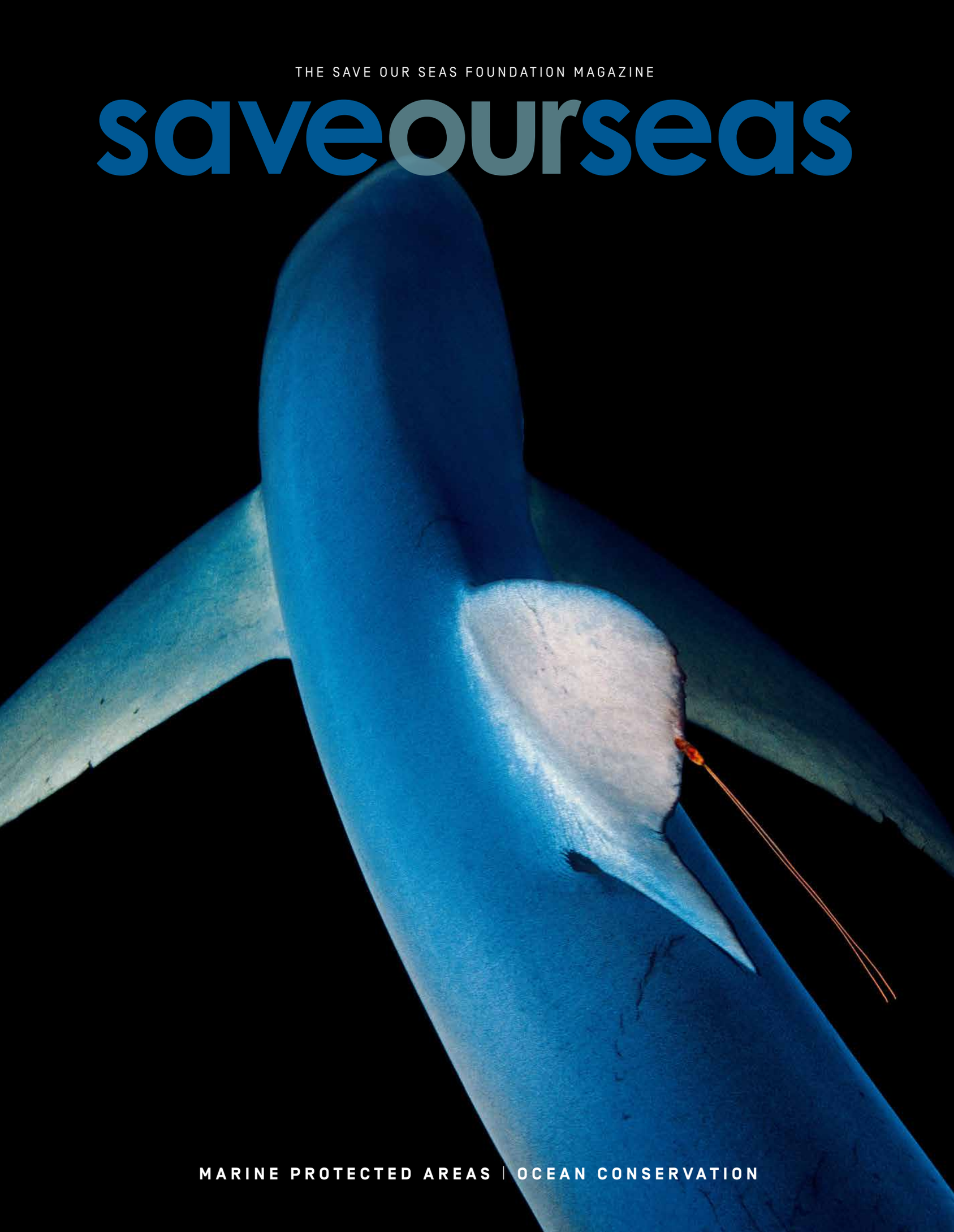
THE SAVE OUR SEAS FOUNDATION MAGAZINE

saveourseas



MARINE PROTECTED AREAS | OCEAN CONSERVATION

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JASON HALL-SPENCER
As a leading scientist in the field of ocean acidification, Jason has been studying underwater volcanoes in the Mediterranean Sea to help predict the effects of ocean acidification due to rising carbon dioxide levels. His research is being used to inform stakeholders about how we can protect iconic ecosystems from the ravages of acidification.

LISA BOONZAIER
After some time in the world of digital magazines and publishing, Lisa embarked on a Master's degree at the University of British Columbia. Under the supervision of Professor Daniel Pauly, she conducted a global assessment of the effectiveness of marine protected area management. In a recent paper, published in *Oryx – The International Journal of Conservation*, she and Pauly determined the extent of marine protected area coverage around the world, and this is currently the most up-to-date summary of its kind.

LUCY KEITH DIAGNE
Lucy has been working to conserve African manatees for more than a decade and has recently earned her doctorate from the College of Veterinary Medicine at the University of Florida. Her study defined the diet of the African manatee and identified its regional population structures, as well as its genetic relationship with other manatee species.

RUTH LEENEY
Ruth's mission to understand Africa's remaining sawfish populations began in West Africa. In 2012 she founded Protect Africa's Sawfishes, a project she continues to direct. Her research has progressed eastwards from Guinea-Bissau to the East African coast and, most recently, Madagascar. She is currently the Sawfish Conservation Officer for the IUCN Shark Specialist Group.

Front cover:
A blue shark, *Prionace glauca*, with parasitic copepod. Photo by Brian J. Skerry | National Geographic Creative

Back cover:
Blue sharks cruise the open blue water near Block Island in the Atlantic Ocean. Photo by David Doubilet | National Geographic Creative

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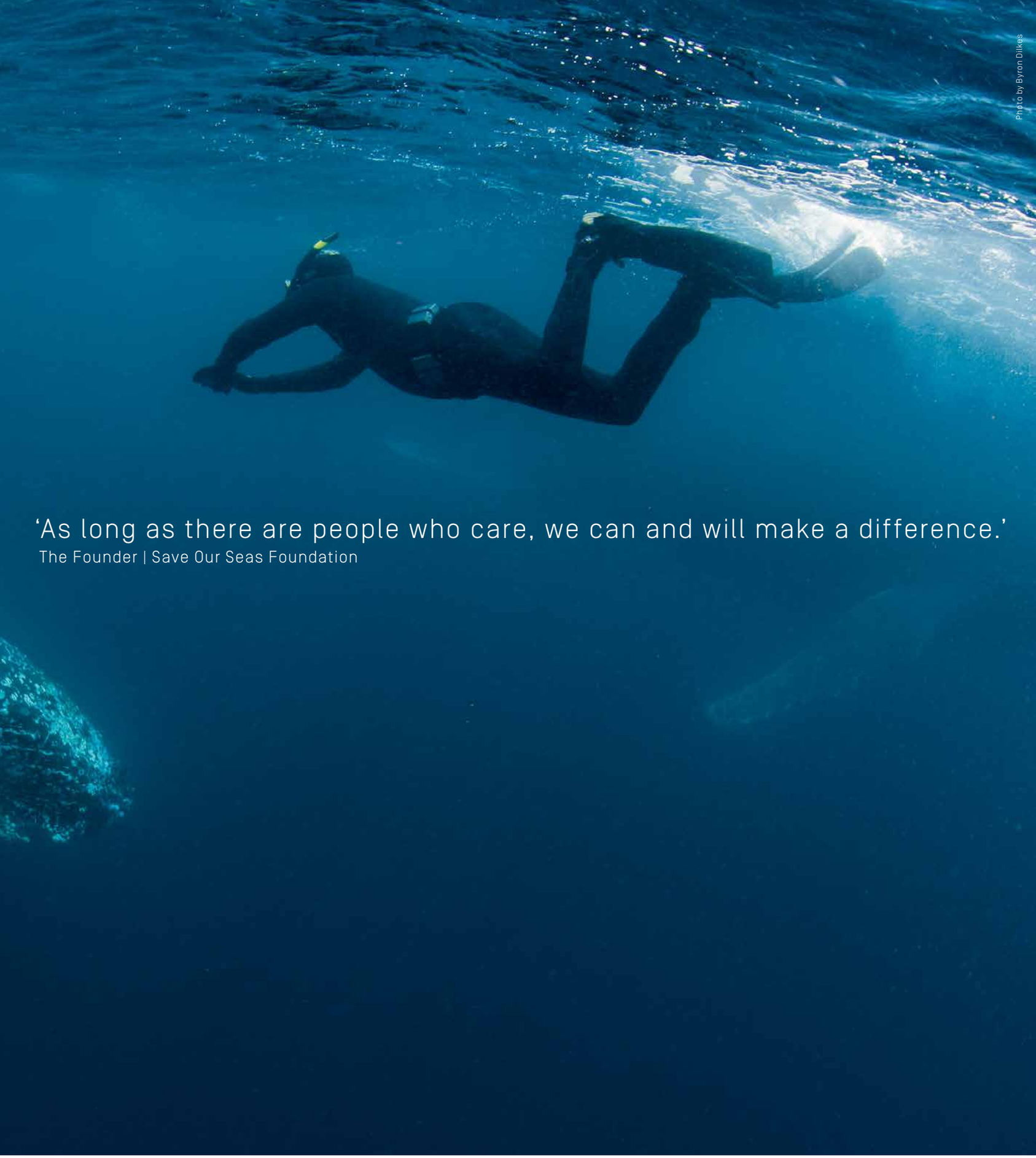
Editorial

Michael C. Scholl
Chief Executive Officer | Save Our Seas Foundation

Since the birth of humankind, the oceans have represented the last frontier; we have always been drawn to this mysterious, vast and compelling ecosystem. But today the birthplace of life on earth is under dire threat from human-related exploitation and other actions, both direct and indirect.

Until not so long ago the great whales were hunted the world over, almost to extinction. Now, however, several populations of these formerly threatened cetacean species are on the path to recovery. Overall, they represent a conservation success story. This shows that, when working together and often led by a few devoted individuals, we can make a real difference.

Since its inception in 2003, the Save Our Seas Foundation has been fully committed to better protecting another pivotal element of complex marine ecosystems: the Chondrichthyes, otherwise known as the cartilaginous fishes.



‘As long as there are people who care, we can and will make a difference.’
The Founder | Save Our Seas Foundation

They include close to 1,200 species of sharks, rays, skates, sawfishes and chimaeras.

In 2016, the Save Our Seas Foundation continues its engagement by making a special call for research applications on some of the most threatened Chondrichthyes: sawfishes. Characterised by long, toothed snouts, these warm-water, shark-like rays are the largest of the rays, reaching a length of more than seven metres (23 feet). Once found in the coastal waters and rivers of more than 90 tropical and subtropical countries, all five species are today classified as Endangered or Critically Endangered.

Inspired by the unparalleled and unequivocal pledge from our Founder, our collaboration and work with passionate and dedicated project leaders continues around the world with a clearly defined responsibility towards these important animals and their respective habitats.

WHERE WE WORK 2016

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2 Shark Education Centre | Eleanor Yeld Hutchings
3 Shark Research Center | Mahmood Shivji

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5 Elasmobranch Biodiversity | Peter Musembi

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The Save Our Seas Foundation was established in 2003 with a mission to protect our oceans by funding and supporting research, conservation and education projects around the world, focusing primarily on charismatic threatened wildlife and their habitats.
In that time, the foundation has sponsored over 200 projects in more than 50 countries, proudly supporting outstanding researchers, educators and conservationists who have contributed to the continued existence of more than 60 of our planet's precious marine species.

To find out more about our funded projects visit: *saveourseas.com/projects*

Photo by Matt Potenski / istock

Photo by Paul Nicklen | National Geographic Creative

SHARK SPOTTERS TEST THE WATER IN AUSTRALIA

ocean view

In March this year, Sarah Waries and Monwabisi Sikweyiya of the Shark Spotters travelled to Australia to explore the feasibility of expanding the non-lethal shark control programme across the Indian Ocean. They were invited by Sea Shepherd and No Shark Cull and visited three states in Australia.

The Shark Spotter programme was developed more than a decade ago in False Bay, South Africa, and improves beach safety by means of innovative and responsible solutions that balance the needs of people with the conservation of sharks. Like South Africa, Australia has a prominent population of white sharks that share coastal waters with ocean users. Australia has implemented culling programmes in the past and still has shark nets and drum lines in place in Queensland.

Waries and Sikweyiya visited 52 sites across the states of Western Australia, New South Wales and Queensland, including well-known surf spots at Margaret River, Byron Bay and Sydney. They judged the feasibility of a site on factors such as elevation, water clarity and water-user activity and found that 17 had potential for the spotting programme.

The Shark Spotter team also engaged the Australian public. They attended stakeholder engagement meetings and hosted four community forums where they spoke to more than 250 people about their sustainable approach to preventing shark bites in South Africa. Their visit also attracted a lot of attention from print and broadcast media in Australia and elsewhere.

Waries views the visit as very positive for the Shark Spotters, but is sceptical that the programme will be expanded to Australia. 'There appear to be strong political agendas around the implementation of shark bite mitigation strategies in Australia,' she said. 'For this reason it does not appear that a spotting programme endorsed by the government will be implemented there any time soon.' However, Sea Shepherd and No Shark Cull have indicated that they will experiment with the programme at a small, community-based level in the hope of convincing the government to come on board at a later stage.

GETTING ON THE LIST

In September 2016 representatives from 182 member countries of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) and international stakeholder organisations will arrive in Johannesburg, South Africa, for the 17th Conference of the Parties (CoP). The conference will run from 24 September to 5 October and delegates will negotiate the listing of new species by CITES, which regulates international trade in endangered species in order to conserve global biodiversity.

The last conference, held in 2013, was significant for the protection it offered elasmobranchs. Five shark species and all manta rays were included in Appendix II, joining sawfishes and other sharks that had already been included in the CITES Appendices over the past decade. This year, four shark species and all mobula rays are on the agenda for the same Appendix. In order to be adopted, proposals will need the support of a two-thirds majority. Once a species has been listed, parties will require a permit to trade in it, and in order to acquire such a permit they will have to demonstrate that products from the relevant species were obtained legally and harvested at sustainable levels.

This year the call to protect elasmobranchs is being led by three island nations. The Maldives is proposing silky sharks, which have been in serious decline for the past 20 years. Apart from some national shark sanctuaries and fishing bans within two regional fisheries, there is currently no fisheries management for silky sharks, whose fins make up 3.5% of the trade in shark fins.

Another proposal on behalf of shark species will also come from the Indian Ocean. Sri Lanka will propose that the three species of thresher shark be added to Appendix II. The nation is a range state for all three species and already affords them full protection in domestic waters. Because of declining thresher shark populations, two Regional Fisheries Management Organisations, the International Commission for the Conservation of Atlantic Tunas (ICCAT) and the Indian Ocean Tuna Commission (IOTC), have also prohibited the catching of these species on the high seas of the Atlantic and Indian oceans respectively. Since the fins of bigeye thresher sharks in their traded form look very similar to those of pelagic and common thresher sharks, Sri Lanka is proposing the pelagic and common thresher as 'look-alike' species.

The third island nation is Fiji, which will champion the listing of mobula rays – specifically *Mobula japanica* and *M. tarapacana*, but also all other mobula species for the same look-alike reason as thresher sharks. Populations of mobula species are showing particularly strong declines, and because the products (gill plates) of mobulas look very similar to one another and to the gill plates of manta rays (which were listed on CITES Appendix II in 2013), it is necessary to protect all nine species. Mobula rays require urgent attention because new data reveal that they are as vulnerable as manta rays and are being increasingly targeted in the gill plate trade.

These three proposals are expected to receive strong support from a number of countries around the world. The tools to identify the proposed shark and ray species are already available and, as in the case of the previously listed elasmobranchs, they are extremely easy to use. The fins and gill plates can be visually identified and can also be confirmed by genetic analysis for prosecution purposes when required. Several international organisations, including the Manta Trust, have offered their full scientific and technical support to proponents and range states of listed and newly proposed species and are actively raising awareness of the threats that these species are facing globally.

Photo by Mauricio Handler | National Geographic Creative

EYE ON SAWFISHES

In early March 2016, the team at the Bimini Biological Field Station (the 'Shark Lab') had an encounter with one of the most threatened animals in our oceans: a sawfish. Lab manager Jack Massuger caught the enigmatic elasmobranch on camera while flying a DJI Phantom drone off South Bimini in The Bahamas. The video clip featuring a Critically Endangered smalltooth sawfish *Pristis pectinata* was a hit on social media and showcased its huge size, incredible camouflage against the seabed and bizarre head-weaponry. Remarkably, this was the second sawfish sighting in South Bimini in just a few days.

In December last year, the director of the Shark Lab, Tristan Guttridge, published a paper about smalltooth sawfishes in The Bahamas. Two of these sawfishes were tagged at Bimini and three at Andros, and researchers tracked their movements. The study showed that The Bahamas has important habitat for sawfishes and that Andros is likley to be a nursery area. Since 2002, only 61 sawfish encounters have been recorded at these locations.

Despite their conservation status, sawfishes are not protected species in The Bahamas, where Bimini's marine habitat has been under threat from contsruction and development for two decades. Guttridge and his team hope that by sharing videos like this they are proving the significance of Bimini as a critical habitat for endangered species like sawfishes and they urge the government of The Bahamas to establish the North Bimini Marine Reserve.

Photo by Matthew Potenski

Former Shark Lab manager Grant Johnson with the 2.7-metre-long smalltooth sawfish caught during the 2007 PIT roundup in the North Sound. The researchers have recently submitted a paper on this highly endangered species, based on observations going back to the 1980s.

MIGRATORY SHARKS BENEFIT FROM SAFE SPACES

A new study has shown that expanding marine protected areas (MPAs) in South Florida could protect 100% of the core home range of bull, great hammerhead and tiger sharks in the region.

Scientists tracked the movements of 86 sharks tagged in South Florida and the northern Bahamas to determine the sharks' core habitat use areas, or where they were spending most of their time. The researchers looked at where these areas fall in relation to zones where fishing is prohibited or where the sharks themselves are already fully protected in parts of the US and The Bahamas' exclusive economic zones. Their results show that currently none of the bull sharks' core use areas are protected from fishing and only 18% of the core use area of great hammerheads and 35% of the core use area of tiger sharks are protected. The region also includes important pupping and feeding grounds for several shark species. Securing their safety in these critical habitats is crucial for their sustainability.

The research was conducted by biologists at the University of Miami's Rosenstiel School of Marine and Atmospheric Science and written up by Dr Neil Hammerschlag. 'There are concerns that spatial protection may not benefit large sharks since they are highly mobile and likely to regularly move in and out of MPAs,' he explains. 'While it's not feasible to protect highly mobile species wherever they go, our findings suggest that significant conservation benefits can be achieved if these species are protected in areas where they spend the majority of their time, such as their core habitat use areas.'

Photo by Michael Scholl

LIFETIME AWARD FOR 'MADAME TORTI'

In March 2016 a Lifetime Achievement Award was bestowed on Dr Jeanne A. Mortimer by the International Sea Turtle Society (ISTS) at its 36th annual symposium, which was held in Lima, Peru. Dr Mortimer has been dedicated to the conservation of sea turtles for four decades and is best known for her work in the Seychelles, where she is known as 'Madame Torti'.

Instrumental in establishing turtle-monitoring projects at dozens of beaches and islands throughout the country, Dr Mortimer also helped to create the Turtle Action Group of Seychelles (TAGS), a network that standardises protocols, shares information and collaborates in turtle and tortoise conservation. She has been active in the Seychelles for more than 30 years and has seen the small island nation become a global leader in environmental conservation. 'I am proud of the Seychelles and of my own small contribution to helping it to achieve this success,' she says. 'Now is an exciting time to be a conservationist working in this pioneering country and I am delighted to be part of this remarkable ongoing process.'

NEW EXPOSURE

Photo by Sirachai Arunrugstichai

In early March 2016 the Save Our Seas Foundation announced the two winners of its second Marine Conservation Photography Grant, who were selected from 134 entrants. Justin Gilligan (35) and Sirachai Arunrugstichai (27) will head to Washington, DC in late June to meet *National Geographic* assignment photographer Thomas P. Peschak and *National Geographic* natural history editor Kathy Moran, who will mentor them during their assignment for the *Save Our Seas* magazine. Both winners caught the attention of the judges because of their dedication to photographing subjects in their own backyard.

Justin Gilligan is from New South Wales, Australia. His work has been published in numerous regional and international magazines, including *Australian Geographic* and *BBC Wildlife*, and he has received an impressive portfolio of awards, including *Australian Geographic*'s Portfolio Prize 2015 for the Photographer of the Year competition. Justin has an Honours degree in marine science and has worked on numerous projects with Australia's Commonwealth and State Fisheries Agencies. He recently published a photography book about the Port Stephens region in New South Wales.

Justin impressed the judging panel with his well-balanced portfolio of beautiful Australian marine biodiversity and conservation and research subjects. 'Both his story and his portfolio contain some of the best home-grown underwater images I've seen from the region,' commented Thomas, while Kathy praised Justin for a photo story that demonstrated 'strong storytelling, an interesting visual voice and lyricism'. Together these qualities combined into a top submission, she added.

Sirachai (Shin) Arunrugstichai is an emerging photographer based in Bangkok, Thailand. He has a background in

Photo by Justin Gilligan

marine biology and initially used photography to document coral reef biodiversity for researchers while working with marine conservation groups. Later he realised that his images could make a bigger impact if he created them for a more public audience. He has freelanced for several organisations and publications, including the International Union for Conservation of Nature and *National Geographic Thailand*.

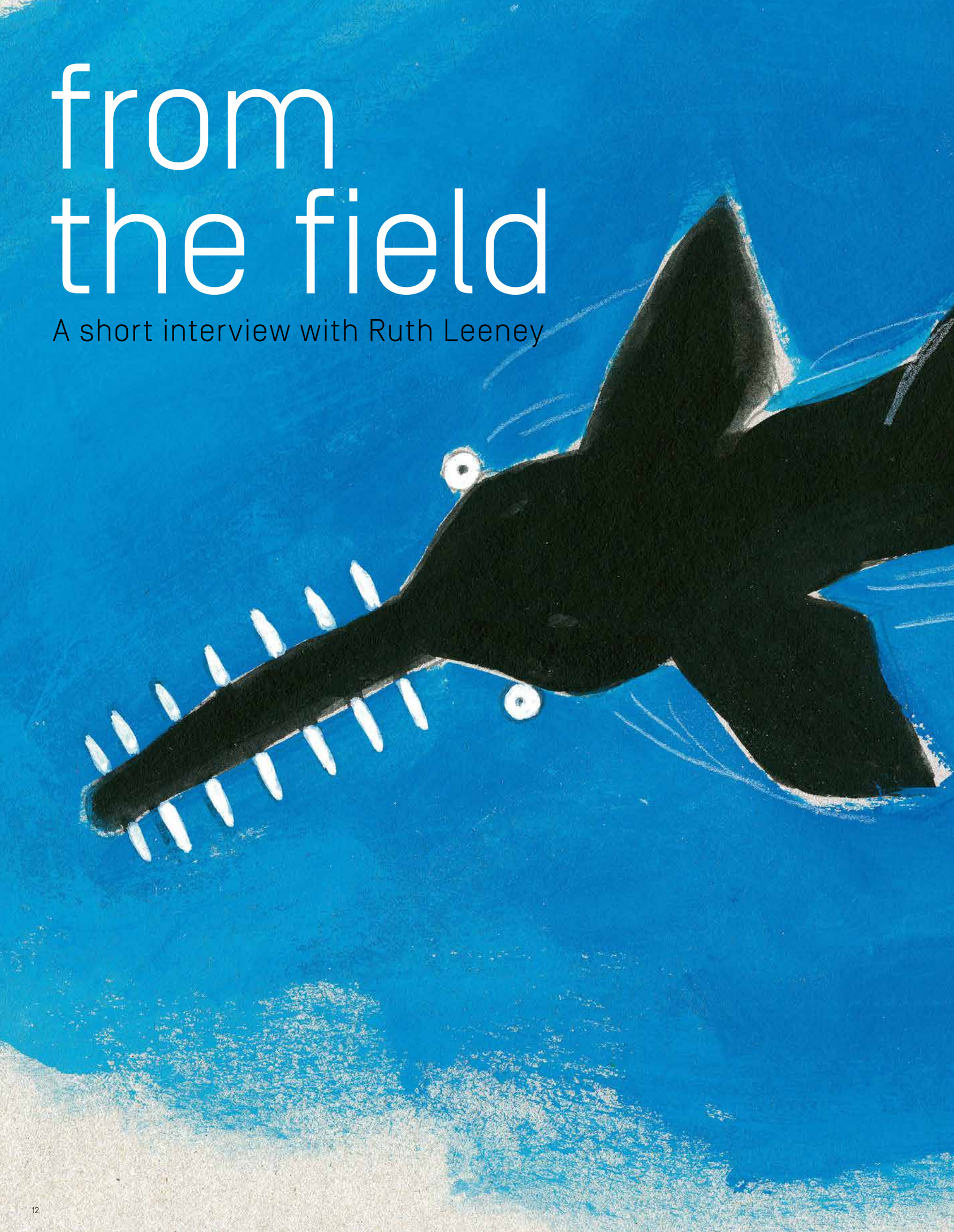
While working as a photographer, Shin has remained active in the scientific community and is researching the conservation biology of Thailand's sharks. His story 'Disappearing predator' has recently been published in *National Geographic Thailand*. He has also won numerous local awards.

Thomas commented that Shin's coverage of by-catch and overfishing 'blew him away', adding that this is 'an incredibly difficult subject to photograph'. He was also impressed by Shin's 'wonderful sense of humour'. Kathy highlighted his 'strong sense of style, narrative and understanding of conservation issues' and said that 'his story was particularly strong and highlighted his sense of narrative and the visual pacing necessary for photojournalism'.

After meeting with Kathy and Thomas at the *National Geographic* offices in Washington, DC, Shin will travel to Bimini in The Bahamas to shoot a story about the impact of development on its fragile ecosystem and Justin will head to Miami to photograph human–wildlife conflict in South Florida.

from the field

A short interview with Ruth Leeney



Artwork by Haydé Ardalan

Sawfishes are among the least understood fishes in the world. How did you become one of the few people to study them?

By accident, really. I was doing interview work in West African fishing communities to assess whether dolphins are regularly targeted as a source of food. Because of that experience, I was asked to collect interview data on sawfishes in Guinea-Bissau in 2012, which was then thought to be one of the last refuges for sawfishes in West Africa. And then I became intrigued!

There aren't many sawfishes left globally. Do they still exist in Africa?

I think they do, but I'm still searching for the photographic proof! So far I have some convincing evidence from a few sites in both Mozambique and Madagascar. Later this year I'll be sampling in some of those areas in the hope of catching a few sawfishes.

Where do you spend most of the year?

It often feels like I spend a lot of my time squashed into various forms of public transport throughout the African continent. Nowhere in particular – any place where sawfishes used to occur and where there is no up-to-date information about them.

What's the most remote place you've been to?

Probably Lac Kinkony, in north-western Madagascar. There are no roads to get there, so you travel in a crowded truck along a potholed, unsealed road for hours (depending on how often the bus breaks down) to a nearby village. Then you walk to the riverbank, get into an uncovered, aluminium shell of a boat and sit in it for another five hours while a local boatman paddles down the river, lifting the boat through narrow straits (we got out and walked the long way around through mud and thigh-deep river channels for that part). You finally emerge into the lake and cross its wide, unshaded expanse to reach one of the dispersed villages along the shore.

Why is it important that we protect sawfishes if there are so few of them left?

Sawfishes are top predators in river, mangrove and coastal ecosystems, so they help to keep these ecosystems in balance. They are also an important part of many traditional cultures in places like Australia, Guinea-Bissau and Panama, so by protecting sawfishes in such areas, we also help to conserve traditional cultures, many of which are also in danger of disappearing. But for me, it's simply because they are unique in so many ways and because if we can't save such a weird and wonderful group of species, what hope is there for the rest of the natural world?

MARINE PROTECTED AREAS

P
ER
?

Photo by Thomas Peschak

It's not a bad idea – to set aside areas of ocean, big or small, where human exploitative activities are limited or banned and in which marine life in all its diversity can be protected. It's also a very large idea, one that has pros and cons, offers many opportunities and potential pitfalls, and sparks animated debate. We have invited scientists who know most about marine protected areas to present what is known about them and how they can – and do – work.

