef decline in the Caribbean, but the case studies presented at The University of Texas meeting identified watershed-based pollutants, as well as coral bleaching and diseases associated with elevated seawater temperatures as the primary concerns. We do not believe it is necessary to identify a single cause for the degradation before taking action---in fact, it is misleading given the expected variability in coral reef resiliency at the species and ecosystem levels, the spatial heterogeneity of each type of stressor, and the synergistic effects of combined stressors.

What if we just sit and wait?

- ***Can reefs adapt? –*** Degradation is often interpreted as a sign of the inability of ecosystems to adapt to unprecedented environmental change. If unchecked, ongoing regional trends in stressors linked to climate change, population growth, fishing, and land development will continue to accentuate the differences between the conditions in which corals and associated ecosystems thrive and those imposed by humans.
- ***Giving them a chance*** – The fossil reef record tells a formidable tale of reef collapse and recovery. The recent rate at which we have imposed changes on coral reefs and associated ecosystems is unprecedented in the current geologic era and the result has been the mortality of corals with adverse effects on fishes and other reef organisms. By reducing the threats from locally controllable stressors, enhancing genetic diversity, and restoring coral populations through coral farming (although to date on a limited scale) we may be able to provide coral reefs and associated ecosystems the respite they need to resist and adapt.
- ***An opportunity for science to step forward –*** Implementation of conservation practices

[1] Jackson et al. (2014). *Status and Trends of Caribbean Coral Reefs: 1970 – 2012*. Global Coral Reef Monitoring Network, IUCN, Gland, Switzerland.

inevitably involves making compromises. Difficult decisions regarding which ecosystems, stressors, and strategies to focus on are not trivial as these choices often have irreversible repercussions. However, coral reef conservation must continue regardless of the uncertainties involved. Scientific information is often inaccessible for decision makers, and potentially useful science can remain hidden and hence unused. Alternative venues facilitating the communication between scientists and decision makers must be created.

- ***Not just a coral reef problem*** – Some key stressors affecting coral reefs and associated ecosystems also represent environmental problems of utmost concern as these pose a risk to public health, coastline vulnerability, food security, and water resource availability, among others. Recognition of these linkages should serve to gather wider consensus on the multiple societal benefits gained by addressing these issues. Educational campaigns that explicitly highlight the economic benefits of functional coral reef systems could serve to further harness the support of both private and public sectors.

What can we do… better?

- ***Reinforce local efforts*** –Many local stressors related to land-based sources of pollution are potentially manageable at the watershed level as many proven mitigation practices are fiscally enforceable through already existing water and soil conservation regulations [*See Coral Bay-St. John inset*]. The same applies to curbing the effects of overfishing by effectively enforcing the proposed restrictions on fish extraction within Marin Protected Areas (MPAs).
- ***A focus on survival through adaptation*** – The genetic adaptability of modern reef-building corals (*Scleractinia*) has been essential in their survival since their emergence on our planet 240 million years ago. Helping corals adapt to current conditions by augmenting their genetic diversity could also play a significant role in their current struggle for survival, but so far little attention has been paid to this option as a potential management strategy.
- ***Managing through coral farming*** – Low-tech coral propagation, often empowered by community-based efforts, has become a cost-effective strategy to reestablish depleted coral species and essential fish habitat functions. However, these efforts have been limited to the scale of individual patches within specific reefs, and thus add limited community- and ecosystem-level benefits. Coral reef restoration through farming and planting can entail more than simply enhancing live coral cover or thicket formation, even if it results in reinstating depleted, slow-growing reef-building species. Coral farming must also foster landscape-level resistance and resilience through strategic planning that maximizes the chances of survival, enhances genetic and demographic diversity, and foments successful sexual reproduction.

Can you hear me now?

- ***Having a voice where it matters*** – Many of the decisions that affect coral reef ecosystems are effected in mostly inaccessible political and economic venues. For example, many coral reefs under United States' jurisdiction lie outside of the continental U.S., and as a result coral reef degradation remains distant and mostly irrelevant in the most pertinent political spheres. Failed attempts or the lack of opportunity to introduce a convincing argument supporting natural resource protection into those discussions is in part to blame for the lack of environmentally - conscious development models that consider coral reefs as an indispensable component of sustainable socio-economic growth [*See Río Magdalena-Islas del Rosario – Colombia inset*].
- ***Supporting community empowerment*** – The value of traditional ecological knowledge in recognizing and effectively responding to signs of coral reef degradation is generally underused. Empowered communities have been proven effective in leveraging coral reef stewardship efforts with government agencies, the private sector, and academia. Other benefits include technical training, enhanced entrepreneurship opportunities, improved quality of life, and truly participatory governance partnerships that could be replicated in other areas of the Caribbean [*See Culebra – Puerto Rico inset*].
- ***Lost in translation*** – Language barriers can further communication gaps as much of the technical information is mostly available in English. This is a particular concern for the Spanish, Portuguese and

French-speaking countries in Latin America and the Insular Caribbean.

