Issue 6. April 2016
ISSN 2052-5273

The Marine Biologist

The magazine of the marine biological community

Sawfish: the disappearing river monsters

Plus

Too hot in paradise!

The importance of 'fish carbon'

Climate change and marine vertebrates

Dramatic seascape shifts in the twilight zone

The Marine Biological Association
Est. 1884
Incorporated by Royal Charter

Great Barrier Reef polychaete diversity | Farming the bluefin
Mysterious mycoplankton | Capturing our Coast

The Marine Biologist
The magazine of the marine biological community

Editorial Office

Correspondence
The Marine Biological Association
Citadel Hill, Plymouth, PL1 2PB, UK
The Marine Biologist is published by the Marine Biological Association, Registered Charity No. 1155893

ISSN number: 2052-5273

Submissions
We welcome submissions of original and relevant material, letters and responses to published articles. For guidance, please see the magazine website at **www.mba.ac.uk/marinebiologist** or contact the Editor.

The Marine Biological Association
Est. 1884
Incorporated by Royal Charter
www.mba.ac.uk

Editorial

In April 2015, a postcard was returned to The Marine Biological Association that had been adrift in the North Sea for over 108 years. Last month we learned that the postcard is a new world record for a message in a bottle. You can find out more on page 4.

The Internet has made it so much easier to collect and check data, and to establish and maintain standards, and there are now many sophisticated and engaging ways for the wider public to get involved in scientific research. In this edition we learn about a new citizen science project called CoCoast which harnesses the enthusiasm of beach-goers in England, and provides data to inform the Marine Conservation Zone process.

Globally, February 2016 was the warmest month in recorded history and the ramifications of climate change ripple through these pages, from an examination of the role of larger marine animals in carbon cycling (did you know that blue whales in the Southern Ocean transport an estimated 88 tons of nitrogen annually to tropical latitudes?), to a new study that assesses the biological responses of vertebrates to climate change. We feel the pain of sea urchins in the Caribbean and find out why these lowly grazers are so vital in efforts to restore coral reefs. On a remote atoll in the Cook Islands people are struggling with the immediate effects of the current El Niño event, a phenomenon that could double in frequency as a result of climate warming[1].

Warming is not the only challenge facing marine life; rising atmospheric CO_2 is driving changes in seawater chemistry. The first study of a deep-water CO_2 vent looks at eco-physical adaptations among seabed organisms whose life histories mean they cannot move away from vents, giving some indication of how twilight zone habitats may change as the seas move toward acidity.

As well as being among the largest fish in the sea, sawfish have special significance in many traditional cultures. We find out why these 'river monsters' are in decline and why their status as totemic animals is important in developing conservation strategies.

We turn from a species in global decline to a discipline suffering the same fate. Taxonomy is vital for documenting, monitoring and conserving diversity in a changing world. Pat Hutchings of the Australian Museum Research Institute gives a timely account of why the specialist work to provide comprehensive inventories of invertebrates—in this case the surprisingly photogenic worms of the Great Barrier Reef—is so important.

It would be hard to find a more neglected group of marine organisms, but MBA Research Fellow Michael Cunliffe reveals how marine fungi are beginning to give up their secrets.

The Marine Biologist is becoming more widely recognized for the quality of its content. Most of the articles in the magazine are written by MBA members which I think bodes well for the future of the Association.

1 http://www.nature.com/nclimate/journal/v4/n2/full/nclimate2100.html

Front cover: A Bijago Islander wearing a headdress topped with a carved representation of a sawfish rostrum, prepares to take part in a traditional ceremonial dance. Image: Ruth H. Leeney.

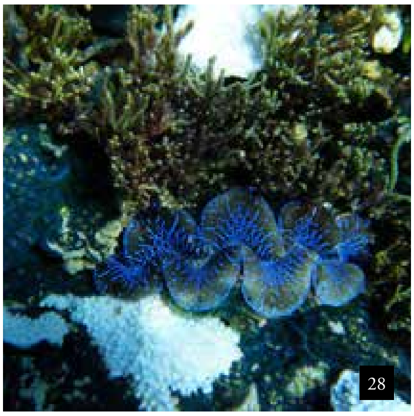
Back cover: Coral bleaching showing on the *toka* (coral heads) in the lagoon of Tongareva atoll, Cook Islands. See page 28 for the full story. Image: Michael White.

Contents

Issue 6. April 2016

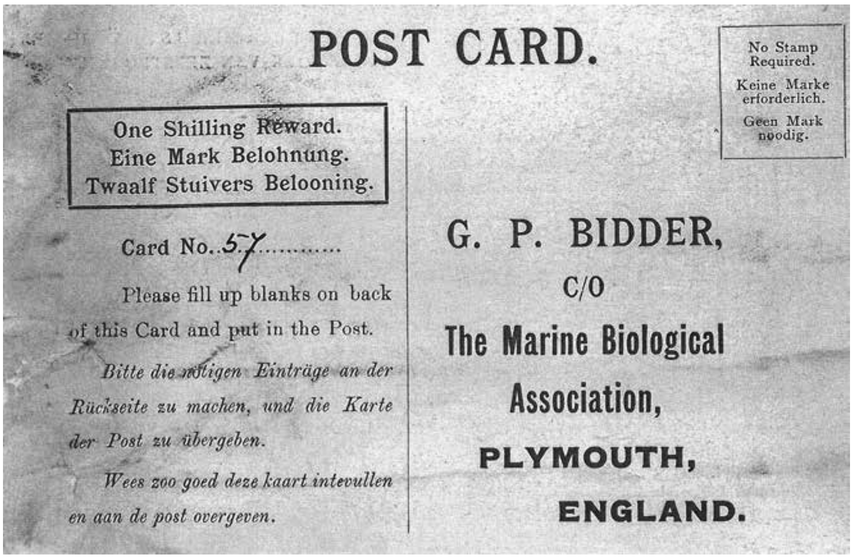
06

14



28

Image credits: Top: Alexander Semenov
Middle: Matthew McDavitt
Bottom: Michael White


POST CARD.

No Stamp Required.
Keine Marke erforderlich.
Geen Mark noodig.

One Shilling Reward.
Eine Mark Belohnung.
Twaalf Stuivers Belooning.

Card No. 57...........

Please fill up blanks on back of this Card and put in the Post.

Bitte die nötigen Einträge an der Rückseite zu machen, und die Karte der Post zu übergeben.

Wees zoo goed deze kaart intevullen en aan de post overgeven.

G. P. BIDDER,
C/O
The Marine Biological Association,
PLYMOUTH,
ENGLAND.

It's official: message in a bottle is the world's oldest

A postcard returned to the Plymouth Laboratory of the Marine Biological Association in April 2015 has been recognized by Guinness World Records as the oldest message in a bottle ever found!

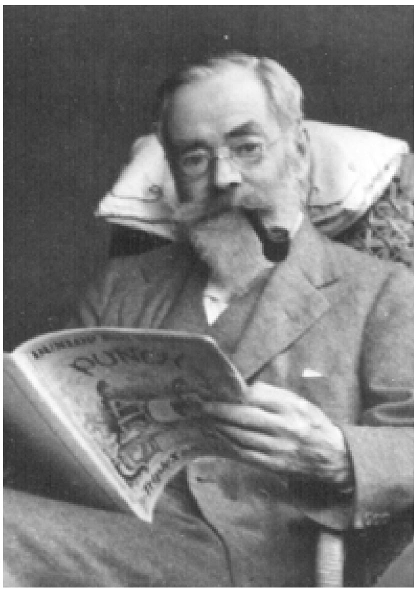
The bottle containing the postcard was released in the southern North Sea in 1906 as part of George Parker Bidder's research into ocean currents, and was picked up 108 years, 4 months, and 18 days later by a walker on a beach on the German island of Amrum.

G. P. Bidder contributed to knowledge on the hydraulics of sponges, and was the inventor of the bottom-trailer – a bottle adjusted to trail a wire so as to float with the current two feet (approximately 0.6m) above the sea bed, and to be caught in trawl nets. Bidder released over 1,000 bottles between 1904 and 1906 and reported a return rate from fishermen (encouraged by a one shilling reward) of around 55%.

Marianne Winkler, a retired post office worker from Heiligenhaus, near Dusseldorf, discovered the bottle while on holiday on Amrum. As instructed (and being unable to remove the cap) she broke the bottle and returned the postcard to G. P. Bidder. This caused quite a stir in the corridors of the MBA and attracted worldwide media attention. The MBA honoured the promise on the postcard and sent Mrs Winkler a reward of one shilling.

Confirmation of the record was received from Guinness World Records in February 2016.

Top: The postcard from the bottle that was adrift in the North Sea for over 108 years.
Below left: A bottom trailer bottle, similar to the one found on Amrum Island.
Below right: George Parker Bidder III, the scientist responsible for the research into ocean currents, ca 1934.
Images: Marine Biological Association.



Fish expected to get dizzier, sooner

A new study predicts that intoxication caused by high levels of CO_2 in seawater will affect fish and other marine creatures by the middle of the century, if CO_2 emissions continue to rise.

High levels of atmospheric CO_2 cause 'hypercapnia', a phenomenon causing effects such as disorientation in fish, impairing their sense of direction and making them more vulnerable to predators.

The University of New South Wales (UNSW) study, published in the journal *Nature*, is the first global analysis of the impact of rising CO_2 emissions on dissolved CO_2 levels in the world's oceans. Using existing datasets of measured seawater CO_2 concentrations from surveys over the past 30 years, the authors used a numerical model which worked out the natural monthly peaks and troughs of dissolved CO_2 concentrations in surface waters across the globe. The outcome was a prediction of areas where amplification of natural oscillations of CO_2 levels will tip over the critical point for fish and other marine creatures to experience episodes of hypercapnia, Levels of atmospheric CO_2 above 650 ppm are predicted to cause hypercapnia.

Describing the results as "staggering", lead author Dr Ben McNeil, of the UNSW Climate Change Research Centre said they "have massive implications for global fisheries and marine ecosystems across the planet".

The scientists have made their dataset available and are offering a prize for other researchers able to improve on their results.

Official figures underestimate global fishing

Food and Agriculture Organization of the United Nations (FAO) global fishing figures are the only global data set of fisheries statistics, and are widely used by policy makers and scholars. These figures suggest 'peak fish' of 86 million tonnes (mt) in 1996 was followed by a slow decline. However, a recent study by Daniel Pauly and Dirk Zeller in *Nature Communications* suggests otherwise: 130 mt in 1996 followed by a much steeper decline, and between 1950 and 2010, reconstructed global catches were 50% higher than official reported data.

Pauly and Zeller used an approach called 'catch reconstruction' which draws data from a wide variety of sources to estimate the catch missing from official reported data. The higher peak was due to accounting for small-scale, illegal and 'problematic' fisheries, recreational fishing and bycatch.

The authors hope the work behind the study will contribute to more accurate data submissions to the FAO.

Welcome to the plastisphere

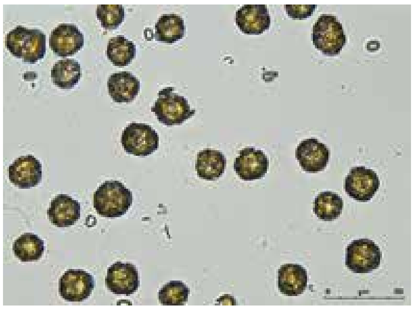
A paper in the *Proceedings of the National Academy of Sciences of the United States of America* (Aug 2015) estimated that 90% of the world's seabirds are likely to have plastic in their stomachs.

If we keep producing and leaking plastic at current rates, the World Economic Forum expects the ocean will "contain 1 tonne of plastic for every 3 tonnes of fish by 2025, and by 2050, more plastics than fish (by weight)."

The rise of the coccolithophores

New research published in *Science* suggests that a long-term, significant increase in coccolithophores—a major group of marine algae which surround themselves with calcium carbonate plates—is a result of increasing atmospheric CO_2, a finding at odds with the expectation that calcifying microalgae will be negatively affected by ocean acidification.

The study used data from the Continuous Plankton Recorder survey to show that between 1965 and 2010 the occurrence of coccolithophores in the North Atlantic increased from around 2% to over 20%. To see which factors best explained this increase, the researchers used Random Forest models, a statistical method suitable to the spatially and temporally discontinuous nature of the dataset. Of over 20 environmental drivers tested, they found that atmospheric CO_2 concentration was the best predictor of coccolithophore occurrence, followed by the Atlantic Multidecadal Oscillation (AMO).



Coccolithus braarudii in culture. Image: Marine Biological Association.

The authors say the magnitude of the increase suggests coccolithophores may be capable of adapting to a high CO_2 world.

More research into different calcifying microalgae species and other geographical areas would strengthen the findings and show a clearer picture of how this important group of primary producers will respond to environmental change.

Bluefin tuna in the UK

Tagged bluefin tuna photographed off the Isle of Harris, the Outer Hebrides, UK. Image: Angus Campbell.

In 2013, Angus Campbell caught a 234 kg Atlantic bluefin tuna with a rod and reel off the Isle of Harris, the Outer Hebrides. Although not out of the realms of possibility, this had never been done before in Scotland. Since then, bluefin tuna have been reported every year from around the UK and Ireland, including a large shoal in Mounts Bay, Cornwall, SW England recorded by Duncan and Hannah Jones from Marine Discovery in August 2015.

These regular sightings off the UK and Ireland suggest bluefin may have recolonized highly productive northern latitudes in significant numbers in recent years. Despite their advanced thermoregulatory capacity, the extent of bluefin distribution is limited by temperature, which hints that this recent spate of sightings may be as a result of climate change. Understanding such changes in the distribution of commercially important stocks and how they may fare in a changing climate is of the utmost scientific importance. Research into the sudden and dramatic appearance of bluefin in UK waters is currently underway to establish what is driving this change in distribution.

Pollutants on the decline, but ...

Pollutants in the marine environment is an ongoing issue; despite restrictions on the use of many chemicals, some are inevitably finding their way into our oceans. A recent study by the Scripps Institute of Oceanography investigated concentrations of pollutants over time, regions and between trophic levels using data from over 2,600 papers published between 1969 and 2012. They discovered that POPs (persistent organic pollutants) are found in nearly every region of the oceans, and could potentially be found within any species of fish. The pollutants investigated included the older 'legacy' chemicals such as DDT and Mercury, but also newer chemicals including coolants and flame retardants.

Using the best data available they discovered that over the last 30 years these POPs are decreasing in concentration, some by 15 - 30% a decade depending on region and pollutant. They compared their findings to US Environmental Protection Agency (EPA) guidelines and found that present concentrations were at or below the thresholds for occasional consumption, with present levels of DDT being considerably below. These decreasing levels indicate that mitigation attempts like the Stockholm Convention are working.

However, they found that the data used was highly variable, with concentrations changing by up to 1,000 fold simply by moving region. This means that even today some fish consumed may have the same concentrations of POPs as 30 years ago.