Words by Lisa Boonzaier

NATURE RESERVES AT

The idea of setting aside a part of the ocean in which the well-being of the natural life in it can be ensured is easy to understand. It sounds very much like the nature reserves we have created on land, a concept most people are familiar with. For many decades we've been protecting areas on *terra firma*. Yellowstone, widely purported to be the first national protected area, was declared in 1872.

We've learnt that on land protected areas can help to alleviate conservation concerns – species loss, habitat loss, human–wildlife conflict – yet they are not a panacea. We know that we can't pollute our waterways, cut down forests, kill off species and wash away our topsoil *outside* protected areas – which the majority of our land is – and still expect ecological systems to continue to function and support us. We realise that we need to manage wisely the parts of the earth that aren't protected too.

To some, marine protected areas represent a silver bullet for a myriad challenges, be they related to conservation, social upliftment or fisheries. This inordinate hope we place in marine protected areas was what drew me to study them and learn about what they can really do.

For as long as I can remember, I've been fascinated by the animals, plants and landscapes around me. I've also been acutely aware, even from a young age, of the lack of balance between the wants of people and the needs of the environment. Stories of how we were mistreating our planet caused me stress and sent me on a path to contribute to a solution. After exploring science, maths, zoology, ecology and genetics during my studies, I landed on marine protected areas for my post-graduate research. I had learnt that – even though it can be difficult to imagine, with forests disappearing, climate changing, urban-scapes growing – on land we actually have a better handle on conservation than in the sea. I learnt that more than 10% of the planet's land was protected in some way, but in the sea the proportion was (until recently) closer to 1%. I saw a tool and a need.

Marine protected areas range from small, locally managed patches of coastline to unimaginably big areas of remote ocean. These latter, the giant marine protected areas of our planet, have been making headlines since the mid-2000s as countries fall over one another to designate bigger and bigger sanctuaries. Yet, despite the increasing efforts to improve the protected area coverage for our oceans, it severely lags behind that for land, with only 4% of the marine environment protected.

'So what?' you might ask. 'Why do we need to protect more of the ocean?'

Scientists generally agree that what we've protected of our oceans so far is nowhere close to what we need to protect in order to stop the loss of natural diversity. It's possible that we need around one-third of the ocean – if not more – to be off-limits to any kind of fishing and other extractive uses.

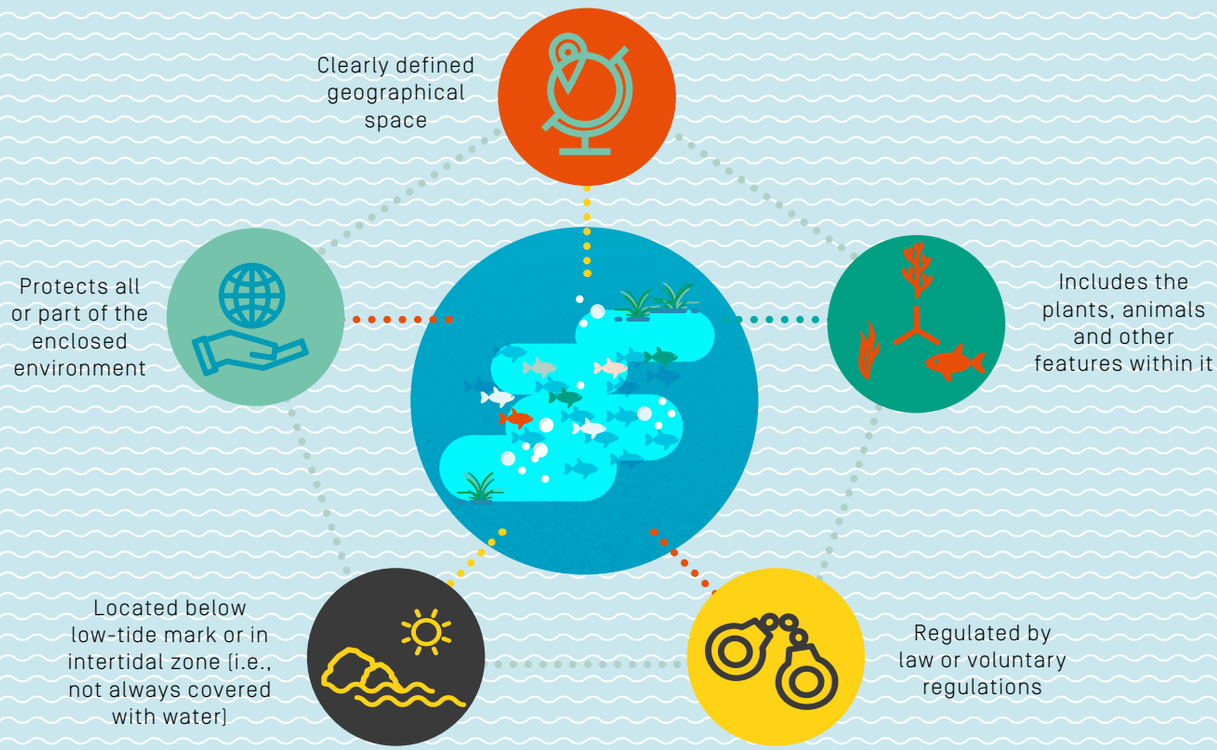
That's 62 times more than what is fully protected now.

Even this dismal figure hides an issue of concern that we know exists in relation to protected areas: they are not equal. Many people think that marine protected areas are universally closed to fishing, but this is not the case. There are many more marine protected areas that are open to extractive uses than are not. Some areas allow oil and gas extraction; others protect only one species.

Areas of the ocean from which you are not allowed to take anything – no fish, crustaceans, oil, gas, sand, nothing – are called no-take marine protected areas and they cover half of 1% of the oceans. No-take marine protected areas produce benefits in terms of the abundance, diversity and size of marine creatures within their boundaries. In fact, some research has shown that protected areas that are not closed to fishing don't look very different in terms of numbers of fish, size of fish and the diversity of species to areas that are free-for-all. But when they are closed to fishing, great things can happen.

In this *Save Our Seas* feature, that's one of the things we'll explore with Sven Kerwath, specialist scientist at the South African Department of Agriculture, Forestry and Fisheries, who led an exciting study on the benefits of the Goukamma marine protected area in South Africa to fishers and to conservation. We also have an article by Daniel Pauly from the University of British Columbia (who supervised my graduate research on marine protected areas) explaining why we need them.

What is a marine protected area?



Infographic by Ivan Colic | Afrographique

SEA THE BEGINNING

Strewn across the Pacific Ocean, far away from any mainland, is a collection of small islands and atolls that are part of the United States. Previously the sites of nuclear tests, weapons storage and other military operations, the waters of some have more recently been collectively protected under the banner of the Pacific Remote Islands Marine National Monument.

Although these islands were originally protected in 2009, 2014 saw a major expansion. In November of that year, Barack Obama increased the joint size of these marine protected areas – which at 219,000 square kilometres (85,000 square miles) was not insignificant to begin with – by almost six-fold. As much as the United States might have liked to claim the title of largest marine protected area for itself, the area is not contiguous. Earlier in the year New Caledonia, a territory of France, had declared an even bigger and truly contiguous protected area – a giant of more than 1.29 million contiguous square kilometres (498,000 square miles). That's marginally larger than the size of Peru.

These two examples of momentous ocean protection, while noteworthy, are not particularly exceptional, but track a decade-long trend of countries declaring very large protected areas in their waters. The year before, Australia declared a vast marine protected area in the Coral Sea and the UK announced the protection of the South Georgia and South Sandwich islands. And the trend is not likely to end soon. Various huge, remote protected areas are in the planning stages around Bermuda, Pitcairn, Ascension and French Polynesia, among other islands. Partly responsible for driving the creation of these large protected areas are international agreements set to encourage ocean protection. In 2006 nations party to the Convention on Biological Diversity agreed that 10% of the world's oceans should be effectively protected by 2012. But two years before the deadline, they realised it wouldn't be met and extended it to 2020.

Despite the area they add to ocean protection, these very large protected areas present concerns for human rights, for enforcement, for sustainable funding, to name a few. To tackle the subject, we've asked Matt Rand, director of the Pew Charitable Trusts' Global Ocean Legacy Project, and Peter Jones from the University College of London to air their views on giant marine protected areas.

There are many types of marine protected area, so many that it can be hard to grapple with and understand the diversity of sites encompassed by the term. I present one system that's been developed to group the thousands of marine protected areas that exist into five 'piles' according to who manages them. We briefly look at an example of each and how they are each working in their own contexts.

At one end of the spectrum are the very large, isolated marine protected areas being designated by governments; at the other lie small, community-managed marine protected areas of the sort that Steve Rocliffe at Blue Ventures is working to see implemented in Madagascar. Steve tells us how catches of octopus have soared compared to the dearth before the protected areas were created.

A salient topic for any discussion about marine protected areas is the future. We are creating these areas in today's environment, but how well will they continue to protect the oceans of the future, which are predicted to be quite different? As the climate warms, sea levels rise, species move and habitats change, will marine protected areas continue to be relevant? To answer this question, Emily Darling, a marine conservation scientist with the Wildlife Conservation Society, tells us about the future of marine protected areas in a changing world.

Follow this story as we track a path through the subject of marine protected areas. Dip in and out of our stories, graphics and photography, and learn about these places, which are creating optimism and opportunities throughout the earth's oceans.

1 million km²

The world's largest marine protected area is about the size of Peru

1.9 million km²

The world's no-take marine protected areas (not allowed to remove anything) are as big as Mexico

14.2 million km²

Total size of the world's marine protected areas - that's about twice the size of Australia

363

Approximate size of the world's oceans (in millions of km²)

OVER 6,000

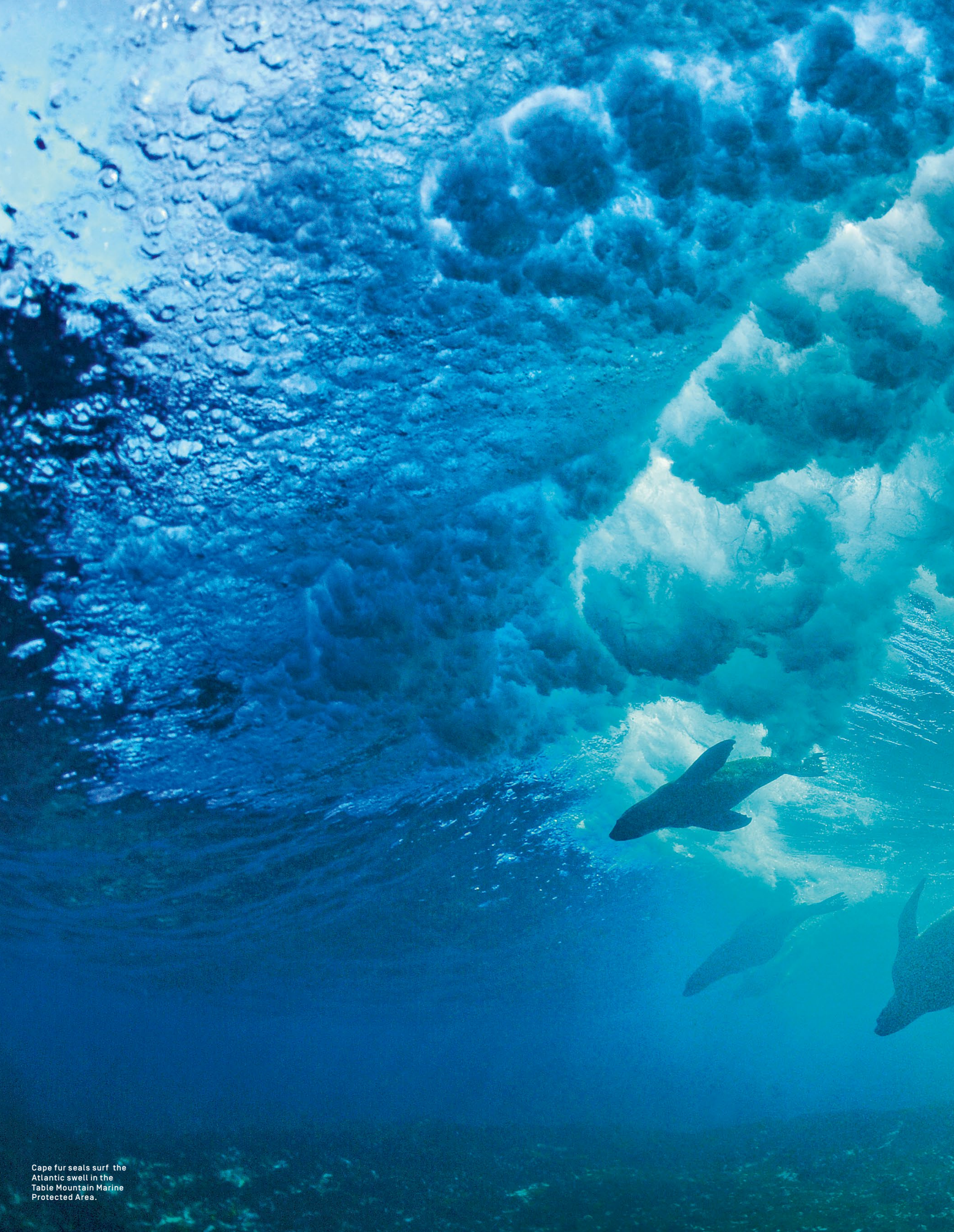
Number of marine protected areas around the world

2.2

Number of creatures and plants (in millions) estimated to live in the ocean

91%

Estimated percentage of undiscovered ocean creatures and plants



Cape fur seals surf the Atlantic swell in the Table Mountain Marine Protected Area.

Photo by Thomas Peschak

GOUKAMMA: A SUCCESS

An inspirational tale of success for both fishermen and fish has played out along the South African coast. At the Goukamma marine protected area, a beautiful, scarlet seabream found only in South African waters is benefiting from protection – and so are the fishermen who catch the species as part of their livelihood.

By comparing how things were before the creation of the protected area and how they are afterwards, Sven Kerwath, a specialist scientist at the South African Department of Agriculture, Forestry and Fisheries, and his colleagues have been able to show the effects of the Goukamma marine protected area on both fish and fishers.

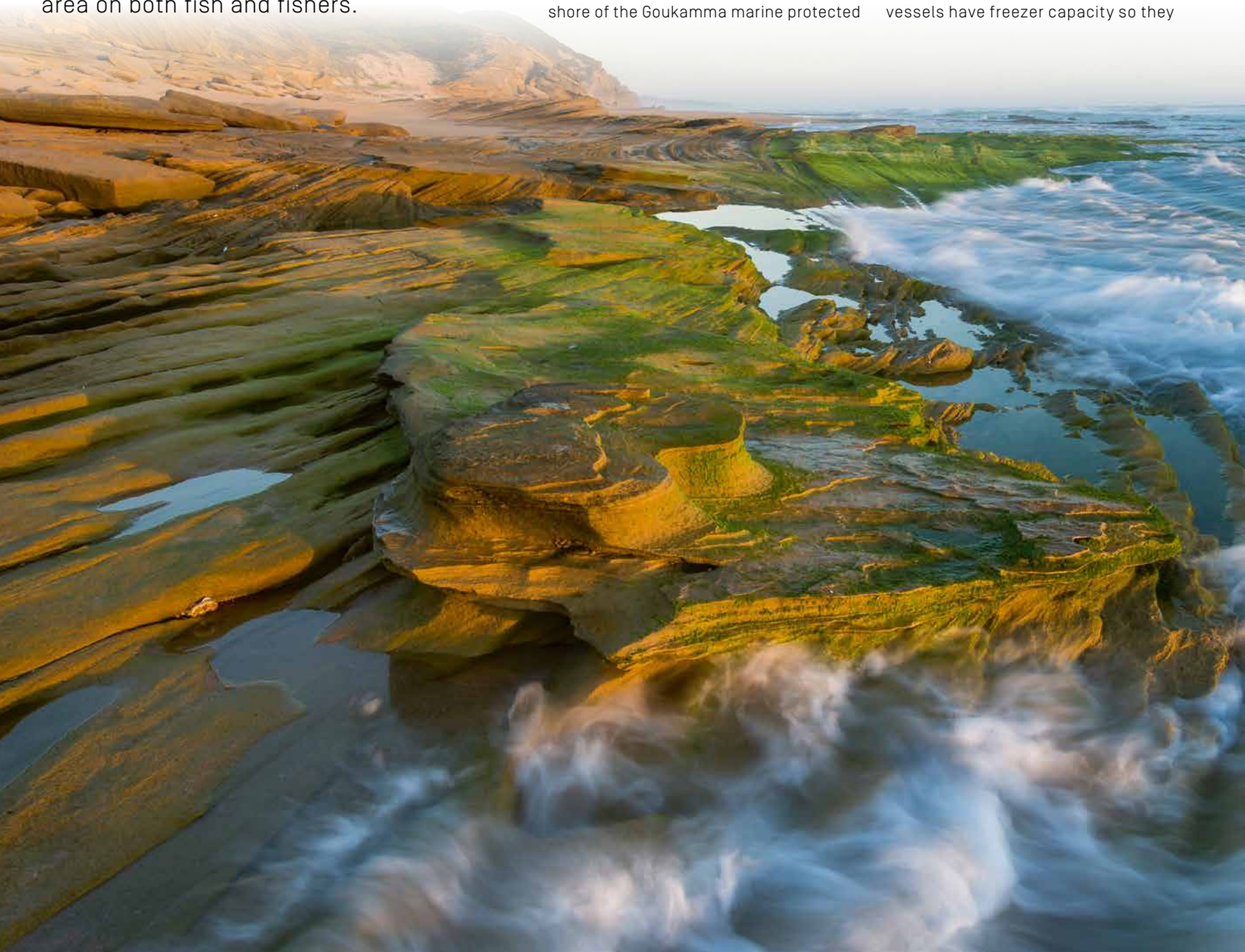
Your study looked at the effects of the Goukamma marine protected area on a specific fish species – red roman – and the local fishermen. Can you paint a picture of what it's like to be there and stick your head under water?

Goukamma is on the Garden Route along South Africa's south coast. It's a medium-sized marine reserve, about 40 square kilometres (15.5 square miles) in extent. The first thing you notice when you dive in an area like Goukamma is that there are many more reef fishes than in fished areas. You have bigger fish, in general; you have a higher diversity as well. You also have more predators. You have a fair number of shark species there.

But you are allowed to fish from the shore of the Goukamma marine protected area and the offshore boundaries are not clear to the fishermen. So there is a lot of fishing along the demarcation line and even slightly inside the protected area.

Who are the fishers around Goukamma, specifically the ones who fish for red roman, the seabream your research concentrated on?

It's a small-scale, essentially artisanal fishery, so from a livelihood point of view most of those people are on the verge of being at subsistence level. The fishing is low impact and small-scale, but high diversity. These are people who depend on the sea for their livelihoods, but over the years their boats have got bigger and slightly more industrialised. Some of the vessels have freezer capacity so they



STORY

can go out overnight and they have started targeting reef fish species, including red roman. And many of these species have since almost disappeared.

What makes the study that you led exceptional?

When I started working for the South African government, I was tasked with overseeing the assessment of the line-fishery. I found this awesome database there: basically the National Marine Line-Fish System, which has all the commercial line-fish records since 1985 from all the fishers. It's actually amazing. The proclamation of Goukamma [in 1990] is somewhere in the middle of the data series, so you have a before–after control impact study design. And that is something that doesn't exist very often around the world apparently – well, otherwise someone else would have done a similar study! And because the red roman seabream is endemic to South Africa, we can assess the entire population.

What did the creation of the Goukamma marine protected area do to catches in the area?

Firstly, the red roman population in general was in decline for many years across the species' entire range before the Goukamma marine protected area was created. That had been shown before. But the interesting thing was that after the marine reserve was established, virtually from the following year, the catches of the fishers around it started to increase, at first very slowly and then, after about five or six years, much more steeply. In all the other areas where the species lives, it either continued to decline or there was no clear trend up or down.

Red roman grow slowly and live a long time, but you still saw their catches increase just one year after Goukamma was created. How is that possible?

Inside the marine reserve, the bigger fish are not fished out, whereas outside they are fished continuously. Inside they can grow, so a difference is established quite quickly. And although fish cross the boundary, more of the smaller fish go into the marine reserve and more of the larger fish come out of it, so there is a net export of biomass.

But after five or six years – the time it takes for the fish to grow to a size that can be harvested – then you see the real effect; to my mind, the important effect. And that's the export of larvae and eggs out of the marine reserve. It was quite amazing that we could actually detect this effect in the fishers' catches.

How did the marine protected area affect the fishermen in the area?

When the marine protected area was established the fishers lost some of their fishing grounds, but because of how their access points are distributed around the reserve, the travel distance from the access points to their fishing sites didn't really change. Because they normally target a number of different reefs, there was actually little change in fishing patterns. So although it's always claimed that fishers are disadvantaged when a marine protected area is designated right on top of their fishing grounds, here it wasn't the case. In our data, we couldn't find any evidence for that.

Did these findings surprise you?

I was very surprised, firstly that what we found sort of matches what is predicted in terms of reserve effects and secondly that there was little evidence of the negative effects that people associate with marine protected areas. It's clear that this marine protected area functions like a bank. Fishers put some of their stock aside and now they reap the benefits. It takes a number of years, but not really a long time.

This well-thought-out study has shown that for small stretches of coast and for this kind of fishery, which exists all over the world, marine protected areas can be the way forward.

There are scientists and fishermen who think that marine protected areas aren't useful for managing fisheries. What do you think?

We've got about five or six different tools that we can use to manage fisheries. And marine protected areas, to my mind, are certainly one of them.

Most of our conventional fisheries regulations, like size limits or bag limits, don't really help some of the reef fish species because they are prone to barotrauma. In other words, if you pull them up from the deep their swim bladders inflate and eventually burst. They are either going to be eaten by seagulls or they are just too damaged to survive, so you can't really release any of those species. So although most of South Africa's marine reserves were not put in place exclusively for the benefit of line-caught fish, they help the stocks tremendously because they represent refuges.

I believe that it's difficult – especially politically – to establish new marine protected areas because people feel they will be at a disadvantage. To my mind, though, it's like saying, 'OK, if I put some of my money into the bank, I will be at a disadvantage because I don't have money in my pocket.' That may be true, but you have it in the bank and there it will grow and you will reap the interest, instead of incurring more debt.

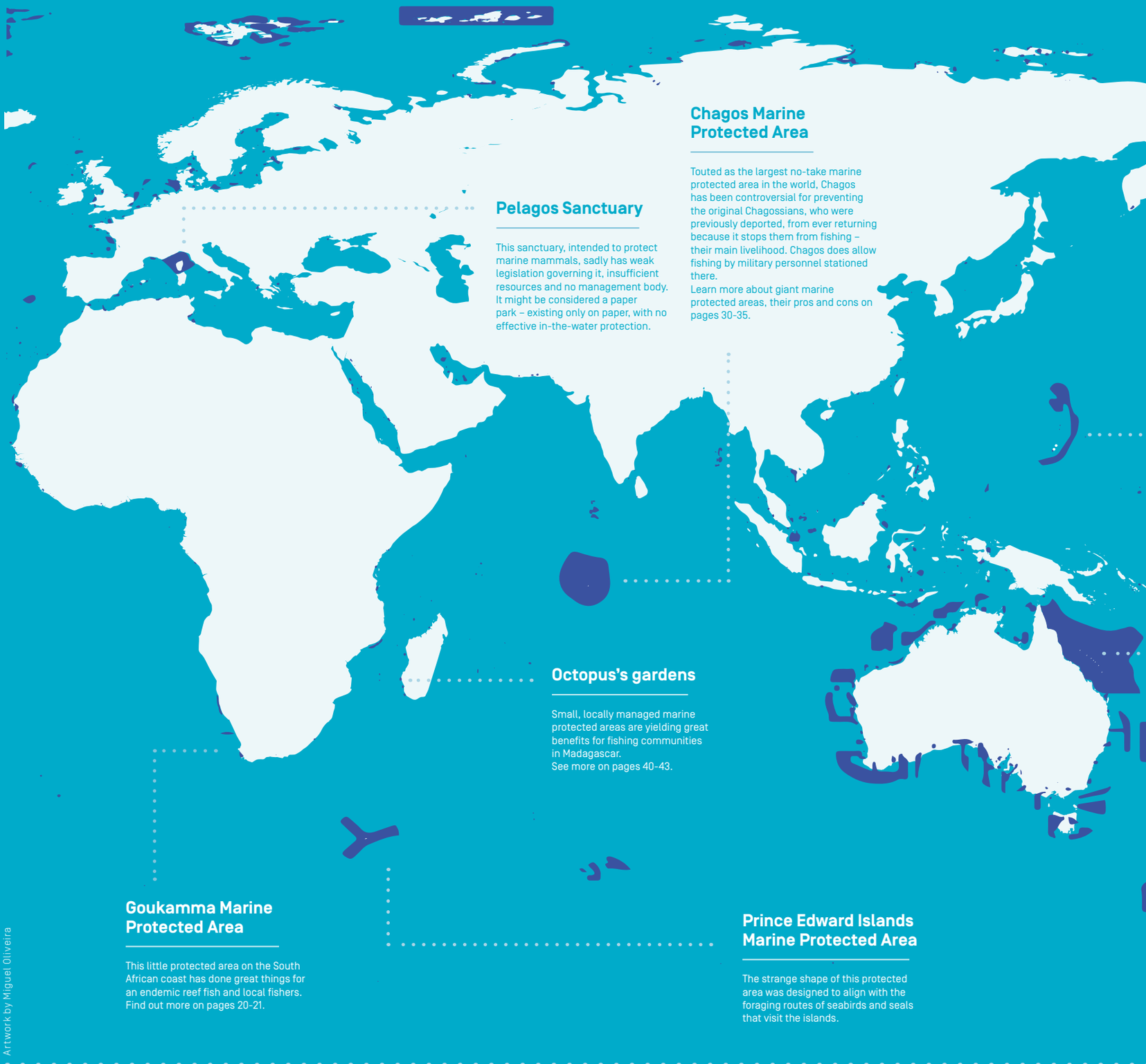
Goukamma Nature Reserve and Marine Protected Area, situated on the Garden Route, near Knysna in South Africa, has shown that carefully managed marine protected areas can become a 'savings bank' for fisheries resources.

Photo by Peter Chadwick

A potato grouper hunts among schools of baitfish that seasonally drape southern Mozambique's reefs. In the Ponta do Ouro Marine Reserve, bottom fishing is prohibited and the marine food web is relatively intact.

Photo by Thomas Peschak

WHERE IN THE WORLD



Chagos Marine Protected Area

Touted as the largest no-take marine protected area in the world, Chagos has been controversial for preventing the original Chagossians, who were previously deported, from ever returning because it stops them from fishing – their main livelihood. Chagos does allow fishing by military personnel stationed there.
Learn more about giant marine protected areas, their pros and cons on pages 30-35.

Pelagos Sanctuary

This sanctuary, intended to protect marine mammals, sadly has weak legislation governing it, insufficient resources and no management body. It might be considered a paper park – existing only on paper, with no effective in-the-water protection.

Octopus's gardens

Small, locally managed marine protected areas are yielding great benefits for fishing communities in Madagascar.
See more on pages 40-43.

Goukamma Marine Protected Area

This little protected area on the South African coast has done great things for an endemic reef fish and local fishers.
Find out more on pages 20-21.