- ***A Caribbean-wide information network*** – Given that regional coral reef degradation is linked to the proliferation of adverse local conditions, curbing of this declining trend requires the widespread replication of effective management strategies. An assemblage of concerned individuals from government agencies, non-government organizations, local communities, and academia such as the one emerging from The University of Texas' workshop is thought to properly represent society's concerns with regards to the degradation of coral reefs and associated ecosystems. The goal of this group is to internally and externally share experiences across geographic locales and backgrounds in order to better express and develop our arguments regarding coral reef conservation. This working group also seeks to communicate results in an adequate framework with simple language for decision makers and communities in general and to improve governance by identifying and building on success stories.

Contributors:
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CASE STUDIES

Local Stressors, Big Challenges- Akumal, Quintana Roo, México

Servicing an excess of 200,000 visitors per year, Akumal is undoubtedly one of Mexico's foremost Caribbean destinations. Land development supporting such a high volume of visitors has been mostly in the form of small luxury hotels and condos that have expanded the amount of built-up land by 200% over the past fifteen years. Concurrently, one of Akumal's most coveted attractions, its coral reef ecosystem, suffered a total cover loss of 77%. Research conducted by Universidad Nacional Autónoma de México at Sisal suggests that coral losses have been the result of an unprecedented high incidence of coral diseases following massive bleaching events in 1998 and 2005. The low resilience of Akumal's reefs has been associated to elevated nutrient concentration of its coastal waters, which is undoubtedly linked to contamination of groundwater aquifers by untreated sewage[2]. Even though parts of Akumal's coral reef ecosystem were declared Marine Protected Areas in 2015 and 2016 (a No-Take Marine Reserve and a Marine Wildlife refuge), the effectiveness of these actions as conservation efforts is limited in that they are meant to tackle stresses related to overfishing and tourist-access, and not to land-based sources of pollution. Even though regional efforts are being developed to address water quality issues, these are yet to alter waste water treatment practices to reduce coastal water contamination. Along with the limited environmental law enforcement in Mexico's Caribbean Coast, Akumal serves as an example of '*deterritorialization*'. Most dwellers are recent newcomers from other states throughout México and therefore lack the historical knowledge to become aware of the consequences of the deterioration of the region's marine environment. As a result, the community as a whole has lacked the cohesion necessary to effectively interact with stakeholders, NGOs, and the government. [For more information please visit http://redoctober.sisal.unam.mx]

[2] Naranjo-García MJ & others. 2014. Role of sediments and nutrients in the condition of a coral reef under tourist pressure: Akumal, México. AGU Fall Meeting Abstract EP13F-06.

Executing Local Actions – Coral Bay, St. John – U.S. Virgin Islands

Even though fewer than 2,000 people live in the rural 3,000-acre watershed draining towards Coral Bay, unmanaged land development represents a serious threat to its marine ecosystems. The Coral Bay Community Council (CBCC) was formed in 2003 with the goal to address the most important issues affecting the Coral Bay community. From the beginning, the most commonly voiced concern was the need to address the sediment-laden stormwater plumes reaching the bay's coral-bearing waters, and this was in agreement with the scientific literature[3]. In 2007, CBCC began developing a Watershed Management Plan through a pair of NOAA and EPA-CARE grants. These grants enabled CBCC to hire a stormwater engineer to evaluate runoff problems associated to poorly regulated road construction. In 2009, CBCC partnered with another local non-governmental organization to secure a $1.5 million NOAA-ARRA grant to implement watershed restoration actions mostly intended to enhance the sediment retention capacity of the watershed through road drainage improvements and the construction of bioretention basins. The effectiveness of such watershed restoration measures have been evaluated by CBCC members and academic institutions such as the University of San Diego and The University of Texas at Austin. Findings reveal that water turbidity within the bay has noticeably improved and that restoration activities have reduced sediment yields by approximately 26%. Although much work still lies ahead, Coral Bay serves as an example of the possibility of executing local actions through partnerships amongst local communities, government agencies, and academic institutions. [For more information please visit:
http://www.coralbaycommunitycouncil.org]