The study—the first of its kind—noted that while these pollutants are decreasing, many are still under-studied and do not currently have any EPA guidelines. The researchers say the next step is to investigate the additive effects of the POPs to expose the real risk to consumers, potentially leading to altered health standards.
Mike Austin

References and links for these stories can be found on *The Marine Biologist* website. Scan the QR code to view the web page.

For marine events, see the **UK Marine Science Events Calendar at www.mba.ac.uk**

For the latest news from the UK marine science community subscribe to the Marine Ripple Effect or follow on Twitter **@MarineRipple**

Worms, glorious worms

A wonderful revelation of the diversity of polychaete worms on the Great Barrier Reef by Pat Hutchings

Way back in 2013, a group of polychaete workers descended on Lizard Island on the Great Barrier Reef, and set up shop at the Lizard Island Research Station (a facility of the Australian Museum, Sydney) for a two-week field trip.

These researchers consisted of established workers, mid- and early-career researchers and a postgraduate student, from seven countries. We also travelled with a professional photographer, and a cook to ensure we were well fed, allowing us to work long hours in the laboratory following diving and snorkelling trips. We sampled over 120 sites around the island, on nearby reefs and on the Outer Barrier 12 nautical miles away. We were blessed with amazingly good weather for the time of year, with the dominant south-east trade winds almost completely falling away for some days allowing us to visit the Outer Barrier. Material was collected and brought back to the station where it was sorted alive, often photographed and then fixed for either morphological or molecular studies back at the researchers' home institutions. A tremendous variety of habitats was sampled including dead coral substrates, seagrass and algal beds, soft sediment between reefs and intertidal sediments. A total of 1,640 lots of polychaetes were databased.

Sorting continued late into the night with families being swapped between workers, facilitating international co-operation, and allowing people to see their worms alive sometimes for the first time. Throughout these two weeks the Co-Directors of the Research Station helped us continually: driving boats, facilitating the export of all the material to people's home institutions and generally making our lives as easy as possible. To satisfy the conditions of the permit issued by the Great Barrier Reef Marine Park Authority most of the material has now been returned to the Australian Museum, Sydney.

So what did we find? 91 new species of polychaetes in 21 families, 67 new records for the Great Barrier Reef and 19 new records for Australia. In addition we still have extensive collections of other polychaete families waiting to be worked up. Within 18 months, everybody had delivered one or more manuscripts for review and in August 2015, two years after the workshop the finished publication (800+ pages) appeared online in *Zootaxa* (See Further reading).

While the number of taxonomists is declining worldwide (this is particularly true in Australia) and natural history museums are reducing their scientific staff, much of our biodiversity still needs to be documented. This is especially true for coral reefs, which are increasingly being impacted by factors such as increasing water temperatures, declining water quality and increasing acidity. While the decline in fish and coral populations is being monitored, far less is known about other groups, especially the invertebrates (excluding the corals). Limited data indicate that increased sedimentation changes the polychaete communities but without comprehensive inventories of the polychaetes and

Spirobranchus corniculatus with its branchial crown and operculum emergent from a live colony of *Porites*. This species can occur in a variety of colours and rapidly retreats back into its calcareous tube embedded in the coral which grows as the coral grows, as any shadows pass. This provides some protection from predation from fish although they can regenerate this crown. Image: Alexander Semenov.

Lanice viridis n. sp, a terebellid worm removed from its tube to reveal its banded buccal feeding tentacles, three pairs of reddish brown branched branchiae and a bright green body. The animal spreads its highly extensile buccal tentacles across the substrate to collect sediment which it ingests and removes the algae and bacteria on the surface of the sediment particles. Image: Alexander Semenov.

other invertebrates it is difficult to assess how the organisms at the bottom of the food chain are changing with increasing anthropogenic impacts on coral reefs. So, the intensive polychaete workshop held at Lizard Island was a very cost-effective way of beginning to document the fauna of this diverse and important component of the benthic ecosystem. However, such workshops have other benefits: participants involve other researchers (the publication includes 33 authors from 27 institutions); work will continue to be published based on the material collected at Lizard, and several future collaborative programmes were planned during the field trip. But probably the most important flow-on effect was the mentoring of younger participants by the established workers, but this was not one way, as some of us learnt new techniques for studying these animals and absorbed the enthusiasm of the youngsters.

Researchers collecting polychaetes living in the sandy sediments and associated algal clumps at extreme low tide in front of Lizard Island Research Station. Image: Alexander Semenov.

I encourage organizations, research stations, funding agencies, and so on to think about hosting such workshops especially on the coral reefs of developing countries where the fauna is often so poorly known. Detailed baseline studies of the biodiversity are critical if we are to develop monitoring and management plans for these areas, which are so often critical for these countries in terms of the benefits to their economy from tourism, feeding their populations and providing some protection to low-lying areas from storms.

Pat Hutchings and Elena Kupriyanova, Australian Museum Research Institute, Australian Museum, Sydney NSW.

Acknowledgments

We would like to thank the Lizard Island Reef Research Foundation for supporting this workshop and the Lizard Island Co-Directors, Dr Anne Hoggett and Dr Lyle Vail, AO.

Further reading

Coral reef-associated fauna of Lizard Island, Great Barrier Reef: polychaetes and allies. Edited by Pat Hutchings & Elena Kupriyanova *Zootaxa* 4019 (1): 001–801 http://www.mapress.com/zootaxa/2015/f/zt04019p002.pdf - open access.

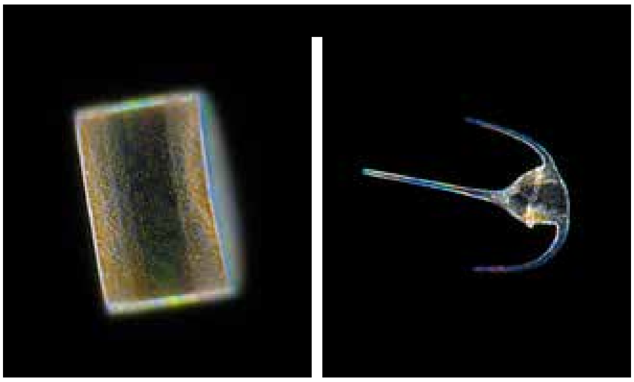
Hutchings, P.A., Peyrot–Clausade, M. & Osnorno, A., 2005. Influence of land runoff on rates and agents of bioerosion of coral substrates. *Marine Pollution Bulletin*, 51: 438–447.

Molecular insights into plankton diversity

Mycoplankton begin to reveal their secrets.
By **Michael Cunliffe**

Plankton are powerful. They produce the oxygen in every second breath that we breathe. Any type of seafood that you can imagine either directly or indirectly exists because of plankton. Plankton regulate our climate, they mitigate our negative impacts on marine ecosystems by degrading many of the pollutants that we produce, and are a source of an amazing array of chemical compounds and enzymes used in human medicine and biotechnology.

How we study and therefore understand plankton has changed drastically. Historic views of plankton diversity were based on painstaking observations of seawater samples using microscopes. Inevitably, the human eye was drawn to the most distinct (and most beautiful) structures, including the glassy frustules of diatoms and the armoured theca of dinoflagellates. Research conducted at the laboratory of the Marine Biological Association in Plymouth, UK, based on microscope assessments of diversity established the foundation of our understanding of plankton biology and ecology.



A diatom (*Conscinodiscus wailesi* (l) and dinoflagellate (*Ceratium tripos*) (r). Images: Richard Kirby.

More recently, through the advent and application of DNA-based tools, plankton that were previously overlooked because they do not have distinct or beautiful structures, or were missed altogether, are now being studied. As a result, our current view of plankton diversity is improving dramatically, including a growing appreciation of the importance of a greater range of groups, such as the bacteria and viruses. DNA-based technologies continue to be developed, with the latest application during the Tara Oceans Expedition showing that the world's oceans contain an even greater diversity of plankton than could ever have been anticipated.

The planktonic fungi (mycoplankton) are only now being truly appreciated because of the application of DNA-based tools. Historic views of marine fungi were largely founded on culture-based surveys of samples collected from coastal regions; however, it has now become apparent that marine fungi are prevalent across a range of marine ecosystems.

Marine mycoplankton exist as either single-celled yeast-types, branched hyphae (which in terrestrial fungi make up a filamentous structure called a mycelium), or as parasites of other plankton. From the genetic studies conducted so far, a consensus pattern of mycoplankton diversity is emerging. Most marine mycoplankton are within the subkingdom Dikarya, which is often referred to as the 'Higher Fungi', and includes the two great phyla Ascomycota and Basidiomycota. Marine mycoplankton assemblages also contain substantial proportions of the 'Basal Fungi', including the phylum Chytridiomycota. Recent molecular evidence suggests that marine-specific groups within these phyla are present in the marine environment that are distinct from their non-marine counterparts.

The functional roles that marine mycoplankton are fulfilling in marine ecosystems are the most exciting, yet least understood, part of the story. It appears that marine mycoplankton occupy similar niches to fungi in terrestrial and freshwater ecosystems. Some mycoplankton probably have the vital role as saprotrophs in marine ecosystems, breaking down non-living organic material using extracellular enzymes. Also, some marine fungi are probably parasites that infect other plankton groups, such as phytoplankton.

Where next for our understanding of mycoplankton? More work is needed to incorporate mycoplankton into a holistic view of the structure and function of marine ecosystems. Long-term time-series surveys of diversity that are run in parallel with the measurement of environmental variables, such as temperature, light and nutrients, continue to form the cornerstone in our understanding of plankton ecology and in defining their roles in marine ecosystems. A six-year time-series study of mycoplankton in the Western English Channel has already shown that, as with other plankton groups, some mycoplankton form interannually repeating 'blooms' that can be accounted for by specific changes in environmental variables, such as seawater temperature and nutrient availability. Research efforts should combine continued time-series observation of mycoplankton assemblages in marine ecosystems with the development of model organisms for laboratory-based experiments. Hopefully soon, as with other plankton groups, the power of mycoplankton can be fully realized.

Michael Cunliffe, Marine Biological Association and Marine Institute, Plymouth University.

Further reading

de Vargas C., Audic S., Henry N., Decelle J., Mahé F., Logares R. *et al* (2015). Eukaryotic plankton diversity in the sunlit ocean. *Science* 348.

Russell F.S., Southward A.J., Boalch G.T., Butler E.I. (1971). Changes in biological conditions in the English Channel off Plymouth during the last half century. *Nature* 234: 468-470.

Southward A.J. (1974). Changes in the plankton community of the Western English Channel. *Nature* 249: 180-181

Taylor J.D., Cunliffe M. (2016). Multi-year assessment of coastal planktonic fungi reveals environmental drivers of diversity and abundance. *The ISME Journal*: doi:10.1038/ismej.2016.1024.

Drastic seascape shifts in the twilight zone

Cristina Linares, lead author of a recent study on deep carbon dioxide vents, takes a glimpse into a more acidic future.

Rising atmospheric carbon dioxide (CO_2) concentration due to anthropogenic activity is driving unprecedented changes in the chemistry of the oceans. The increasing interest in understanding how these changes will affect marine life has placed ocean acidification (OA) amidst the hottest research topics of recent decades. To date, laboratory experiments carried out on a wide range of marine organisms in one or several of their life stages, have shown differential responses and sensitivities. These experiments are essential to identify individual responses to OA; however, experimental studies fail to predict the long-term consequences of OA on marine ecosystems as well as the ability of marine organisms to acclimate and adapt to increasing seawater acidity.

Natural CO_2 vents provide crucial empirical data on marine ecosystems already acclimatized to acidified waters. Great efforts have been placed, world-wide, in investigating these vents in recent years. They include temperate benthic assemblages in Italy, and coral reefs in Papua New Guinea and Japan. However, most of them are found in very shallow water (3–5 m depth), and similar studies at mesophotic and greater depths are essentially lacking.

In a recently published study, we investigated for the first time CO_2 vents at mesophotic depths. These vents, displaying pH levels (around 7.8 on average) similar to those expected to occur at the end of this century, are found at 40 m depth in the Columbretes Islands Marine Reserve, in the Western Mediterranean Sea. In contrast to temperate shallow water assemblages, mesophotic habitats in the Mediterranean Sea are mainly characterized by a large dominance of calcifying organisms such as coralligenous and maerl, and high carbonate production. Calcareous red algae are the main framework builders in both habitats, providing structural complexity and, hence, favouring biodiversity. Given the critical ecological functions and the high sensitivity of coralline algae and other calcifying organisms to OA, coralligenous and maerl rank amongst the most vulnerable habitats in a high-CO_2 ocean. This highlights the relevance of studying the previously poorly investigated effects of acidification in these habitats.

To date, naturally acidified ecosystems such as these vents have revealed strong impacts on both individual organisms and community structure, with a significant reorganization of shallow marine assemblages where some organisms are winners and others are losers. However, in this study we found dramatic seascape changes inside these vents, affecting entire habitats. A kelp forest of the Mediterranean endemic *Laminaria rodriguezii* dominates inside the vents (Figure 1) while the most representative assemblages outside the vents are coralligenous outcrops and maerl beds (Figure 2). The most common species in both coralligenous and maerl beds are coralline algae, gorgonians and calcareous bryozoans. Fleshy algae such as fucoids or rodophytes are present both inside and outside the vents.

Fig. 1. A kelp forest of *Laminaria rodriguezi* inside the vents. Image: Bernat Hereu.

Fig 2. The seascape outside the vents dominated by coralligenous outcrops and maerl beds. Image: Diego K. Kersting.

Nevertheless, it seems that *Laminaria* compete better in these acidified environments and the tallest canopies of the kelp may inhibit the growth of the other algal species.

As expected, calcifying organisms are the dominant species outside the vents. Only the calcareous alga *Peyssonnelia rosa-marina* is found inside the venting spots while other coralline algae and bryozoans with high-magnesium calcite skeletons are totally absent inside the vents. The type of calcification can explain the presence of *P. rosa-marina*, which calcifies aragonite and has shown to be resilient to moderately low pH compared to other encrusting corallines. Recent discoveries of different types of carbonate composition, such as dolomite, in crustose coralline algae and its lower solubility in comparison to magnesium calcite demonstrates that some encrusting algae can better resist acidification than we would expect, which highlights the need for further research on the carbonate composition of these organisms. Since most of the studies on calcification mechanisms in macroalgae were conducted several decades ago, new technologies and methodologies could be applied to gain a more contemporary understanding of how marine macroalgae calcify.

The discovery of this *Laminaria* forest at 40 m depth is particularly significant since stands of *L. rodriguezii* were known to thrive between 65 and 95 m depth and had never been reported above 60 m depth. Moreover this species is considered endangered as it develops best in rhodolith beds, from where it has almost disappeared due to trawling activities.