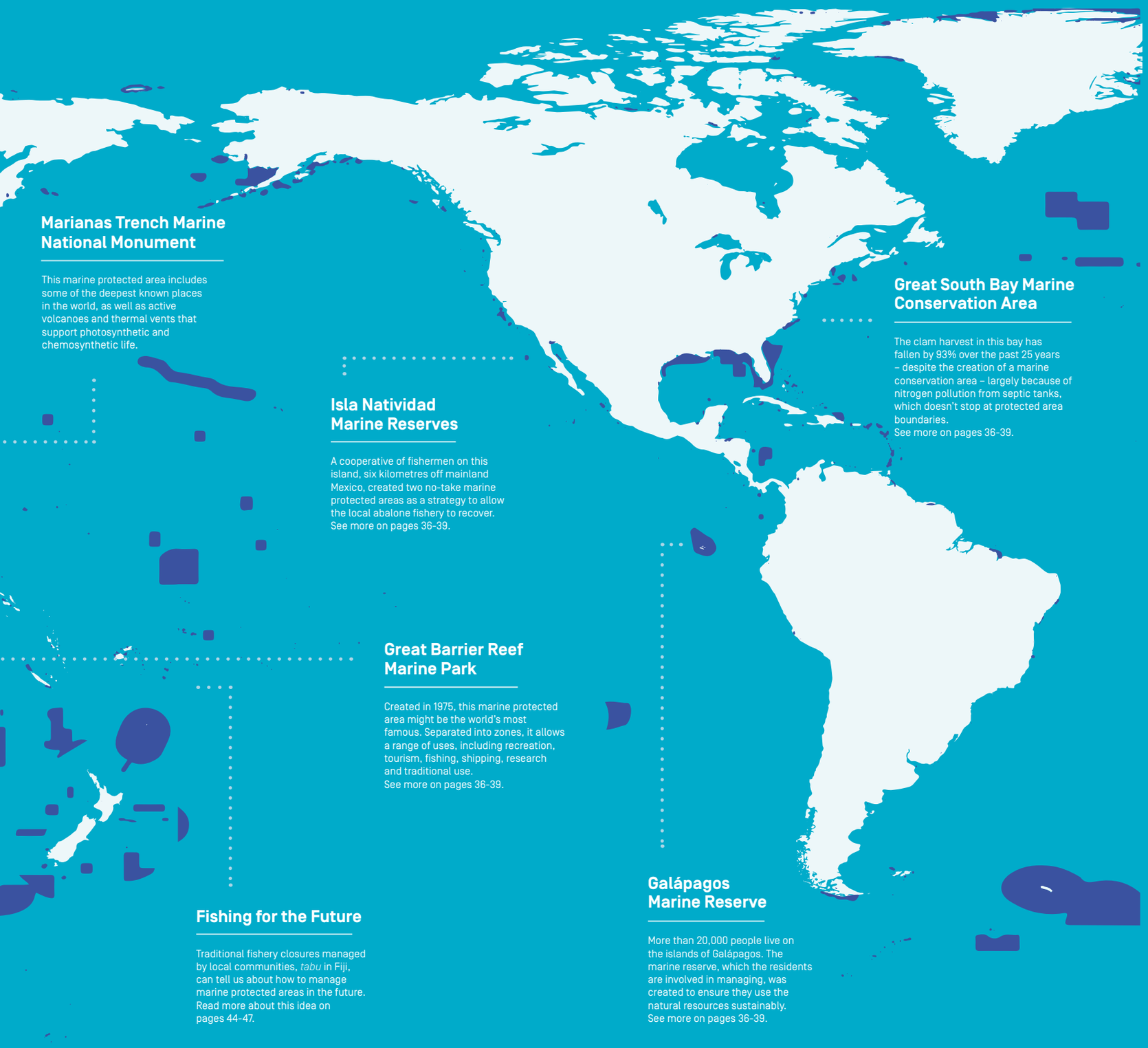
Prince Edward Islands Marine Protected Area

The strange shape of this protected area was designed to align with the foraging routes of seabirds and seals that visit the islands.

Artwork by Miguel Oliveira

Source: IUCN and UNEP-WCMC (2013). The World Database on Protected Areas (WDPA) Official Map Series: Marine Protected Areas. Series M01. WDPA October 2013 Release.

Marine protected areas large and small – many too small to be seen at this scale – have been created around the world. This map shows our progress in protecting our oceans up to 2013, according to information from the World Database on Protected Areas.



Marianas Trench Marine National Monument

This marine protected area includes some of the deepest known places in the world, as well as active volcanoes and thermal vents that support photosynthetic and chemosynthetic life.

Isla Natividad Marine Reserves

A cooperative of fishermen on this island, six kilometres off mainland Mexico, created two no-take marine protected areas as a strategy to allow the local abalone fishery to recover.
See more on pages 36-39.

Great South Bay Marine Conservation Area

The clam harvest in this bay has fallen by 93% over the past 25 years – despite the creation of a marine conservation area – largely because of nitrogen pollution from septic tanks, which doesn't stop at protected area boundaries.
See more on pages 36-39.

Great Barrier Reef Marine Park

Created in 1975, this marine protected area might be the world's most famous. Separated into zones, it allows a range of uses, including recreation, tourism, fishing, shipping, research and traditional use.
See more on pages 36-39.

Fishing for the Future

Traditional fishery closures managed by local communities, *tabu* in Fiji, can tell us about how to manage marine protected areas in the future.
Read more about this idea on pages 44-47.

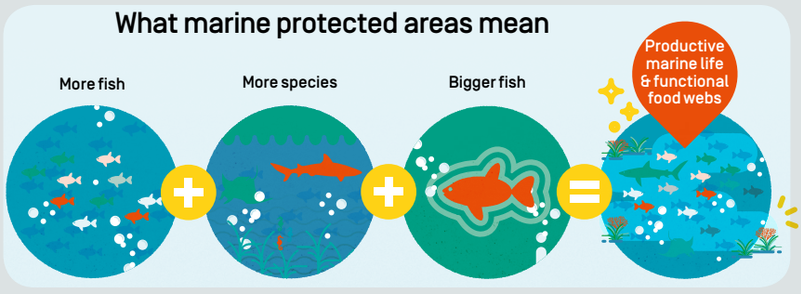
Galápagos Marine Reserve

More than 20,000 people live on the islands of Galápagos. The marine reserve, which the residents are involved in managing, was created to ensure they use the natural resources sustainably.
See more on pages 36-39.

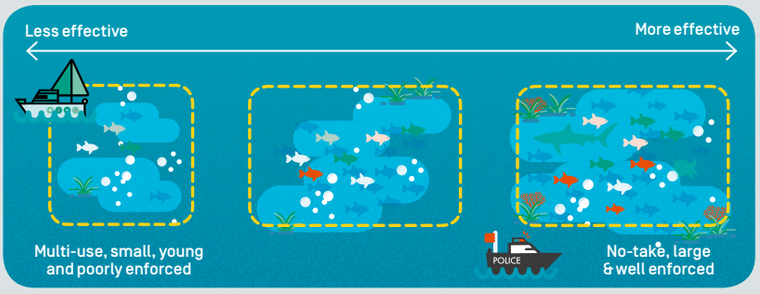
Map available at: *www.protectplanetocean.org*; WDPA available at *www.protectedplanet.net*

Feeding frenzy: whitetip reef shark feeding in the Maldives. The island nation declared its waters a sanctuary for sharks in 2010.

Photo by Mohamed Shareef | Getty Images



Inside well-managed marine protected areas, there are more animals and plants, a greater diversity of species and bigger individuals. Together these mean more marine life, higher productivity, functional food webs and healthier ecosystems.



Not all marine protected areas are closed to fishing. Some are no-take areas from which nothing may be removed, whereas others have multiple regulations controlling the activities allowed to take place. No-take marine protected areas are more effective than those that allow extractive activities.

AN ANTIDOTE TO HIGH-TECH FISHING

Words by Daniel Pauly

Daniel Pauly has been described as a rock-star scientist and I was fortunate enough to be guided by this eminent researcher through my graduate studies. Describing how industrial fishing has decimated fish stocks over the past 130 years, he explains why marine protected areas are needed to conserve some species and enable others to recover.

Industrial fishing began in the 1880s, when steam trawlers started to be deployed along the coasts of the British Isles. Frighteningly efficient, they soon liquidated coastal stocks of bottom fish – fish that had previously been exploited by subsistence and artisanal fisheries for centuries, even millennia, but had persisted.

The steam trawlers then had to expand their range into the open North and Irish seas and subsequently beyond, all the way into North Atlantic and Icelandic waters. The same expansion, but shifted a decade or so later, occurred with the nascent industrial fisheries of France, Germany, Russia, the United States and Japan. It's a recurring pattern: the introduction of industrial fishing begets expansion because trawlers and other industrial fishing vessels (such as purse seiners) generate a pressure that generally cannot be tolerated by the species being targeted at a given fishing ground – and even less by the by-catch species, which are, by definition, subjected to unregulated fishing. Thus, one stock disappears after the other, and new stocks in previously unfished areas have to be found.

This depletion–expansion dynamic prevailed through much of the 20th century, albeit with the interruption of two world wars, which radically reduced industrial fishing and allowed fish to recover – if only temporarily – especially in the North Atlantic. In some areas, when this effect was strong, like in the North Sea, the recovery after a temporary reduction in fishing established the principle not only that stock abundance was inversely related to fishing intensity, but also that overfished stocks could recover, and some within a few years. In the last quarter of the 20th century, some countries, for example the US and Norway, built on this to counter the depletion–expansion dynamic of their fisheries. They allowed the stocks they had overexploited to rebuild, which the stocks did and now support vibrant 'new' fisheries.

In most other countries, however, the depletion–expansion dynamic continued. Thanks to their onboard technology, trawlers and other industrial vessels could fish anywhere in the world, in deep or shallow waters or far from coastlines, and in conditions from tropical to polar. These developments meant that previous obstacles to fishing – depth, distance, ice cover and inclement weather – could now be overcome. We could fish everywhere, anytime we wanted. And we did.

As a consequence, essentially all fish resources in the world are being fished. Given that most of the world's fisheries are not managed (or that their management is so ineffectual as to be non-existent), this also means that fish with characteristics that render them more vulnerable to fishing than other species, or which are highly sought after, are increasingly under the threat of extinction. This is particularly well illustrated by the sawfishes (*Pritis* spp.), whose long, saw-like rostra get caught in any net they encounter; by the manta rays now hunted because of the alleged curative value of their gill plates; or by the many species of large sharks being decimated by targeted fishing, driven by the high commercial value of their fins, which are used for shark-fin soup.

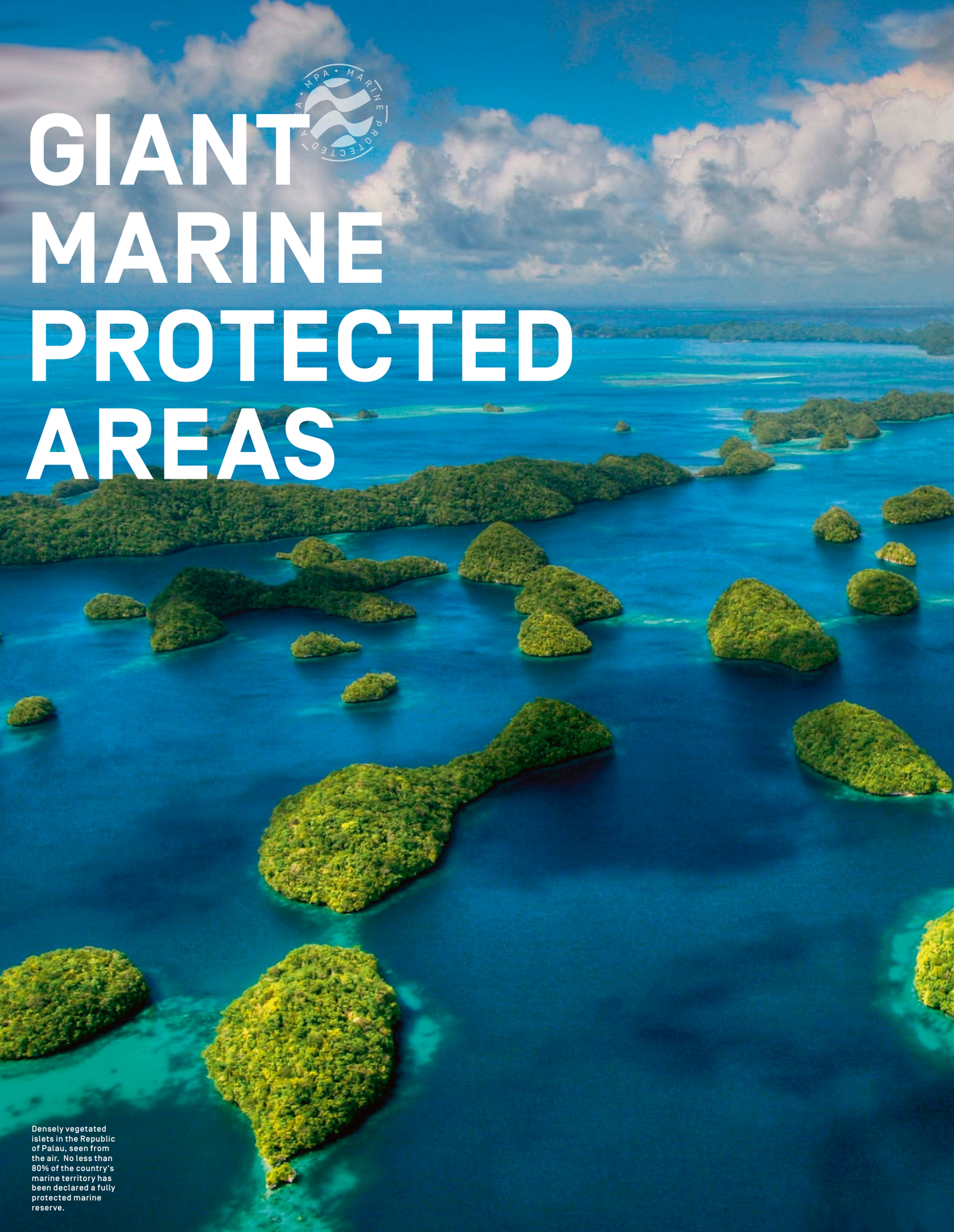
These species cannot withstand any fishery that is anything but extremely well managed (which is rare), and they will thus thrive only in the few places where they are left alone. Such places are marine protected areas or, more precisely, no-take marine reserves. Moreover, in addition to sheltering the biodiversity that sawfishes, manta rays and large sharks represent, marine protected areas safeguard thousands of other species – and the ecosystems in which they are embedded – from the depredations of industrial fisheries that are driven by an increasingly out-of-control demand, especially from East Asia and the rich countries of Europe and North America.

That marine protected areas are effective in protecting marine life is amply demonstrated in the scientific literature: within them, biomass and biodiversity are higher and individual fishes are larger, thus producing more eggs and larvae that can enrich surrounding areas. This is not surprising. After all, fishing removes fish from the ecosystem; thus ceasing to fish, given time, should reverse its effects.

There are obviously a number of factors that intervene in the effectiveness of the protection afforded by marine protected areas, such as the degree to which the regulations protecting biodiversity are enforced, the size of the protected area and the fishing activity surrounding the protected area. Nevertheless, the principle holds that marine protected areas, and especially no-take marine reserves, are our best defence against the depletion–expansion dynamic that characterises industrial fisheries, especially now that they are operating in all ocean areas.

It is thus encouraging that the fraction of the oceans that was protected by a motley collection of small, often ineffective marine protected areas, and whose growth had long been anaemic, has increased massively in recent years. This occurred through the creation of very large marine reserves around uninhabited islands in the Pacific and Indian oceans. The constructive example that these reserves provided has even jump-started a debate about the feasibility of protecting the High Seas, or at least some parts of the oceans currently beyond national jurisdiction, which we must do if they are not to be transformed to a seascape with more plastic than fish.

GIANT MARINE PROTECTED AREAS



Densely vegetated islets in the Republic of Palau, seen from the air. No less than 80% of the country's marine territory has been declared a fully protected marine reserve.

Very large and remote marine protected areas are popping up in the oceans and in the media. Are they valuable for the health of marine life and of humanity? We asked Matt Rand, director of the Pew Charitable Trusts' Global Ocean Legacy Project, and Peter Jones from the University College of London to tackle the subject.

- Helping to reverse a downward trend
- Taking us down the wrong path?

Photo by Tan Yilmaz / Getty Image

Let's get the bad news out of the way: our oceans are imperilled. Some estimates indicate that 90% of global fish stocks are either fully exploited – that is, at their maximum catch potential – or overexploited. Illegal fishing accounts for up to US$23.5-billion of the world seafood market every year, or about one in five fishes taken from the ocean. Acidification and warming threaten all coral reefs and are changing the chemical balance of the seas. Some form of human activity occurs on almost every parcel of the ocean, often with destructive consequences.

As a fisherman, scuba diver and kayaker, I have seen the evidence at first hand: fewer fish in the water than in decades past, visible pollution on and beneath the surface and vast areas of dead coral where dazzling reefs once thrived. Not only do these effects hurt biodiversity, they also threaten humans, especially people who live in small island nations that depend on a healthy ocean for food, jobs, tourism, traditions and community cohesion.

Now for the good news: in some parts of the ocean, the establishment of large, fully protected marine reserves is reversing these trends. By creating huge ocean sanctuaries that have complete protection from fishing and other industrial activities, local people and governments are helping entire marine ecosystems to cope with and recover from unexpected environmental changes. In fact, in 2015 more of the ocean was protected through new reserves than during any previous year in history. These efforts were led by communities and governments in the Pacific, including Palau, Easter Island, the Pitcairn Islands and New Zealand's Kermadec region.

Large, fully protected marine reserves help the ocean and coastal cultures by:

- **Safeguarding biodiversity.** Studies of more than 120 marine reserves around the world found that reserves result in average increases of 21% in the diversity of life and 28% in the size of fishes and other marine organisms. They also have, on average, 450% more biomass (the total weight of marine life) than is found in unprotected areas. Reserves can be particularly valuable in protecting threatened, endangered or unique marine life.
- **Providing ecological benefits to neighbouring unprotected ecosystems.** Marine animals move freely into and out of protected waters. Because nearby areas often have lower biodiversity than reserves do, this movement can help improve biodiversity and maintain ecological balance in the areas around reserves.
- **Protecting predators and maintaining ecosystem stability.** Recent science published in *Ecology Letters* highlights the critical role that healthy populations of large marine predators play in stabilising ecosystems and rebuilding healthy food webs. Marine reserves can help build these populations. At one site in the Philippines, predatory fish biomass continued to increase exponentially 18 years after the establishment of a reserve. These ecosystems are then better able to cope with and recover from unexpected environmental changes.

A study published in February 2014 in the journal *Nature* (see citation on page 35) found that large, highly protected, isolated, well-enforced and long-standing marine reserves have 14 times as much shark biomass, twice as many large fish and five times as much fish biomass as do unprotected areas.

But that's not all. Over the past decade I have been privileged to work with coastal communities – including some very remote ones that are home to indigenous people with traditions deeply rooted to the ocean – on the creation of reserves. For some cultures, including many in the Pacific, protecting the environment honours long-held practices and beliefs. And in every case, the local people led the charge to preserve a healthy ocean environment that would continue to support their communities.

Those instincts are sound. Research shows that marine reserves:

- **Support local economies.** Vibrant, healthy oceans attract tourism, which is critical to many island communities. For example, more than half the visitors to Palau go there for diving, an activity that generates about US$90-million each year for the nation's economy.
- **Strengthen reefs, thus making coastal areas more resilient to storms.** A study published in 2013 in *Conservation Letters* found that marine reserves that prohibit fishing for parrotfish may make coral reefs six times more resilient to coral bleaching. That effect, when bolstered by other actions to mitigate warming waters, could reduce the amount of reef lost to storm damage by one-third. Other research has shown that healthy coral reefs reduce risks to coastal areas from storms, flooding and erosion. Nearly 200 million people living near coasts worldwide could benefit from the risk reduction provided by healthy reefs.

As Palau's President Tommy E. Remengesau Jr. said upon signing the law that designated 80% of his country's marine territory a fully protected marine reserve, 'Island communities have been among the hardest-hit by the threats facing the ocean. Creating this sanctuary is … essential to our survival.' The 500,000-square-kilometre (193,000-square-mile) reserve in Palau's waters, and the remaining 20% of the country's waters that were set aside for domestic fishermen, will help provide food security to the island nation and ensure that its centuries-old traditions survive.

The evidence is clear: giant marine protected areas help to increase fish populations, restore ocean health and improve the lives of people, all of which are critical factors given that the ocean covers nearly three-quarters of the planet and is essential to life on earth. It helps regulate global chemistry and climate and is home to more than two million species, many of which still await discovery. This rich biodiversity enhances the fisheries that provide food for more than four billion people around the world.

But right now only 2% of the ocean is fully protected in no-take marine protected areas, a mere fraction of the 30% protection that leading scientists say is needed to ensure a sustainable marine environment into the future. Increasing the area of ocean protected by reserves is a critical element of a broad conservation strategy. Reserves work and are a key tool for addressing many challenges to the ocean's health.

An ancient Moai statue on a hillside at night on Easter Island (Rapa Nui) in the south-eastern Pacific Ocean. The island falls within Chilean territory and its government has proposed the Easter Island Marine Park, which would protect more than 630,000 square kilometres of ocean.

Photo by Randy Olson | National Geographic Creative

Words by Matt Rand

HELPING TO REVERSE A DOWNWARD TREND

Words by Peter Jones

TAKING US DOWN THE WRONG PATH?

Illegal fishing poses a major threat to Palau. In June 2015, the government burned four Vietnamese 'blue boats' that were caught fishing illegally and found with a number of protected species on board. Because the Palau National Marine Sanctuary now exists, it is easier to identify and stop illegal fishing in the country's exclusive economic zone.

Targets for marine conservation have been important since 1998, when 1,605 scientists from around the world signed a call for governments to protect 20% of the world's seas from all threats by 2020. Since then, several formal targets for marine protected area coverage have been announced. The most significant of these is the Convention on Biological Diversity's Aichi target, which stipulates that at least 10% of the world's seas should be effectively conserved through systems of marine protected areas by 2020.

Increasingly, the targets have been achieved by designating giant marine protected areas, often around remote islands. The first of these was the 340,000-square-kilometre (131,275-square-mile) Northwestern Hawaiian Islands Coral Reef Ecosystem Reserve, designated in 2000 and larger than all of the United States' national parks combined. This giant marine protected area was later included in the Papahānaumokuākea Marine National Monument, which is even larger at 362,000 square kilometres (139,800 square miles). Initially open to bottom trawling, the area was protected from all fishing in 2011 because, although 'bigger is better', it is also considered that 'no-take is best'. The race was on.

There have been many more designations in the competition to declare the largest marine protected areas in the world and add to the list of 'flagship' giant sanctuaries. Many governments have joined in the race and it has been enthusiastically supported by conservation campaign groups and donors – all keen to gain the green credentials associated with such designations. This has led to 80% of global marine protected area coverage being contained in just 16 such large, remote reserves, so without them we would be even further from achieving the 10% target. Recent research on the effectiveness of marine protected areas* provides scientific evidence to support the race. It found that there are five key features of marine protected areas that promote the achievement of effective conservation: they need to be large, well enforced, no-take, old and isolated from areas that are fished. However, a related paper argues that marine protected areas are increasingly biased towards remote areas that haven't been

Photo by Jeff Barabe | The Pew Charitable Trusts

commercially exploited. This means that they can often be closed with limited political costs (they tend to be remote, in overseas territories where few, if any, voters live) and with relatively small economic costs (commercial exploiters tend to be foreign fishing vessels).

From the perspective of national governments, it is clear that giant and remote marine protected areas are win-win in that they gain green credentials and contribute to achieving the Aichi target. Why go through the politically and economically expensive process of designating small marine protected areas around the mainland when you can designate vast marine protected areas in overseas territories with minimal costs and many gains? From the perspective of conservation campaigners and donors, such sanctuaries deliver high-profile benefits in that they safeguard large areas of relatively pristine sea from the pressures of the fishing industry. The persuasiveness of such rationales is evident in the growing number of them and the proportion of global marine protected area coverage that they represent.

There are, however, several major problems with this trend, as the Aichi target is about much more than coverage. It states that marine protected areas must be effective in that restrictions are enforced – but vastness and remoteness pose major challenges to enforcement. Although emerging technology that uses satellite surveillance can help to detect illegal fishing vessels, it is still difficult to intercept them with fisheries patrol boats (which are very expensive to operate in out-of-the-way areas) or by gaining enough evidence remotely to secure a guilty verdict in court. Detection alone is not enough; vessels must be detained, sufficient evidence gathered, successful prosecutions achieved and penalties applied that are sufficient to deter other fishers. There are concerns that the pace at which the giant marine protected areas are being designated exceeds the pace at which enforcement capacity is being developed, and that some are 'paper parks' that provide only an illusion of marine conservation.

The Aichi target also specifies that systems of marine protected areas should be representative in that they protect typical examples of species and habitats in each of the world's marine bioregions. They should also be close enough to one another that ecological processes can be connected. Focusing on a few very large and remote marine protected areas will not achieve representative and well-connected networks of marine protected areas, as they will always be patchy and separated by large expanses of unprotected ocean. Inshore 'metropolitan' seas with lots of users represent a challenge, but such areas need to be included in marine protected area networks if the latter are to be representative and well connected. It could also be argued that it is important to conserve places that are under pressure and that people rely on, even if such marine protected areas may have to be smaller and provide for some fishing. Marine conservation should be as much about promoting sustainable use in metropolitan seas as it is about promoting no use in remote, residual seas.

Last but certainly not least, the Aichi target states that marine protected area networks should be equitably managed, in that their costs and benefits should be fairly distributed. Giant and remote marine protected areas are inclined to be located where only a small number of people live, yet these people tend to depend heavily on marine resources. It would therefore be unfair to close the area to extractive activities. Although such people may be politically remote, their rights should not be marginalised by marine protected areas.

The race to designate marine protected areas that are vast and remote could be slowing progress towards achieving the Aichi target for effective, representative, well-connected and equitable networks of marine protected areas. It may even be taking us down the wrong track. It's clear that in the same way that marine protected areas need to conserve a diversity of species, networks of them need to include a diversity of types of protected areas – not only giant ones, but also smaller ones in metropolitan seas that promote sustainable use. It is important that the race towards giant marine protected areas does not divert attention, resources and political will away from the other types of sanctuary that are necessary for fulfilling marine conservation targets.

* Edgar GJ et al. 2014. Global conservation outcomes depend on marine protected areas with five key features. *Nature* 506: 216–220: doi:10.1038/nature13022

A MOTLEY COLLECTION

Words by Lisa Boonzaier

An aerial view of the Great Barrier Reef, Queensland, Australia.

The diversity of marine protected areas that exists can be so mind-boggling that I sometimes find it difficult to imagine how they were ever grouped under one name! That name, 'marine protected area', broadly describes any part of the ocean that has been set aside for the conservation of nature. Some people consider these places true marine protected areas only if they are permanent; others recognise only no-take marine protected areas. Marine protected areas may only protect the sea floor, or conversely, only the water column above. They can be managed by governments or communities, NGOs or private enterprises. They can also be managed jointly.

A marine protected area for one species? Yes, that exists. Marine protected areas where trawling is allowed? They exist too. Marine protected areas smaller than 0.5 square kilometres (0.2 square miles)? Those exist. A marine protected area bigger than a country? Yup, that's a real thing too.

One of the most useful ways for thinking about types of marine protected areas that I've come across splits them into groups based on who looks after and manages them, and how. This is not a perfect system – there is a continuous range of types of management for marine protected areas – but it helps to explain the diversity of protected areas in the ocean and group them into like piles, even if they are artificially neat.

Managed by government

Great Barrier Reef Marine Park, Australia
Darwin Mounds candidate Special Area of Conservation, UK
Governments are the agencies mainly responsible for managing these marine protected areas. They have well-defined goals and rules, and the responsibilities of government and the obligations of the public are clear. These types of marine protected areas seem to be more common in economically developed countries with strong governance.

The Great Barrier Reef Marine Park (pictured) is one example of a marine protected area managed primarily by government, but where there is still space for public involvement. During the process of rezoning the Great Barrier Reef Marine Park between 1999 and 2004, a consultation process garnered more than 31,000 submissions from the public – one of the most comprehensive public consultation processes in Australia's history.

Community-led

Isla Natividad marine reserves, Mexico
Os Miñarzos Marine Reserve of Fishing Interest, Spain
At these marine protected areas, local communities take a lead in sustainably managing marine resources, which are essential for their social and economic well-being. External organisations, like NGOs or government agencies, might still have an important role in supporting these community-led initiatives, though. This approach can be effective in certain contexts, particularly when the sustainable use of resources rather than the conservation of biodiversity is the main objective. At Isla Natividad, Mexico, the main objective of the two marine reserves, voluntarily established by the local fishing cooperative, is to rebuild numbers of abalone in the island's fishing grounds. The regulations are enforced by the cooperative, which also manages the reserves.