Subcontinental-sized Stressors, Río Magdalena, Colombia

In addition to the same array of stressors affecting coral systems throughout the region, those located in the southwestern Caribbean may also be affected by large river systems originating as far away as the Northern Andes. With a drainage area of 257,000 km^2 and an average annual yield of 188 Million tons of sediment per year, Río Magdalena in Colombia is the main contributor of continental sediment fluxes to the Caribbean Sea. Since the 17th century, the 114-km long Canal del Dique has diverted about 5% of Río Magdalena's flow away from its natural deltaic environment, which includes the 4,280 km^2 lagoon complex of Ciénaga Grande de Santa Marta. Complications due to the artificial sediment accumulation patterns in the Canal del Dique and economic pressures desiring improved navigation through Río Magdalena led to the decision to open alternative outlets towards Bahía de Cartagena throughout the 20th century. This led to the obliteration of benthic communities of coral and seagrass beds in Bahía de Cartagena, now buried up to 12 m deep in recently deposited sediments. In addition, the relocation of the outlet of such a major river system has allowed large quantities of runoff, sediment, and other pollutants to gain access to Parque Nacional Islas del Rosario, a 145 km^2 area representing Colombia's major continental coral reef ecosystem[4]. Significant decreases in the abundance of coral cover in this ecosystem since the mid-1980s have been unequivocally linked to concurrent dredging activities along Canal del Dique. The Río Magdalena case serves as an example in which scientific information facilitated by an ensemble of academics supported by the private sector has introduced the

Bahía de Cartagena (Photo by ECORAL)

[3] Ramos-Scharrón & MacDonald. 2007. Measurement and prediction of natural and anthropogenic sediment sources, St. John, US Virgin Islands. *Catena* 71: 250-266.

[4] Restrepo & others. 2016. Coral reefs chronically exposed to river sediment plumes in the southwestern Caribbean: Rosario Islands, Colombia. *Science of the Total Environment* 553: 316-329.

Out-planted Staghorn coral in Culebra (Photo by SAM)

need for coral reef conservation into national-level economic development discussions. [For more information please visit http://www.ecoral.co/]

Community-Based Actions, Culebra Island – Puerto Rico

The island of Culebra has housed a number of community-based coral reef conservation projects. In collaboration with local agencies and the local community, two nonprofit organizations (Protectores de Cuencas Inc. and Ridge to Reefs Inc.) developed the Culebra Watershed Management Plan that identified numerous land-based sources of coastal water contamination including failing septic tanks and erosion hotspots, among others. Structural and non-structural erosion control methods, including hydroseeding and restoration of vegetated areas, have been implemented in a number of locations as a result of these efforts [http://protectoresdecuencas.weebly.com/]. Another type of project that has been implemented in Culebra is the *Community-Based Coral Aquaculture and Reef Rehabilitation Program*. Launched in 2003 in the island of Culebra through a collaborative effort led by Sociedad Ambiente Marino (SAM), the Culebra Island Fishers Association, Coralations, Inc., and the University of Puerto Rico at Río Piedras, the project was originally aimed at replenishing populations of Staghorn coral (*Acropora cervicornis*) depleted by military training activities. However, the project has expanded to include Elkhorn coral (*Acropora palmata*) and other locations even beyond Puerto Rico. Efforts have produced over 20,000 out-planted corals into depleted reefs which have resulted in fostering thicket development and documented increases in fish species richness, abundance and biomass. Moreover, the project triggered a significant switch in community-based participation through extensive hands-on training, education and participation. Efforts led to a major empowerment of SAM which aided in securing external funding, staff and volunteer training opportunities, and fomenting collaborations with academia and government institutions. As a result, SAM and UPR researchers have co-authored over 15 peer-reviewed articles about multiple topics beyond coral farming[5]. The SAM example serves as a model of how a single community-based coral farming project may evolve into an independently funded, multi-objective organization dedicated to coral reef restoration, education, and research [For more information please visit: http://sampr.org/es/].

[5] Hernández-Delgado & others. 2014. Community-based coral reef rehabilitation in a changing climate: Lessons learned from hurricanes, extreme rainfall, and changing land use impacts. *Open Journal of Ecology* 4(14): Article Id 50930.