Kelps and fucoids have already undergone significant changes in their distribution with important losses observed in several regions of the Atlantic Ocean and Mediterranean Sea. Although they are known to be vulnerable to physical and chemical changes in the marine environment, the responses of algal dominated ecosystems to anthropogenic climate change are complex, involving both negative and positive responses. On one hand, recent declines and losses have been linked to increases in ocean temperature. On the other hand, acidified waters seem to benefit most fleshy algae by enhancing their growth and productivity and their competitive ability. However, the outcome of competitive relationships among fleshy algae as well as between fleshy algae and other calcifying organisms remains unclear, especially if multiple stressors such as warming and acidification interact. Like corals and trees, these canopy-forming algae are key habitat structuring species that harbour incredible biodiversity, providing important ecosystem services. Hence, a full understanding of the effects of climate change on these ecosystems is crucial in order to develop accurate long-term predictions of marine ecosystems and for effective conservation and management of marine resources.

Beyond significant changes in species composition and abundances observed in previous studies at other CO_2 vent systems, this study demonstrates that OA will likely act as an important driver for dramatic long-term shifts in benthic ecosystems, triggering the substitution of entire habitats in this century and even leading to depth distribution shifts similar to the observed altitudinal changes in terrestrial ecosystems caused by global warming. These shifts in the distribution and dominance of key benthic ecosystems could have broad ecological and socio-economic implications since coralligenous, maerl and kelp are essential habitats for many commercial fish species.

Cristina Linares (cristinalinares@ub.edu) Department of Ecology, University of Barcelona.

Further reading

Brodie J. *et al*., 2014. The future of the NE Atlantic benthic flora in a high CO2 world. *Ecology and Evolution* 4, 2787–2789.

Hall-Spencer J.M. *et al*., 2008. Volcanic carbon dioxide vents show ecosystem effects of ocean acidification. *Nature* 454: 96–99.

Harley C.D.G., *et al*., 2012. Effects of climate change on global seaweed communities. *Journal of Phycology* 48: 1064–1078.

Linares C. *et al*., 2015. Persistent natural acidification drives major distribution shifts in marine benthic ecosystems. *Proceedings of the Royal Society, B* 282: 0587. doi: 10.1098/rspb.2015.0587.

Climate change and marine vertebrates

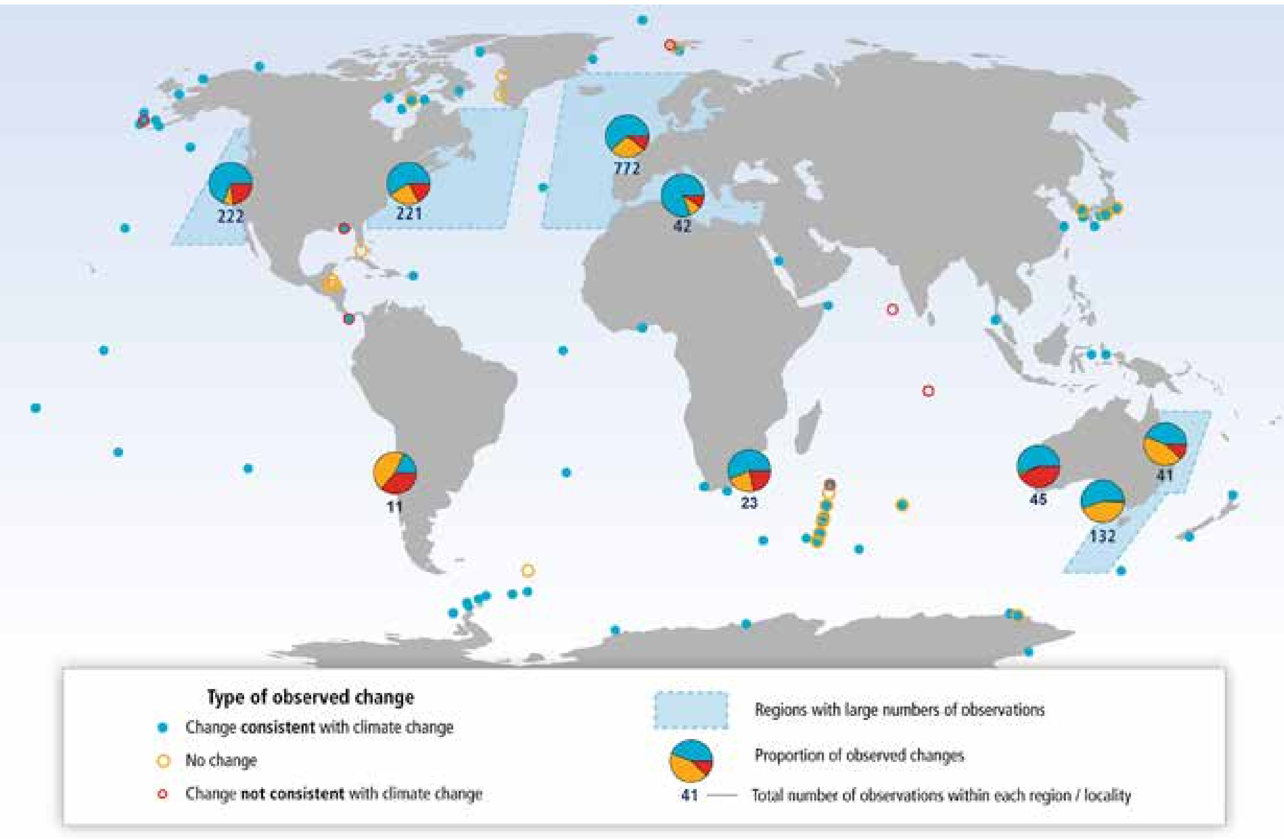
By Elvira Poloczanska

Anthropogenic greenhouse gas emissions have, and will, result in profound changes in the physics and chemistry of the ocean with consequences for marine taxa and maritime industries. The global ocean has absorbed 93% of the extra energy arising from anthropogenic greenhouse gas emissions, resulting in nearly a degree Celsius increase in global sea surface temperatures since the beginning of the 20th century. The surface waters of all three ocean basins have warmed at rates that exceed those expected if there were no human influence over the past century. At deeper depths, between 700 and 2000 m, warming has also been observed and there is evidence of an anthropogenic signal. The ocean has also taken up ~30% of anthropogenic carbon dioxide (CO_2) released into the atmosphere, decreasing ocean pH and fundamentally changing ocean carbonate chemistry in all ocean regions, but particularly in the cooler waters of high latitudes.

Global and regional studies have provided evidence of widespread biological responses to the recent changes in the ocean, in terms of changes in the distribution, phenology (the timing of recurrent biological events such as egg-laying in seabirds), demography and physiology of multiple species from the polar oceans to tropical seas. One challenge for ecologists is to undertake formal 'attribution' analyses, to estimate the contribution of climate change in driving observed responses. However, other approaches such as meta-analyses have provided high confidence that anthropogenic climate change has impacted marine life. In the study shown in Figure 1, synthesizing information from over 200 scientific studies, we find 'fingerprints' of climate change in the patterns of observed biological changes that are uniquely predicted as responses to global warming; for example, the global redistribution of marine life into cooler, generally higher latitude or deeper waters and the advancement of spring phenologies across multiple ocean regions. We found that 84% of observed changes were in the direction consistent with theoretical expectations for how species would respond to global warming. Our study included multiple taxonomic groups such as plankton, benthic invertebrates and marine vertebrates.

Given their roles in our food, economies, culture and recreation, marine vertebrates—fish, marine mammals, seabirds and marine reptiles—are the most prominent organisms in the ocean. Fish are the dominant vertebrate group; there are estimated to be some 22,000 species, and fish were also the most common taxonomic group in our fingerprint study. Fish provide protein to human populations and support economies and food security in many regions of the world. Marine mammals are relatively small taxonomic groups but are also economically and culturally important, comprising some 130 species of cetaceans (whales, dolphins and porpoises), pinnipeds (walruses, seals and sea lions) and sirenians (dugongs and manatees). We include polar bears as marine mammals given their dependence on sea ice to hunt their main prey: seals. Seabirds (350 species) also depend on the ocean

Fig. 1. Global distribution and regional location of marine ecological climate-impact studies showing responses that are consistent with climate change (blue), inconsistent (red) or no response detected (yellow). Pie charts show the proportions within regions. From Poloczanska *et al.* 2013 *Nature Climate Change*.



for food. There are some 70 species of marine reptiles, dominated by sea snakes with seven species of sea turtles.

The responses observed to changing climate differ among marine vertebrate groups. For example, distribution shifts for fish, and phenology and demography for seabirds, reflecting historical research interests and the challenges of working in the ocean. Fish tend to be sampled over large geographical areas by nets and acoustics, whereas seabirds are much studied at breeding colonies. There are many complexities in understanding and predicting marine vertebrate responses to climate change. Fish are ectotherms and derive oxygen from seawater, which means their responses to

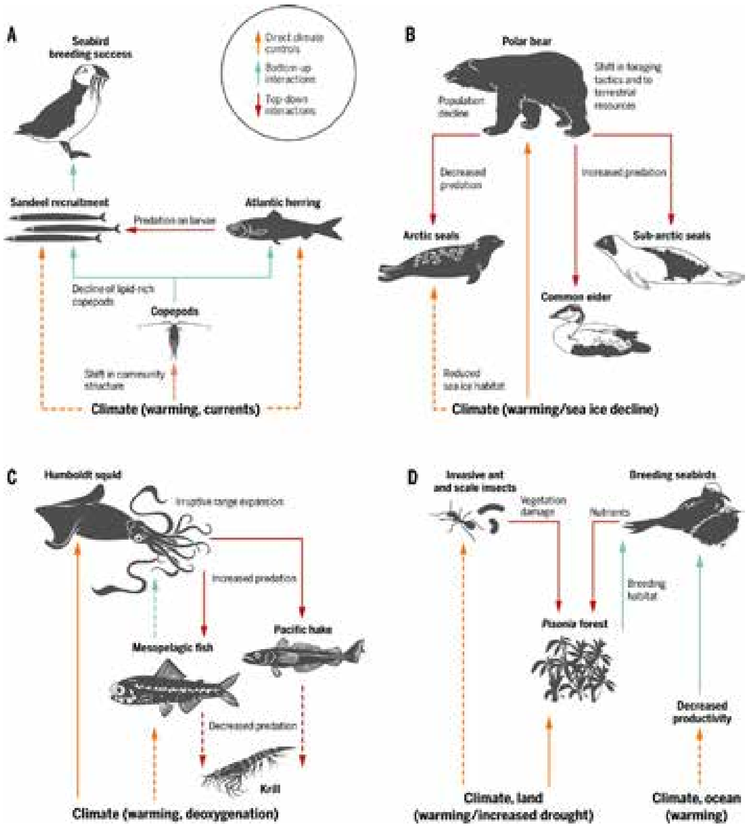


Fig. 2. Four case studies illustrating the complex mechanisms by which climate change can indirectly affect marine vertebrates via trophic interactions. (a) bottom-up effects in the North Sea, (b) climate-mediated top-down effects of polar bears in the Arctic (c) potential climate-mediated trophic cascade in the California Current System driven by range expansion of Humboldt squid and (d) marine-terrestrial coupling and ecological cascade on Coral Sea islands in the southwest Pacific. Each case study is a simplified schematic. Orange arrows = direct climate controls; blue arrows = bottom-up interactions; red arrows = top-down interactions; solid lines = well supported; dashed lines = hypothesized. From Sydeman *et al.* 2015 Science

climate change may be direct and physiological. Many fish display complex life histories, occupying different habitats at different life stages, thus indicating the potential for divergent vulnerabilities to environmental changes. Impacts can also be indirect, through predator–prey interactions and other trophic mechanisms. Marine mammals, reptiles and seabirds are ectothermic and derive oxygen from the atmosphere. Their responses to climate change are likely to be indirect, and tempered by availability of food. The high metabolic rate of seabirds, in particular, necessitates regular access to food resources to maintain body condition. Thus, understanding climate change impacts on marine ecosystem primary and secondary productivity, and the availability of prey to these consumers, is vital to predicting responses to climate change in the future. Potential pathways of response are illustrated in Figure 2.

Distribution shifts

The role of climate change in driving distribution shifts of marine species is currently garnering considerable attention given the potential ramifications for fisheries, marine management, conservation and policy. Globally, leading edges of the distributions of multiple marine plankton, invertebrates and vertebrates have extended by 72 km per decade on average but with considerable variability both within and between groups, which reflects taxonomic and regional differences in life histories, dispersal capacity, habitat and food availability, fishing pressure and natural climate variability among others (Figure 3). A good example is the East Australian Current (EAC), which transports warm-water southwards, and which was introduced to a generation of children in the animated film *Finding Nemo* as a 'highway' that carries tropical fish and turtles to Sydney and beyond. The EAC has strengthened and contributed to a recent rapid warming of ocean waters off south-east Australia and there is strong evidence of an anthropogenic signal in the strengthening. Around 30% of coastal fish species in the region have exhibited concurrent polewards shifts in their distributions or increases in abundance due to enhanced transport of larvae and juveniles and/or ocean warming benefiting warmer water species.

Abundant evidence comes from the Northern Hemisphere: recent increases in warm-water assemblages concurrent with regional warming have been observed in mid- to high-latitude ocean regions including the Bering Sea, Barents Sea, Nordic Sea and North Sea. Shifts in depth have also been documented, for example, in the northern Gulf of Mexico, where the coastlines prohibit polewards distributional shifts, demersal fish assemblages shifted deeper instead. Fishing complicates interpretations of climate-driven redistributions as it often has greater and more immediate effects on fish populations; for example, the distribution of cod in the North Sea has shifted northwards, eastwards and deeper over the past century. The northwards shift and deepening has been linked to warming, however, the shift eastwards was attributed to fishing pressure.

There are many other factors that will precipitate or inhibit the redistribution of marine species to which climate scientists, oceanographers and marine biologists are giving increased focus; for example, understanding how the oxygen content of ocean waters will change. There is evidence that the oxygen content of the upper layers of the ocean has declined over the past 60 years, particularly in the equatorial Pacific and Atlantic, and that this decline contains an anthropogenic signal. Oxygen availability is also an important determinant of fish metabolic rates and their ability to cope with warming, ultimately affecting growth and body size. Theoretical and modelling evidence suggests oxygen declines will result in reduction in the body size of fish. Oxygenated waters are particularly important for top predators such as tuna and billfish, and modelling evidence suggests that polewards and vertical contractions of their (oxygenated) habitats will occur as climate changes.