Photo by Paul Chesley
National Geographic Creative

Managed by non-governmental and private organisations

Great South Bay Marine Conservation Area, United States
Chumbe Island Coral Park, Tanzania
Non-governmental or private organisations are mainly responsible for managing and enforcing these marine protected areas. Part of Great South Bay on the east coast of the United States, less than 100 kilometres (62 miles) from downtown New York, has been managed by the Nature Conservancy for 13 years. It aims to re-build the clam and sea-grass beds that used to line the bay's floor. Although clam-stocking programmes showed promise for increasing the number of young clams in central Great South Bay, major threats originating from coastal land use and pollution continue. The Nature Conservancy is working with governments and communities to address the broader land-based impacts both within and outside the protected area.

Managed jointly

Galápagos Marine Reserve, Ecuador
Seaflower Marine Protected Area, Colombia
Tubbataha Reefs Natural Park, Philippines
To manage these marine protected areas, central governments share authority and responsibility with lower levels of government or private or non-governmental organisations. This approach seems to be characteristic of less economically developed countries where there is a degree of commitment to conservation, but weak government capacity. The Galápagos Marine Reserve is one of these marine protected areas where locals involved in tourism, fishing and guiding, as well as environmental NGOs and scientific bodies, are included in decision-making through participative management boards.

Others: no clear management

Sadly, there are more protected areas without any clear governance in the ocean (and on land) than there should be. Lack of political leadership and capacity hinders the development of effective governance and enforcement for these sites. Research from 10 years ago showed that just 9% of marine protected areas on coral reefs effectively prevented poaching in their waters and that less than 0.1% of the world's coral reefs lay in marine protected areas that were able to prevent extractive activities (that is, no-take areas without poaching). Marine 'protected' areas like this are generally no different to other parts of the ocean.

This system for classifying marine protected areas and the associated examples were drawn from the work of Peter Jones and colleagues in their development of a framework for analysing marine protected area governance approaches (*www.mpag.info*).

A school of scalloped hammerhead sharks *Sphyrna lewini* on the surface at Malpelo Island off the Pacific coast of Colombia. The vast marine protected area surrounding the island is a no-fishing zone and provides critical habitat for threatened species.

Photo by Tobias Friedrich | SeaPics.com

OCTOPUS'S GARDEN IN MADAGASCAR

Words by Steve Rocliffe

The Vezo ancestors can be surprisingly fussy drinkers. Among these master seafarers, lemonade and *Fanta* are appreciated, *Coca Cola* is not. On an isolated sandbank off Madagascar's south-western coast, the small group of village elders I'm with swig mouthfuls of orange and yellow fizz from sticky bottles warmed by the heat of the day. Venance, the village president, sprinkles rum into the sea, offering thanks for the undersea bounty he hopes the community will receive.

The broad reef flat that abuts this remote bank has been closed to octopus fishing for the past two months, but today it is to be reopened. Hundreds of fishers from Venance's village of Andavadoaka have turned out for the occasion and are waiting expectantly for the ceremony to conclude. Their brightly painted canoes are drawn up on the foreshore nearby, patched sails flapping in the light breeze.

Despite the recent arrival of high-speed mobile Internet, this part of Madagascar feels remote. The potholed tarmac on the drive here ended before sunrise yesterday, a few miles north of the regional capital of Toliara. Over the seven hours that followed, our 4x4 shuddered its way along a rutted sandy track, through forbidding thickets of spiny plants found nowhere else on earth.

Andavadoaka's isolation is part of its appeal. The Vezo fishers who first migrated here discovered a submarine world of astonishing abundance and diversity. Fishing trips to the expansive coral reefs lying just offshore yielded pirogues filled to the gunwales with the weight of the day's catch. Villagers

didn't dare to swim at dawn or dusk because of all the sharks.

But this underwater Eden was not to last. In recent decades, overfishing, climate change and population growth have steadily emptied these waters, not only putting at risk the food supply and livelihoods of tens of thousands of people, but also endangering the fragile reefs of an island so rich in unique plant and animal life that it is known as the eighth continent.

With their existence under threat, the Vezo have not sat idly by as this crisis has unfolded. Aptly for a people whose name translates as 'those who struggle against the sea', they've fought back, village by village. With the support of British marine conservation organisation Blue Ventures and the assistance of an unlikely eight-legged ally, they're working to return these seas to abundance.

Photo by Garth Cripps

A Vezo fisherman sails out to a reef flat to fish for octopus. For such fishers, who live in very isolated communities, octopus is one of the few ways of earning cash. It keeps for much longer than fish does, and so can be trucked out on ice by commercial collectors and exported to Europe and Japan. The demand from international markets for seafood has driven overfishing even in such isolated places as this fishing village in south-western Madagascar.

In this part of Madagascar, octopus is a vital source of food and income for local communities. Catches that aren't eaten locally are exported all the way to the dinner plates of southern Europe. Yet a decade ago, octopus stocks were in trouble. With concern for this important resource mounting, Andavadoaka's village elders and Blue Ventures hatched a radical plan that would see them temporarily close a small reef to octopus fishing. Since octopuses grow fast but die young and because the bigger they are the more eggs they produce, a ban of just a few months should help numbers to rebound, they reasoned.

The plan worked. When the closure was lifted, fishers caught far larger octopuses – and far more of them. So impressive were the results that, before long, nearby villages were establishing closures of their own. And within three years, Andavadoaka had joined forces with two dozen neighbours to create a locally managed marine area known as Velondriake, a Vezo word meaning 'to live with the sea'. Across an area of reefs, lagoons, mangroves and sea-grass beds the size of a quarter of a million football pitches, destructive practices such as poison fishing have been banned, while marine reserves permanently off limits to all fishing have been established.

But that isn't the end of the story. Inspired by the success of Velondriake, coastal communities across the country have followed suit, grouping together to establish more than 60 similar initiatives. This growing network now covers over 11% of Madagascar's seabed and has even received a seal of approval from the highest level of government. President Rajaonarimampianina has endorsed this locally centred revolution as a way of helping to protect ever greater swathes of the fragile waters that lap Madagascar's shores.

Back on the sandbank at the heart of the Velondriake, the tide reaches its lowest ebb. Venance polishes off the rest of the rum and, with a dramatic pause worthy of Harold Pinter, proclaims the reef open to fishing once more. Amid much cheering, the large crowd of fishers quickly disperses across the immense reef flat, faces painted yellow with a natural sunblock of ground bark. Under the beating sun, they scour the shallows for the dens that house their elusive prey, using spears to deftly extract impressively large creatures from improbably tiny holes.

For these fishers, seafood is the only source of protein in almost every meal – and even one meal a day is by no means assured. Income hovers at about $1 per day. But while life remains challenging for the Vezo, they are undoubtedly reaping rewards from this unconventional approach to marine conservation. Researchers have found that in the month after bans were lifted at more than 30 sites, villagers harvested over 700% more octopus than in the month before the bans were imposed. Communities discovered that, on average, a dollar's worth of octopus left in the ocean had grown to $1.81 by the end of a closure.

By themselves, the closures and the community-managed protected areas that followed will not be enough to overcome the complex environmental and social challenges that lie ahead. But they are undoubtedly a step towards a more hopeful future for Madagascar's fragile coastal ecosystems and those, like the Vezo, who depend upon them for survival.

A fisherwoman ranges over a vast reef flat at low tide, scanning the shallow water for an octopus den, from which she'll tease out the octopus and then kill it using her spear. She pulls along the octopus she has already caught, attached to a string in her hand.

Photo by Garth Cripps

ADAPTING TO CHANGE

Words by Emily Darling

Currents, oceanographic fronts and eddies swirl around the north-western coast of Madagascar, pushing ocean waters through an intricate pattern of islands, shallow bays and deep channels. As an established hotspot of biodiversity in the Western Indian Ocean, Madagascar's coral reefs are home to the second highest number of reef-building corals and fish species in the world. Rolling backward into the water, scientists plunge into the country's first community-led marine protected areas, where schools of colourful fishes dart into the safety of fields of delicate table corals.

In 1998, an El Niño event and marine heat wave led to widespread coral bleaching here in north-western Madagascar and around the world, killing about one-sixth of the planet's corals. Today, the reefs off Madagascar's north-western coast have made a remarkable recovery. They are protected not only by laws for marine protection, but also potentially by the ocean itself, as upwelling from the deep Mozambique Channel brings cooler water to heat-sensitive corals.

This means that the reefs of north-western Madagascar may be a sanctuary area for coral that escapes the worst impacts of climate change – in other words, a climate refuge. They may also give us a glimpse into some stories of hope for future marine protected areas in a rapidly changing world.

Since the late 1960s, marine protected areas have been an important strategy for ocean conservation and ecosystem-based fisheries management. Today they face a number of threats: the warming and acidification of the oceans, the emerging development of underwater oil and gas exploitation, illegal fishing and the rising demand for shark fins and manta ray gill plates, to name a few. Thousands of species of whales, sharks, rays and fish remain largely unprotected; a recent study found that 97% of marine species have

A diver swims over poached abalone shells in Cape Town's Table Mountain National Park in South Africa.

less than 10% of their range represented in a marine protected area.

Overall, marine protected areas – especially no-take marine reserves – work for biodiversity within their borders, but they face an uncertain future. What features of future marine protected areas are likely to contribute to their continued effectiveness and longevity? As nations move to meet Aichi targets and Sustainable Development Goals for 10% of ocean and coastal protection, adapting to change can be an important consideration for future marine protected areas. I argue that there are three strategic goals that future marine protected areas need to achieve if they are to keep up with our rapidly changing world:

- to integrate climate refuges;
- to support and strengthen customary practices; and
- to embrace new technologies and big data for strategic conservation.

Our future will be defined by climate change. Affecting every continent and ocean, the impacts of climate change do not stop at the borders of protected areas. Warming, acidification and sea-level rise are expected to lead to storms that are more frequent and more intense; a decrease in ocean productivity; shifts in the ranges of species; and an overall reorganisation of coastal and marine environments. Although there is some evidence that marine protected areas can increase resilience so that the environment can absorb and recover from climate impacts, there is also evidence of the opposite: that marine protected areas increase vulnerability by safeguarding sensitive species that are susceptible to climate change.

Climate change must be factored into the design and implementation of marine protected areas. To address ocean warming, scientists expect cooler refuges to help populations persist, thus buying time for animals and plants to adapt to a warmer environment. Some policies are recognising this.

Photo by Thomas Peschak

Marine protected areas play multiple roles in the bid to protect the biodiversity of our oceans and shores. Looking at the current and future challenges facing the marine environment, Emily Darling explains how they can, and should, adapt to a changing world.

A scientist examines coral in the Ponta Do Oro Marine Reserve, Mozambique.

A new Thermal Refugia Protection Policy in California, for example, seeks to identify and protect cold-water refuges for the benefit of salmon as rivers warm. On coral reefs, scientists are searching for the oceanographic conditions that may signal cool-climate refuges, like those potentially in north-western Madagascar. Surprisingly, even stressful environments may provide some refuge. Turbid near-shore conditions, for example, may shield corals from the harmful interaction between temperature and light that promotes coral bleaching.

When it comes to ocean acidification, there may be few places where marine species can escape waters that have become more acidic. However, scientists are investigating how the principles being used to address ocean warming could be applied to ocean acidification. For example, if we can understand the chemistry of the oceans and how it changes, we could identify locations where acidification impacts may be weaker. Until then, marine species may have to learn to cope with changes in the oceans' chemistry.

Climate refuges might keep marine systems on life support long enough for species to adapt or acclimatise to changing conditions. Measuring the patterns of climate impacts globally and pinpointing the locations of climate refuges are the critical next steps to the incorporation of climate refuges into the design of marine protected areas. Importantly, refuges may shift over time as the impacts of climate change accelerate. Marine protected areas may need to adapt as well, for example by shifting their boundaries as species move to cooler waters. In the face of overwhelming uncertainty, a focus on climate refuges can provide clear conservation action.

As human populations grow and our demands and dependence on marine resources increase, sustainable fisheries face substantial challenges. Marine protected areas, specifically ones that are closed to fishing, are increasingly advocated as a component of fisheries management. It is an approach that has both costs and benefits, but future marine protected areas could gain even more if lessons were to be learnt from the indigenous peoples and customary practices that have governed marine resources for thousands of years.

In the archipelago nation of Fiji in the South Pacific, scientists from the Wildlife Conservation Society have been learning from traditional *tabu* (pronounced 'tambu') fishery closures managed by local communities. In 2014, the village of Koro Island planned a traditional *tabu* harvest for their reefs and 10 scientists, myself included, joined them. Using thick vines harvested from

Photo by Thomas Peschak

forests, the villagers created a lasso around the reef. Over several hours, we swam and kicked and beat the water with our arms to scare the fish into the centre of the lasso and, eventually, a gill net. In the span of one afternoon we caught more than 1,000 fish – enough to feed every family in the village and the neighbouring village. Closing the *tabu* the following day would enable the fish populations to recover until the next harvest.

Traditional marine closures, such as *tabus*, that manage fishes like a crop and are periodically harvested can be sustainable. Marine protected areas can support these practices by ensuring that people have exclusive rights to managing their local biodiversity and fisheries, and provide tools for communities to monitor and track the status of their resources. Rights, access and monitoring are key features of the scientific theory linked to shared resources like fisheries. Applying this theory to real-world examples and understanding how effective community-based resource management can scale-up and diffuse to more communities is at the forefront of conservation research.

In the Global South (Africa, Latin America and developing Asia), community-managed marine protected areas may be known as locally managed marine areas (LMMA). LMMAs are a type of spatial management developed from the principle that local communities can be more effective than central governments at managing marine resources. Whether this type of traditional spatial management meets international policies on biodiversity (like the Convention on Biological Diversity's Aichi target) remains an ongoing conversation. In most cases, a nation's LMMAs do not meet the formal definition of a protected area. Understanding how community-based conservation can meet these formal definitions – and contribute to international policy targets of 10% protection – is a key consideration for future marine protected areas. For example, although many LMMAs prioritise livelihoods and food security, they also offer opportunities to achieve biodiversity conservation while recognising traditional practices. Future marine protected areas can gain by learning from community-based management and customary practices, as well as the biodiversity benefits they provide.

New technologies are an emerging frontier for marine protected areas. With open technologies, global online access and the era of big data, fishing activities that were previously 'somewhere over the horizon' can now be viewed online and in real time. The recently launched Global Fishing Watch (*www.globalfishingwatch.org*), for example, uses a global feed of vessel locations from satellite information to reveal the movements of fishing boats and their activities over time. By pairing this information with the locations of marine protected areas, citizens and decision-makers can identify illegal fishing and evaluate the effectiveness of management decisions. Conservation drones are another example of technological 'eyes in the sky' to detect illegal fishing activities for a fraction of the cost of traditional patrol boats.

Scientists are also working together with larger datasets than ever before to improve our understanding of marine protected areas. For example, a recent study of 17,348 marine species identified 'protection gaps' for 245 of them that are not in any marine protected areas. Similar studies are bringing together global collaborative datasets on reef fishes, corals and governance, and helping us to understand the effectiveness of marine protected areas. This information can guide the strategic implementation of new marine protected areas.

Technology, big data and collaborative partnerships between scientists, governments and stakeholders offer hope for strategic and targeted investment in marine protected areas that produce real, positive effects. Collaborative partnerships like Global FinPrint (*www.globalfinprint.org*) and the Global Sharks and Rays Initiative leverage numerous NGOs, donors and international organisations to create large and comprehensive impacts. These initiatives recognise that measuring the number of square kilometres of marine protected area is not enough for conservation; we must evaluate the actual on-the-ground impact of marine protected areas and other conservation strategies if we are going to restore marine biodiversity and maintain it into the future.

In the coming decades, the planet will continue to experience rapid social, economic, technological and environmental change. Marine protected areas will play an important role in how we conserve and sustainably manage our oceans. We must make smarter and more strategic decisions about marine resources and the livelihoods, cultures and food security they support. We can anticipate the impacts of climate change and integrate climate refuges into planning in order to buy time for marine biodiversity and human societies to adapt and respond to ongoing change. We can incorporate the practices of traditional fisheries and learn from cultures that have been managing their natural resources for thousands of years. Science and technology can help us find this balance by improving our understanding of the role that customary practices play in marine management and by finding new innovations for people and nature in an era of big data.

Back in Madagascar, the first wave of community-managed marine protected areas provides hope for a hotspot of biodiversity in the Western Indian Ocean. Below the surface, it is heartening for our team surveying the new marine protected areas to see that healthy coral reefs can survive and recover from unprecedented climate events and can continue to support biodiversity and local livelihoods. These reefs have been protected by the people who depend on them and by the swirling ocean currents of the Mozambique Channel. In an uncertain and rapidly changing future, there are many smart and strategic actions that can protect our oceans. But we must continue to search for innovations and work together to achieve impact. Overall, the future of marine protected areas is to adapt to our rapidly changing world in order to give marine life the best chance of survival and resilience in the coming decades.

Photo by Thomas Peschak | National Geographic Creative

The De Hoop marine reserve situated near the southernmost tip of Africa is the continent's most important calving and nursery ground for southern right whales.

THE CONCLUSION

IN SUMMARY

Words by Lisa Boonzaier

Marine protected areas are a provocative topic. Throw out the term at a dinner table of ocean-lovers, fishermen, biologists, conservationists and divers and everyone is bound to have an opinion. Yet common threads have emerged in the science: marine protected areas are good for conserving marine biodiversity. More and bigger fish live inside marine protected areas. There is a greater variety of life inside marine protected areas. And social benefits can accrue – even to fishermen (as we saw on pages 20–21). Marine protected areas provide refuges from fishing that are otherwise growing scarcer each year as vessels encroach on more and more of the ocean.

Another thread to emerge is that not all marine protected areas are equal. Marine protected areas are diverse. And this is not a drawback – it is an asset. There are many types of areas in the ocean that are protected and it is reasonable that we need all kinds of them: those managed by communities, those managed by government, those managed privately, and jointly; the very large, remote marine protected areas and the small, local ones; those that are entirely closed to fishing and those that allow certain kinds of fishing. The options and combinations are all but endless. Marine protected areas are varied, multifaceted tools that can (and should) be moulded to suit particular circumstances and solve specific problems. Each situation is different. And this diversity of marine protected areas will help to create a more resilient protected area system in a changing world.

We also know that marine protected areas are not a miracle panacea; alone they cannot cure all our oceans' troubles. Oases of protection in oceans that are otherwise uncared for will not lead to seeing our planet and people thrive. For that to happen we need to manage entire oceans with care. Doing that requires more tools: control of the amount of fish taken from the oceans; limits on the number of boats plying the seas; restrictions governing what and how much can and can't be dumped into marine waters; restrictions on carbon dioxide and other greenhouse gas emissions; and bans on destructive fishing methods. Marine protected areas are among these options – they are one of the ways we can look after our oceans.

And although the future is uncertain, we have ways and opportunities to make marine protected areas work in a changing world. As obstacles arise, so do solutions. Yes, the climate is warming, but our ability to understand global systems is improving. Yes, small communities are disproportionately affected by the declines in fish numbers, but their knowledge is helping the world to find solutions. As Emily Darling points out, we have ways to manage this uncertain future, and we are thinking ahead about tackling it.

These common threads are at the foundation of the marine protected area field, yet there are areas of contention at a higher level. What about the giant, remote marine protected areas? When are marine protected areas good for fisheries management? How do we improve enforcement? These are important areas of debate, ones that need to be thoroughly explored through science and discussion. But the basics remain: marine protected areas are a tool and one to be taken seriously. And the debate among specialists should not drown out the main message for the public and decision-makers: we need more of them.

Only about 4% of the ocean is represented in some sort of protected area at present. Even with the creation of a handful of very large marine protected areas in recent years – which tend to dominate statistics of protection – the oceans are dismally under-protected. And even if one assumes that all of the very large marine protected areas on the cards were to be successfully declared in coming years (I've done the research), we're looking at 5.1% rather than 4% of the ocean being protected in some way. So we'd still be some distance away from the 30% that scientists think is necessary to curb the loss of species, or even the 10% goal of the Convention on Biological Diversity.

It is not enough to declare only small protected areas on a scale that makes no difference to the large, global battle of halting the loss of biodiversity. We can see this from past trends in protected area establishment. Yet by the same token, declaring only very large protected areas in remote parts of the ocean that face no threat is not going to address this sufficiently either. Unfortunately, the question of whether to prioritise the protection of remote, uncontested, intact or non-remote, exploited, imminently threatened locations has no immediate, science-based resolution. Nevertheless, a key principle remains and can be agreed upon: we need more marine protection than we have now.

It is the job of scientists to test and contest the effects of interventions (like marine protected areas) and while their voices may seem conflicting and confusing from the outside, the underlying value of marine protected areas for conservation is less and less frequently the topic of debate. Voices and evidence in support of marine protected areas are gathering and rising to the top.

More fish. Bigger fish. More types of fish. More fish available for catching. More sharks. Greater genetic diversity. Research sites. Beautiful places for people to visit and be inspired by. Space for recreation. Ecotourism ventures. Educational opportunities. A source of pride. Not every marine protected area offers all these benefits, but collectively they offer a solution in a sea of dwindling resources and tragedies.

For me this is the simple and clear message: marine protected areas are a good tool and we need more of them. We need marine protected areas for the oceans and, considering that more than half of the earth is ocean, we need them for the planet. We need them for the sake of human life, but not only for ourselves – for all life.

Blacktip reef sharks *Carcharhinus melanopterus* have found refuge in the giant marine protected area designated by the island nation of Palau in the Western Pacific Ocean.

Photo by Doug Sloss | SeaPics.com

Reef fishes and sharks abound off D'Arros island and St Joseph Atoll in the Seychelles. This intact and healthy marine environment enables sharks and fishes to hunt with ease.

Photo by Thomas Peschak

Words by Lucy Keith Diagne
Photos by Thomas Peschak

Discovering the f

Elusive and enigmatic, the African manatee faces threats that can only be mitigated when more is known about it. And therein lies the problem: resources for biologists in Africa are rudimentary, to say the least. Lucy Keith Diagne has set up a network to overcome the challenges they face.

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A juvenile manatee in N'dogo Lagoon, Gabon. The African manatee is so elusive that local people believe it is a magical spirit.

It's no wonder that many Africans think that 'their' manatee is a magical spirit, one they call Mamiwata. The animal is so elusive and lives in such remote, dark, muddy waters that it's easy to see why it is often likened to an apparition. Just getting a glimpse of a nose or a tail is a rare surprise, and most people outside Africa have no idea that the species exists. Although the African manatee *Trichechus senegalensis* looks much like its better-known cousin in Florida, it is generally smaller and has more protruding eyes.

We know much less about the African manatee because not only is it more difficult to find and study in the wild, but also there are few resources for biologists in Africa to study it. The lack of research on this species compared to the other manatees has led to it being nicknamed 'the forgotten sirenian'. According to the IUCN Red List of Threatened Species™, the African manatee is 'the least studied large mammal in Africa'. For the past 10 years I've been trying to change that. But it hasn't been easy.

In addition to the challenges to studying them, the threats to African manatees are many. The animals are hunted, accidentally caught in fishing gear and trapped in dams and their habitat is being destroyed. Hunting is intensive in many places and manatee meat is openly sold in markets and restaurants, even though the species is legally protected in every country where it occurs. This is because the meat is considered a delicacy and is a traditional food item in many cultures. In Cameroon, for example, manatee is traditionally served at wedding feasts.

Although there is a lot of legislation to protect the species – national laws in all countries where it occurs and listings on Appendix I of CITES (the Convention on International Trade in Endangered Species), CMS (Convention of Migratory Species) and the US Endangered Species and Marine Mammal Protection acts – there is little enforcement to deter poachers. Moreover, accurate numbers of manatees hunted and sold have barely been recorded, so there is no information available to compel wildlife law enforcement agencies to administer the laws. As for the other threats, there's been almost no documentation of manatees caught incidentally in fishing nets or trapped in dams. In recent times hydroelectric and agricultural dams have isolated manatee populations in many major waterways, including the Niger and Senegal rivers and Lake Volta in Ghana. Individuals have also been killed in the dam structures themselves, trapped or crushed in the gates. Another three huge, multi-purpose dams have been under construction along the Niger River since 2008, all of which will restrict manatee habitat further and lead to the genetic isolation of some populations.

Although the African manatee is difficult to study, there are some things we do know about it. Its range, larger than the area of continental USA, spans 21 countries on the western side of Africa, from the Senegal River at the southern border of Mauritania southwards along the Atlantic coast to the Longa River in central Angola. It also occurs up rivers extending more than 2,500 kilometres inland in countries such as Mali and Chad, and around tropical islands off the coast of Guinea-Bissau. It lives in a wide variety of ecosystems, from lagoons in lush equatorial rainforests to rivers at the edge of the Sahara Desert and other habitats in between. Its lifespan is at least 39 years. But we don't know much else about its life history: how long a young calf is dependent on its mother, or when a manatee reaches sexual maturity and begins to reproduce, or even the size of an individual's home range.

When I started working with African manatees in 2006, there were only a handful of people already doing so – and more people who wanted to study them but didn't know how to begin. So in 2008 I set about forming a collaborative network of African biologists and training its members to study manatees in the wild and address the threats throughout the species' range.

The network is growing and I am still providing practical training on how to

find and study manatees and collect samples. I'm also donating field equipment, such as GPS units, binoculars and depth-sounders to researchers, and offering guidance on such things as the design of study plans and the writing of grant applications and reports. The goals of this regional network are to increase research on manatee ecology, physiology and behaviour; to share information; to conduct educational outreach; and to communicate the results of research to wildlife managers, the scientific community and the public at large. Network members include researchers who are affiliated to governments, universities and NGOs in 19 African countries, and the challenge today is to make their projects sustainable over the long term.

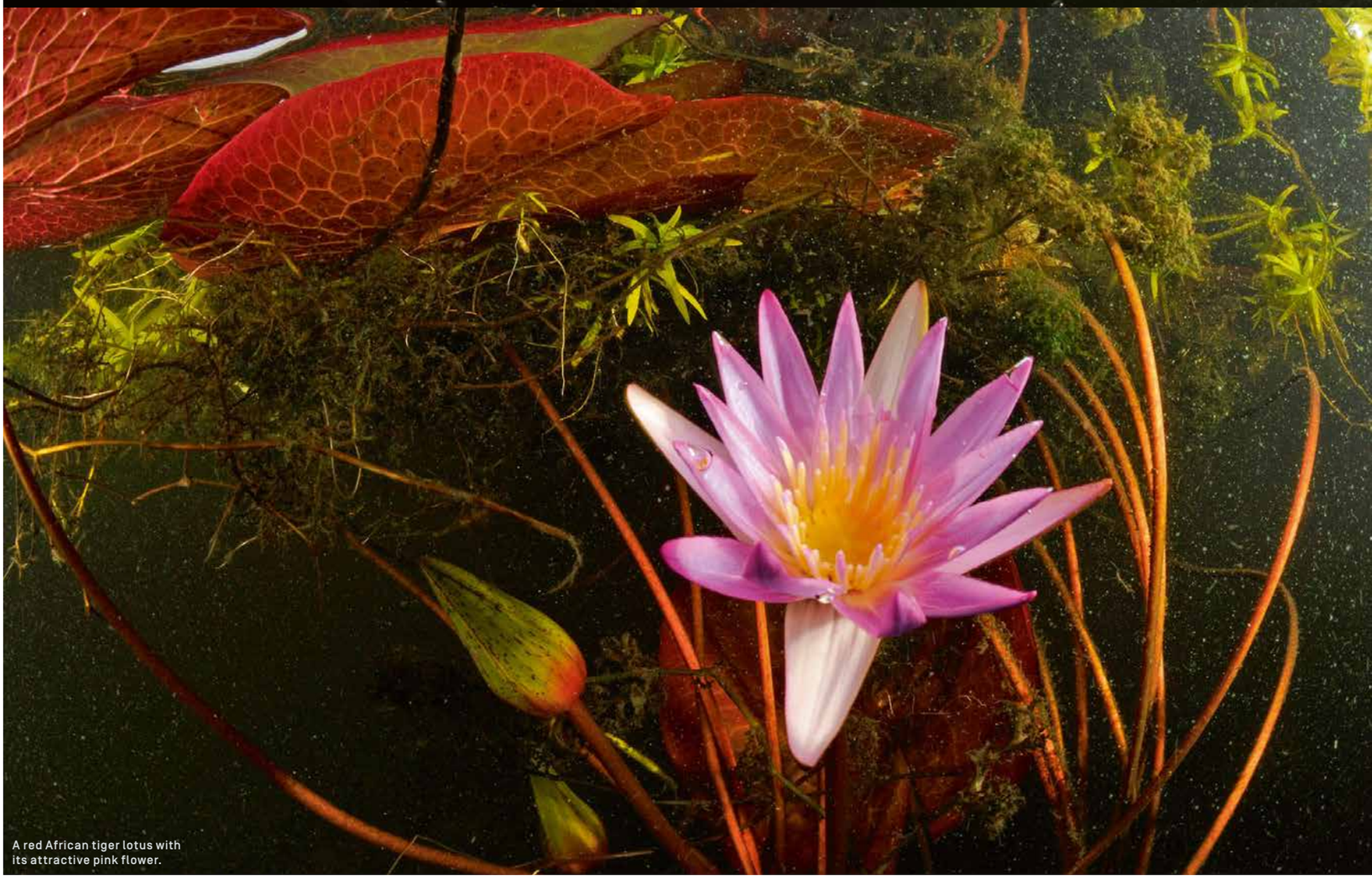
Building and sustaining a range-wide effort of research, conservation, management, training and educational outreach will take many years to achieve, but a sense of community is reinforced by an online discussion group and partnerships between colleagues from neighbouring countries. Project collaborators share authorship on publications, which strengthens the network, gives recognition to their work within their home countries and, it is hoped, inspires further work.