18th Annual Reef Conservation UK (RCUK) Meeting
28th November 2015

The 18th annual Reef Conservation UK (RCUK) meeting took place at ZSL London Zoo on 28th November 2015. Over 135 coral reef scientists gathered for a day of talks and posters on practical reef conservation, impacts of global stressors on reefs and coral reef ecology. Plenary talks were given by Elizabeth Wood (Marine Conservation Society) and Jan Helge Fosså (Institute of Marine Sciences in Norway), and this year for the first time we awarded prizes for the best student talk and poster. The day opened with a reflection on the ISRS Consensus statement on Climate Change and Coral Bleaching, particularly appropriate with COP21 starting a couple of days later in Paris.

Elizabeth Wood's plenary focused on the challenges of long-term coral reef conservation in the Semporna Islands Project and Tun Sakaran Marine Park, Sabah, Malaysia. The talk illustrated the interactions between increasing reef resource demand by local populations, severe declines in marine resources and the urgent need to strengthen marine resource governance. While they have had some successes, issues such as fish bombing remain stubbornly persistent leading to new technological approaches, such as acoustic detection arrays, allowing fish bomb locations to be triangulated.

Jan Helge Fosså's plenary talk focused on deep sea *Lophelia* reefs off the Norwegian coast. These reefs and their management provide a contrasting story, with much of the protection driven by a partnership between local fishers and scientists, both arguing that reefs were being destroyed by bottom trawling, leading to declining fish catches. In response, Norway became the first European country to protect cold-water coral reefs though bans on bottom trawling. Jan Helge Fosså finished with the exciting news that the Norwegian government is currently considering nine further *Lophelia* reef areas for protection.

Student presentation awards were introduced this year for the first time, and we were very grateful that the ISRS agreed to sponsor the best student talk award. Competition was tough, but the winning talk was by Eslam Osman (University of Essex) who gave a highly engaging (and entertaining) talk on his PhD research on *Symbiodinium* adaptions to different thermal regimes in the Red Sea. The best poster award, sponsored by RCUK, went to Anna East (University of Oxford), for her poster on surveying of mesophotic reefs, providing an overview of the research methods she used on a recent University of Oxford expedition to Honduras.

Above, Eslam Osman (University of Essex) receiving the ISRS-sponsored best student talk award from David Curnick, and below Anna East (University of Oxford) receiving the corresponding best poster award.

Overall it was an insightful day, providing a chance for everyone with an interest in reef research, from experienced researchers to undergraduate students, the chance to meet and discuss reef ecology and conservation. For anyone who missed the day, you can get a flavour from the discussion on twitter (hashtag: #RCUK18) and on our account @ReefConsUK. We look forward to welcoming you to the 19th RCUK conference. More information will posted online in the coming months at: www.zsl.org/rcuk, and keep an eye out for the new RCUK website coming soon, keeping you updated with news on UK reef research throughout the year.

Dominic Andradi-Brown[1], Robert Yarlett[2] and Kirsty Richards[3] on behalf of the RCUK committee.

[1]University of Oxford,[2]University of Exeter, [3]Zoological Society of London

PROGRAMMES & PROJECTS

Overviews of Ongoing Programmes and Projects

Ten Years of the Mitsubishi Corporation Global Coral Reef Conservation Project: a vision for the future of citizen science

世界各国のサンゴ礁を保全することを目指し、三菱商事は 2005 年度より「サンゴ礁保全プロジェクト」を実施しています。研究への財政的な支援、社内外からアースウオッチとの共同でボランティアを派遣（年2回）し、調査研究活動への参加を通じて、環境問題への理解を深めようとのプログラムを行っています。プロジェクトでは、沖縄、セーシェル、オーストラリアの 3 拠点を中心に、さまざまな角度からサンゴ礁保全のための研究を展開しています。2006 年から 2011 年までは米国ミッドウェイでの研究を行い、2011 年からオーストラリアのグレートバリアリーフで新しいプロジェクトを開始しました。沖縄では静岡大学、琉球大学、国際環境 NGO アースウォッチ・ジャパンと協力し、サンゴの白化現象や病気のメカニズムの解明により白化の原因はサンゴ内部にあることを突き止めました。またサンゴ礁の基礎生産量の再評価や抗菌物質の探索等の研究を実施しています。オーストラリア海洋科学研究所は三菱商事、アースウォッチオーストラリアと協力し、グレートバリアリーフのサンゴ礁の病気についての調査研究をしています。季節変動、光、温度や水質が、サンゴの黒帯病にどのような影響を与えるのかを研究調査しています。セーシェル共和国を囲むインド洋では英国エセックス大学を中心に、同大学、セーシェル海洋公園管理局海洋技術研究センター、アースウォッチ・ヨーロッパと三菱商事が協力し、同国のキュリーズ島において様々なサンゴ礁の生態や環境ストレスに対する反応について研究・調査活動を実施しています。10年以上の研究調査からサンゴの白化のメカニズムの新たな解明、サンゴの胃腔中の酸素や栄養塩濃度の解明、サンゴ礁の基礎生産の再評価、シアノバクテリアと窒素固定の重要性の解明、サンゴの病気の病原菌の同定、海洋酸性化のサンゴとサンゴ礁生物群集の動態の解明、研究者と企業と NGO と市民による研究活動のモデルケースの確立等多くの成果を得ています。今後も本プロジェクトは継続して新たな目標に向けて研究を推進します。