Phenology

With the exception of seabird breeding metrics, observations of changing phenology in response to climate change are less well observed than distribution shifts. Globally, spring phenology, such as the timing of plankton blooms, the peak appearance of larval fish, and migrations in fish and sea turtles, have become earlier by 4.4 days per decade

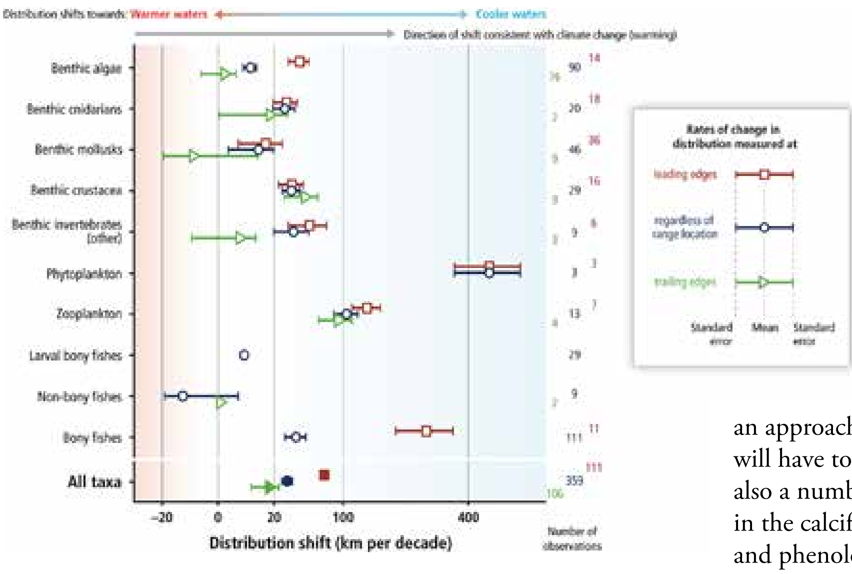


Fig. 3. Rates of change in distribution (kilometers per decade) for marine taxonomic groups, measured at the leading edges (red), trailing edges (green) and calculated using all data regardless of range location (blue). Distribution shifts have been square-root transformed. Positive distribution changes are consistent with warming (poleward into previously cooler waters). From Poloczanska *et al.* 2013 Nature Climate Change

on average. However, for seabirds, the shifts in phenologies were not significantly different from zero owing to regional advances and delays in breeding dates, even among seabirds breeding in the same region. Seabird species have different feeding methods, diets and dispersal patterns outside of the breeding season (e.g., some are coastal such as little penguins whereas others such as puffins and albatross are highly pelagic), and it is likely that an integration of environmental signals, including food availability across foraging grounds outside of breeding seasons, influences the timing of spring migrations and breeding phenologies. Phenological shifts can be adaptive if they track shifts in the timing of prey availability; however, the differences in observed rates of shift among taxonomic groups suggests warming may exacerbate mismatch among predators and prey, potentially disrupting food webs.

Towards understanding climate change impacts

Climate change imposes strong selective pressures on species and populations, driving phenotypic and genetic responses. The evidence of observed climate-change impacts is currently limited to the performance, phenology and distribution of marine organisms, with little understanding or evidence of evolutionary responses to recent climate change. Observations of evolutionary adaptation to climate change are notably lacking, despite an increasing number of short-term experimental studies. Whether marine vertebrates can keep evolutionary pace with unprecedented (at least in their recent evolutionary history) rates of environmental change is a question still to be addressed.

There are a number of promising lines of research aimed at tackling the difficult, yet crucial, question of how marine biodiversity will respond and reorganize in response to changing climate, with the development of new indices and modelling approaches and increased access to biological data through global observation programmes such as the Ocean Biogeographic Information System (OBIS; www.iobis.org). An example is the concept of the 'velocity of climate change' – the speed and direction of isotherm (lines of equal temperature) shift, and the extension of this into climate trajectories that map the movement of isotherms through time, thus representing an approach to define the climatic pathways that species will have to follow to track their thermal niches. There are also a number of challenges. For example, how will changes in the calcification, demography, abundance, distribution and phenology of the different life stages of marine species manifest at an ecosystem level? An emerging area of research (and concern) is that of ocean acidification. A variety of lines of evidence from experimental and modelling studies indicate that ocean acidification will affect marine organisms over the 21st century, but the resulting long-term consequences for marine species' population dynamics and ecosystem functioning are yet to be identified. Developing a greater capability for monitoring and understanding climate change and ocean acidification impacts is critical for future management of ocean and coastal marine life.

Elvira Poloczanska (Elvira.Poloczanska@csiro.au)

Further Reading

Sydeman, W.J., Poloczanska, E.S., Reed, T.E. and Thompson, S.A. (2015) Climate change and marine vertebrates. *Science* 350: 772-777.

García Molinos, J.G., Halpern, B.S., Schoeman, D.S., Brown. C.J., Kiessling, W., Moore, P.J., Pandolfi, J.M., Poloczanska, E.S., Richardson, A.J., and Burrows, M.T (2016) Climate velocity and the future redistribution of marine biodiversity. *Nature Climate Change*, 6, pp83

Poloczanska, E.S., Brown, C., Sydeman, W., Kiessling, W., Schoeman, D., Moore, P., Brander, K., Bruno, J.F., Buckley, L.B., Burrows, M.T., Duarte, C.M., Halpern, B.S., Holding, J., Kappel, C.V., O'Connor, M.I., Pandolfi, J.M., Parmesan, C., Schwing, F., Thompson, S.A. and Richardson, AJ. (2013) Global imprint of climate change on marine life. *Nature Climate Change* 3:919-925.

Sawfishes are among the most bizarre and fascinating of all aquatic animals. They look like sharks, but are actually rays, and have a formidable, chainsaw-like rostrum or saw which can be up to one-quarter of the sawfish's total body length. The rostrum is a highly sensitive structure, used to detect, stun and kill prey, which includes various fish, shrimp and other invertebrates living on or in the sediment. There are five species of sawfish, two of which—the Largetooth and Green Sawfish—can reach at least seven metres in length, making them the largest (or at least the longest) fish in the oceans after whale sharks and basking sharks. They are one of only a handful of shark and ray species that can live in both fresh and saltwater, and what little we know of the lifecycles of sawfishes suggests that they use a wide range of habitats—rivers, mangroves and estuaries as juveniles, coastal and offshore seas as adults.

Unbelievable though it may seem for such large and distinctive animals that are found in coastal areas and along rivers, close to human settlements, scientists still know remarkably little about the ecology and behaviour of sawfishes. What is clear is that, worldwide, sawfish populations have declined dramatically in recent decades, mainly due to the increased use of fishing nets (in which sawfishes become entangled, making them an easy target for fishers) and the loss of important habitats, especially mangrove forest. A recently-published study by scientists working for the Shark Specialist Group of the IUCN (International Union for the Conservation of Nature) determined that of all chondrichthyans (sharks, rays and chimaeras), the sawfishes are at greatest risk of extinction. Sawfishes were once widespread throughout the tropical and sub-tropical waters of the Atlantic, Indian and Pacific Oceans, with their ranges extending through the waters of at least 90 countries. Of these countries, at least 20 have now lost all of the sawfish populations formerly found there, and at least another 43 have lost one species of sawfish. This is based on the best available information, but for significant parts of their former range, basic up-to-date information on the persistence of sawfish populations is lacking. Nonetheless, the current distribution range of sawfishes is certainly a shadow of what it was several decades ago, and they can now be reliably found in only two strongholds: Florida, US, and Queensland and the Northern Territory, Australia.

In the face of such sombre findings, the IUCN in 2014 published a Global Conservation Strategy for sawfishes, outlining the steps that need to be taken to protect any remaining sawfish populations and to encourage recovery of depleted populations. Since this report was published, and motivated by the gaps in data, multiple research

Searching for river monsters

By **Ruth H. Leeney**

Largetooth Sawfish (*Pristis pristis*) in Australian waters. Image: Miguel Clavero.

projects have sprung up to collect baseline information on sawfishes, particularly in many of the regions where information has until now been lacking – Africa, and South and Central America in particular. The findings of these projects are diverse. Those in several West African countries such as The Gambia and Guinea-Bissau have confirmed the precipitous decline of sawfishes alongside a waning familiarity with sawfishes among local people. A similar decline has been reported from northern Peru, although several catches of adult Largetooth sawfish have occurred there in recent years. In contrast, sawfishes still appear to be caught with at least some regularity in parts of East Africa, and information currently being collected by numerous teams in Central America may too have surprises in store.

It is hardly unexpected, given the imposing appearance of sawfishes, that they hold special significance in many traditional cultures around the world. A stylized image of a sawfish appears on all the bank notes and coins of the West African Franc (CFA), the currency of several West African nations, as it symbolizes prosperity and fecundity in the region. Sawfish rostra used to be placed on the roofs of houses in The Gambia and Senegal, to protect the inhabitants from accidents such as fire, or from evil spirits. In Guinea-Bissau, primarily in the Bijagós Archipelago, sawfishes are among the totemic animals symbolizing the forces of nature. They feature in the dances and ceremonies which are integral to the Bijagó culture, in which young men wear triangular headdresses which used to be topped with a real sawfish rostrum. Sawfishes are now so rarely encountered in Guinea-Bissau that a small saw carved from wood is now more commonly seen on these headdresses. In Panama, the Emberá and Wounaan peoples believe that sawfishes harboured powerful spirits, the assistance of which shamans would call upon during healing ceremonies, whilst the Kuna people believe that sawfishes are special protectors that will rescue them from drowning. The cultural importance of sawfishes to these and many other communities can be an important element to consider in developing conservation strategies. People are more likely to protect a species if it is a key part of their heritage or their traditional practices. By learning about these links between communities and their natural environment, conservationists and managers may be able to

Top: Kuna "mola" applique cloth made by a female artist from the Guna Yala region of Atlantic coastal Panama. It depicts the sawfish, *Sukku*, which the Kuna people view as a special animal ally of mankind, protecting them from malevolent sea creatures in this world. Image: Matthew McDavitt.
Bottom left: A Bijago Islander wearing a traditional headdress, topped with a wooden representation of a sawfish rostrum. Image: Simon Wearne.
Bottom right: Two Largetooth Sawfish rostra, both over a metre in length, from Madagascar. Image: Ruth H. Leeney.

Top: Largetooth Sawfish (*Pristis pristis*) caught by researchers in Australia. Image: Michael Lawrence Taylor.
Bottom: Largetooth Sawfish. Image: Miguel Clavero.

develop more locally-relevant, effective conservation strategies for sawfishes. This type of approach is synergistic, insomuch as the successful conservation of sawfishes in communities where they are culturally significant can in turn contribute to the conservation of those cultures, which are themselves, in some places, at risk of disappearing.

To my mind, there are two major hurdles currently facing sawfish conservation. The first is the lack of up-to-date information on where sawfish populations still exist and, as was mentioned earlier, a number of groups and projects are now tackling this challenge. The second, far greater hurdle is that many of these remaining sawfish populations will invariably be located in developing countries, most likely in rural, hard-to-reach areas which are difficult to monitor. In such areas, human communities are often hugely reliant on fisheries in freshwater and coastal habitats as a means of survival, and anything a fisher catches is used as food or as a saleable commodity. If sawfishes are to be effectively protected in these areas, the conservation or management plan must take the needs of the nearby human communities into consideration, and must involve them in the process of developing and implementing the plan. Alternative ways for community members to produce food or earn money may need to be developed, so that they are less reliant on fishing, thereby removing the primary threat to sawfishes everywhere—the ubiquity of fishing nets. Raising awareness will be a key factor, to help communities understand why it is important to protect their local population of sawfish, and how they will benefit from doing so. Ultimately, these programmes should aim to create a sense of stewardship for sawfishes within communities, and an understanding of the need for top predators as part of healthy marine and freshwater ecosystems.

of all the sharks, rays and chimaeras, the sawfishes are at greatest risk of extinction

Recent genetic studies have revealed fascinating insights into sawfish life history and have significant implications for how the conservation of this group of endangered fish is approached. A study in Florida revealed that remarkably, Smalltooth Sawfish can reproduce asexually. Using DNA fingerprinting, researchers showed that about 3% of the sampled sawfish population had apparently been created through female-only reproduction. The authors hypothesized that this type of reproduction, known as parthenogenesis, may help depleted populations to maintain numbers during periods of rarity when encounters with members of the other sex were unlikely. However, since this type of reproduction reduces the genetic diversity of the population and since all wild populations of vertebrates need genetic diversity in order to remain resilient to environmental changes, parthenogenesis is certainly not going to save sawfishes and they still need urgent conservation—a means by which they can escape extinction in the longer-term. Research in northern Australia has shown that Largetooth sawfish in adjacent river systems are genetically distinct, meaning that female Largetooth sawfish (like salmon) are philopatric, returning to the same river they were born in, to give birth to their own pups. This implies that once a population in a certain river drainage has become extinct, it may be unrecoverable, since sawfishes in adjacent areas would be unlikely to move in to 'new' habitats to replenish depleted or locally extinct populations. All the more reason, then, to seek out and document any remaining sawfish populations, as soon as possible, before they invariably meet the same fate as have so many before. Once scientists and governments know where these extant populations

Want to find out more about sawfishes?

Visit the Sawfish Conservation Society's website, where you can learn more about the different groups working to protect sawfishes worldwide, download printable species identification guides (in 5 languages) and even find games and children's stories about sawfishes. www.sawfishconservationsociety.org

The IUCN Global Sawfish Conservation Strategy is available online: www.dulvy.com/global-sawfish-conservation-strategy.html are, they can begin to tackle the threats facing sawfishes in each area, to implement national legislation to protect the sawfishes and their habitats, and most importantly, to work closely with the communities in those areas to implement conservation measures. In other words, there is great potential to develop holistic, ecosystem-approach conservation plans which can benefit not just sawfishes but also their riverine, mangrove and coastal habitats and the artisanal fishing communities that depend on those ecosystems.

Ruth Leeney (ruth.leeney@gmail.com) is a post-doctoral research fellow at Simon Fraser University, Canada, and is the Sawfish Conservation Officer for the IUCN's Shark Specialist Group. She is the founder of Protect Africa's Sawfishes, which has since 2012 conducted baseline surveys for sawfishes in five African countries.

Further reading

Harrison, L.R. and Dulvy, N.K. (eds). 2014. *Sawfish: A Global Strategy for Conservation.* IUCN Species Survival Commission's Shark Specialist Group, Vancouver, Canada. ISBN: 978-0-9561063-3-9

Dulvy N.K., Davidson L.N.K., Kyne P.M., Simpfendorfer C.A., Harrison, L.R., CARLSON J.K. and Fordham S.V. Ghosts of the coast: global extinction risk and conservation of sawfishes. 2014. *Aquatic Conservation: Marine and Freshwater Ecosystems*. DOI: 10.1002/aqc.2525

Fields *et al*. 2015. Facultative parthenogenesis in a Critically Endangered wild vertebrate. *Current Biology* 25: R439–R447. https://www.researchgate.net/publication/277558854_Facultative_parthenogenesis_in_a_critically_endangered_wild_vertebrate

Farming the Bluefin

Bonnie Waycott reports on pioneering efforts by Japan's Kinki University to breed and raise bluefin tuna in captivity.

Established in 1948, the Kindai University Fisheries Laboratory in Shirahama town, Wakayama Prefecture, Japan, sits on an inlet with a breathtaking view of the ocean and surrounding hills. It is home to a new farming method which

could one day offer the world more sustainable and stable supplies of tuna.