The large extent and the remoteness of the areas we cover mean that we must make the best use possible of the scientific tools and methods at our disposal in order to learn more about the ecology of the African manatee and estimate more rapidly the number of different populations in Africa, the sizes of these populations and the impact of hunting on them. All this additional knowledge will help us to conserve manatees in Africa.

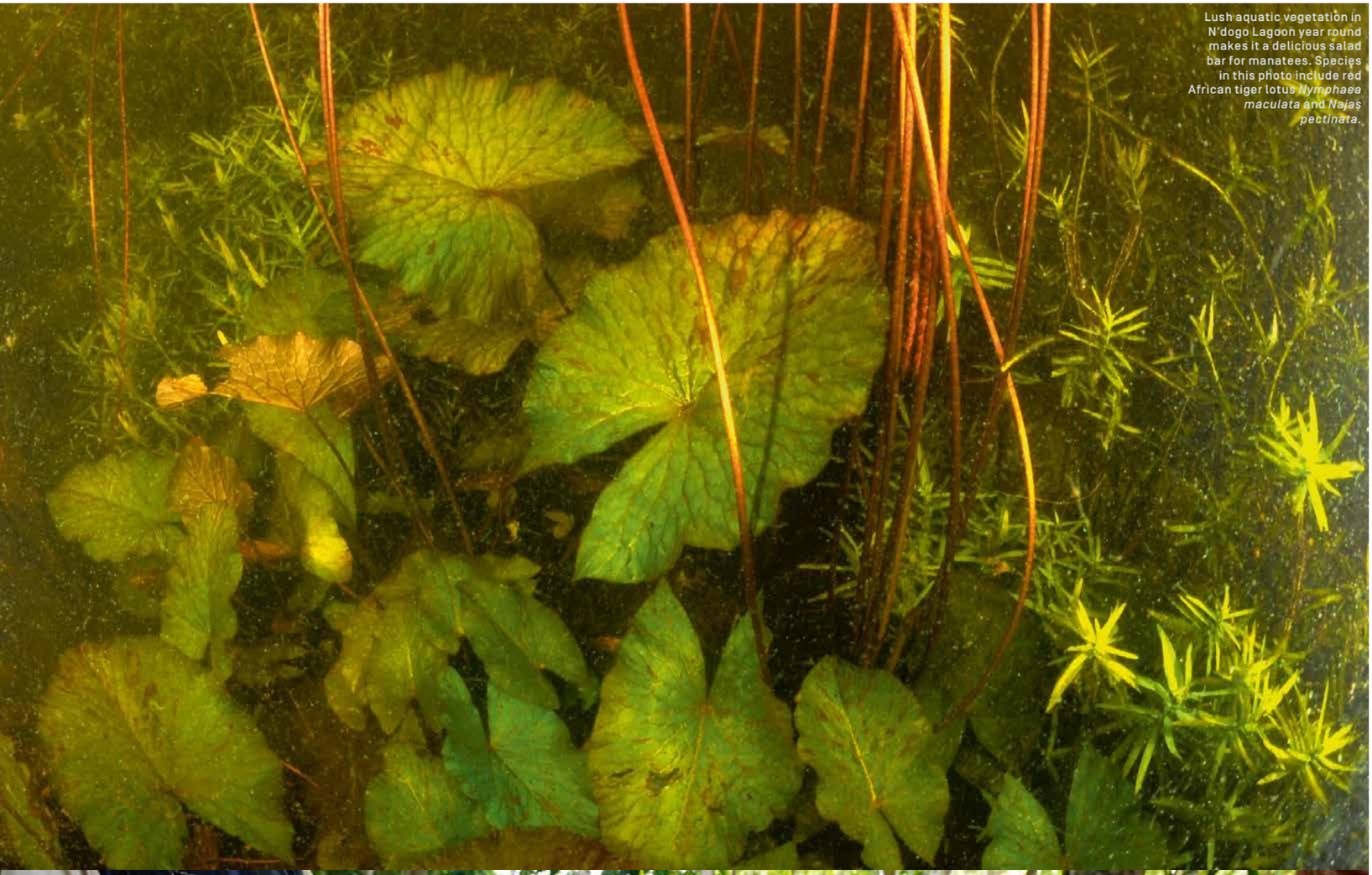
Genetic analysis is one such tool. It can determine the number, diversity and sizes of populations, as well as where distinct populations occur and where the boundaries of their ranges lie. Because low genetic diversity can signal both low population size and the long-term impact of hunting, genetic analysis can be very effective in the conservation and management of threatened species and populations. Physiology studies can also be very helpful, telling us about growth rates, longevity, disease and baseline health.

Since 2009, Dr Lucy Keith Diagne has been using stable isotopes to study the diet of the African manatee. Unlike other manatee species, these animals regularly eat fish and molluscs in addition to more than 70 plant species, including (clockwise from top left) water lilies *Nymphaea lotus*, *Najas pectinata*, mangrove seeds *Rhizophora racemosa*, and African onion *Crinum natans*.

An African manatee in N'dogo Lagoon, Gabon, where sightings of the species are common. Elsewhere in Africa it is rarely seen.



A red African tiger lotus with its attractive pink flower.



Lush aquatic vegetation in N'dogo Lagoon year round makes it a delicious salad bar for manatees. Species in this photo include red African tiger lotus *Nymphaea maculata* and *Najas pectinata*.

A captured manatee is monitored closely during sampling for a permitted research study at N'dogo Lagoon.

A juvenile African manatee captured in Gabon by Lucy's scientific team is brought ashore for a work-up during which measurements are taken, its health is checked, blood and urine are collected and samples are taken for genetic analysis. Although manatees can be comfortable ashore if they are kept cool and wet, the team monitored closely this individual's breathing and heart rate during the sampling. The samples collected are extremely valuable for increasing our understanding of this little-studied species. Lucy and her team have now collected more than 200 genetics samples from 13 countries.

Feeding ecology and migration patterns can be studied using stable isotopes, a tool that identifies what an animal has been eating over time. All these techniques are used regularly to study other animals, but have been widely applied to the study of African manatees only since 2009.

The large number of threats to African manatees gives urgency to our work. The first priority is to understand how many unique populations of the species exist across its large range. It is not only a reduction in population size that makes a species vulnerable to extinction; its resilience is often determined by the strength of its genetic diversity – or how many distinct populations there are. Over 10 years my collaborators and I have collected 78 manatee samples from 12 countries in order to determine where distinct populations occur. Through my genetics research I have identified 25 new mitochondrial haplotypes (these are unique versions of the same gene) for the African manatee – an exciting revelation because only five mitochondrial haplotypes had been known previously. These markers identified four separate populations: one in coastal West Africa (Senegal, Guinea and Guinea-Bissau); an inland population in the Senegal River; an inland Niger River population with samples coming from Mali, Niger, Chad and Cameroon; and a large population in the coastal rivers and lagoons of West and Central Africa (Ivory Coast, Ghana, Benin, Cameroon and Gabon).

This study is a first step, and with additional samples we will be able to continue defining more fine-scale population structure, both regionally and within specific countries. The results will aid conservation efforts by informing wildlife managers where unique populations exist, where they should focus trans-boundary conservation and management efforts – when populations cross borders – and where they need to assist specific isolated populations.

The African manatee is also special in that it differs from other manatees by regularly feeding on fish and molluscs in addition to more than 70 species of plants. While working in Africa over the years, I was told by local people in many countries that manatees eat mussels, clams and fish – a diet very different from that of all other manatee species, which are considered to be strict herbivores. I heard these reports so often from people in countries thousands of miles apart that I decided I had to investigate.

Recently, using the technique of analysing stable isotopes, I found that in Senegal manatees eat at least four species of fish as well as freshwater mussels and estuarine clams – food items that made up 50% of their diet! So, unlike the other two manatee species (the West Indian and Amazonian), African manatees have a varied, omnivorous diet. For a species previously considered to be a herbivore, this is pretty big news. But why is this important? This study gives us accurate information about the food items that manatees need, which can help managers to prioritise the protection of places where they are abundant. This new information also tells us which species we need to monitor as important food sources for manatees. As an example, now that we know that manatees in Senegal depend on molluscs and fish, we need to resolve conflicts with fishermen and help to conserve not just the plants the manatees eat, but all the food species they depend upon. This dietary analysis of African manatees in Senegal was the first for the species, and I look forward to understanding manatee diets in other countries.

As African researchers begin studies in their home countries, many other, new research projects are taking shape as well. Studies of manatee habitat and distribution are under way in Senegal, the Gambia, Mali, Ghana, Benin, Nigeria, Cameroon, Gabon and Angola. At least 10 young African biologists are currently working on graduate degrees that focus on the distribution, physiology and behaviour of African manatees. In June 2015 I initiated an advanced two-year training and mentoring programme for eight researchers from Cameroon, Gabon and the Democratic Republic of Congo who are studying manatees in their countries, documenting the impact of illegal hunting and leading educational campaigns to raise awareness about the manatee's protected status.

For a long-term effort such as this, which is also operating on a continental scale, there will always be challenges. Manatee conservation programmes in Africa too often depend upon the work of specific individuals. We need more training and for efforts to be integrated into broader conservation programmes. More university-level students need to become involved and we need more laboratories for sample analysis. This species is likely to be conserved only through a network of localised, grass-root efforts by African researchers dedicated to long-term conservation and education in their countries – and we believe we're off to a good start.

The elusive African manatee, which arrived on the continent 3.5 to four million years ago, is an important part of many ecosystems in Africa and deserves to be protected. I hope that one day people around the world will know about – and will want to help conserve – this unique marine mammal that has inspired the myth of Mamiwata across Africa.

A manatee rises to take a breath in N'dogo Lagoon. Although there is a lot of legislation to protect the African manatee, including its listing in CITES Appendix 1, there is little enforcement to deter poachers.

A fisherman can be seen above the water in N'dogo Lagoon. Lucy and her collaborators are working with West African communities to implement conservation programmes for the African manatee.

Getting community buy-in

In addition to conducting research projects, the manatee network has initiated several promising new conservation efforts in recent years, including three in Senegal, Mali and Nigeria.

- At Lake Guiers, a manatee hotspot in Senegal, local communities have got together to create and administer a natural reserve. Tocc Tocc is the first protected area established specifically for African manatees. Community leaders from five villages in northern Senegal worked together to form a conservation committee and draw up regulations for the protected area on Lake Guiers, which is recognised by Senegal's National Parks Ministry and by the Ramsar Convention as a Wetland of International Importance. Twenty eco-guards, who act as rangers, have been hired from the five villages and trained to conduct regular patrols and enforcement, as well as collect data on manatees and other wildlife using the refuge. Tocc Tocc sells collection permits for several species of plants in the reserve and is now being developed as an ecotourism site in order to become self-sustaining.
- In central Mali, researcher Soumaile Berthe is working with seven communities along the Bani and Niger rivers to establish protected areas for manatees and encourage participation in 'Friends of the Manatee' clubs. These clubs now have more than 500 members, who harnessed public support to create five small protected areas near villages, including an important freshwater spring where manatees come to drink.
- At Nigeria's Lekki Lagoon outside Lagos, manatee researcher Dunsin Bolaji offered manatee hunters an alternative, proposing that if they gave up hunting and removed all their traps, he would teach them how to breed and raise catfish. He would also supply them with all the equipment and juvenile fish they needed to get started. At first the hunters were sceptical, but a few decided to try and the programme has become wildly successful. Two years later, 17 hunters are part of the programme and all 14 manatee traps in the area have been removed. The former hunters now have 14 sustainable catfish aquaculture cages and have already sold more than one tonne of fish, using some of the proceeds to keep their aquaculture business going. The year before the project began, this community killed 133 manatees; the year after, it killed none.

Three additional communities in the area and manatee researchers in other countries have now also requested this training so that they can provide a viable alternative to manatee hunting. Once the manatee network has raised the necessary funds, we will expand this programme.

After a long day waiting to catch manatees for their study, veterinarian Ken Cameron and lead scientist Lucy Keith Diagne return to camp without deploying a satellite tag on a manatee. Catching the elusive African manatee requires a lot of time and patience, but it's worth it to better understand this fascinating animal.


INSPECTED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A postage stamp from Niger in 1962 depicts an African manatee. The species has featured on the stamps of 12 countries, including some (Central African Republic, São Tomé and Rwanda) where it is not found. It seems that people are so fascinated by this mysterious sirenian that they want to claim it as their own.

Drones acro

Surf washes across the reef on the fringes of St Joseph Atoll. By using drones to generate aerial maps, researchers will be able to better manage the area and track how it changes over time.

Photo by Thomas Pespisak

Drones get their share of negative press relating to privacy issues and military usage, but there's far more to them than that. Drone Adventures, an association of volunteers, was founded three years ago to demonstrate that drones are perfect for humanitarian and nature conservation purposes too. To prove the point, the Save Our Seas Foundation recruited Drone Adventures to help its researchers at D'Arros Island and St Joseph Atoll in the Seychelles.

Words by Sonja Betschart, Drone Adventures

Drones have become a major force in the civilian world over the past three years as people are becoming aware of more and more applications for them. The most obvious are aerial photography, mapping and surveillance, but there are many, many more. Just about any movie you see today has scenes that were filmed using drones; civil engineers worldwide get help from drones every day to produce maps and 3D models for their projects; and the future of merchandise transport has opened up, with drones being used to deliver parcels right to the consumer's front door.

But why is there all this hype about drones? Many reasons come to mind, the most important of which is probably that drones give us new perspectives and open up new possibilities – and all at a fraction of the cost of current technologies such as satellite imaging or photographs taken from manned aircraft. Drones, moreover, are easy to use, which makes them available to a large number of people with little or no specialist knowledge of operating them.

In many areas of nature conservation drones can be a game changer. They enable researchers and conservationists to create quickly and cheaply their own high-resolution maps and 3D models that can then be used to analyse information and to answer questions relating to the environment. An example is our Savmap initiative, in which we developed a monitoring tool for sustainable land-use management and the conservation of rare species in Namibia's semi-arid savanna. Drones are also an excellent tool for tracking poaching activities and acquiring imagery that enables researchers to analyse inaccessible areas and count animals.

Until now, though, little use has been made of drones for marine conservation. Although their endurance, wind resistance and reliability have improved immeasurably over the past few years, the harsh environments and long distances that are integral to marine conservation have raised some serious challenges for drones. At Drone Adventures we are always open to trying something new and willing to push the boundaries of the 'drones are good' concept. When Michael Scholl of the Save Our Seas Foundation (SOSF) asked if we were interested in mapping St Joseph Atoll in the Seychelles and collecting imagery for the research projects under way there, we were very curious to find out how drones could help marine conservation.

In late November 2015 we packed up the equipment we needed for a week-long mission on site and prayed to the weather gods to be kind to us and our drones on this risky venture. We needed all the help we could get to map the 25 square kilometres (10 square miles) of St Joseph Atoll and obtain aerial imagery from very low altitude that would reveal shark pups, rays and turtles in the shallow water below.

Our main task was to create a high-resolution base map of the entire atoll, which is approximately eight kilometres (five miles) long and five kilometres (three miles) wide. Our four eBee drones, equipped with consumer-grade compact cameras, would have to obtain overlapping aerial images and we would then have to turn these images into a map, using Pix4Dmapper mapping software. But there are a number of challenges inherent in this undertaking. First of all, water reflects sunlight that interferes with the reconstruction process, so mapping water with aerial imagery by drone has been impossible until now. Secondly, to be able to reconstruct overlapping images, the features that the mapping software detects in order to create the map must be identical from one image to the next. Water, however, has no distinctive features and, with reflecting sunlight making the situation worse, the chances of reconstructing images into a map are close to zero. Featureless sand and dense forest are the next worst things to water when it comes to drone mapping. And, as you'll have guessed, St Joseph is made up of water, sand and islands with dense forest! This is the main reason that so far few atolls, if any, have been mapped using drones.

We reached D'Arros Island and its neighbour St Joseph Atoll by charter plane and as we flew in we were encouraged when we saw that the atoll was full of underwater features that could be distinctly seen in the shallow water. Full of optimism, we couldn't wait to unpack our drones and give it a try, hoping that the images we obtained would capture as little sun reflection and as many underwater features as possible and thus give us a good chance of reconstructing

Photos by Dominique Scholl

the images into a map. As soon as we had landed on D'Arros, we attached the wings to one of our drones and sent it out. It returned with images of a small part of the atoll, which we processed overnight. To our great relief, we discovered the next morning that the images reconstructed perfectly into both a 3D model and a map.

Now that the most important issue had been resolved, a series of other logistical challenges relating to flying our drones was waiting to be tackled. The first challenge was distance. Although drones are fantastic tools for taking aerial images in terms of cost, availability and ease of operation, their reach is limited compared to that of manned aircraft. The furthest point of St Joseph Atoll lies a good eight kilometres (five miles) from D'Arros, which is quite a stretch for radio communication and for a safe emergency landing and retrieval if necessary.

The second challenge was take-off and landing. Even though our fixed-wing drones don't need much space to get into the air and come down, they still require an open area free of trees and other obstacles for a smooth and safe take-off and landing. Like any other electronic devices, the drone and its camera are not fans of water or sudden shocks, nor of tree-tops (it's difficult to retrieve them) or fine sand (it takes hours to clean sand from the camera shutter – hours that are better spent in the air).

Weather was the third challenge. We can plan and prepare for many things, but ideal flying weather is not one of them. Our drones do not like too much wind (stronger than 10 metres per second) or rain, which interferes with the electronics and can result in an emergency landing – not ideal over open water. Both are frequent at St Joseph. We chose the end of November for our mission as weather statistics show that wind and rain are least likely at this time of year. And the weather gods rewarded us with a week of very gentle winds, or none at all, and very occasional rain that fell early in the morning.

Our fourth challenge was the tide. Like the weather, the tide cycle was beyond our influence. We wanted to map the atoll at both high tide and low tide, so the windows for flying the drones and obtaining images were very small.

To create a map with uniform lighting, colours and water level, our best chance was to map the atoll in a very short timeframe, which is why we took four drones so that we could fly them simultaneously and get the images needed in just over an hour. Our flight plans were prepared well ahead, but the challenge lay in flying the drones at the ideal moment: when the tide was just right, when there was little wind and no rain, and preferably not between 11am and 4pm, when there was too much reflection from the sun onto the water. We also had to make sure take-off was from a safe location and that we could maintain radio contact. Thanks to the good weather, we found these ideal moments twice, both during high and low tide, and were able to acquire close to 1,800 images each time.

The images reconstructed perfectly into two maps with a resolution of 15 centimetres (six inches) each, which is about five times more precise than the best satellite map and 10 times better than the Google maps that the local research team had used to date for their daily work. The first analysis using the new maps, conducted by Dr Rainer von Brandis, the scientific director of the SOSF D'Arros Research Centre, enabled him to identify important changes in the shores and sand banks that couldn't be seen on the Google maps and satellite imagery. Further analysis will enable the scientists to establish details and features of the atoll environment, such as coral reefs, that have eluded them until now due to the low resolution of the maps they were using. In addition, as our maps are not just maps but geo-referenced true orthomosaics, the D'Arros research team can now measure distances and features with an accuracy of up to 15 centimetres and locate any spot in the atoll with the same precision, two new possibilities that could be very useful for all future research work on site.

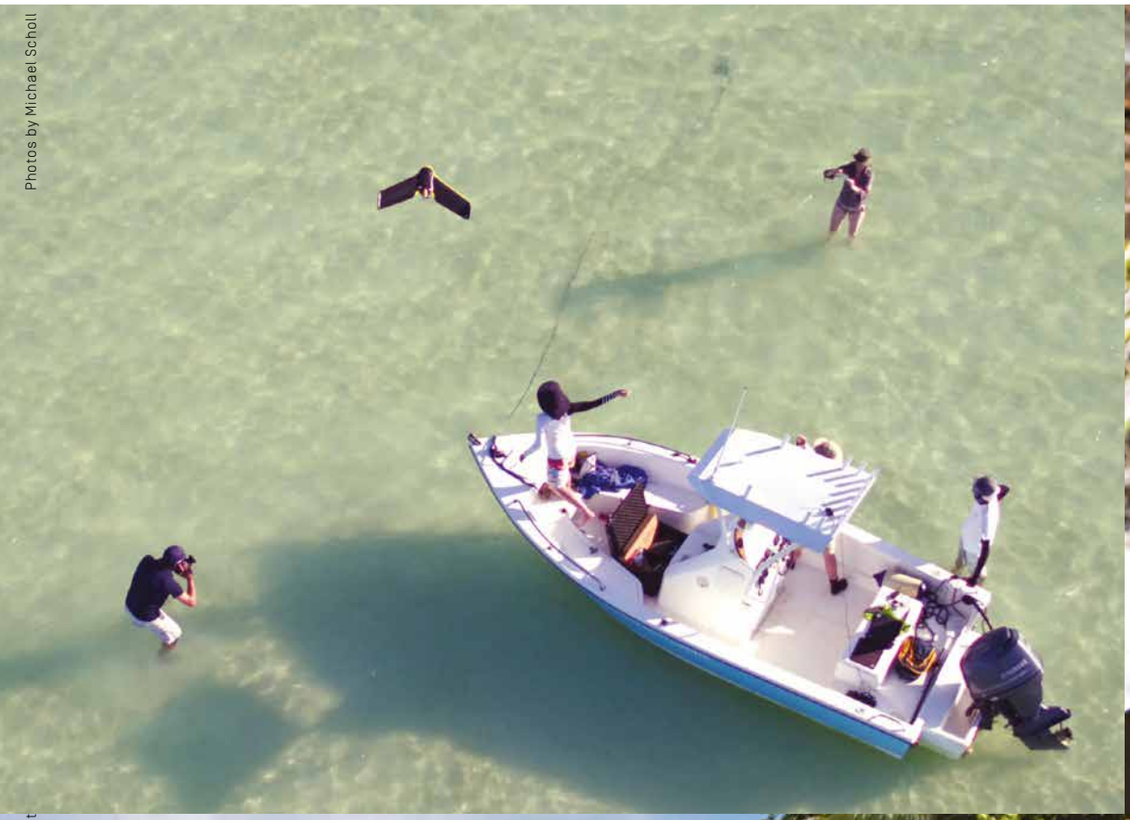
Once all the images needed for the base map were in the bag – or crunching in our laptops to generate the maps – we were ready to move on to the next goal we had set ourselves: to fly our drones at very low altitude, 50 metres (165 feet) or lower, to obtain aerial images for transects and species analysis. Just the idea of capturing images of shark pups smaller than 20 centimetres (eight inches) long was motivation enough to overcome our fear that flying so low over water

↑ Sonja Betschart, expedition leader for Drone Adventures, checks the belly-mounted camera on the eBee mapping drone before launch.

← Dr Rainer von Brandis watches Alexandre Habersaat, software engineer at senseFly, as he launches the eBee mapping drone from the research boat at St Joseph Atoll.

Stéphanie Cettou, customer support engineer at senseFly, watches the eBee drone ascend, having just launched it from the research boat.

Photos by Michael Scholl



Stéphanie Cettou and Alexandre Habersaat inspecting the eBee drone one last time before launching four identical drones simultaneously to map the entire atoll.

Photos by Dominique Scholl

Photo by Sonja Betschart

Dominique Scholl and Alexandre Habersaat recover the drone after an hour-long flight over the atoll and a perfect landing on D'Arros Island.

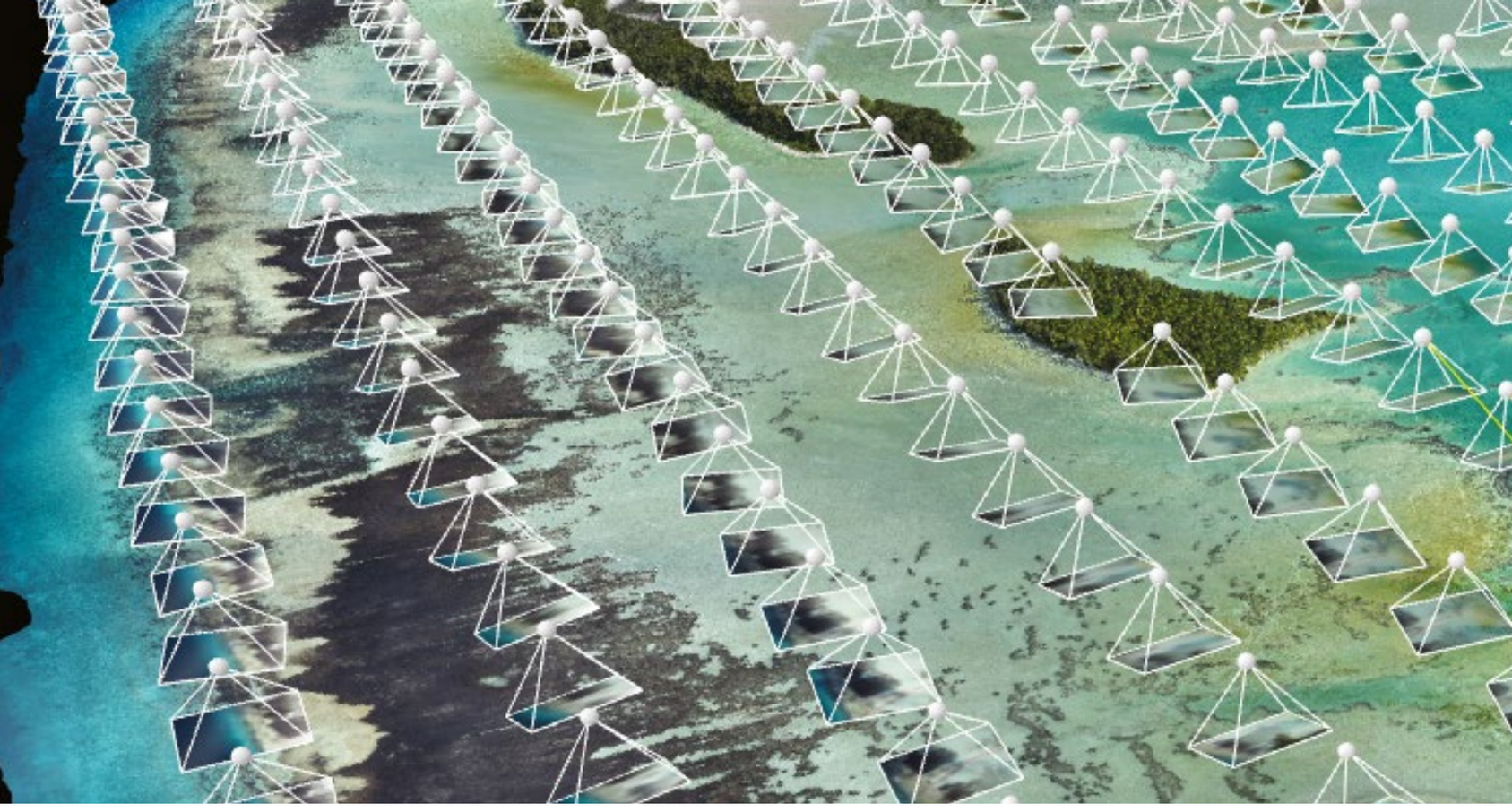
Photo by Michael Scholl

The eBee drone soars above a coconut forest on D'Arros Island and is followed closely by birds that seem to be captivated by this strange black and yellow bird that has been flying over the islands for the past few days.