In 2005 the Mitsubishi Corporation joined forces with Shizuoka University (Japan), the University of California, Santa Cruz, (USA), Essex University (UK), and the Earthwatch Institute, to establish the Global Coral Reef Conservation Project (GCCRP). In 2011, they were joined in this endeavour by the Australian Institute of Marine Science (AIMS). The core team members have been Yoshimi SUZUKI, Beatriz E. CASARETO and Toshiyuki SUZUKI (Shizuoka University, Japan), Yoshikatsu NAKANO and Hiroyuki FUJIMURA (University of the Ryukyus, Japan), Tatsuo NAKAI (Kokushikan University, Japan), David BOURNE and Yui SATO (AIMS, Australia), David SMITH (Essex University, UK), Cassandra NICHOLS (Earthwatch Australia), Paul LAIRD (Earthwatch UK), Shigeo YASUDA (Earthwatch Japan), and Yoshiyuki NOJIMA (Mitsubishi Corporation Japan).

Since its inception the project has focused on three research locations – Okinawa (Japan), Midway Island (USA) in the Pacific, and the Seychelles in the Indian Ocean. To these were added, in 2011, the Great Barrier Reef in Australia (Fig. 1).

Over the past 10 years regional teams based in each location have been working towards identifying the environmental stressors that have been affecting the health of corals and other reef organisms at their respective sites. The scope of research has ranged from assessment of the socio-ecological factors impacting coral reefs at the macro-scale to laboratory-based experiments to decipher mechanisms and causes of reef deterioration at the micro-scale. The projects have also provided outstanding opportunities for engaging non-scientist citizens (including Mitsubishi Corporation employees) in field research, whilst also building environmental awareness and

Figure 1. Research sites of GCRCP with the participation of citizens.

capacity among local stakeholders and young scientists. These activities have been facilitated by the Earthwatch Institute, a long-established international organization with considerable experience of promoting projects that bridge the gap between science and the community.

As is now well established, coral reefs are in marked decline, with independent global reef monitoring studies documenting widespread losses of coral cover, reef habitat and associated biodiversity. These losses are now clearly known to be driven by both global and local anthropogenic stresses. Global stressors include (1) elevated seawater temperatures associated with global climate change, resulting in coral bleaching and mass mortality, and (2) ocean acidification, due to increased dissolved oceanic carbon dioxide, resulting in weakening of skeletons of reef-building organisms such as corals. Local stressors include (3) disease outbreaks in corals and other reef organisms, (4) the direct and indirect effects of overfishing, and (5) reduced water quality associated with increasing coastal habitat degradation, effluent discharge and changing land practices. Across our study areas these conditions are collectively resulting in multiple synergistic stressors that are reducing coral ecosystem health and resilience. Such impacts have been well documented by the different studies undertaken in the different focal areas.

The work of the Japanese team has included elucidation of a novel underlying mechanism contributing to coral bleaching[1]. Normal and abnormal morphological types of zooxanthellae cells are observed in coral tissues, with the abnormal cells being expelled when corals are below their thermal threshold. However, when corals a subjected to thermal stress above their threshold, the abundance of healthy zooxanthellae declines and the proportion of shrunken/abnormal cells increases. These shrunken cells contain 132, 173–cyclopheophorbide an enol (cPPB-aE), a compound which is derived from degradation of chlorophylls and is not fluorescent. This lack of fluorescence function precludes the formation of reactive oxygen species, so that it appears formation of cPPB-aE in shrunken zooxanthellae may be a mechanism for avoiding oxidative stress.

The Australian contingent of the Mitsubishi funded Earthwatch Project has monitored the recovery of coral communities from catastrophic disturbances caused by storm-activities. On the Great Barrier Reef, coral communities around Orpheus Island were devastated by cyclone Yasi, which hit the region in April 2011 and effectively removed 100% of the corals from the exposed shallow regions (above 7 m deep). Data collected over the past 5 years has mapped the recovery of coral communities, demonstrating continued high coral recruitment to the sites and the increasing size classes of previously recruited corals. The results have provided a picture enabling comparison of coral populations from before and after the cyclone. This area has also been previously impacted by black band disease and the dynamics of disease within the recovering coral populations is being investigated, alongside intensive studies elucidating the interacting environmental and microbial factors contributing to the disease outbreak[2].