Bluefin tuna farming began in the area in 1970 when small tuna juveniles were caught off Wakayama Prefecture using set nets. However, problems soon arose – bluefin bruise easily and must swim continuously to breathe as their gills take in little oxygen. Their scales are small and fragile, so they can die from getting caught up in the nets. The Laboratory then turned its attention to catching juveniles on lines. It raised these fish to adulthood, and incubated their eggs to produce farm-raised tuna. The complete farming of bluefin tuna was achieved in 2002.

Professor Keitaro Kato is the Laboratory's deputy head. "Spawning in captivity continued from 1979 to 1983, but then there was nothing for 11 years," he explained. "Just as doubts were being cast over our research, we produced 70,000–80,000 young fish."

The Laboratory's method is called full-cycle aquaculture. This involves incubating and raising a fish to adulthood, then taking and incubating the eggs to begin the cycle anew. Today, 50,000–100,000 juveniles and 80–100 tonnes of edible tuna are produced annually.

Fertilized eggs are collected from the water surface and hatch into larvae in about 32 hours. The larvae are raised in tanks on land until they are around 6–7 centimetres long – this takes around 50 days. The fry are then transferred to ocean net cages where they are reared under lights to prevent collisions at night. About 3 months after hatching, the fish reach around 30 centimetres long and weigh around 300g. It takes the fish two years to reach over 1 metre in length and weigh 20kg, at which point they are shipped to market.

One key factor to ensuring sustainable operations is the replacement of fishmeal feed with plant protein. The Laboratory believes that relying on wild fish for feed limits the stabilization of production, and it is researching vegetable-based alternatives such as soybean, corn meal and sugar cane. Replicating the best conditions for bluefin is also hard, as the fish are sensitive to factors like water temperature, currents and noise, so the Laboratory takes blood samples from every tuna harvested, and maps their entire DNA to isolate the best genetic characters for disease resist-

Ocean net cages in which bluefin tuna are raised to market size. Image: Bonnie Waycott.

Feeding time for bluefin tuna raised by the Fisheries Laboratory of Kindai University. Image: Bonnie Waycott.

ance, growth and sex identification. It is also working to prevent floating deaths in tanks by decreasing aeration and creating an oil film on the surface of the water. However, this inhibits swim bladder inflation in the larvae, raising body density and causing the larvae to sink and die, so a surface skimmer is used to remove the oil from the water when the larvae are big enough to avoid getting trapped at the surface. The challenge here is to add and remove the oil at exactly the right moment.

Despite the many challenges, the Laboratory's techniques are being recognized worldwide. Japan is sharing its expertise in different places with different species—such as yellowfin aquaculture in Panama—to contribute to industrial development. Overseas exports are being considered to meet the rising demand for Japanese food.

The Laboratory believes the future is bright, with huge potential for Japanese aquaculture and exports. It hopes to triple total tuna production to 240 tonnes a year by 2020, while striving to continue its research. Its eventual aim is to expand the range of species it can cultivate whilst at the same time reducing pressure on wild fish stocks through the reintroduction of fish.

Bonnie Waycott Mem.MBA

Fish poo and the climate challenge

Image: Steven Lutz.

Angela Martin looks at the science behind the headlines

Over the past few years, stories about how whales, sharks, fish and other marine vertebrates are important for tackling climate change have been appearing in mainstream news. In 2014, the UK's ITV News covered how 'Fish capture and store 1 million tonnes of carbon', while *The Guardian* newspaper in the UK ran a story titled 'Why whale poo matters'. Are these bold claims a case of the media not letting facts get in the way of a good story, or is there a real fire beneath the smoke?

Ultimately, the causes of climate change need to be directly addressed, including extraction and use of fossil fuels, emissions driven by unsustainable patterns of consumption, and inefficient agricultural practices. As part of a multi-dimensional solution, under article 5 of the recent Paris Agreement, nations have additionally committed to protect and enhance natural carbon sinks. The ocean is the world's largest active carbon sink, and is estimated to have removed 50% of anthropogenic emissions of CO_2 from the atmosphere (Sabine *et al.*, 2004). The ocean is known to capture atmospheric carbon through physical processes (diffusion of CO_2 as a gas) and biologically, through photosynthesis. When carbon reaches deep ocean waters and sediments, it can be stored for centuries. Thus, understanding the processes that contribute to carbon cycling by the ocean is a key factor to improving our understanding of climate change and managing its impacts.

Since the 1970s, sediment traps have been the primary apparatus used to measure movement of carbon from surface waters to the deep. These traps sit on the sea bed collecting particles that drift to the bottom of the ocean. Bacteria and tiny marine organisms called plankton, easily caught in sediment traps, are the most studied vectors of transport for biological ocean carbon. However, sediment traps do not effectively measure carbon movement by marine vertebrates. This is one potential reason that marine vertebrates are not included in most models of carbon cycling. Interest in the ocean's role in atmospheric chemistry and technological advancements has improved the data quality and range of observations at sea. Over the past ten years, many scientific publications have reported direct connections between large animals and nutrient cycling, and particularly carbon cycling (Roman *et al.*, 2014; Wilmers *et al.*, 2012).

Fish carbon, an over-simplified but accessible term, is used to describe the carbon interactions of all marine vertebrates: turtles; sea birds; mammals such as whales and dolphins, and fish such as sharks, tuna and sardines. Fish carbon research focuses on increasing understanding of how marine vertebrate activity and natural life processes provide pathways, pumps and trophic cascades that:

- Enhance uptake and long-term storage of atmospheric carbon into the oceans via photosynthesis of dissolved CO_2 by marine plants (plankton and seagrasses)
- Facilitate transport of biological carbon from ocean surface to deep water and sediment (via biomass, carcasses and excretion)
- Provide a pH buffer against ocean acidification

(through metabolic activity of bony fish)

The current scientific evidence suggests that marine vertebrates play various undervalued roles in carbon cycling. Very few studies have quantified the impact of marine vertebrates on carbon capture and storage per year. The figures quoted in this article are based on fragmented data, and therefore provide an indication only of the potential significance. Below is a short summary of the published information thus far.

There are eight fish carbon mechanisms described in the scientific literature (see Diagram 1 below), these are:

1. Trophic Cascade Carbon

Several recent studies have found that natural predation of grazing and burrowing animals in seagrass meadows and saltmarshes helps to maintain the optimal carbon function of these ecosystems. A publication by Heithaus *et al.* (2014) found that healthy seagrass ecosystems in Australia were maintained by shark populations, which restricted grazing activity by sea turtles. In areas where shark populations had declined, the study found that the structure of seagrass meadows was altered due to sea turtle grazing. In these instances, the carbon capture and storage function of the ecosystem was degraded. Heithaus *et al.* (2014) also found that in areas with few turtles, carbon function of seagrass meadows was also diminished, as the meadows were dominated by algae. A follow up study by Atwood *et al.* (2015) found that, in all coastal vegetative ecosystems that capture and store atmospheric carbon (seagrass, saltmarsh and mangroves), predation is critical to maintenance and increasing reserves of carbon. This study found that recreational overfishing of predatory fish and crabs from the Cape Cod marshes contributed to the reduced carbon storage capacity of the ecosystem by 17,000 tonnes of carbon annually.

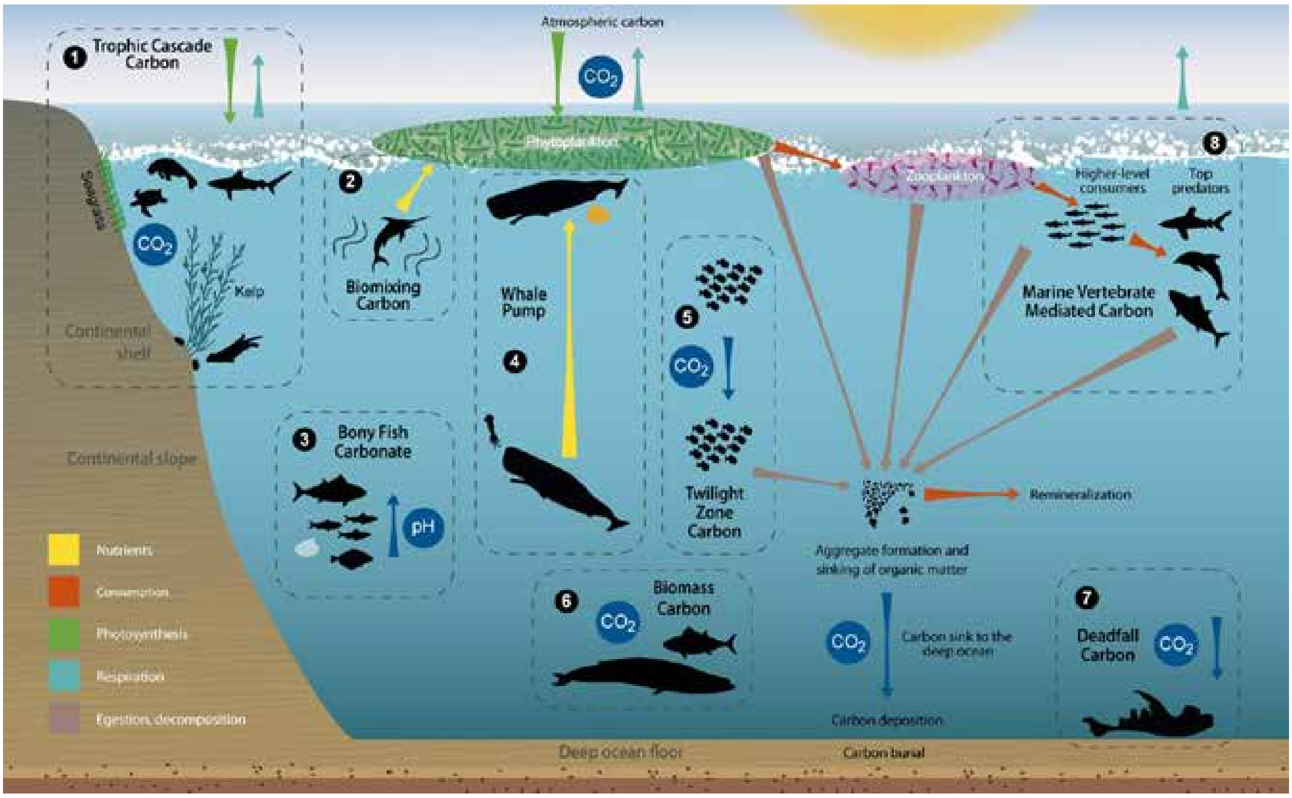
2. Biomixing Carbon

Movement of animals through the water column mixes water and moves nutrients. In the open ocean, marine vertebrates can bring nutrients from the deep to otherwise nutrient-limited surface waters, enhancing primary production by phytoplankton, and thus uptake of atmospheric CO_2. Biomixing of nutrients through movement has been reported for all sizes of marine animals, and a study by Dewar *et al.* (2006) estimated that biomixing by marine vertebrates contributed one-third of the total ocean mixing, comparable to the effect of tides or winds. Building on this, Lavery *et al.* (2012) found that the population of 80 sperm whales in Hawaii could enhance carbon capture by 60,000 tonnes annually through biomixing.

3. Bony Fish Carbonate

A study by Wilson *et al.* (2011) reported that bony fish (teleosts) constantly consume seawater, the calcium ions from which react with their intestinal gut fluid to form high magnesium calcite, a form of calcium carbonate with magnesium carbonate in the crystals. These authors found that this waste product is produced and secreted at high rates throughout the life of bony fish, and even in the absence of feeding. Dissolution of calcium carbonate,

Diagram 1: Marine vertebrate carbon services: eight carbon pathways, pumps and trophic cascades (Lutz and Martin (2014)).



which is alkaline, can act as a pH buffer. The magnesium content of these secretions, combined with shallow depth and warm water, increases the likelihood that it will dissolve. Through the natural process of consuming seawater, bony fish produce a waste product that can provide a natural pH buffer against ocean acidification.

4. Whale Pump

Movement of nutrients by whales, known as the whale pump, can occur both vertically, between depth and surface, and horizontally, across oceans. In areas where nutrients are limited, the whale pump provides a rich source of nutrients for photosynthesis by phytoplankton, and therefore increases uptake of atmospheric CO_2 into oceans (Roman *et al.*, 2014). The article in *The Guardian* 'Why whale poo matters' is based on this mechanism. Vertical movement of nutrients occurs when deep-diving whales feed at depth, and excrete nutrient rich, faecal plumes upon return to surface waters. Horizontal movement of nutrients, also known as the great whale conveyor belt, occurs when whales migrate. Baleen whales move from rich feeding grounds to breeding grounds with reduced nutrient availability, where they release nutrients through urine, dead skin cells and placenta. Blue whales in the Southern Ocean are estimated to transport 88 tons of nitrogen annually to their birthing grounds in lower tropical latitudes (Roman *et al.*, 2014). This enables photosynthesis and carbon capture by phytoplankton.

Whales accumulate and store carbon in their biomass, and move nutrients across oceans, stimulating photosynthesis. At the end of their long lives, the carbon stored in whales' bodies may enter deep-sea food chains and sediments, where it can be stored on millennial timescales. Image: Peter G. Allinson.

5. Twilight Zone Carbon

Deep water (twilight zone) fish feed on organisms in the upper ocean and transport consumed organic carbon to deeper waters, where it is stored in biomass or excreted. Because the release of this carbon is at depth, the carbon is less likely to be remineralized, and thus can be stored in the oceans and out of the atmosphere for centuries (Davison *et al.*, 2013). The amount and value of carbon sequestration by twilight zone fish off the UK–Irish continental slope is estimated to be over one million tonnes of carbon per year (Trueman *et al.*, 2014); the basis of the ITV News item mentioned earlier. In terms of equivalent carbon finance, this represents between £6 and £10.5 million per year (Trueman *et al.*, 2014).

6. Biomass Carbon

As with all living creatures, marine vertebrates store carbon in their biomass. However, as marine vertebrates include the largest animals, and the longest-lived, such as whales, the carbon in these animals is stored out of the atmosphere on timescales comparable to some trees (Pershing *et al.*, 2010).

7. Deadfall Carbon

When the carcasses of marine vertebrates sink, the biomass carbon is exported to the ocean floor, entering benthic food webs and sometimes sediments. Pershing *et al.* (2010) estimated that the combined global populations of eight species of whales sequestered 29,000 tonnes of carbon per year through the deadfall carbon pathway. This study also estimated that the pre-whaling populations of these same eight species would have contributed closer to 200,000 tonnes of carbon per year.

8. Marine Vertebrate Mediated Carbon

Through food webs, marine vertebrates consume carbon. Where this carbon is not incorporated into their biomass, it can be transferred to deep waters via faecal material. Carbon particles associated with fish waste are orders of magnitude larger than those associated

The roundnose grenadier *Coryphaenoides rupestris*. Deep sea fish contribute to carbon storage: research in 2014 estimated that deep sea fish off the UK-Irish continental shelf sequester over 1 million tonnes of CO_2 every year. Image: MAR-ECO/Odd Aksel Bergstad.

with plankton, and in the few species that have been studied these rapidly sink to depth (Saba and Steinberg, 2012). Fish excrement provides an efficient mechanism to export carbon from surface waters to sediments, where it may be sequestered on geological timescales.