Screengrab of Postflight
Terra 3D | Pix4D software

Photo by Sonja Betschart

The Drone Adventures team, Stéphanie Cettou, Alexandre Habersaat and Sonja Betschart, celebrates after a successful week-long expedition on D'Arros Island and St Joseph Atoll with no material losses.



and up to seven kilometres (four miles) from the nearest take-off and landing site would be very risky. The areas and transect lines established for these flights matched up with the exact locations of previous transects done by boat and species counts carried out on foot in the shallow water. Although the D'Arros researchers were interested mainly in getting photographs of shark pups (blacktip, whitetip and lemon sharks) and juvenile stingrays, they were also keen to obtain close-up, high-resolution aerial imagery of the coral reefs, as well as any other species that could be identified.

A first series of flights at approximately 50 metres above sea level enabled us to get about a thousand images at a resolution of two centimetres (0.8 inch) per pixel. Quickly looking through the images, the D'Arros researchers could already identify various species, including shark pups, and the resolution was good enough for them to identify and count the different ray species in the shallow waters along St Joseph's beaches, to determine the structure of the coral reefs around D'Arros and to see turtles and shark pups. However, to identify accurately the species of the shark pups and to measure their size with certainty, a better resolution was needed.

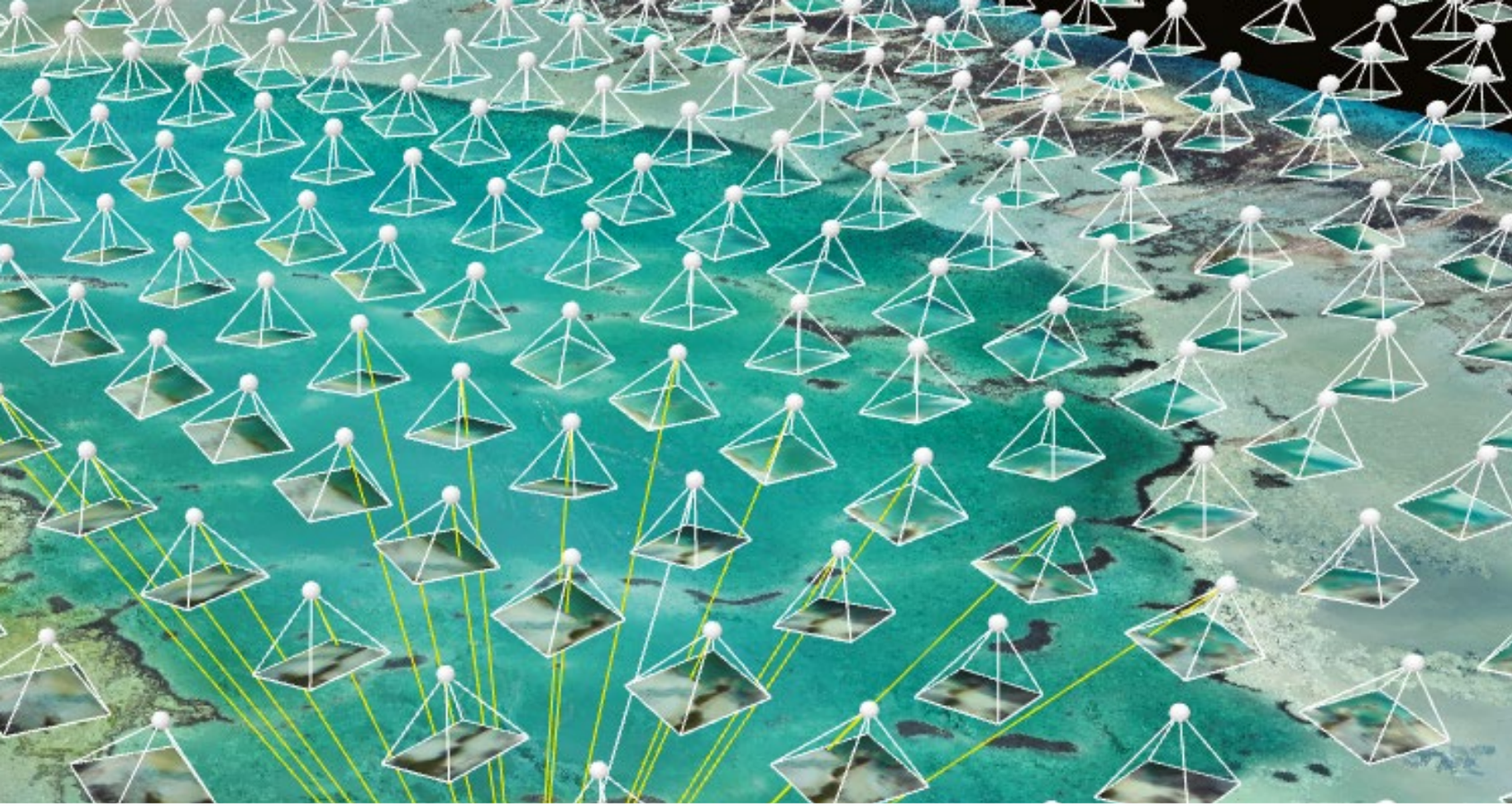
As the flights at 50 metres went smoothly and the weather conditions were still ideal, we decided to get more images of the shallow pools where shark pups were abundant at high tide. At the same time we would double the resolution to one centimetre (0.4 inch) per pixel by halving the altitude to a very low 25 metres (82 feet) above water level. To be certain that this could be done without drowning one of our drones and that we could obtain images that were not blurred (due to being so close to the water surface and flying at a speed of about 50 kilometres, or 30 miles, per hour), we decided on a test flight launched and monitored from a boat in the middle of the atoll. This would enable us to keep a close eye on the drone and retrieve it in case wind conditions forced it to crash. Once again, everything went smoothly and the images were still clear enough for analysis. So we waited for the next high tide the following day and sent the four drones off to fly over the designated areas, clicking away without the shark pups, juvenile rays and turtles imagining that their photographs were being taken just above them.

Compared to traditional transects and counts done by boat or on foot, the use of drones brings the important advantage of not interfering with the species' habitat. Counts done with drone imagery are much more reliable in terms of natural conditions in a specific habitat and are more accurate, as each individual is counted only once and all individuals can be seen over a large area. The lower flying altitude enabled the researchers to identify the shark pups correctly. By zooming in on the image, they could also measure the pups' length very precisely, as one pixel corresponded to one centimetre. All the images obtained have been left with the D'Arros researchers, who will now sit at their computer screens identifying, counting, measuring and geo-referencing the many shark pups, rays and turtles photographed.

We had some flying time left and, as we are always keen to operate the drones at all times of day and night to gather new information, we asked the researchers to give us some additional challenges. One was to identify the health of trees on one of the islands in the atoll. The scientists had realised that, over time, they were seeing more and more dead or dying trees as they cruised past the island in their boats. They surmise that the rising sea level is pushing salt water into the island's ground water, but the vegetation is so dense that they couldn't make out the extent of the dying trees on the island as a whole.

Having equipped one of our drones with a near-infrared camera, we used it to photograph the complete island and then converted the images into not only a map, but also a vegetation index. This index, known as a Normalised Difference Vegetation Index (NDVI), is a simple indicator that can be used to analyse a patch of vegetation and assess whether any of it is living and green. A first quick analysis showed that trees are dying off or are under heavy stress not only at the shoreline, as spotted from the boats, but even more extensively in the island's interior.

By repeatedly producing NDVIs of the same area every six or 12 months, it is possible to measure to what extent – and how quickly – trees are dying. Without drones, such an analysis would be possible only by using manned aircraft. The expense of such an exercise would be too high to make it feasible. In other



words, the use of drones enables researchers themselves to produce meaningful data much more quickly and cheaply. This in turn leads to greater understanding about species and their habitats and the ability to communicate new insights that can stimulate more positive conservation action.

Another challenge the researchers came up with was to find turtle nests using drones and thermal cameras. The chances for success were slim, but it was certainly worth a try. We equipped one of our eBee drones with a thermal camera and flew it along the shoreline of D'Arros in an attempt to obtain thermal imaging of the beaches all around the island. It is well known that turtles visit this shore at night to lay their eggs and that there is a lot of nesting activity. We decided to send the drone out at 5 am as this is when it is likely to be coolest on D'Arros, although on this particular morning the temperature was already 28 °C at that time. After our first night flight on D'Arros, we very excited as we scanned quickly through more than 5,000 thermal images on our laptop – and were disappointed, but not surprised, to find no colour in the image, and therefore no temperature difference on the sandy beaches. This failure to produce meaningful data was due to two factors: first, the very small difference between the ambient temperature (28 °C) and the temperature of the turtle eggs (reportedly 26–32 °C); and, possibly more importantly, the depth (about 50 centimetres, or 20 inches) at which the eggs are buried in the sand, often hidden under bushes. Nevertheless, it was worth the try. We did at least discover at what point nature defeats even the latest technology. And, with the many other useful results achieved during the week, our efforts overall shed more light on how drone imagery can help marine conservation.

A wide variety of drones is available to bring new perspectives and opportunities to research and nature conservation today. At D'Arros and St Joseph we used senseFly's eBee drones, a fixed-wing craft that weighs only 700 grams and ensures that flights are easy to plan. It is fully automatic when executing a mapping flight, which gives best results, complete control and great safety. Fixed-wing drones are ideal for mapping large areas and covering long distances, but they are more sensitive to wind and always fly at a constant speed. They were certainly the best choice for the results we were looking for at D'Arros and St Joseph. Copters – either quadcopters or octocopters – are better for spotting a certain type of animal while getting still or video imagery. They come into their own for spotting sharks and whales close to shore or, as happened at D'Arros, for easily finding, filming and photographing manta rays that were feeding just off the beach. Choosing the right kind of drone to fit the mission at hand, weather conditions and the distances to be covered not only guarantees the best results, but also reduces expenses and the risk of, for example, a drone sinking to the bottom of the ocean.

This first marine conservation mission enabled us to test out various applications for drones and produce several baselines for the researchers: a high-resolution map of the complete atoll, vegetation indexes for two islands and aerial imagery at very high resolution to establish undisturbed animal counts for transect and specific research areas. Two of the most important advantages of drone mapping technology are its low cost and the ease of use for just about anyone, both of which allow the same flights to be repeated easily. In addition, the data obtained are converted effortlessly into maps, 3D models or indexes that enable the researchers to analyse accurately the current environment and the changes that occur. Because the results are always very visual (as demonstrated by the stunning map of St Joseph Atoll), they are excellent for communication and in presentations.

Drones are also valuable tools for shark spotters in their daily work. As the technology for both drones and cameras improves, more and more possible applications will be added in the coming months and years. As for us, we are extremely happy that we could provide answers to questions such as 'Can an atoll be mapped using drones?' or 'Is drone imagery good enough for research in the marine environment?'. So when you ask 'What's next?' my answer will be 'Bimini!' or 'D'Arros in November 2016!' Above all, we want to keep on pushing the boundaries of using drones for marine conservation – and keep on having fun while we do it.

Screengrab of Postflight Terra 3D | Pix4D software showing the complexity required to integrate and match thousands of images into a three dimentional model of St Joseph Atoll.

DRONE ADVENTURES

This high-resolution map is a composite of thousands of images captured with drones flying simultaneously. The software ensures that any moving objects are discarded, but the circular images show some of the fauna and flora that was recorded during low-altitude flights.

Combined, D'Arros and St Joseph share a coral reef area of almost 2,000 hectares. This pristine ecosystem provides critical habitat for hundreds of species on land and in the ocean.

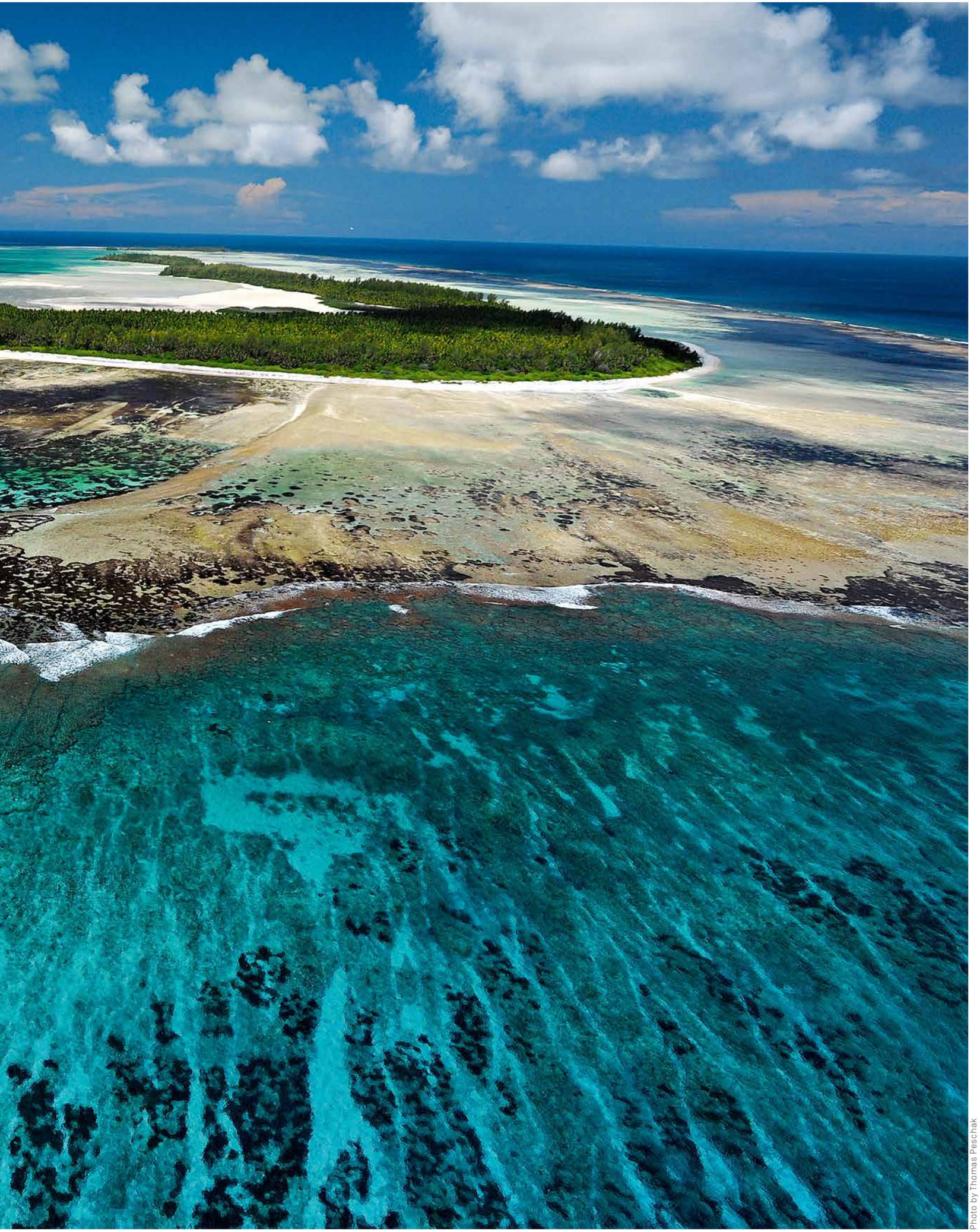
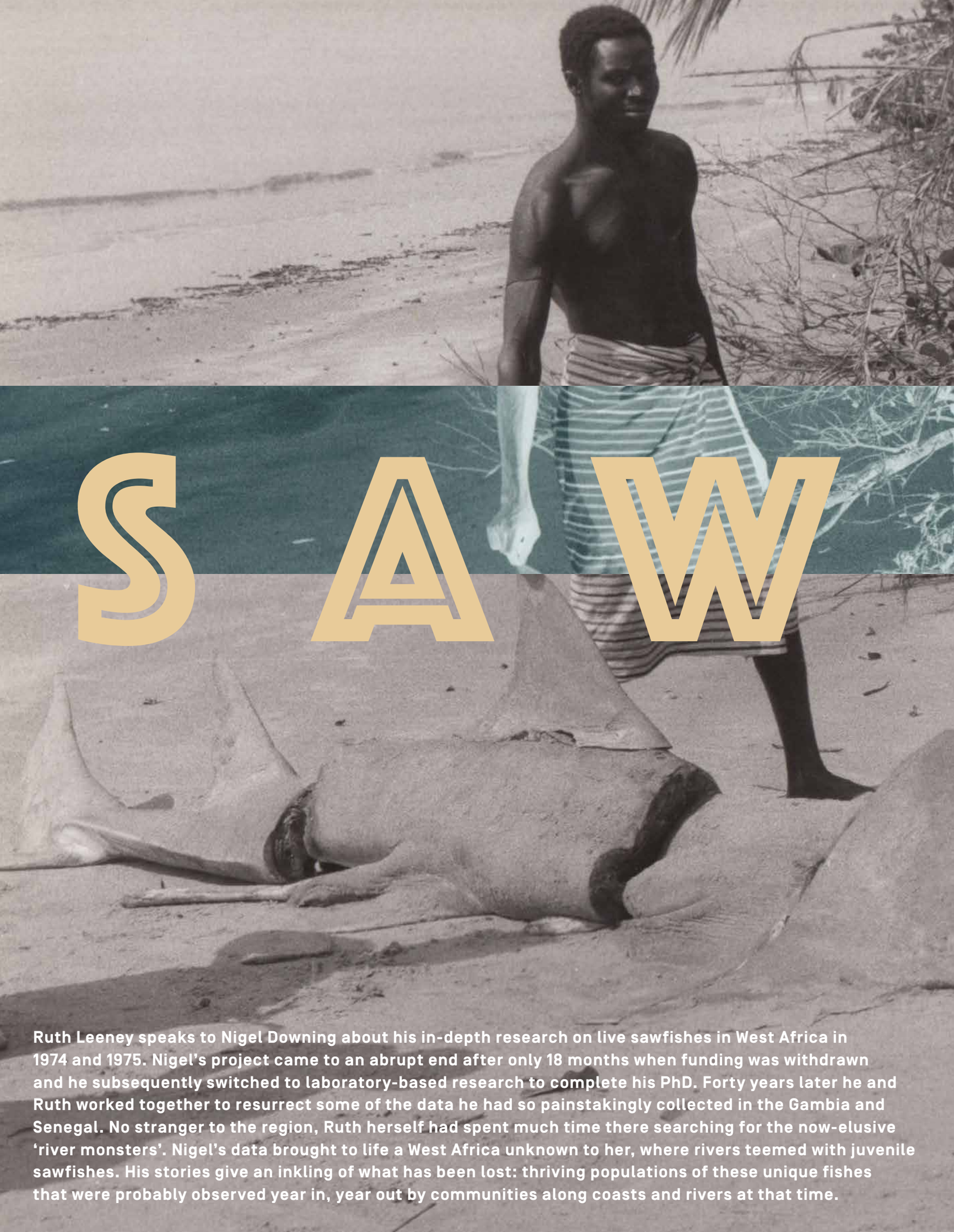


Photo by Thomas Peschak



SAW

Ruth Leeney speaks to Nigel Downing about his in-depth research on live sawfishes in West Africa in 1974 and 1975. Nigel's project came to an abrupt end after only 18 months when funding was withdrawn and he subsequently switched to laboratory-based research to complete his PhD. Forty years later he and Ruth worked together to resurrect some of the data he had so painstakingly collected in the Gambia and Senegal. No stranger to the region, Ruth herself had spent much time there searching for the now-elusive 'river monsters'. Nigel's data brought to life a West Africa unknown to her, where rivers teemed with juvenile sawfishes. His stories give an inkling of what has been lost: thriving populations of these unique fishes that were probably observed year in, year out by communities along coasts and rivers at that time.

WEST AFRICAN SAWFISHES: A WINDOW INTO THEIR LOST WORLD

FISH

Photo by Nigel Downing

This 4.5-metres largetooth sawfish was caught in October 1975 and reconstructed for the photograph. The sawfishes were a nuisance for local fishermen because they became entangled in their nets and damaged them.

WHAT WERE YOUR RESEARCH OBJECTIVES IN WEST AFRICA?

Dr Jean Maetz, a French physiologist who ran a radio-isotope laboratory in the south of France, was keen to discover how elasmobranchs survive in fresh water. He proposed that I find suitable animals, catch them, look after them in captivity locally and then arrange the transport of about 20 of them by air to his laboratory. Then I would work with him using radio isotopes to study the flux of water and ions in and out of the fish under experimental conditions. This last part I never achieved.

AMBITIOUS AND EXCITING GOALS! WHERE DID THE IDEA FOR THE PROJECT COME FROM?

When as an undergraduate I listened to a lecture about osmotic and ionic physiology, I was informed that cartilaginous fish were stenohaline – unable to tolerate large variations in salinity. While there are teleosts (bony fish) that can move from sea water to fresh water and vice versa, salmon being the best-known example, we were told that elasmobranchs were restricted to the sea. However, I knew otherwise. As a young boy in South Africa I was well aware of the Zambezi shark (bull shark), which had been held responsible for a spate of attacks off Durban's beaches in the 1960s. I even remember an ambulance arriving to pick up a victim from a beach where we used to swim. I also knew that this shark swam up rivers and had frequently been observed in fresh water. Further, having spent several months working at the Oceanographic Research Institute at the Durban Aquarium before going up to university, I knew that sawfishes were also found in rivers as well as the sea.

So, three things compelled me to do this project: I really like sharks; field work was my thing; and I was curious to find out how euryhaline elasmobranchs control their salt and water balance (osmoregulate) as they move between salt water and fresh water.

WERE YOU AWARE THAT SAWFISHES WERE PRESENT IN YOUR STUDY AREAS WHEN YOU FIRST STARTED THE PROJECT IN THE GAMBIA AND SENEGAL?

My initial plan was to head back to South Africa, use the Durban Aquarium facilities and collect from the rivers and estuaries of Zululand, but that fell through. Dr Maetz said he had heard there were sawfishes in West Africa and so, as a result of hearsay, I ended up working between the Gambia and Senegal, both of which proved to be excellent places to capture bull sharks and sawfishes. By that point I had realised, from my time at the Durban Aquarium, that keeping bull sharks alive and healthy in captivity was going to be far more difficult than looking after sawfishes. The latter can happily spend hours on the bottom using their spiracles to ventilate, whereas bull sharks need to keep swimming. For that reason, sawfishes became my primary study species.

CAN YOU PAINT A PICTURE OF YOUR FIELD WORK AND DAY-TO-DAY ACTIVITIES IN THE GAMBIA AND SENEGAL?

I was based in Thiaroye, on the outskirts of Dakar (the capital of Senegal), at a French laboratory. However, I set out for the field very early on to establish where best to find the fish I needed. I discounted the Senegal River from the outset and investigated instead most of the Gambia River, by road in Senegal and by road and boat in the Gambia. Finally, I established two field bases in the Casamance, in southern Senegal, because sawfishes appeared to be more numerous in the Casamance River. It was also easier to work there than anywhere else.

Initially, my main priority was to find out where, when and how to catch small sawfishes. Individuals can grow to several metres in length and, for obvious reasons, I preferred them to be the size of neonates. Once I had located them, the next phase was to keep them in captivity locally. Thiaroye and the Casamance are miles apart and there were no holding facilities at either place. So in Thiaroye I had to build tanks and equip them with water circulation and filtration systems, while along the Casamance River I constructed pens in which to hold recently caught sawfishes. Finally there was the issue of transporting them from the pens to the tanks.

All of this took me six months and I had been given only eight months to get the fish to France! I was given an extension to collect again in 1975 and, with all the infrastructure and logistics firmly in place, I conducted an intensive sampling season in the Casamance River.

A typical day in the field began well before dawn, when I got up, left the empty classroom where I slept and went to pick up a local fisherman, Timothé, who helped me with all my work in the Casamance. We would go back to the classroom and cook and wolf down huge bowls of porridge, washing them down with cups of tea or hot chocolate. We then made our way to the river by car with all the equipment: fuel, transport tank, net, syringes, portable centrifuge, battery, ice and much more. After dragging the boat into the water, engine attached, we loaded all the equipment and made our way to the river mouth. Then we set the net and waited.

We knew when anything was snagged in the net and went to retrieve it immediately. If it was a sawfish, one of us held it firmly in the water while the other patiently disentangled the rostrum from the net. This could sometimes take up to 20 minutes. The animal was sexed and measured and sometimes we took a blood sample too. It was released into the transport tank and the water circulation system switched on. If another sawfish had been caught in the meantime we would retrieve that one too. Then we had to dash to the holding pen to release the sawfish before heading back to continue netting.

At the end of the day we retrieved the net and Timothé repaired it if necessary while I took care of the boat and loaded up the equipment for the next day. I wrote my notes up by gaslight, cooked myself a meal and fell into bed, exhausted. The days were long and tiring.

By June 1975 I had a holding pen in the river filled with small sawfishes. As I was preparing to transport them north, I was told that lightning had struck my tanks and that the research vessel that was to transport them had broken down. I released all the sawfishes back into the river and headed for home. Although dispirited, I was happy that I now knew how, when and where to catch sawfishes and, most importantly, how to look after them.

YOU TOOK A REMARKABLE, SOMEWHAT POIGNANT PHOTOGRAPH OF AN ADULT FEMALE SAWFISH THAT HAD BEEN LANDED ON A BEACH IN THE GAMBIA. CAN YOU DESCRIBE THE EXPERIENCE OF SEEING HER BEING BROUGHT TO SHORE?

I was very excited. Only a few days previously I had helped to collect an equally large female at Niani Maru, several hundred kilometres up the Gambia River and in fresh water. Now here one had been taken in the sea not far from the river's mouth and she was pregnant with 15 young. It was such a shame that she did not deliver them. I felt overwhelmed to see so many baby sawfishes so near to term, all out of the one huge female. I could only surmise that she too was about to make the journey upstream to give birth. Instead, in no time at all she was reduced to chunks of meat, ready to be dried, then to be bagged up and exported to Ghana. I was saddened by the demise of such a magnificent animal and her young, but I had no idea then of how endangered sawfishes would become.

FORTY YEARS ON, SAWFISHES ARE IN DANGER OF GOING EXTINCT THROUGHOUT MUCH OF THE WORLD AND MAY EVEN HAVE DISAPPEARED FROM THE AREAS WHERE YOU SAW SO MANY OF THEM. HOW DOES THAT MAKE YOU FEEL?

I don't wish to be too morbidly philosophical, but I believe very strongly that we are stewards of the world we live in

Photo by Nigel Downing

and we are doing a pretty poor job of looking after it. The loss of sawfishes is global, with the exception of a couple of places – Florida and Western Australia – where they are properly protected. I am sad that they are probably no longer present in significant numbers in West Africa. In other parts of the world, their recovery will depend on credible and guaranteed protection being put in place, which may be too much to ask of some countries.

The fishing net has been blamed for the decline in sawfishes in West Africa. Although they may now fetch a good price, largely because of their fins, back in the 1970s the fishermen did not particularly like catching sawfishes. They were not valued as fresh food and they made a huge mess of their nets.

WHAT INFLUENCE DID YOUR TIME WORKING ON SAWFISHES IN WEST AFRICA HAVE ON THE REST OF YOUR LIFE, YOUR INTERESTS OR ATTITUDES?

Overwhelmingly I feel a sense of privilege. I have to pinch myself sometimes to realise what I lived through and witnessed some 40 years ago. The experience of working largely alone and undertaking the task I did certainly formed me and I would never trade it for anything, tough though it was at times.

Nigel's description of the time he spent studying sawfishes in West Africa provides a solemn and somewhat dramatic contrast to the present day and highlights the almost complete loss of these extraordinary creatures from the coasts and rivers of Senegal, the Gambia and many other West African countries over just a few decades. I hope, however, that his story will inspire others, as it has me, to seek out and protect any remaining sawfish populations in far-flung corners of the world, lest they too meet the same fate.

Leeney RH, Downing N. 2016. Sawfishes in The Gambia and Senegal: shifting baselines over 40 years. *Aquatic Conservation: Marine and Freshwater Ecosystems* 26: 265–278.

In 1974 and 1975 Dr Downing studied sawfishes in Senegal and the Gambia. He worked in collaboration with local fishermen, who brought him any sawfishes they had caught.

Nigel places a juvenile sawfish in the holding tank. During the rainy season there was an abundance of sawfish pups in the Casamance and Gambia rivers.