The University of Essex team, working in the Seychelles, demonstrated a high degree of spatial & temporal variability in coastal seawater carbon chemistry. Open water control sites were found to vary little but there was considerable variation in values recorded within seagrass & mangrove habitats[3]. Overall it appears that the seagrass beds experience a higher mean pH but the mangrove systems a lower pH than observed in open water. Corals persist in these environments but in situ incubations demonstrate that this is at a physiological cost with reductions in gross productivity & calcification. Seagrass beds may buffer changes in ocean chemistry while mangroves may provide an OA pre-adaptive ecosystem service for corals. Experimental manipulations to control carbon chemistry indicate that corals within mangrove and seagrass beds are better able to manage metabolic

[1] Suzuki T, Casareto BE, Shioi Y, Ishikawa Y, Suzuki Y (2015): Finding of 132, 173-cyclopheophorbide a enol as a degradation product of Chlorophyll in shrunk zooxanthellae of the coral *Montipora digitata*. J Phycol 51: 37-45 [doi: 10.1111/jpy.12253]

[2] Sato, Y., Bourne, D.G., and Willis, B.L. (2009) Dynamics of seasonal outbreaks of black band disease in an assemblage of *Montipora* species at Pelorus Island (Great Barrier Reef, Australia). Proc Roy Soc B 276: 2795-2803.

[3] Camp, E.F., Suggett, D.J., Gendron, G., Jompa, J., Manfrino, C., and Smith, D.J. (2016) Mangrove and seagrass beds provide different biogeochemical services for corals threatened by climate change. Frontiers in Marine Science 3, doi: 10.3389/fmars.2016.00052.

demands of productivity and calcification across a range of pH, but whether this is an acclamatory or adaptive responses is yet to be ascertained.

The projects being conducted at all three sites (Okinawa, GBR and Seychelles) address many of the major impacts experienced by coral reefs globally. For example, bleaching and disease events have been well documented in many parts of the world and are impacting the reef ecosystems at each of these sites. These impacts are overlaid with other natural disturbances such as cyclones and typhoons that have major destructive impact on the reefs. A changing climate is now a reality and this is currently being experienced through the widespread bleaching episodes reported across reefs of the world. Combined with the insipid creep of a changing ocean chemistry, the predictions for reefs into the future are dire. Within our regions, local social and ecological pressures demand research outcomes that can provide innovative solutions to improve the outcomes for these contrasting reef ecosystems. Linking the expertise within each of these projects provides a powerful means for building capacity and addressing key reef based issues in a global setting. It is intended to develop solutions that can build resilience into coral ecosystems, and so ultimately provide direct benefits tor societies dependent on these habitats.

To mitigate the loss of coral reefs and associated coastal habitats, innovative global initiatives are urgently required to provide real world solutions. Therefore, going forward, we plan to build on this momentum and hereby commit to:

- Coordinate our under-pinning science activit-ies to identify key drivers of coral habitat loss.
- Document the perform-ance of reefs both now and into the future under varying disturb-ance based senarios.
- Translate the under-pinning science into real world management outcomes that can influence and change policies directly relating to marine and reef based issues.
- Increase awareness of the value of marine ecosystems to communities, policy makers and governments.
- Inform local stakeholders to create behavioural changes to reduce human impacts on coral reef ecosystems and improve coral reef resilience.
- Build capacity within key global regions to monitor and protect coral reefs.

Since globally all ecosystems are influenced by multiple synergistic pressures, research findings in one location often provide insights into ecological and social systems in other locations. Thus we hope that this global initiative will continue to be at the forefront of work contributing to better outcomes for coral ecosystems and greater benefits for the societies dependent upon them.