So, while the fire that fuels the sensational media stories seems to be well alight, it is still in its infancy. Each of the studies quoted has described only one or two of a potential eight mechanisms of carbon movement within the ocean water column. Most of the studies were focused on a single population or species. Further knowledge gaps to be considered include release of CO_2 by marine vertebrates through respiration, and the fate of biological carbon that reaches the sea floor. Based on the current fragmented data, it is impossible to estimate the total significance of fish carbon, but this figure is absolutely worth knowing. Ocean conservation is one route to meet national commitments to article 5 of the Paris Agreement, with real potential to improve atmospheric carbon capture. Restoration of marine vertebrate populations and ocean ecosystems would also have additional benefits, including supporting biodiversity conservation and sustainability targets. Protecting marine ecosystems and organisms to enhance their contribution to carbon capture and storage might just be a cost-effective, cross-cutting and high impact component of broader climate change mitigation and adaptation plans.

Angela Martin MSc. Mem.MBA, Blue Climate Solutions, A Project of The Ocean Foundation, Essex, UK.

Blue Climate Solutions is dedicated to promoting conservation of the world's oceans, its ecosystems and biodiversity, as a proactive and viable action to reduce the impact of climate change. Our objective is to protect and enhance the natural carbon sinks provided by coastal and ocean ecosystems and organisms. A particular focus of BCS is improving understanding of the role of marine vertebrates in capture of atmospheric carbon and long-term carbon storage in the ocean, a concept we have termed Fish Carbon. www.bluecsolutions.org

Further reading

Lutz S.J. and Martin A.H. 2014. Fish Carbon: Marine Vertebrate Carbon Services. GRID-Arendal, Arendal, Norway. ISBN: 978-82-7701-146-2

Atwood T.B., Connolly R.M., Ritchie E.G., Lovelock C.E., Heithaus M.R., Hays G.C., Fourqurean J.W., Macreadie P.I. 2015. Predators help protect carbon stocks in blue carbon ecosystems. *Nature Climate Change Perspectives* 2763 DOI 10.1038

Trueman C.N., Johnston G., O'Hea B., MacKenzie K.M. 2014. Trophic interactions of fish communities at midwater depths enhance long-term carbon storage and benthic production on continental slopes. *Proc. R. Soc. B* 281:20140669

Rebuilding the Caribbean, one sea urchin at a time

By Max Bodmer

Since the birth of the package holiday in the mid-19th century, sea urchins have wreaked havoc with the appendages of holidaymakers. For most people the waters of the Caribbean are an irresistible draw but, with long-spined sea urchin (*Diadema antillarum*, Figure 1) population densities of 5–10 m^{-2}, one misplaced step could mean that the remainder of your time in paradise is spent painstakingly removing spines from the sole of your foot. For those that cursed their existence, a dream came true in 1983–84 as an unknown pathogen caused population reductions of 95–99% across all Caribbean coral reefs. However, it did not take long for people to recognize that the realization of this dream had created a nightmare.

When densities are high enough, the long-spined sea urchin can remove the entire daily net growth of macroalgae from the reef, which stimulates hard coral growth. Hard corals provide the habitat structure and living-space needed to promote biodiversity and ecosystem function.

However, disease rendered this key species functionally extinct throughout the Caribbean in the early 1980s.

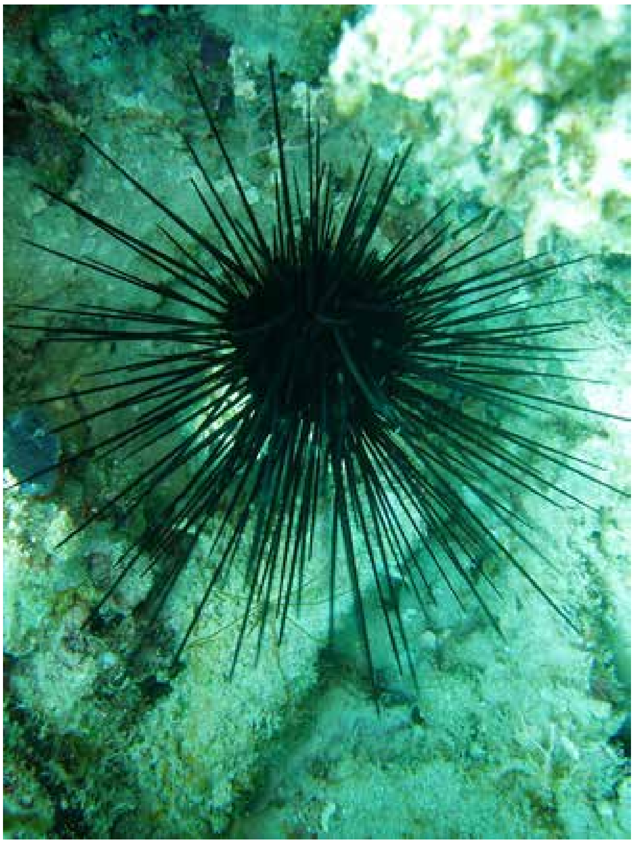


Fig 1. An adult long-spined sea urchin removing macroalgae from the reef. A yellowline arrow crab is sheltering in its spines to protect itself from the threat of predation.
Image: Carol Battram / Operation Wallacea.

Infected urchins were first detected on Panamanian reefs in January 1983 and, by January 1984 all populations had been reduced to a regional average of just 0.01 m^{-2}. Loss of these urchins is a major driving force behind the onset of the near-ubiquitous macroalgal phase-shifts that currently plague Caribbean reefs. Phase-shifts occur, in part, when proliferation of fast-growing macroalgae is left unchecked by herbivory so that it grows to smother the reef. This decreases hard coral cover and reduces biodiversity.

Over the last four decades, hard coral cover has declined by over 50% throughout the Caribbean; from a region-wide average of 34.8% in 1972 to just 16.3% in 2012. This dramatic coral loss has caused declines in fish and invertebrate populations and, if it continues, will negatively impact the 43 million people that rely on Caribbean reefs for survival. The International Union for Conservation of Nature estimates that Caribbean reefs generate over US$3 billion per year from tourism and fisheries alone. But, as reefs continue to degenerate, fisheries will become less productive, and SCUBA divers will take their money to less severely impacted reefs.

The continued macroalgal invasion of Caribbean coral reefs is, at least partially, attributable to the fact that recovery from the cataclysmic urchin mass-mortality event has been universally poor. Coral reef researchers and conservation managers unanimously agree that long-spined sea urchin populations must be restored in order to reverse the continuing upward trend in macroalgal growth.

Restoration of a species in decline is a notoriously difficult endeavour, but ecologists from Operation Wallacea (Opwall), a volunteer-led biodiversity research organization based in the UK, think that they may have come up with a solution.

Banco Capiro is a recently discovered reef system located 8 km offshore in Tela Bay, Honduras. With densities of 2.55 m^{-2}, Banco Capiro has the largest post-mortality long-spined sea urchin populations anywhere in the Caribbean. Ecosystem functions are restored when densities exceed 1 m^{-2}, so it is perhaps unsurprising that the extraordinary urchin densities on Banco Capiro coincide with an unprecedentedly high average hard coral cover of over 60%.

Since 2013, Opwall researchers have been hoping to unlock the secrets of Banco Capiro to elucidate the barriers preventing the wholesale recovery of the long-spined sea urchin. What is so special about Banco Capiro that populations have recovered there but not elsewhere?

Comparison of the ecological structure of Banco Capiro to the nearby 'typical' reefs around the island of Utila indicates that long-spined sea urchin populations are failing to recover because macroalgal phase-shifts have flattened reefs to such an extent that there is now a shortage of hiding places in which juveniles can avoid predation. Somewhat ironically, it was its own functional extinction which stimulated the phase-shifts that caused the reef flattening that is now preventing its recovery. This finding indicates that conservation managers may stimulate population recovery by manipulating the fundamental structure of the reef.

There is no magic bullet that can be used to stimulate population recovery over the entire 3.5 million km^2 area of the Caribbean. The only way urchin densities will be increased on a regional-scale is by augmenting populations on a local-scale. Deployment of artificial reefs (ARs) at numerous locations around the Caribbean would increase the availability of juvenile predation refuges and stimulate population recovery on a local-scale (Figure 2).

So why are we not just cruising around the Caribbean dropping concrete onto coral reefs? It is possible that this simple solution would be a highly effective way to increase habitat availability, but at this point there are too many unknowns for it to be seriously considered.

Is restoration of the long-spined sea urchin a worthwhile pursuit in a warming world? The Intergovernmental Panel on Climate Change predicts that sea surface temperatures (SSTs) in the Caribbean will increase by 0.68–3.14°C by 2100. If urchins lack resistance to these increases, efforts to restore populations may ultimately prove futile and scarce conservation resources should be expended on other initiatives.

Opwall researchers investigated the effect of rising SST on the predator avoidance responses of the long-spined sea urchin. They found that urchins are likely to be resistant to near-term SST increases, but, in the long-term they may succumb to thermal stress. These findings suggest that, on balance, population restoration is worthwhile in the face of climate change. Even if they are ultimately doomed, immediate augmentation of populations will increase ecosystem resilience and buy conservation managers time to create longer-term solutions.

The negative consequences of rising SST on predator avoidance responses were reduced when urchins were taken from areas of high habitat complexity. ARs enhance habitat complexity, therefore their use may mitigate the effects of climate change and increase the probability of long-term population survival.

So, we now know that the restoration of the long-spined sea urchin is worthwhile and will almost certainly have beneficial impacts on reefs around the Caribbean, that the barriers preventing natural recovery have been identified, and that deployment of ARs made from cheap and readily available building materials may help to overcome these barriers, whilst offering the added bonus of mitigating the negative effects of future climatic changes. Surely now is the time to start throwing the concrete overboard?

Nothing in life is ever that simple. Rehabilitation of the long-spined sea urchin will require ARs to be placed on 1000s of reefs across the entire extent of the Caribbean. Who is going to pay for the materials? Where is the manpower needed to install them going to come from? Is wide-scale AR deployment really a logistically feasible management strategy?

Public awareness of environmental issues is increasing, and this is clearly seen in the dive industry. With the increasing prominence of initiatives such as the PADI's (Professional Association of Diving Instructors) Project AWARE, ecologists must capitalize on people's interests and engage the masses in active conservation. By designing an 'Artificial Reef Construction' SCUBA diving speciality, Opwall scientists hope to overcome the logistical, financial and manpower issues associated with wide-scale AR distribution.

Fig 2. Long-spined sea urchins enjoying shelter from predation in the three-dimensional complexity provided by breeze-blocks.

Dive centres throughout the Caribbean could charge customers to learn about the importance of reef restoration and assist with AR construction. The majority of recreational divers will need to learn new advanced underwater skills; people can benefit from the personal development aspects of the programme, whilst also engaging their conservation interests. Dive centres are financially incentivized to assist with the construction of ARs and are obliged to provide materials and logistical support for the course to be completed. If enough dive centres across the entirety of the Caribbean teach this speciality, there may be so many hotspots of local urchin density increases that it actually represents a region-wide population recovery. Reinstatement of their ecosystem services will reverse the misfortunes of the reef. This will not only have beneficial ecological effects, but it will also help to sustain, if not improve, the socioeconomic circumstances of the millions of people that rely on the Caribbean's coral reefs for survival.

So next time you find yourself gazing out wistfully over the crystal clear waters of the Caribbean, spare a thought for the homeless long-spined sea urchin… and maybe throw in a breeze-block or two for good luck!

Max Bodmer (max.bodmer@opwall.com) Operation Wallacea http://opwall.com

Too hot in paradise!

Despite a traditional and sustainable approach to managing resources, a remote Pacific atoll finds itself on the front line of a warming world.
By **Michael White**.

Tongareva (09° South; 158° West) is the largest and remotest atoll in the Cook Islands. The population is small, living in two villages, with a mainly subsistence lifestyle gathering food and daily resources from nature. There is a peripheral need for money to pay power and phone-bills and order bulk cargo, such as rice, flour and coffee, from Hawai'i. Shipping, however, is rare.

The Community has a sacred duty to pass on a healthy, diverse and abundant ecosystem to our descendants, as our Ancestors passed it down to us: "We would not want our great-grandchildren to think we did not care enough to leave them food and resources to live their lives".

We achieve sustainability through *rahui*—traditional opening and closing of a harvest. When *rahui* is in place it is *tapu* (forbidden) to take that particular resource. An important aspect of *rahui* is to monitor the closed stock, so wise decisions can be made whether to re-open the harvest or extend prohibition. As this is a Community decision it needs no enforcement. This approach has allowed islanders to survive remotely for centuries, so we have, or had until recently, a pristine environment that has people as an integral part.

In May 2015, the El Niño Southern Oscillation occurred, causing changes to prevailing weather and ocean patterns. Apart from reduced rainfall and winds shifting southwards Tongareva was untouched until December 2015. Suddenly, the lagoon water temperature rose to 33–35°C all month and on the ocean surface sometimes to 32°C. The author found the first coral bleaching on 21 December. During rapid surveys, bleaching was found along most areas of the outer reef (77 km circumference). Worse was that many *toka* (coral heads) in the huge lagoon (233 km^2) had suffered badly. These *toka* are important habitats for shellfish and myriad fish species. One of our most important resources is *pasua,* the small giant clam (*Tridacna maxima*). This clam is always protected by *rahui*; typically we only open the harvest for a week every 18 months or so. Religion is woven deeply through every aspect of society, so harvesting of *pasua* begins with prayers, after which both villages collect shellfish every day. It is hard work; we open and clean our shells overnight. At the weekend we say prayers of thanks and have a Community feast to celebrate a successful and safe harvest.


The upper surface of a coral head shows some resistance to bleaching; corals probably acclimatize to higher temperatures during diurnal low water.


Live *pasua* (small giant clam, *Tridacna maxima*), and blue algae colonizing dead corals.

In January 2016 we found that most *pasua* in the southern two-thirds of the lagoon were dead. The presence of bleached corals everywhere explained their likely fate. Corals have zooxanthellae living within their tissues, and these symbiotic dinoflagellates photosynthesize making high-energy food from CO_2 using solar energy. Most nutrition (95%) goes to the coral host. Elevated seawater temperature, increased solar radiation, or more likely increased ultraviolet radiation, causes zooxanthellae to produce nutrients faster (4–8 times) than corals can manage. Under these conditions some radical oxygen molecules become toxic so corals expel the dinoflagellates by shedding dermal cells: the symbionts provided the bright colouring and thus *bleaching* is the white carbonate skeleton remaining. Corals can still filter-feed on zooplankton, but may no longer have sufficient gastrodermal cells for survival. *Pasua* colouring also derives from zooxanthellae. Some clams were observed with a coloured half and


Various coral species are bleaching and blue algae is encroaching; it is unclear what will happen to the resident fishes.