THE KING OF THE FISHES

RUTH H. LEENEY

The ambitious research carried out by Nigel Downing more than 40 years ago should have set the stage for a wealth of exciting studies on sawfishes in West African waters. Instead, sawfishes sank back into oblivion, noted perhaps only by local fishers whose nets they got entangled in. By the time I started to search for these once-symbolic and abundant creatures of Africa's rivers and coasts, they had all but disappeared. I was probably 20 years too late.

To date, my work has focused on a very simple goal: documenting where in Africa sawfish populations persist. After all, conservation strategies for sawfishes cannot be developed if we do not know where the species still occur, the specific threats they face in those areas and the governments and communities we need to engage. But these remarkable fishes are now so rare, and perhaps are found only in such remote areas, that searching for them is like looking for a needle in a haystack. The most cost- and time-efficient way to get a feeling for whether sawfishes are still encountered in any given place is by talking to local fishers. They know the waters upon which they depend for their livelihoods better than most and they have years, or even decades, of experience from which they can paint a long-term picture of the ecology and changes in those waters.

For several years I focused my efforts in West Africa, but research in Guinea-Bissau, the Gambia and Liberia suggested that most fishers had last seen sawfishes several decades previously – and many younger fishers had never seen a sawfish in their lifetime. I then became aware of occasional but ongoing reports of sawfish rostra turning up in markets in north-western Madagascar. Despite intensive shark fisheries throughout Malagasy waters, it seemed that sawfishes might still be present. It was here too that the most recent scientific report of sawfishes in African waters had occurred: in 2001 Japanese scientists documented the capture of two largetooth sawfishes by Malagasy fishers. And so it was that in 2015, funded by the Save Our Seas Foundation, I spent three months collecting baseline data in the north, north-west and west of Madagascar and met a number of communities that stated that they still encountered sawfishes. I will be returning to Madagascar this year to continue this work and to begin sampling in key habitats in the hope that I will be able to confirm that sawfishes are still present there.

I believe that there is still hope for sawfishes in African waters. But my colleagues and I will have to act fast and, given the considerable challenges that communities and governments in African nations face in managing their fisheries, external support from the international conservation and research communities will be essential. A holistic approach to the conservation of sawfishes will not only ensure the protection and sustainable use of these unique species, but will also benefit the river, mangrove and coastal ecosystems they inhabit, as well as the human communities that depend on those ecosystems for their livelihoods. Sawfishes really can be, as they are called by one community in north-western Madagscar, *le roi des poissons* – the 'king of the fishes'.

Ruth H. Leeney is the founder and director of Protect Africa's Sawfishes and the Sawfish Conservation Officer for the IUCN Shark Specialist Group. Updates on her sawfish work can be followed on the Protect Africa's Sawfishes Facebook page.

Photo by Nigel Downing

DEVILS' A

Two Palestinian children look out of a window in a mural painted by Akot, a German artist who made paintings out of houses destroyed in the Israeli offensive on Gaza in July and August 2014. The mural depicts the face of a Palestinian child looking for a future and the words 'I see hope in the eyes of our children' in Arabic.

DVOCATE

CONSERVING MOBULAS IN GAZA

A fisherman holds up a large piece of mobula meat. It is not a popular food source among Palestinians, but because it is inexpensive, it is consumed by the poor.

Words by Philippa Ehrlich
Photos by Wissam Nassar

Giant devil rays are not a popular target for Gaza's fishers, yet when hundreds of the mobulids mysteriously appeared within the limited range of their nets, they rushed to land them. The strange phenomenon of the rays' sudden arrival puzzled marine researcher Mohammed Abudaya and he set out to discover what was behind it – and learn more about the political background to the fishermen's response.

In the last few days of February 2013, news pages around the world depicted gory scenes on beaches along the Gaza Strip. Unlike the usual stories from the beleaguered Palestinian territory, these images were not political. Rather, they showed a dimly lit beach littered with hundreds of massive, flattish carcasses of what might easily be mistaken for manta rays. In a video published by the *International Business Times* (*IBT*), boats deep in the water and heavily laden with large, black fish can be seen approaching the shore.

Throughout the dark hours of the morning and into the first few hours of daylight, fishermen worked in pairs to drag the hefty animals off the boats and onto the sand, where they laid them out in rows: a macabre jigsaw of triangular carcasses stretching to the far end of the beach. As day broke, horse-drawn carts were brought down to the shore. Tons of meat were loaded into them and ferried to markets throughout Gaza to be sold for about US$2 per kilogram.

The gruesome images and footage went viral and sensation-seeking journalism sent conflicting reports of the landings around the world. The lives of fishermen are among the hardest in Palestine and in the video published by the *IBT* the men can be heard thanking God for their good fortune. Many local publications referred to the event as 'a gift from God' – a phrase misinterpreted by international media houses, which stated that the hundreds of rays had 'washed ashore' over the course of two days and suggested that a mass stranding had taken place.

For the next few days possible reasons for the incident were debated in comment forums and on social media around the world – and one local television report caught the attention of a certain Dr Mohammed Abudaya in Palestine. A marine and coastal management lecturer and researcher at the Islamic University of Gaza and Al-Azhar University, Mohammed became determined to understand the science behind how more than 500 endangered rays had been caught and killed in just a few days on Palestinian shores. He was contacted by Daniel Fernando of the Manta Trust, who offered support and encouraged him to get in touch with the Save Our Seas Foundation to apply for funding.

The species that was landed, the giant devil ray *Mobula mobular*, is the largest in its genus and the only one found in the Mediterranean Sea. It has been classified as Endangered by the International Union of the Conservation of Nature (IUCN) because of its low reproductive capacity, limited range and high propensity for being taken as by-catch. In the past, according to Gazan fishermen, these rays were often present in Palestinian waters around March, but until the massive haul in 2013 they had not been seen for six years.

Soon after the landings Mohammed started his work into the mystery behind Gaza's Mediterranean devils. He has been working along the Palestinian coast since 2001, when he became involved in a project called Gaza Coastal Management that formulated a management plan for marine ecology and tackled local fisheries management and overfishing. All fish species, including sharks and rays, came under his scrutiny, but even as a marine scientist he had not come across the giant devil ray until 2013. 'Nobody talks about fishing for *Mobula mobular* in the Eastern Mediterranean and nobody has tackled this issue from a scientific point of view before. I am the first one, which makes me very proud,' he says.

In fact, very little is known about the giant devil ray anywhere in its range. Until 2011, when Italian biologists published a paper describing its diving behaviour, the only available information came from by-catch data and opportunistic sightings. Growing up to 6.5 metres (21 feet) long and up to five metres (16 feet) wide, but generally seen at about three metres (10 feet) long, the giant devil ray is second in size only to oceanic mantas among the mobulids.

Like the pygmy devil ray, its better-known, flying cousin, the giant devil ray travels in groups, stays close to the surface and migrates across vast distances. It feeds on plankton, small pelagic fishes and krill, and scientists believe that it lives for about 20 years. As in most elasmobranchs, the underlying weakness in the giant devil ray's capacity to cope with pressure is its very slow rate of reproduction. A female gives birth to only one live pup and is pregnant for a staggering 25 months. Newborns can be almost two metres (6.5 feet) wide and the largest on record weighed 35 kilograms (77 pounds)!

When researching the giant devil ray, the Italian team, led by Simonepietro Canese, satellite-tagged three individuals in the Central Mediterranean and tracked their movements over the next four months. The rays in this population are believed to arrive in the Central Mediterranean in June and July and leave again in mid-September. The satellite data showed that the animals dive to depths of between 600 and 700 metres (2,000 and 2,300 feet), but spend more than 80% of their time between the surface and 50 metres (165 feet), presumably because they prefer the warmer water temperatures of 20–29 degrees Celsius (68–84 degrees Fahrenheit). This tendency to stay close to the surface has made the giant devil ray susceptible to becoming incidental by-catch, especially in floating drift nets that were used to target swordfish – a method that is now illegal. However, the rays are still caught on long-lines and in purse-seine and trawl nets and are also vulnerable to oil spills and heavy marine traffic. The IUCN suspects that over the past 60 years (three generations), 50% of the entire population of giant devil rays in the Mediterranean has disappeared.

For an already vulnerable species, a catch of over 500 in just two days could be disastrous. Although mobula rays are not targeted in most of the Mediterranean, Palestinian fishermen have very few options and elasmobranchs are an important resource for them. The Gaza Strip is home to more than 1.7 million people and is considered to have the 13th highest population growth rate in the world. And, with only 45 kilometres (28 miles) of coastline, the local marine ecosystem is under major pressure.

Since 2013, Mohammed has focused on creating a basis for understanding the Eastern Mediterranean population of giant devil rays from both a biological and a socio-economic point of view. From his conversations with fishermen he has learnt that Gaza's devil rays migrate from the north-eastern Mediterranean (Turkey, the Greek Islands, Cyprus and Malta) to arrive in the south-east (Palestine, Egypt, Syria and Israel) in about mid-January. Then in late April or early May, they return northward. Mohammed believes that, like the population in the Central Mediterranean, they are following warmer temperatures and travelling to Palestinian waters to mate. 'Ninety nine per cent of the animals we see in our waters are adults, big adults,' he explains. 'They always move in groups: one or two females, and then the rest are males. Scientifically speaking, this is the mating habit of mobulids. I think they are seeking the warm water for mating and then it seems they return to the North Mediterranean to give birth.'

→ Mohammed Abudaya on a fishing boat with its catch of giant devil rays.

↓ There are currently 3,500 fishermen trying to make a living from Gaza's 45-kilometre-long coastline. They are only permitted to fish between three and 12 nautical miles from shore, depending on the current restrictions imposed by the Israeli government.


DENVER

← Fishermen drag giant devil rays from their boats onto the beach. Growing to more than six metres in length, these are the largest of the mobulas.

↓ Earning a living to support their families is a daily struggle for Gaza's fishermen. It is common for children to work in the fish markets at night to help their parents.

To understand what was behind the fishermen's massive haul in 2013, it is necessary to look at both the scientific data and the political situation at the time. Access to the sea has been a contentious issue in Israeli–Palestinian relations since the year 2000. According to the 1993 Oslo Peace Accord, Palestinians should be allowed to fish as far as 20 nautical miles from their coastline. However, fishing rights have become a means of control for the Israelis, who increase or decrease restrictions based on the political climate at the time. This has crippled the local fishing industry and reduced the once wealthy fishing community to paupers.

Until 2006, Palestinians could travel up to 12 nautical miles in search of fish, but since then they have been limited to fishing within 3–6 nautical miles of the coast. In those last few days of February 2013, the stage was set for a fateful collision between man and ray. A huge aggregation of giant devil rays was travelling along the Gazan coastline, moving with the warmer water and mating. For reasons we may never know, they swam into shallower water, within reach of the hungry Palestinian fishing fleet. The fishing boats had not come across anything like this for six years and the unfortunate mobulas winged their way straight into a wall of purse-seine nets, giving fishermen one of the greatest hauls they had ever seen. For them it was a bounty so great that it had to be a blessing from God, or at least compensation for the misery that the Israeli restrictions had brought to them and their families.

The fishermen were excited by the sheer volume of their catch, but even in Gaza mobula rays are not a desired food source. The meat is sold for a very low price and, as Mohammed explains, 'Most of the fishermen don't consume the meat of this species. They say to me, "It's not nice meat. We don't like it."' Poor people eat the rays because at US$2–3 per kilogram it is affordable; other seafood options can cost as much as US$7–12 per kilogram. Statistically, Palestinians consume the least fish of any nation in the Mediterranean. Even someone who earns well can only afford to eat fish about once a week. Most cannot buy it even once a month.

Fishers will catch whatever they can within the limited fishing zone in order to eke out a living and cover fuel costs. But, according to 39-year-old Nehad El Hessi, most would not choose to target devil rays at all because they generally cannot net the quantities that make it worthwhile. 'Last year I went to sea several times during the season to catch mobula, but only managed to catch a few,' he says. 'The money I earned from selling them did not cover fuel costs and the expense of paying my crew. Going after mobula is something we don't like doing at all. If we had a choice, we would go for other species, but the permitted fishing zone is empty of fish.' Ideally, fishermen trawl for shrimps or fish species like mullet and sardines or they catch pelagics, including large sharks. When mobulas are caught, it is generally in purse-seine nets.

The most serious global threat facing mobulid rays today is the international trade in manta and mobula gill rakers, which are dried and sold in East and South-East Asia for use in traditional Chinese medicine. From what Mohammed has learnt in interviews, there used to be a modest gill-raker trade in Gaza, but it has not existed for many years. Fishermen would sell the gills to Egyptian dealers, who in turn sold them to the international market. Now, because of tight restrictions on movement between Egypt and Palestine, it is very difficult for Palestinians to get access to the trade and only a handful of the fishermen that Mohammed spoke to had ever been involved in it. Although the Egyptian government has banned fishing for giant devil rays, some illegal fishing continues.

In addition to investigating the fishery over the past three years, Mohammed has been collecting biometric data and DNA samples at various landing sites along the Gazan shore during devil ray season. Catch numbers have varied greatly over that time. In 2014, the fishing zone was limited to three nautical miles during mobula season and only 30 devil rays were caught. The number rose to 84 the following year and within the first few months of 2016 Mohammed and his team had collected data from 150 specimens, most of which were caught within five nautical miles of the shore.

It is still a mystery why giant devil rays are swimming so close to the coastline when they move past Gaza, but by the time they return again we should have some answers. On 1 April this year, Mohammed fitted satellite tags to three rays: two males and a female. The information collected by the tags will give him the empirical evidence he needs to confirm the migratory patterns of the rays. This will be critical for understanding their movements and implementing protective measures within the Eastern Mediterranean.

In the meantime, the researcher and his team will continue to work with fishermen in a bid to protect Gaza's mobulas. 'I believe that at the local level it's easy to convince our people to take part in conservation. This year we will be conducting conservation awareness sessions with the fishers. We expect that after some very intense workshops, they will voluntarily stop catching shark and ray species,' he explains. Fishery officials have a very supportive relationship with Gaza's fishermen and Mohammed has asked them to assist him during workshops. From the sessions he has held so far, he has learnt that fishermen know very little about the life history of elasmobranchs and they were not aware that the giant devil ray is an Endangered species. He has also started conversations with the Palestinian government about formulating a regulatory framework to protect devil rays and other vulnerable elasmobranchs.

Mohammed believes that his efforts are already starting to pay dividends. Of the 150 rays killed so far in 2016, 95 were targeted and 55 were netted as bycatch. Although the overall number has increased, he views this as a positive statistic. If such a large proportion of the animals are being caught unintentionally, it means that fishers are choosing to not target them, which would not have happened in the past.

Conservationists may find it difficult to accept the slaughter of so many endangered animals, but it is just as difficult to not sympathise with the fishermen. In 2000 there were 10,000 people making a modest but stable living from the sea. Since then thousands of families have lost their income and currently 3,500 fishers are working on 700 boats in Palestinian waters and earning less than US$200 per month. Fishermen who have taken the risk of fishing outside the restricted zone in a desperate attempt to increase their catch have lost their boats – in some cases even their lives. Others have been forced to undress at gunpoint and swim from their vessels to Israeli navy boats, regardless of weather conditions.

In the face of this kind of desperation, it is difficult to imagine how Palestinian fishermen might be open to the conservation of mobulas or any other animal.

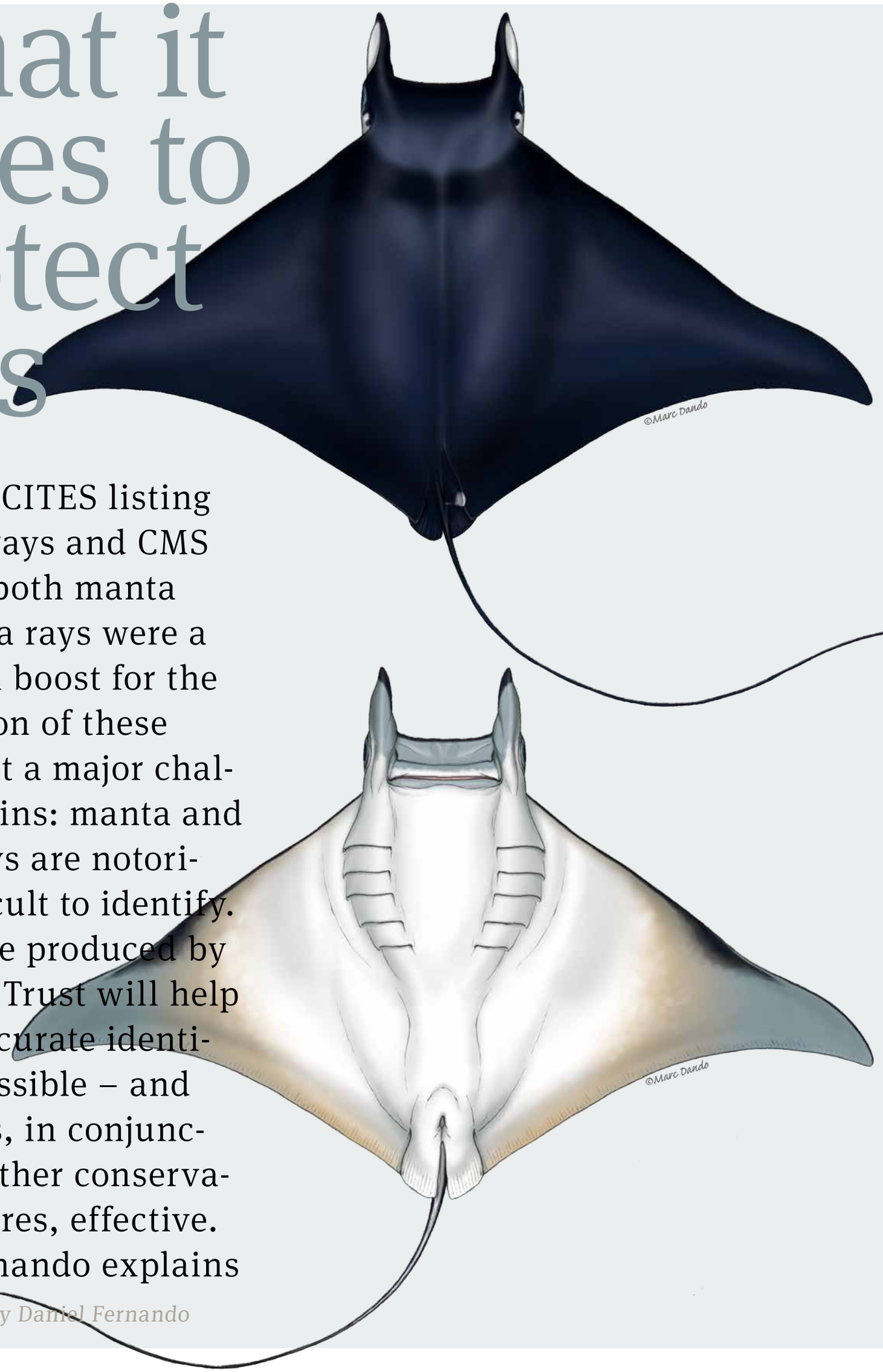
But Mohammed sees it differently. 'Why? I have asked many fishermen this question. They told me, if the sea were open and they were allowed to go further than six nautical miles, they would not even stop their boats and look at this species. They would have no time for it. There are too many other fish they could go after,' he explains.

This was echoed by 42-year-old Shaker Salah. 'We are forced to catch mobulas because we are fishing in a very limited zone and we need to cover the expenses of fuel and feed our children,' he says. 'If the fishing zone was expanded, we would not target this species at all.' If this is true, there is hope for the mobulas, especially as the Israeli government has recently increased Gaza's fishing zone from six to nine nautical miles along the southern part of the coastline.

And despite the difficulties and isolation that he experiences as a conservationist in Gaza, where he has access to electricity for only six to eight hours a day, Mohammed believes that there is more to saving giant devil rays in Palestinian waters than economics. 'It's a psychological thing,' he says. 'Our people here have been suffering from the occupation since 1948, for more than 60 years. Our people are very emotional. We care about everything because we are suffering, our parents are suffering, our grandfathers and grandmothers are suffering. We care about everything and we feel for everybody, because we like everybody to feel with us. Last year I did three awareness sessions where I showed a video of a pregnant mobula. Some of the fishermen started to blame themselves. One of them said to me, "Imagine that this species is your wife. And she is pregnant and somebody tries to attack her." I tell you something, if you speak to a person who is suffering or under pressure, it will be easier to convince them than a person living in good conditions. We have suffered for so long, why would we want make something else suffer, even if it is a fish or an animal?'

A policeman observes tens of rays that have been landed at Gaza in the early hours of the morning. Before Dr Abudaya began his workshops, fishermen were not aware this mobula is an Endangered species.

What it takes to protect rays



The recent CITES listing for manta rays and CMS listing for both manta and mobula rays were a substantial boost for the conservation of these species, but a major challenge remains: manta and mobula rays are notoriously difficult to identify. An ID guide produced by The Manta Trust will help to make accurate identification possible – and the listings, in conjunction with other conservation measures, effective. Daniel Fernando explains how. *Words by Daniel Fernando*

Dorsal and ventral illustration of bentfin devil ray *Mobula thurstonii.*

Over the past few years, significant advances have been made in helping to protect sharks and mobulid rays and in improving the conservation of these marine animals. To a large extent, the advances were made possible by increased awareness of the threats to these vulnerable species from by-catch and from target fisheries, which are driven by the international trade for shark fins and mobulid gill plates. This awareness has, in turn, been generated through the knowledge gained from key data relating to the life-history characteristics of these species, such as age at maturity, rates of reproduction, longevity and so on. In order to obtain such key baseline data, scientific researchers and citizen scientists alike must be able to identify specimens down to species level – and they must do so clearly and accurately, so that the data collected do not produce results that misrepresent the species in question. This is the premise for the creation of the Manta Trust's mobulid identification guide, which will be released within the next few months.

In March 2013, at a meeting in Bangkok, the Manta Trust and colleagues from several international NGOs witnessed the successful listing of manta rays under Appendix II of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). This precautionary approach adopted by the international community clearly signalled that the unregulated trade of manta gill plates from unsustainable stocks would no longer be tolerated – and it was a very welcome announcement! However, this was just the first step in the process.

Following the announcement, regional workshops were established to help researchers in the field and customs officials at international borders to identify the different manta ray and other ray species, and also their dried gill plates (the gill plates are the most valuable part of the ray due to their use as a supposed remedy in Chinese medicine). Preliminary versions of the mobulid identification guide and gill plate identification guide, created by co-author Guy Stevens at the Manta Trust, played a large part in the training workshops. These workshops are a vital step in the implementation of CITES listings, as they develop capacity for national management and scientific authorities to conform to data standards that are essential for demonstrating that specimens originate from a sustainable population and therefore can continue to be traded internationally, albeit under a stringent permit system. Countries unable to conform to the standards would have to adopt strict measures to restrict trade and improve the local management of fish stocks.

Countries that are uncertain about the status of their manta fisheries are then encouraged to develop research programmes to collect data in order to assess the size and vulnerability of their manta populations. Based on the data collected, CITES management authorities would have the information necessary to determine whether sustainable trade could be authorised or additional national controls should be mandated. In addition, countries engaged in international trade can use resources such as this ID guide to separate the export of controlled products, such as manta gill plates, from the export of products of other traded species. They can also ensure that the appropriate non-detriment findings and export permits, according to CITES regulations, are included.

Some countries, convinced of the positive effects of ecotourism on their national economy, have gone a step further and completely banned all national manta fisheries. A recent example is Indonesia, which used to make a significant contribution to the global trade in manta ray gill plates. The closure of the manta fishery in Indonesia will enable populations to recover from their depleted state and boost ecotourism even further. It also provides researchers with a unique opportunity not only to study closely a population that has been given the opportunity to recover, but also to assess the potential of similar fishery closures for other species, including the closely related mobula rays.

From a biological standpoint mobula rays, although smaller, are extremely similar to manta rays. They too are facing a severe decline globally and were listed under Appendix I and Appendix II of the Convention on the Conservation of Migratory Species of Wild Animals (CMS) in Ecuador in November 2014. This listing, proposed by the government of Fiji, has helped to highlight the vulnerability of these species and the fact that they were often overlooked, mistaken for other species or ignored because they were too difficult to identify to species level. As a result, they were severely under-reported in fisheries statistics. To overcome these challenges, new legislation is now needed in regional fisheries management organisations and at a national level.

Nations attempting to manage fisheries strictly, whether at a local, regional or international level, face two major challenges: to introduce scientific recommendations into legislation, and to ensure that any such regulations are implemented and enforced appropriately. The limiting factor of both these challenges has always been the lack of scientific data, which for manta and mobula rays could be as complicated as the absence of detailed stock assessments, or as simple as knowing which species are present in a given region.

The incredible challenge of accurately distinguishing between the nine mobula ray species is the primary cause for the fundamental lack of knowledge about this genus. Life-history data for most of the nine species are still not readily available and it is anticipated that further research, similar to that being conducted on manta rays, could reveal that at least some mobula populations are even more conservative than currently estimated. If this were the case, it would make the introduction of local fisheries regulations even more urgent in order to manage and protect these species appropriately.

Furthermore, the fact that these species are threatened due to the global trade in gill plates suggests that further declines are to be expected, unless this trade is also managed through conventions such as CITES. Consequently, researchers studying these rays will need to compile scientific data to validate any proposed listings and, as is being done for manta rays, assess national or regional stocks to determine the potential for sustainable trade. The identification guide would be an invaluable resource for these processes. It would help, too, to determine where research should be focused in order to fill current data gaps.

There is also a project under way, carried out by the Molecular Ecology and Fisheries Genetics Laboratory at Bangor University, to create a mobulid genetic identification kit for all 11 manta and mobula species that will complement the mobulid identification guide. This kit will not only lend additional support for customs officials enforcing CITES and other legislation, in particular for prosecution purposes, but it will also improve our understanding of population connectivity. Information about population structure is vital to augment knowledge used to establish marine sanctuaries that can protect the core habitats and home ranges of all mobulid ray species. Both the kit and guide will also provide the tools necessary for other countries to follow in the footsteps of Indonesia and ban manta fisheries entirely – even to take a step further and prohibit the fishing of mobula rays as well.

It is my hope – and that of my co-authors from the Manta Trust, Giuseppe Notarbartolo Di Sciara and Guy Stevens – that the global mobulid identification guide we are creating, thanks to funding from the Save Our Seas Foundation, will enable researchers around the world to collect vast amounts of information to fill the gaps in our knowledge about these incredibly charismatic rays. This updated knowledge will result in the publication of new scientific literature that will support the promulgation of local and global legislation – be it through conventions such as CITES or national initiatives such as marine protected areas – to guarantee that both manta and mobula rays receive the protection they deserve and are given the opportunity to recover their populations to a state of equilibrium.

Q&A

In conversation with Erin Dillon

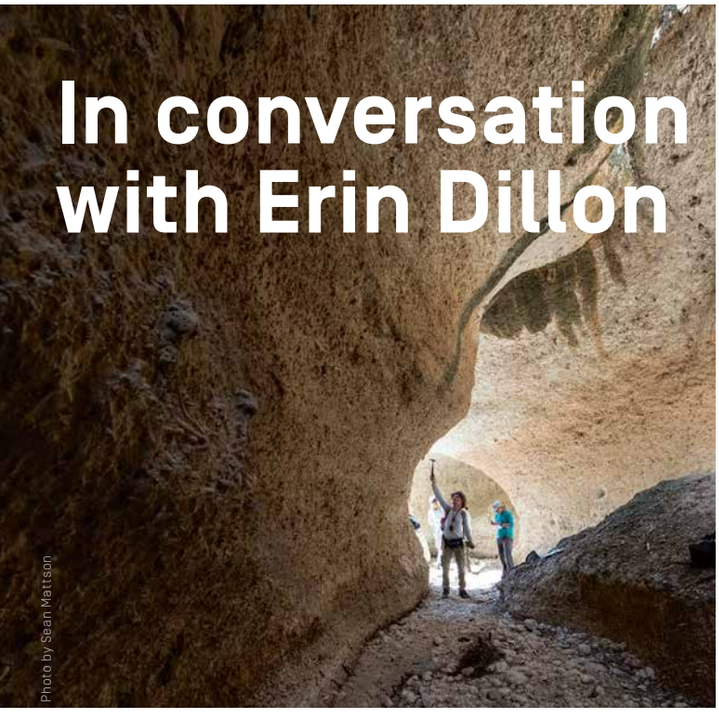


Photo by Sean Mattson

As part of a project called Baseline Caribbean, Erin Dillon is pioneering a new method of shark palaeontology that uses fossilised scales (dermal denticles) to discover what pristine shark communities looked like in Bocas del Toro, Panama. Philippa Ehrlich spoke to her about her study.