Yoshimi Suzuki, Shizuoka University, Japan (email: seysuzu@ipc.shizuoka.ac.jp)
David Bourne, Australian Institute of Marine Science, Australia (email: d.bourne@aims. gov.au)
David Smith, University of Essex, UK
Email: djsmitc@essex.ac.uk
Beatriz Estela Casareto, Shizuoka University, Japan (email: dcbeatr@ipc.shizuoka.ac.jp)

Partnerships in Global Coral Reef Conservation Project

Finance/field volunteer: Mitsubishi Corporation →
Citizen science: Earthwatch Institute →

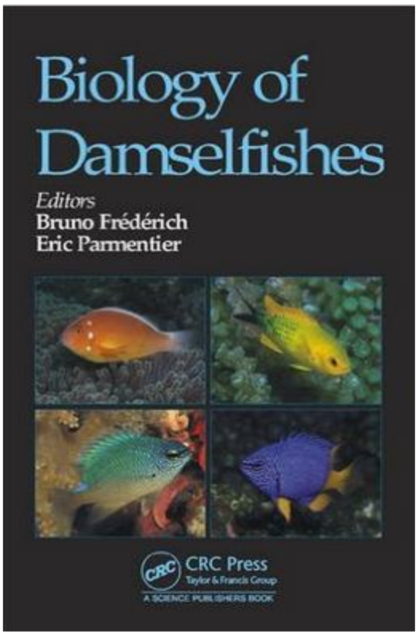
Research:
Shizuoka University (Japan)
University of the Ryukyus (Japan)
Kokushikan University (Japan)
University of California, Santa Cruz (USA)
Essex University (UK)
Australian Institute of Marine Science (Australia)

GCRCP workshop supported by Mitsubishi Corporation, June 2015, Tokyo

Figure 2. The Mitsubishi Corporation Global Coral Reef Conservation Project: structures and people.

REEF SHELF

Information on New Manuals, Reports and Guides



Biology of Damselfishes
Parmentier E, Frédérich B (editors)

CRC Press, 2016 (in press)
ISBN-10: 1482212099. US$139.95

Damselfishes (Pomacentridae) are a reef fish family showing high diversity and many interesting characteristics in their way of life (sound production, sex change, farming and gregarious behavior, settlement, diet). The book contains 15 chapters written by multiple researchers.

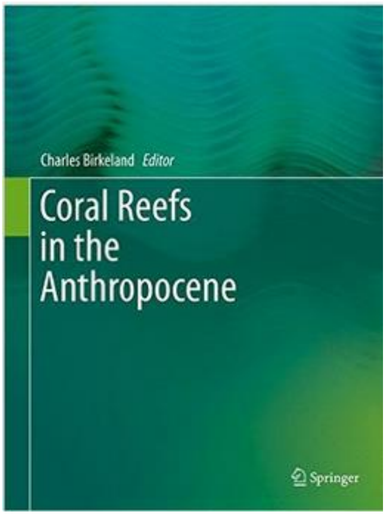
Ethnobiology of Corals and Coral Reefs
Narchi NE and Price LL

Springer, December 2015
ISBN 9783319237633
Hard copy and digital: US$159.00

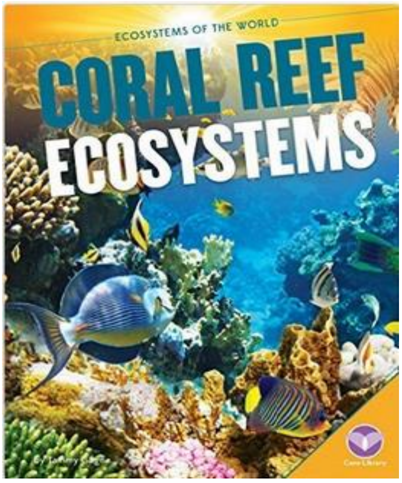
This book explores the ethnobiology of corals by examining the various ways in which humans have both exploited and taken care of coral and coralline habitats. It explores the various circumstances of human-coral coexistence by providing scientifically sound perspectives and experiences from across the globe. Corals are a vital part of the marine environment, since they promote and sustain marine and global biodiversity while providing numerous other environmental and cultural services. (We plan a full review for the next issue)

Coral Reefs in the Anthropocene
Birkeland C

Springer, November 2015
ISBN 9789401772495
hard copy & digital: US$159.20



This volume investigates the effects of human activities on coral reefs, which provide important life-supporting systems to surrounding natural and human communities. It examines the self-reinforcing ecological, economic and technological mechanisms that degrade coral reef ecosystems around the world. A resource for all those interested in learning how human activities have affected this vital ecosystem around the world. (We plan a full review in the next issue.)



Coral Reef Ecosystems
Gagne T

Abdo Publishing, August 2015
ISBN 9781629699189
also for tablets and on the web: US$25.65

This is a short book (25 pages) intended for school age children, introducing coral reef ecosystems, the plants and animals that thrive there, climate, food web, and threats. Readers will also learn about the most well-known coral reefs and their unique characteristics. Aligned to US Common Core Standards and correlated to state standards.