Two metres depth, bleaching is at different stages and blue algae also making an impact.


Bleaching starts from tips of coral branches.

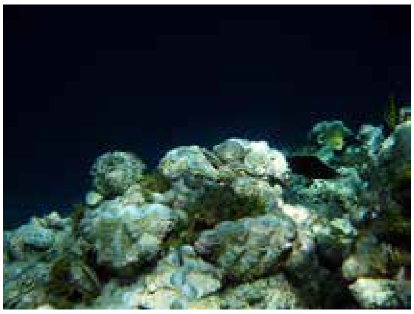

About 4 metres depth: it is likely that in a few days all colour will have gone.


Some species seem very vulnerable to warming, several of the deeper corals are bleached too.


Blue algae creeping over dead corals.


Intermediate expulsion of zooxanthellae from the small giant clam *Tridacna maxima*.


Most zooxanthellae gone from a small giant clam.


Dead clams at 8-10 m depth: these may have a more limited temperature range than shallower clams.

the other already bleached: the process of death seems to happen in stages. Once clams died other creatures ate them.

The northern part of the lagoon still had a few clams alive, but a blue (algae) growth had colonized dead corals and was rapidly spreading across living ones and other bivalves that were more resilient to high temperatures. Presumably this is also a consequence of a changing ecosystem.

For many people in the industrial–consumer world climate change is something that means little, or perhaps it may occur at some far off time in the future; maybe it isn't even true! For us in the South Pacific it is real, current and serious. Our atolls are mainly less than a metre above sea level, but we would delay leaving our homelands by building stilt-houses, and using solar-powered hydroponics; freshwater is all rainfall anyway.

I'll mention two more things. A year ago our atoll got overwashed, thanks to a combination of super-moon, king tides and, unusually, a westerly wind. A wall of water built up and rushed through the village into the lagoon; we even had a sea turtle (*honu*) washed ashore. Tongareva is the most important *honu* habitat in the Cook Islands; we have mating, juvenile development and year-round nesting on one uninhabited *motu* (islet). We let them nest in peace.

In 2015 much of the forest fell down due to high levels of windborne salt, little rain and very hot weather. Most trees behind the main *honu* nesting-beach have died. The sex of *honu* embryos is determined by temperature—females from warmer nests, more males from cooler clutches—so the absence of shade skews towards feminization. Our Community Environmental Society *Hakono Hararanga* (Incorporated) is busily restoring the forest, but it is a 20 km trip in a small boat and the lagoon can be rough.

The most amazing thing learned from this environmental disaster is just how successful our traditional management approaches are; there were many thousands of large clams and new ones growing. These *pasua* would have served us well for years. Sadly, neither *rahui* nor legislation can protect us from human folly. Our prayer to the world is that you end your carbon-intensive lifestyle and learn the true consequences of your consumer habits. *Kia Manuia*.

Dr Michael White (crwban681@yahoo.co.uk) Principal Investigator for sea turtles in the Cook Islands and President of *Hakono Hararanga*.

Acknowledgements

Special thanks go to our *Hakono Hararanga* members, especially Ru Taime our Chairman.

Filling in the gaps

Alistair Green works with communities to improve our knowledge of sea turtles in a remote part of Western Australia.

A loggerhead turtle (*Caretta caretta*) photographed during a daytime survey. Image: Nicholas Goldsmith.

Sea turtles are widely accepted as functionally important, flagship species for marine conservation. They have a high public profile, are widely distributed in tropical and warm temperate ecosystems and are susceptible to many well-known anthropogenic threats (e.g. fisheries by-catch, habitat loss and climate change) throughout their complex life cycles. However, despite the high level of attention turtles receive, there are still significant gaps in our knowledge of their basic biology in many regions, particularly those that are remote or otherwise inaccessible.

The South-East Indian Ocean population of loggerhead sea turtles (*Caretta caretta*) is the least well-studied of the seven management units for this species. Information on the status of this population is limited; therefore, it is critical that we implement research and monitoring programmes to answer basic questions such as: how many females in this population nest in a given year? Where do they nest and why? How many clutches do females lay per year? What influences hatching success? How often do females migrate between feeding and breeding grounds? Where are their primary feeding sites?

The Gnaraloo Turtle Conservation Program (GTCP) is a monitoring, research and community engagement programme located in a remote part of Western Australia (WA), approximately 1,100 km north of the city of Perth. It was initiated in 2008 by a private wilderness tourism business—making it unusual among turtle conservation programmes—based at Gnaraloo Station, a working pastoral station covering some 90,000 ha of coastal outback. The GTCP aims to identify, monitor and protect sea turtle rookeries found within the southern part of the Ningaloo Coast World Heritage Area, where little research has taken place historically. Furthermore, the GTCP aims to increase public awareness of turtle and marine conservation by giving presentations to school and community groups on-site and throughout WA and the rest of Australia.

Each turtle nesting season, the GTCP recruits a small field team (typically five people) who conduct daily beach surveys to count and interpret turtle tracks in order to establish the size and species composition of rookeries at Gnaraloo. Annual monitoring since 2008/2009 has revealed that Gnaraloo Bay—the main turtle nesting beach on the station—receives an average of just over 400 nests per season. Preliminary surveys on Cape Farquhar, a more isolated beach, 22 km north of Gnaraloo Bay, suggest that this site may receive a comparable, or slightly lower, number of nests each year. Approximately 97% of nests on Gnaraloo beaches are from loggerhead turtles, with green turtles (2%) and, possibly, hawksbill turtles, nesting rarely.

The main loggerhead turtle rookery for the south-east Indian Ocean is located on Dirk Hartog Island, at the mouth of Shark Bay, approximately 200 km south of Gnaraloo. Some 1000–3000 females nest on 80 km of beach at this site annually. Thus, the rookeries at Gnaraloo are relatively small. However, small rookeries that are geographically distant from primary, high-density nesting sites can still play an important role in population dynamics. Due to a condensed nesting area, the main nesting site at Dirk Hartog Island has the potential to be wiped out by extreme events. Should this happen, the sea turtle population at Gnaraloo Bay can act as a population buffer. Therefore, Gnaraloo Bay Rookery is an important nesting beach that contributes to genetic diversity for this understudied population.

The GTCP operates in cooperation with the Gnaraloo Feral Animal Control Program (GFACP), which was implemented to reduce the impact of feral predators on sea turtle nests on the Gnaraloo coast. Prior to 2008 nest predation was a major issue, with over 80% of nests being affected by feral animals; however, since the 2010/2011 season, feral predation has been reduced and maintained at 0%, providing complete protection of sea turtle eggs and hatchlings from foxes, feral cats, and wild dogs. The effectiveness of the GFACP is independently monitored by the GTCP team during field surveys (i.e. feral predator track counts). The work carried out by the field team and their collaboration with GFACP is critical for the on-going protection of Gnaraloo rookeries.

In 2016 the GTCP began satellite tagging of the nesting loggerheads led by Aub Strydom (University of Queensland). Little is known of the foraging habitats and breeding grounds for this population, therefore, this will enable critical spatial and temporal data to be gleaned. To coincide with the tagging programme, the world's first purpose-built turtle tracking app has been created. The "Turtle Tracker" app allows users around the world to view and track the female turtles making their migrations. This novel approach utilizes current technology and interlinks it with conservation, enabling mainstream audiences to learn about research. The satellite tags will regularly fix and transmit a GPS location when the turtle comes to the surface to breathe or is returning to nest. The app is already up and running with five females having been released, so you can follow them throughout the nesting season and beyond. We are hoping to discover how these turtles move while on the breeding ground near Gnaraloo and identify where they go to feed once they are done nesting. Turtles spend around 75% of their adult life cycle in their feeding zones, so it is vital to know where the females that nest at Gnaraloo go for their effective conservation. "Turtle Tracker" is free and can be downloaded for Apple, Google and Windows phones.

Alistair Green (alistairskipgreen@gmail.com) Gnaraloo Turtle Conservation Program.

Above: a loggerhead turtle being fitted with a satellite tag. Image: Alistair Green. Right: a tagged loggerhead turtle is released. Images: Kimberly Nielsen.

Spreading the word

The GTCP provides a strong focus on community engagement. Public engagement and widespread awareness of environmental issues provides a connection between researchers and members of the public that can inspire conservation. In the field at Gnaraloo, community members and school groups are invited to join the GTCP on day/night beach surveys to learn about monitoring techniques and sea turtle conservation. Once the nesting season concludes, the team travels south along the WA coast, stopping at different towns between Gnaraloo and Perth to give presentations to students and community members. During the 2014/2015 season, the field team reached over 7,000 people, highlighting the programme's focus on raising awareness for sea turtles and conservation through education.

Capturing Our Coast – a new initiative in marine citizen science

By **Jacqui Pocklington** and **Jane Delany**.

With the incredible proliferation of 'citizen science' projects around the world, this term is becoming entrenched in daily use. Engaging the skills and motivation of volunteers allows scientists to get fantastic coverage, both geographically and over time, which they couldn't otherwise achieve. Such approaches to data collection also empower participants, increasing their understanding of threats to habitats and ecological processes, to act more sustainably and perhaps even more proactively on a political level. Finding the balance between getting robust data and ensuring an enjoyable and transformational experience for volunteers is a key aim of a new project in England called Capturing Our Coast (CoCoast).

CoCoast builds on the success of The Big Sea Survey which ran in north-east England from 2010–2013, and trained over 350 people. The data collected by Big Sea contributed new population records of stalked jellyfish, and new invasive species records of the tunicate *Corella eumyota*. The data was also used as supporting evidence in the bid for the newly designated Marine Conservation Zone 'Tranche 2 Coquet to St Mary's'.

CoCoast goes further, and not just in size. We wanted the data to contribute meaningfully to conservation strategies and policies, rather than focusing simply on species recording. To this end the team has spent considerable time consulting with the scientific community, statutory agencies and organizations with conservation remits to identify what the evidence gaps and scientific questions are to which volunteers could contribute.

We wanted the data to contribute meaningfully to conservation strategies and policies

Participants will collect quantitative data in intertidal areas (predominantly rocky shores), that shed light, for example, on distributional range shifts, responses to temperature change in terms of breeding success, and interactions between invasive and native species. A very powerful aspect of this approach is conducting experimental studies simultaneously around the coast, across latitudes and environmental conditions.

On the surface, this might appear daunting to members of the public who may just want opportunities to engage with our rich marine life, and not to be burdened with overly complex tasks. But the structure of CoCoast allows many levels of participation, and there is something to suit everyone who signs up. All of our tasks are straightforward and manageable, but collectively they build up to an impressive dataset that can be analysed in complex ways; the data will ultimately be publically available via the National Biodiversity Network gateway, allowing others to extract information and draw further conclusions.

Following attendance at an introductory training session, volunteers select a package of species to survey, as rarely or frequently as they wish, at locations of their choosing. This is the activity we expect most volunteers to be involved in. It is this concentration of effort on a small set of adopted species that quickly allows the volunteer to gain confidence and become specialized in identification; this adds to how robust the returned data will be, and we have strong evidence from the pilot study (Big Sea Survey) that this approach works beautifully. It facilitates the volunteer to survey independently, without any requirement to be accompanied by an 'expert', so putting the citizen into the 'citizen science', and ensuring their involvement truly matters. Once hooked, volunteers can decide which of the other studies they wish to engage in, independently, or in teams. Flexibility and

Above: The kelp *Alaria esculenta* Image: Heather Sugden. Below: The periwinkle *Littorina obtusata*. Image: Leoni Adams.

scope is paramount to retaining volunteers, and ensuring ongoing interest. Our studies include the investigation of population changes using digital photographic records of fixed areas surveyed repeatedly over time. Volunteers can contribute either by taking the images, and/or processing these images, and other datasets, online, adopting a crowd-sourcing approach pioneered by Oxford University's '*Galaxy Zooniverse*' programme. This has the additional benefit of opening up CoCoast to volunteers who do not live adjacent to a coast but would like to get involved.

The project is led by Newcastle University, and involves the universities of Hull, Portsmouth, Bangor and the Scottish Association for Marine Science, along with the Marine Biological Association, Marine Conservation Society, Earthwatch Institute, Natural History Museum, Northumberland Wildlife Trust, Cefas, Durham Heritage Coast, Thanet Coast and North West Coastal Forum. This level of involvement of scientists, policy-makers and managers is unique in marine citizen science, certainly in the UK, and is itself an exciting aspect of the project. We furthermore want to share best practice, and work with other existing projects and organizations. Our intention with CoCoast will hopefully be a UK-wide joining up of marine public engagement and science, and an exemplar model of citizen science that is founded on multiple-partnerships working together to support volunteers with the common goal of protecting our UK seas.

Rocky shore surveying in north-east England. Image: Jacqui Pocklington.

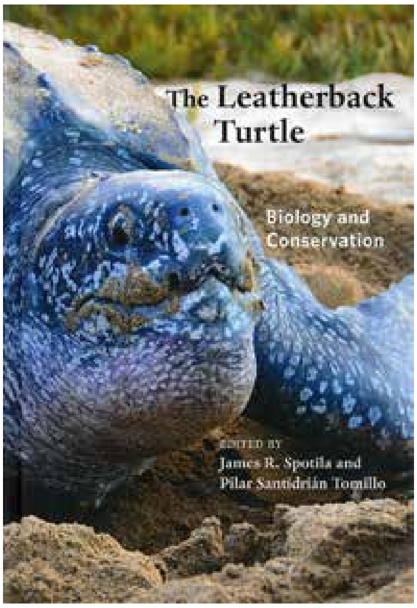
Please visit www.capturingourcoast.co.uk to find out more, and register at a hub near you.

Dr Jacqui Pocklington (Jacqueline.Pocklington@newcastle.ac.uk), National Coordinator, Capturing Our Coast, Newcastle University.

Dr Jane Delany (Jane.Delany@newcastle.ac.uk), Project Lead, Capturing Our Coast, Newcastle University.

Reviews

The Leatherback Turtle: Biology and Conservation



James R. Spotila and Pilar Santidrian Tomillo (Eds)
ISBN: 978-1-4214-1708-0
Published by: Johns Hopkins University Press, Baltimore

Times they are a-changing; man's environmental footprint is getting bigger; species are being marginalized, none more so than the global population of the leatherback turtle. These beautiful marine creatures inhabit as many oceanic corners of the planet as man himself yet they are deemed at significant risk of disappearing in years to come if more is not done to conserve both their dwindling numbers and their equally fragile environments. They are defined as being vulnerable by the IUCN Red List of Threatened Species: in other words now is the time to begin taking greater action to conserve the leatherback turtle.

The authors identify capture in fisheries (both intentional and as bycatch), the direct removal of turtles and eggs for human use, coastal developments and climate change and sea level rise as principal factors which threaten leatherback turtles. Despite being protected by Conventions and national and international laws, the existence of the species is still under threat. The publication of this book is therefore timely and it is hoped that the information contained within its covers will help those working at the forefront of leatherback turtle conservation to be more successful in their efforts.