Plymouth Routines in Multivariate Ecological Research (PRIMER)

PRIMER-E Ltd, Version 7, 2015
http//:www.primer-e.com

PRIMER is the popular software package / tool box used by many marine biologists for community ecological analysis. New features include coherence and shade plots, a Wizard feature that batch processes data from transformation through multiple routines (resemblance, clustering, Multidimensional scaling, Analysis of Similarity tests, and Shade plots). Earlier versions required the user to manually execute these routines. Permanova is also included in the V 7 package. Individual and institutional purchase, upgrades from earlier versions, and information about week-long training workshops are available from PRIMER-E Ltd, 3 Meadow View, Lutton Ivybridge, Devon PL21 9RH, United Kingdom (email: primer@primer-e.com; phone: +44(0)1752 837121)

Discovering Scott Reef: 20 years of exploration and research
Gilmour J, Smith L, Cook K, Pincock S

Australian Institute of Marine Science, 2013
Available in multiple PDF files (19.5 MB)

Scott Reef is an isolated coral reef system that rises steeply from the depths of northwestern Australia's continental shelf. Scientists from many organizations have studied the reef's physical environment and biological communities. The results have revealed important insights into a complex ecosystem – findings that are also relevant to the sustainable management of other coral reefs around the world. This book presents an account of the research effort at Scott Reef, sharing new understanding of this remote and beautiful part of Australia.

Biology of Butterflyfishes
Pratchett MS, Berumen ML, Kapoor BG (editors)

CRC Press, 2013.
ISBN-10: 1466582898.
US$121.95

Butterflyfishes (family Chaetodontidae) are a highly conspicuous fish on coral reefs throughout the world. In light of their strong dependence on coral, they are often regarded as the epitome of coral reef fishes. This volume examines the ecology and conservation of coral reef butterflyfishes. It provides important insights on their evolution and key events and adaptations that have led to their proliferation. Key to the longevity of butterflyfishes is the evolution of coral-feeding—a central focus of the ecological chapters in this volume. The book also highlights major threats and challenges related to the conservation of butterflyfishes and ends with an overview of current and suggested future research directions.

REEF ARRIVALS

France and Madagascar: incoming hosts of the ICRI Secretariat 2016-2018

On 1 June 2016, the ICRI Secretariat will be changing hosts, with its reins being passed from Japan and Thailand to France and Madagascar. The Government of France has hosted ICRI twice in the past (1999-2000; 2009-2011) and will become the first Government to host ICRI for a third time. Last year, France celebrated the 15th anniversary of its national Coral Reef Initiative (IFRECOR), and we are excited to see this enthusiasm and leadership translating again onto the wider ICRI stage. Madagascar is situated in the western rim of the Indian Ocean, and its southwestern coast is home to the third largest coral reef system in the world. Madagascar has been involved with ICRI over the years and will be joining the secretariat team for the first time. The new ICRI Secretariat will continue to implement the "ICRI Continuing Call to Action" and the "ICRI Framework for Action 2013". More information on their Plan of Action for 2016-2018 will be coming up soon!

REEF DEPARTURES

Memories of recently departed members and reef scientist

Paul Jokiel

We regret to inform the coral science community that Dr. Paul Jokiel passed away late April in Washington D. C. where he was participating in a NSF proposal review panel. Paul was a brilliant scientist and great humanitarian who contributed greatly to marine science and coral biology. His research covered a wide range of coral reef ecology and management topics that included landmark work in identifying coral-algal thermal limits that provided a basis for understanding coral bleaching, and the importance of UV radiation in determining the composition of reef communities. At age 75 he was still active and hard at work, leading a group of Ph.D's and grad students that recently received a three year NSF grant to continue their research on the effects of ocean acidification on coral growth, survival and diversity.

As important as his personal research was, it was perhaps superseded by his influence on colleagues and students. For years Paul organized and ran the Hawaiʻi Institute of Marine Biology Summer Program, where dozens of grad students came to conduct projects directed or advised by him and other invited researchers. Many of these students are now prominent coral scientists and look back on Paul as their first mentor in the field. His positive outlook on life and compassion will live on in the legacy he leaves behind.

Much more can and will be said in a memoriam to be prepared for the next issue of Reef Encounter. For now we are all deeply saddened and will miss Paul terribly, and we extend our regrets to his family and many, many friends.

Steve Coles, Ku'ulei Rodgers, and the entire HIMB Coral Ecology Lab

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 opposite, 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 is supplied.

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

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

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

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).

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 to 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 relative 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 type 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 being 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