This publication comprises an encyclopaedic amount of highly technical information: it is not a layman's read requiring at least an advanced undergraduate / postgraduate knowledge of animal biology and the Class Reptilia, though most of the book's content is geared to scientists working with the turtles in the field.

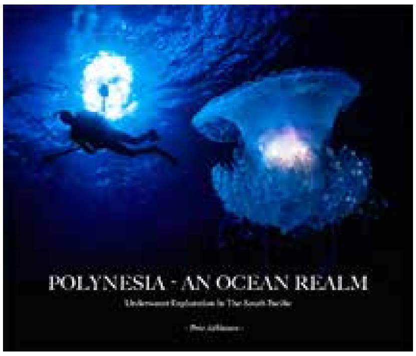
The book is written by 31 international authors—two of which act as editors—and is divided into five main parts covering: biology; life history and reproduction; population status and trends; from egg to adulthood and the future of the leatherback turtle. Each part is then subdivided further into chapters. Within each chapter are experimental data presented as tables, diagrams, graphs and occasionally coloured photographs. To minimise the strain of reading small print in large concentrations the pages have been split vertically; references quoted are very much up-to-date for a book of this type and at the end of each chapter there is a bibliography. Inevitably, there is variability in both the quality and subsequent clarity of figures between chapters and this is an area where future editions could be improved. However, praise must be given for the inclusion of excellent coloured photographs showing skull dissections between pages 48 and 50 and those of the animals *in situ* between pages 128 and 129.

As I mentioned earlier this is a book for specialists as reflected in the quality of the data, the technical use of language, the sheer volume of pertinent material and the price of £45.00. That said, I would expect a copy to be found in every marine biological library, aboard research vessels, in marine ecological laboratories and on the shelves of those at the forefront of leatherback turtle conservation. The value of the information contained in one accessible place should offset any concern over cost since savings will be made in the time it would otherwise take to track down the individual elements.

In my opinion this is a great book written by enthusiastic biologists committed to securing a future for the leatherback turtle so that generations of humankind will be able to appreciate their natural beauty in the wild. Furthermore, I would encourage the authors and their progeny to ensure that this important publication goes through many updated future editions.

Dr Stephen R Hoskins
CBiol FRSB FLS

Polynesia - An Ocean Realm



Author: Pete Atkinson
Available from:
www.peteatkinson.com/book

Polynesia, an Ocean Realm should come with a health warning: not to be read during a high latitude winter! This is an eBook laid out in 12 chapters, charting nearly 10 years of diving and exploration in Polynesia, aboard *Eila*, an 11m Bermudan cutter. The author has the can-do approach of a true adventurer and the book is a beguiling snapshot of a time, perhaps gone forever, when it was possible to simply buy a yacht and sail away without qualifications, safety gear, experience or insurance.

The text takes a back seat to the (almost all pre-digital) images, which are abundant and spectacular. Fortunately, this would be an absorbing read even without the images because the writing is fluent, in places lyrical, and strongly evokes the atmosphere of these extraordinary places.

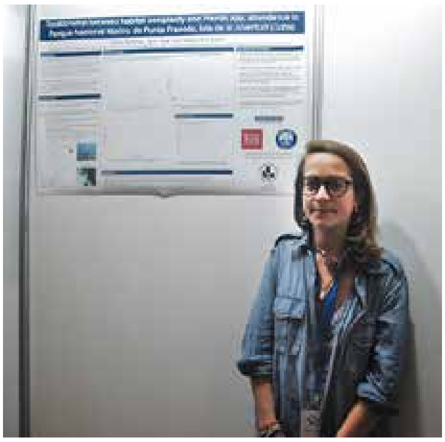
Pete Atkinson studied marine biology and he blends his biological knowledge with entertaining observations of life on the reef: "There are thickets of staghorn *Acropora*, new on top, dead, algae-covered and guarded by belligerent damselfish, below. Both *Stegastes* and *Hemiglyphidodon* damsels farm filamentous green algae, weeding out undesirable species, which allows favoured species to flourish. Wrasse and surgeonfish sneak in to crop the algae, warned off by the 'thok thok' of the damsels in distress".

The author's keen interest in people and distrust of materialism and development give him an innate understanding of Polynesian life, which he describes in some detail. Reading these pages it is easy to slip into the slow pace of South Pacific life; from the dramatic beauty of the Society Islands to the culture of the Cook Islands.

Pete Atkinson's aim is to inspire people to follow their dreams; the Polynesian islands had better brace themselves for an influx of visitors.

Guy Baker

Panama conference for MBA bursary winner



The 68th Gulf and Caribbean Fisheries Institute in Panama in November 2015 was a great opportunity for me to take my first steps into Marine Biology, Ecology and Conservation. As an undergraduate Geography student, I am trying to take any opportunity I come across to steer my academic career towards my driving passion, which is the world of marine research.

The GCFI conference has definitely been a highlight in this sense: for an entire week, marine researchers, stakeholders and managers came together to discuss current issues, solutions and research projects on a broad range of topics – spanning shark conservation to fisheries management. Being able to listen to presentations covering all of these themes meant I could learn about techniques, methodologies and areas of research that I had never been exposed to given my academic background, giving me ideas and inspiration for future research projects that I will hopefully be able to undertake.

An entire day was dedicated to research on the invasive *Pterois* species, the lionfish, one of the biggest threats faced by Caribbean reefs at the moment. This was an especially useful session for me, given that I am working on this very topic for my undergraduate dissertation. The friendly atmosphere meant I could approach both students and professors in the same way, mutually exchanging ideas, results and opinions. The dedicated lionfish poster session gave me the incredible opportunity of presenting my own results, and the invaluable comments and suggestions I have received from experts in the field have already helped me to improve the quality of my research project.

Overall, the week spent at GCFI was great – not only because of all that I learnt, but also because of all the people I was able to meet and connections I was able to form. I am sure they will go a long way in helping me build a career as a marine researcher and I truly appreciate the opportunity I have been given.

Giulia Cardoso (giulia.cardoso@kcl.ac.uk)

Dr Bill Ballantine QSO MBE (1937–2015)

The 'father of marine conservation in New Zealand' and an influential individual in the field of marine conservation worldwide died on 1 November 2015. Bill Ballantine will be known to students of marine biology in Britain for his 1961 'Biologically-defined exposure scale' for rocky shores, itself a major contribution to understanding marine ecosystems. Less well-known are the studies of limpets that he started during his PhD, which included 'occupying a bench' at the MBA Laboratory between 1958 and 1961, and returning there occasionally to continue those studies.

Bill made his mark internationally by insisting that we needed marine reserves if scientists were to study marine life in as close as possible to natural conditions; appointed in 1964 as the first Director of the Marine Laboratory at Leigh, New Zealand, that conservation imperative translated into the establishment of the marine reserve there in 1977 and the start of a string of reserves around the country.

Bill was always ready with strong advice to his students—I don't think that I would have worked out a way

to represent wave exposure effects on rocky subtidal communities without Bill's insistent guidance in the library at Orielton Field Centre, Pembrokeshire. Back in New Zealand, Bill's 'hospitality' led to many a guest from Britain, including myself, going home with the message to just get on with setting up marine reserves.

Those of us who had the privilege to know Bill will remember an individual passionate about conservation who did not suffer bureaucrats gladly, who 'managed' opponents, who could be cantankerous and seemingly impossible but who made things possible.

Keith Hiscock

Further reading

Ballantine, W.J. 1961. A biologically-defined exposure scale for the comparative description of rocky shores. *Field Studies* 1(3), 1–19.

Ballantine, W. J. 2014. Fifty years on: Lessons from marine reserves in New Zealand and principles for a worldwide network. *Biological Conservation* 176, 297–307.

Mezzotints of exotic marine organisms

An old printmaking technique is uniquely suited to representing deep-sea creatures.

A Plymouth-based printmaker and member of the MBA for nearly 20 years, my work has long had a marine theme. Through the medium of etching I have produced prints of many creatures from local mackerel and plankton to more exotic Argonauts, sea dragons and whales.

Since hearing about their discovery as a child, I have had a fascination with the mysterious fossil fish, the coelacanths. Sketches of the preserved specimen at the Natural History Museum, London became the start of a series. Bob Forster was a great inspiration with his recollections and material from the MBA expedition.

My connection with the MBA is extremely special to me; my late father was a GP and used some of the facilities at the MBA Laboratory for research into asthma, so as well as happy memories of the aquarium, I was extremely fortunate to have grown up knowing so many eminent MBA members. My interest in squid and nautilus came from Eric Denton, Quentin Bone, John Gilpin-Brown, Vic Howarth and Hans Meves. The mezzotint printmaking technique (see box below) is especially suited to my current work on twilight zone fish. Like the coelacanths, these sea-dwellers from the depths emerge from the darkness, perfect for the dense blackness so characteristic of the technique.

Again, a visit to the Natural History Museum was a wonderful treat, studying and drawing bizarre viperfish, dragon fish, hatchetfish, fangtooth, anglerfish and even the wonderfully named whipnose seadevil with its fearsome teeth, jaws, lures and light organs.

Mezzotints are produced on copper plates. The entire surface of the plate is roughed with the mezzotint rocker, a tool shaped like a wide chisel with a curved and serrated edge. By rocking the toothed edge backwards and forwards over the plate, a rough burr is cast up which holds the ink. Once this is completed, a drawing can be transferred onto the plate, using carbon paper. The textured ground reads as a uniform dark whilst the areas to be lightened are scraped and burnished—therefore, working from dark to light—a reverse technique to etching and engraving. The preparation of the plate can take 20 hours or more before the artist can start work on the design, but the beautiful, soft, velvety finish and the richness of its blacks is so unique to the mezzotint process that it more than justifies the skill and patience involved. In the 18th Century, small boys were employed to 'rock' the plates up and the extreme tediousness of the

work, combined with the poor pay and working conditions, sent many of the unfortunate boys into mental decline, hence the term 'off one's rocker'.

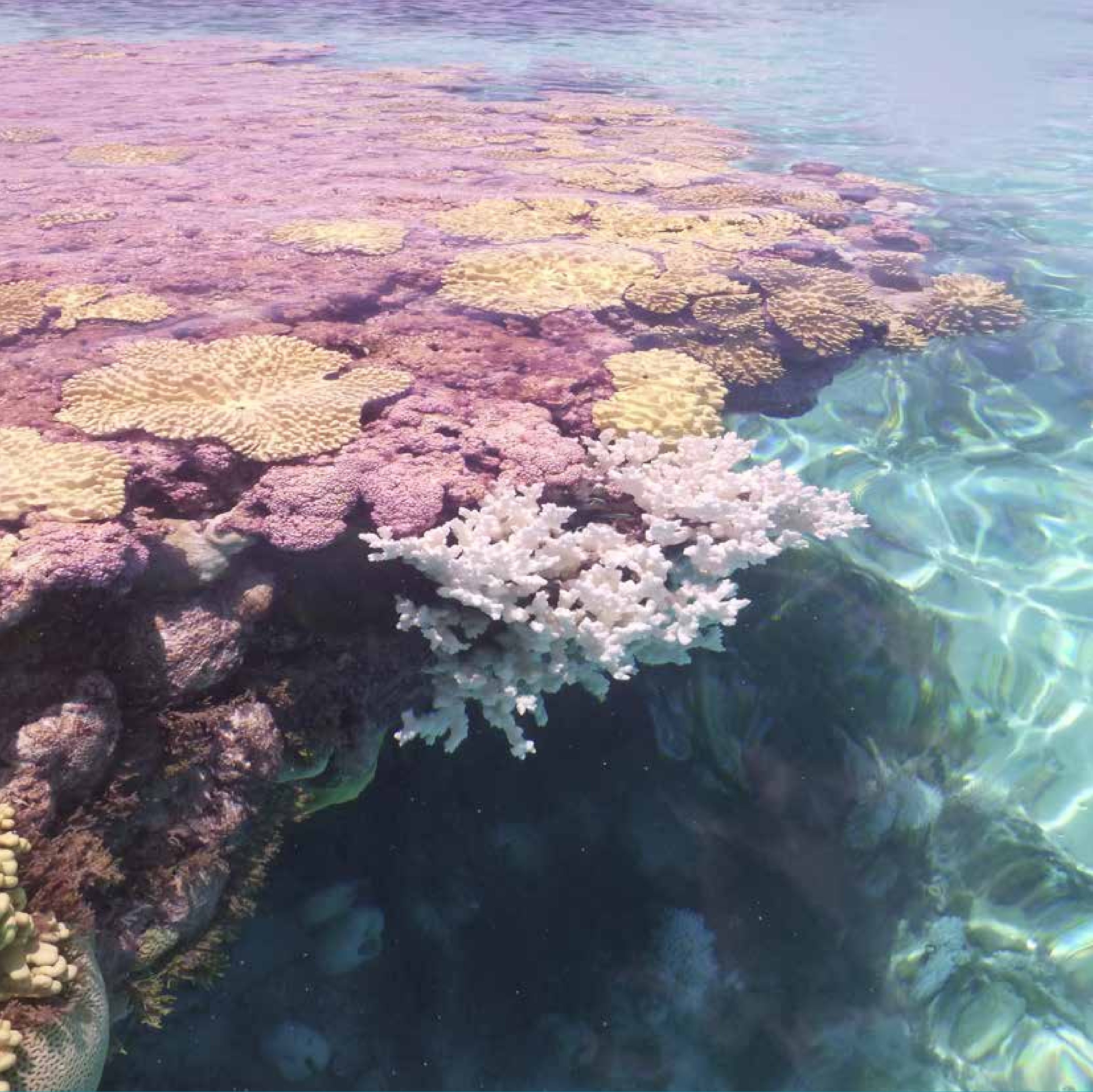
Sadly, I have to 'rock' the plates myself ...

My work has always been influenced by the books I have read, the people I have met and the places I have visited. One of my favourite visits was as a small child to the Musée Océanographique in Monaco where, after looking at the shell collection, I was asked by my mother if I wanted to go and look for some shells on the beach. Apparently I replied that we wouldn't find any as the Prince had got them all in his museum!

Debby Mason (debby@debbymason.com) www.debbymason.com

The mezzotint or 'half tone process' was invented in the 17th Century by Ludwig von Siegen. The process was found to be especially useful for the reproduction of paintings due to its ability to capture the subtlest gradations of tone from blacks to glowing highlights. The technique was perfected by Prince Rupert of the Rhine, an accomplished artist, son of Frederick V of Bohemia and nephew of Charles I of England. His many contacts with the royal court in England undoubtedly accelerated the reception of the mezzotint process enjoyed there. The mezzotint became popular, and was often referred to as 'The English Manner'.

Below: Depictions by Debby Mason of the common nautilus (*Nautilus pompilius*) (l) and fangtooth (*Anoplogaster* sp.) (r) using the mezzotint process.



Issue 7 of *The Marine Biologist*

The Marine Biologist
The magazine of the marine biological community

October 2016

www.mba.ac.uk/marinebiologist