How did you become a shark palaeo-ecologist?

I attended a talk by Loren McClenachan in 2013. She was presenting her research on historical ecology, which involves looking at shifting baselines and analysing photos to investigate how the sizes of fish had changed over time. It was a really neat study and was probably my first introduction to historical ecology. It got me thinking about different tools that people can use to look at change over time in ecosystems, both in terms of community ecology and how people are influencing them. Then I got the opportunity to come down to Panama to work at the Smithsonian Tropical Research Institute (STRI) as an intern in Aaron O'Dea's lab. He does a lot of research in palaeo-ecology and was working on this Baseline Caribbean project, which is essentially trying to reconstruct entire reef communities using time points from about 7,000 years ago, before major exploitation by humans. Aaron and his collaborators hadn't really started looking at denticles yet. They'd found them in a couple of sediment cores, but they were very rare, so the team hadn't begun to investigate them further. This gave me an opportunity to explore the denticle question a bit more and start to look at how shark communities were changing over time.

Why is Bocas del Toro such an appropriate study site?

Bocas is a neat site because there is an exposed, really rare and beautifully preserved mid-Holocene reef that dates back about 7,000 years. It gives us a window into the past, into what 'pristine', pre-fishing, pre-exploitation communities may have looked like. You can walk through the different reef zones. You can see where there might have been sea grass in one area and how there was a lot of staghorn coral on the reef itself. This species of coral is now listed as Critically Endangered on the IUCN Red List of Threatened Species™. The region has also been well studied by scientists at STRI, and there are modern reefs neighbouring the fossil reefs, all within the same sheltered fringing reef environment.

Can you walk me through your method?

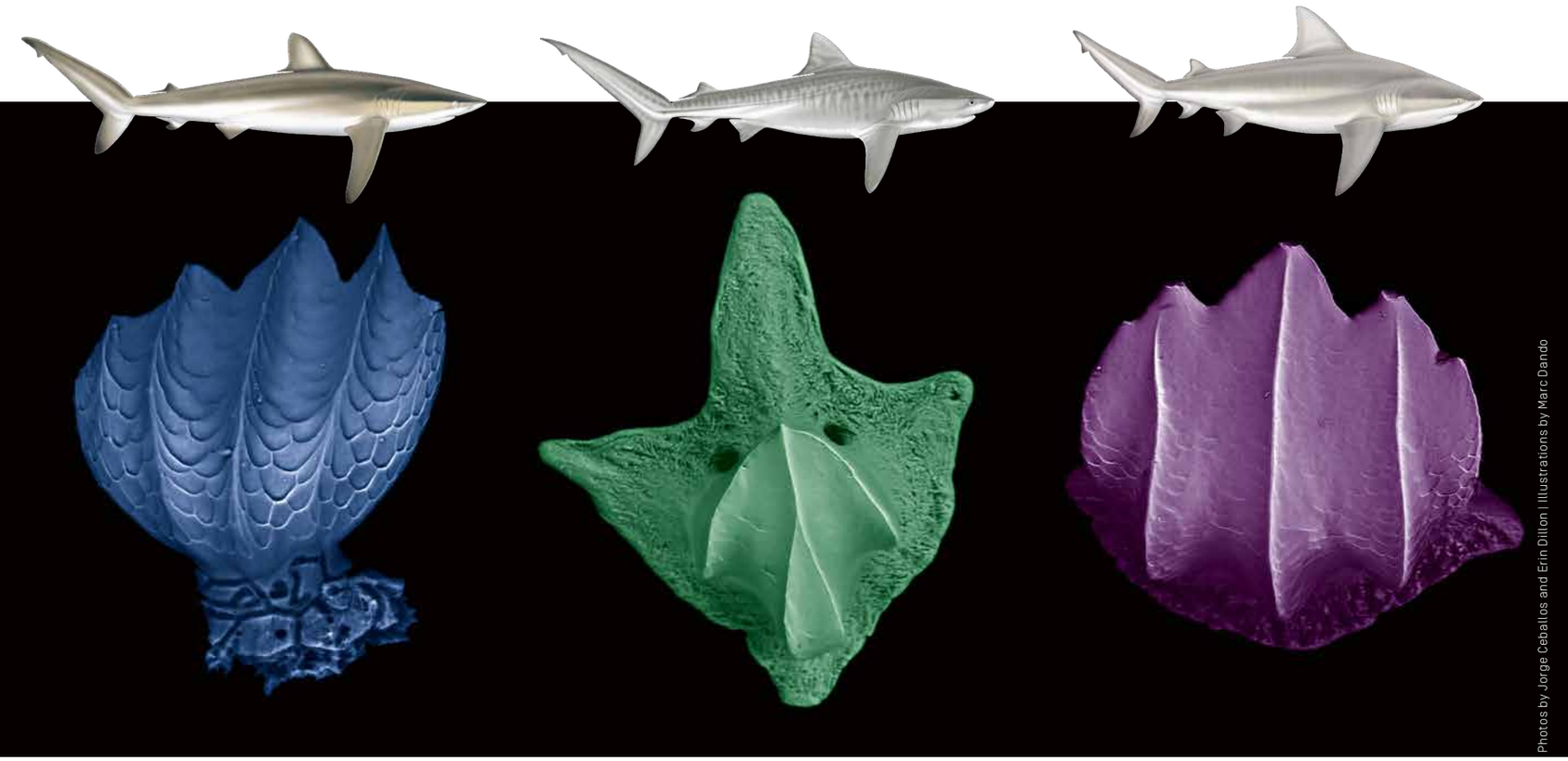
We collect large bags of reef sediments from the fossil site and then do the same on the nearby modern reefs using scuba. All this carbonate material gets digested down using acetic acid, leaving us with things such as fish ear bones (otoliths), fish teeth, the spiny skeletal parts of sponges (spicules) and shark denticles. These are picked out of the samples manually using a paintbrush. We then compare the fossils with the modern samples to look at change over time in a similar environment. Historical reefs are usually covered up by modern reefs or mangroves, so this exposed site presents us with a unique opportunity to use palaeontology to look at the past in Bocas del Toro.

So what was Bocas del Toro like 7,000 years ago?

About 7,000 years ago it looked like there were a lot more corals, especially staghorn coral *Acropora cervicornis* and branching finger corals *Porites* spp. There's been an unprecedented shift to lettuce coral *Agaricia tenuifolia* within the past century. But a coral reef is much more than just the coral. Our lab is focused on reconstructing the whole reef community. All the data are getting worked up right now. We're looking at fish ear bones and teeth, we're looking at dermal denticles and we're looking at sponge spicules, for example, but the picture is still pretty preliminary in terms of piecing together the entire community. In terms of relative abundance, it appears that there are fewer fish and fewer sharks today, but also that the communities have shifted. We're still trying to work out exactly how those shifts occurred.

How have shark communities shifted?

We've seen a wide diversity of denticle forms, both in the modern sediment and in the 7,000-year-old sediment. However, it does look like there's been a shift in the forms that we're seeing. Different types of sharks have different forms of denticles that have various functions. For instance, fast-swimming sharks have thin denticles with many narrowly spaced ridges, whereas bottom-dwelling sharks possess thicker, smoother denticles that form a protective armour. I've been working a lot on our reference collection right now to verify the existing descriptions of denticle types using measurable traits and to better understand the variation of denticles across different families of sharks. I'm also measuring the denticles to explore



Photos by Jorge Ceballos and Erin Dillon | Illustrations by Marc Dando

what other ecological information we may be able to glean from them. I then apply what I've learnt about these relationships between denticle form and shark ecology to the isolated denticles I find preserved in reef sediments. We've observed an increase in the relative abundance of thicker 'abrasion strength' denticles that are often found on nurse sharks and a decrease in thinner, ridged denticles that are often found on requiem and hammerhead sharks. This suggests that there has been a shift in the community of sharks: a decrease in the faster, predatory sharks and an increase (or no change) in nurse sharks. This makes sense, given that nurse sharks aren't of very high commercial value. They are nocturnal bottom-dwellers, so they may also avoid being caught as bycatch by fishermen. It's promising that we're seeing plausible trends with this novel approach.

Can dermal denticles help us to understand questions about abundance or only relative abundance?

Right now, we're looking at relative abundance; that is, whether there was relatively more of one group of sharks than another in the past as compared to the present. We can work this out by looking at denticle accumulation in the sediment. Sharks continually shed their denticles. These denticles are transported a little bit through the water column and they eventually settle on the substrate surface. At the same time, there is sedimentation and reef growth, so we look at the number of denticles per a given amount of sediment. We take bulk samples that are approximately 10 centimetres (four inches) deep from the substrate surface. Then we can use some of our existing sediment core data to understand how fast the reefs were growing at that time and approximately how much time that 10 centimetres represents. This can give you a relative measure of how many sharks there were based on the composition of denticles. We still need to investigate denticle shedding rates and how well the different denticle types are preserved, as well as compare the denticles we find in the sediments to modern surveys of the living shark communities in order to understand absolute abundance.

Do you have plans to expand the study to other sites?

In Dominican Republic there's another really neat suite of fossil reefs that are between 7,000 and 9,000 years old. Visiting this site can show us whether the composition of pre-human communities of sharks varied over space as well. We hope to see the same trend at the two sites, but even if we don't, that's also going to paint a really interesting picture of how different locations even within the Caribbean had very different pristine shark communities. And we're hoping to do something similar at Palmyra Atoll, in the Northern Line Islands. A collaborator of ours has collected sediment from Palmyra, which is considered to be one of the gold standards of 'pristine' in the Pacific.

What kind of interest have you had in your research?

I've talked to several people in Panama and the United States. Other researchers seem very excited about the potential of the tool and the prospect of developing it further, because the unique insight that it can give us into shark baselines is not really accessible by traditional survey methods. This information is locked in the past. Scientists have tried to use fishing logs, interviews and other anecdotal accounts. They have even looked at pottery, photos and historical illustrations to reconstruct the past, but these don't always give you an empirical answer. So in that sense, fossilised denticles are really one of the few ways to understand quantitatively what healthy shark communities looked like in the past.

↑ SEM (Scanning Electron Microscope) images of a dermal denticle from the dorsal fin of a modern shark: (left to right) silky shark *Carcharhinus falciformis*, tiger shark *Galeocerdo cuvier* and bull shark *C. leucas*.

← Aaron O'Dea and Erin Dillon marvel at the thousands of years of uninterrupted growth of staghorn coral *Acropora cervicornis* in this coral cave at Cañada Honda in the Enriquillo Basin, Dominican Republic.

the CO_2 conundrum

Words by Jason Hall-Spencer

Our use of finite natural resources is accelerating. Coupled with our poor management of renewable resources, this means that the earth has entered a phase of mass extinction; biodiversity is being lost across the planet.

Since the 1950s, coastal ecosystems have been radically transformed by human activities. The oceans have fared no better. Within a generation, fishing vessels using fossil fuels have removed most large fish from ecosystems and caused continental shelf habitats to lose their diversity. Extensive damage is now also occurring all along the edges of continental shelves and even on remote sea mounts.

The good news is that governments are at last getting serious about cutting carbon dioxide (CO_2) emissions and enforcing restrictions on destructive practices.

A changing planet

The past 60 years have without doubt seen the most profound transformation of our relationship with the natural world in the history of humankind. Since 1950, the human population has trebled (now at 7.3 billion, it is still rising fast); water use is up from 1,800 to 5,800 cubic kilometres per year; the number of rivers dammed has risen from 4,000 to 28,000; fertiliser consumption has jumped from 40 million to 280 million tonnes a year, quadrupling inputs of nitrogen to the coastal zone; and 65% of the atmospheric ozone has been lost. Motor vehicle use is up from 30 million to 750 million vehicles on the road and international tourism has really boomed, rising from fewer than one million arrivals per year in the 1950s to 600 million today.

All this has led to a great acceleration in our use of the earth's resources. Atmospheric methane and CO_2 concentrations have increased, causing the temperature of surface sea water to rise. We know from ice-core data that these warming gases are at much higher levels than at any time in the past 800,000 years, an era that includes a sequence of glacial periods and warm periods. Now we have entered unknown territory, as the excess CO_2 in the atmosphere is acidifying the oceans.

The monitoring of surface sea water off Hawaii and on both sides of the North Atlantic clearly shows increases in CO_2 levels that are tracking atmospheric increases. Carbon dioxide forms carbonic acid when it dissolves in water and has caused a 34% increase in the acidity (i.e., the concentration of hydrogen ions, H+) of sea water since 1800; by 2100 it will have caused an increase of about a 150% in surface ocean acidity. This is the fastest rate of chemical ocean change for millions of years, and perhaps in all time, since the rate at which fossil fuels are being burnt is geologically unique. In effect, the amount of carbon taken up by the oceans at present equates to every person on earth throwing carbon of the weight of a bowling ball into the sea every day.

Clearly ocean acidification is not acting in isolation. Rising CO_2 levels are also causing ocean warming, which is damaging tropical coral reefs, melting Arctic ice, thawing tundra and causing the distributions of many marine species to shift towards the poles. In low-latitude areas, warming waters are causing oxygen depletion, as warm water can't hold as much oxygen as cold water can. Also at low latitudes, mid-ocean gyres with low productivity are expanding because increased thermal stratification suppresses mixing and so starves surface waters of the nutrients that underpin productivity in the food web.

Research into ocean acidification is the 'new kid on the block' among planetary environmental issues. As evidence rolls in from across the globe it is becoming clear that many organisms are likely to be affected because not only does ocean acidification increase the amount of carbon available for photosynthesis and so is a resource for primary production, but it also lowers the amount of carbonate in the water, so that it can become corrosive to exposed skeletons and shells.

The acidification of the oceans has myriad biological ramifications because the transport of materials across cell membranes is influenced by H+ concentrations and so this can affect reproduction, behaviour, respiration and growth. This is thought to explain why the fossil shells found after high-CO_2 mass extinctions are dwarf forms, since smaller animals are better able to cope with the stress of ocean acidification.

Studying ocean acidification

One of the earliest studies of the biological effects of ocean acidification was carried out in aquaria in which corals switched from calcification to dissolution as CO_2 levels rose. This study was followed by a slew of high-profile papers pointing out that unless we get a grip on CO_2 emissions, tropical coral reefs will disappear.

As I specialise in temperate systems, this work on tropical coral reefs set me wondering about what ocean acidification might do to the organisms that live off Plymouth in south-western England and the corals that form deep north-east Atlantic reefs. One way to approach this question is to visit places that resemble what we expect the future to be like. A comparison of coral reefs of the Bahamas with those off Panama shows, for example, that coral reefs begin to crumble as carbonate saturation states fall. So today we find robust reefs in the Caribbean but eroded reefs in the low-carbonate waters of the tropical East Pacific. Studying places

Ocean acidification, caused by the addition of huge amounts of carbon dioxide to the marine environment, is a problem that has come to the fore relatively recently. Jason Hall-Spencer, Professor of Marine Biology at Plymouth University, places it within the context of the myriad other threats that face the world's oceans.

that already experience the lower carbonate conditions of a high-CO_2 world enables us to find out about the ecological effects of ocean acidification.

Research has begun in coastal areas that are acidified by CO_2, showing which organisms thrive and which are most vulnerable. This approach augments laboratory work, which is usually short-term and concentrates on organisms that are isolated from competitors, parasites and grazers. Volcanic activity causes CO_2 to bubble up from the sea floor, acidifying large areas for hundreds of years. It's tricky to find areas without the confounding effects of sulphur or toxic metals, but it can be done.

We have discovered that chronic exposure to increases in CO_2 around volcanic seeps alters food webs and causes the loss of marine biodiversity in the Mediterranean Sea, the Gulf of California and off Papua New Guinea. Key groups, like sea urchins and coralline algae, are consistently compromised and fish reproduction is disrupted.

It is not all doom and gloom, however; higher CO_2 levels stimulate the growth of certain diatoms, macro-algae and sea grasses. If temperatures remain low enough, the symbiotic algae of corals and anemones do well, as do numerous invasive species of seaweed. Some organisms adapt to long-term acidification, and species with protective tissues – including some corals in the tropics and mussels in temperate areas – often tolerate acidified sea water. Unfortunately, the combination of acidification and rising temperatures is often deadly, as the fall in carbonate saturation causes coral skeletons to dissolve and increased CO_2 levels stimulate the growth of fleshy algae that smother reefs.

Glass half empty?

As evidence about the effects of ocean acidification has started to build up we can begin to speculate about what our oceans may look like in coming decades if we do not get a grip on CO_2 emissions. It seems highly likely that iconic coral reefs will be a shadow of their former glory, with far fewer coral species and consequently a much lower diversity of many other organisms, from noisy nocturnal shrimps to colourful shoals of fish.

Carbon dioxide emissions will continue to warm the ocean's surface, repeatedly hitting reef systems with the stress of bleaching and spreading coral disease. This means that our grandchildren will probably only know dead reef rock covered in turf algae – and they'd better watch out, since soft-bodied jellyfish thrive in acidified waters. The few surviving coral reefs off Florida, for example, are likely to be lost in a vicious circle of coral decline and increased storminess that causes the breakdown of coral habitat through erosion and run-off from land. Even deep-water coral reefs, although far from coastal impacts, are unlikely to escape widespread damage, since rising CO_2 levels are expected to eat away at the reef structure.

Perhaps most people will be oblivious to these changes, just as only those who watch old Cousteau films are struck by the loss of large fish at sites the world over. As a tourist in New Zealand, I was blissfully ignorant of the local conservation situation – until local biologists explained to me how invasive species had ravaged the terrestrial flora and fauna. It's a bit like this when I take journalists to see areas with very high CO_2 levels near underwater volcanoes. They are often struck by how much life there is within the wafting sea grasses and seaweeds. It's not until we swim out of an acidified zone that they notice what was missing. The dappled greens and browns of the acidified waters are pretty enough, but nothing compared to the riot of colour that meets the eye at present-day CO_2 levels in gardens of pink encrusting algae, rasping purple sea urchins and bright yellow coral polyps.

Glass half full?

Even though human activities in the oceans and coastal zones continue to increase, we already have the know-how to ensure that marine environments are protected and managed sustainably. For a long time the oceans were to most people 'out of sight and out of mind', but in the information age it is ever easier to communicate solutions to the problems faced by our blue planet. Now that the science is better informed about practices that are clearly destructive and about the effects of rising CO_2 levels, we can focus on decisive avenues for action that will make a difference.

As individuals, we can reduce our carbon footprint and buy products that support sustainable fisheries and aquaculture. As societies, we can harness knowledge about marine biology to help improve the political, legal and institutional frameworks that focus on reducing CO_2 emissions and to showcase success stories in better marine governance.

We are beginning to see a shift in the way coastal zones are managed, since we now need to factor in the effects of increased CO_2 levels on sea level, storminess, heat waves and acidification. To stand a chance of protecting coral reefs and other iconic marine habitats, we need to integrate better the challenges associated with climate change and at the same time rein in the most obviously damaging activities, like the extermination of large marine organisms, the fuel-thirsty trawling or mining of the seabed and the pollution of coastal habitats.

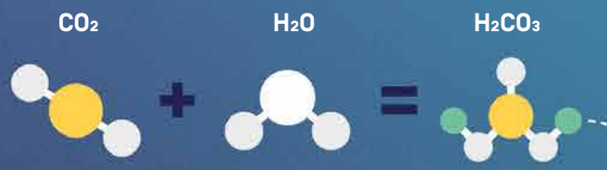
WHAT IS OCEAN ACIDIFICATION?

HOW DOES IT WORK?

The ocean **absorbs lots of CO_2** from the atmosphere.

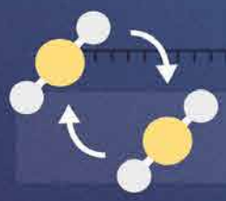
The amount it absorbs is the same as **every person on earth** throwing a **bowling ball** of **CO_2** into the ocean — **every day.**

Different things happen to CO_2 once it's in the ocean.



Some of the **CO_2** combines with **water** to form **carbonic acid**, which then breaks apart, releasing a **hydrogen ion.**

Hydrogen ions make the ocean more acidic.



HISTORICALLY the addition and removal of CO_2 were **in equilibrium.**

BUT TODAY the rate of CO_2 addition is

100x FASTER

The ocean is already

34% MORE ACIDIC

WHAT'S LIKELY TO HAPPEN?

Evidence about the effects of ocean acidification is building, but scientists are uncertain about the extent of the changes. Here are some likely scenarios:

It will be **more difficult** for many animals to **build shells**. One reason for this is less carbonate in the ocean water – a necessary building block in skeletons and shells. Animals like corals and molluscs are at risk.

The shells of **very small algae could also be affected**. As these form the base of the marine food web, their dwindling numbers might **change ocean ecosystems completely.**

WHAT CAN WE DO ABOUT IT?

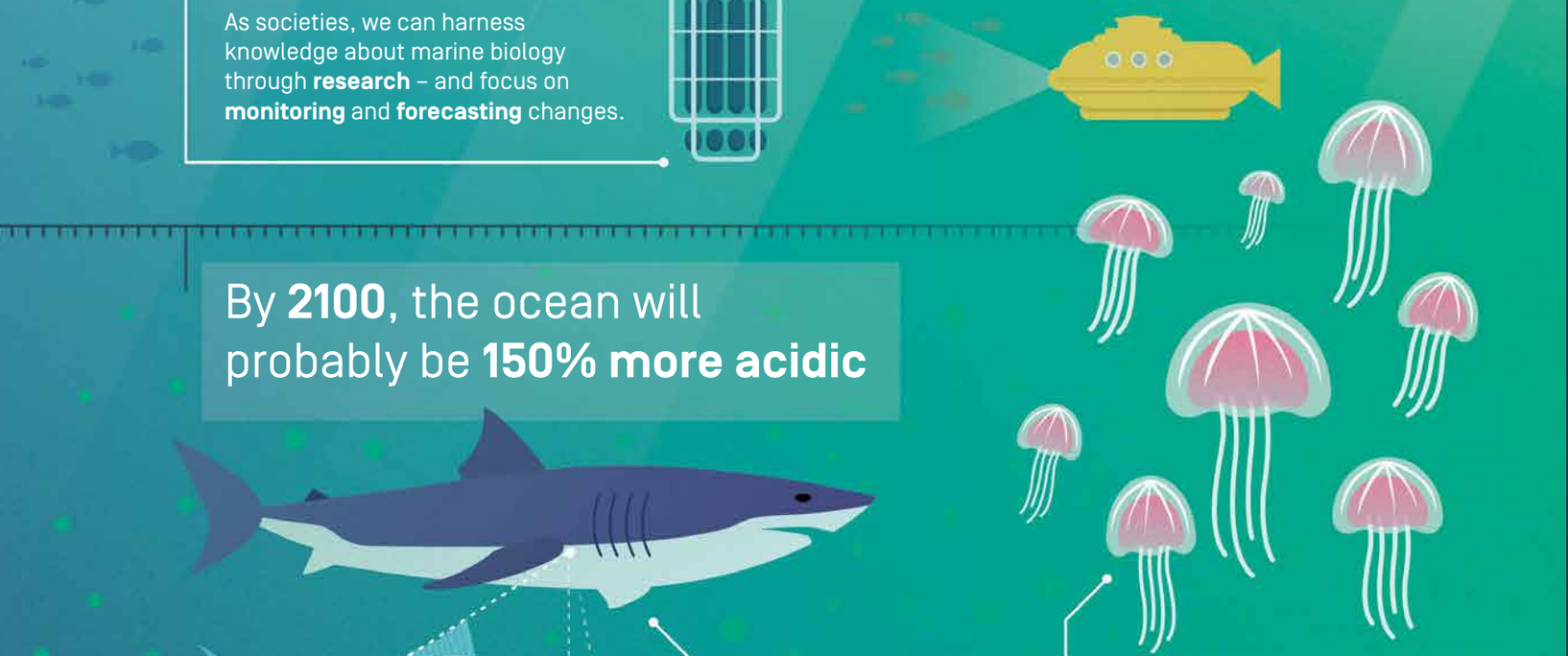
We can't stop ocean acidification entirely, but we can do our best to mitigate the impacts and protect those affected.

1.
As individuals, we can **reduce our carbon footprint** and buy products that support sustainable fisheries and aquaculture.

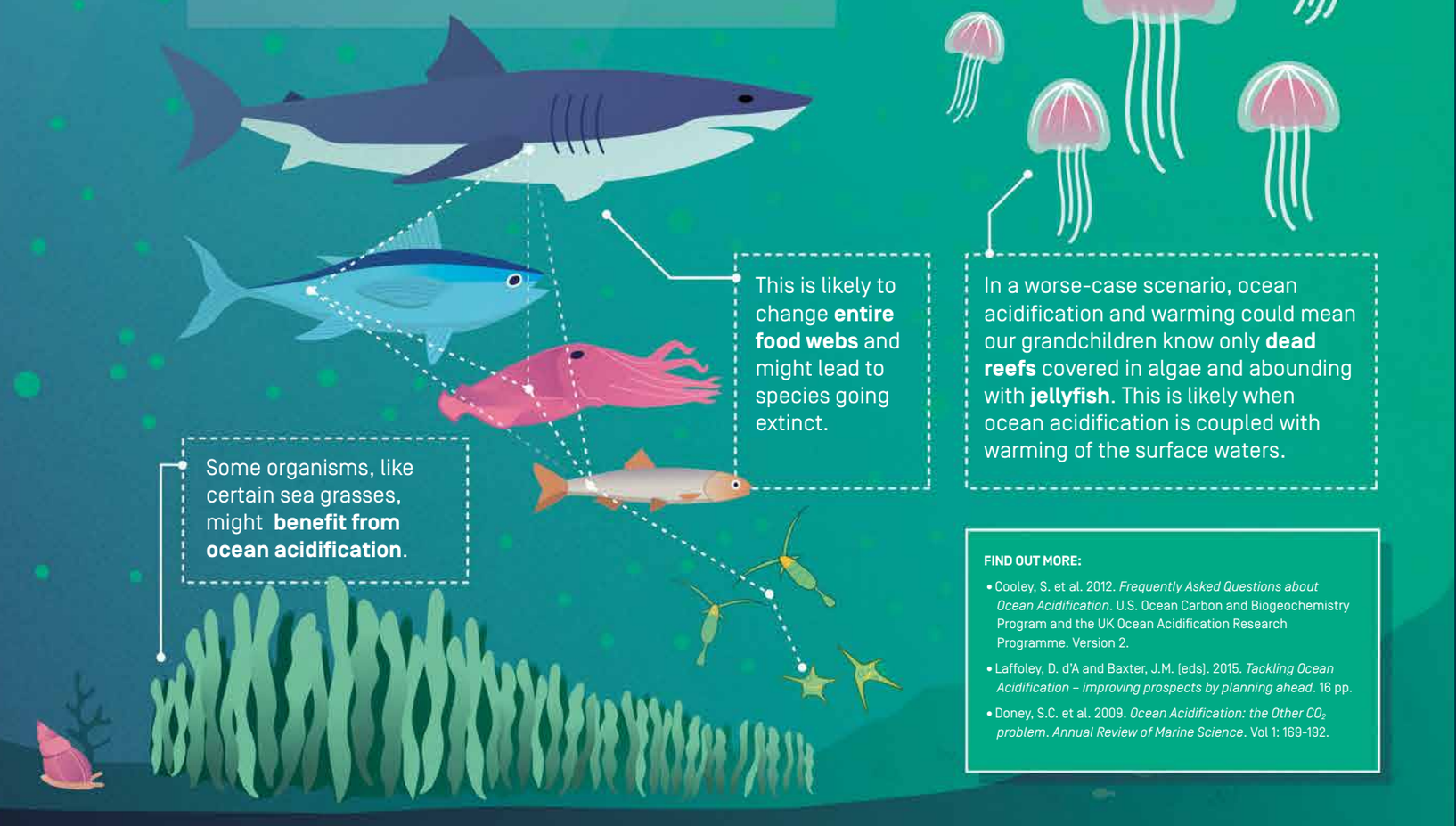
2.
As societies, we can harness knowledge about marine biology through **research** – and focus on **monitoring** and **forecasting** changes.

3.
Support initiatives and policies that **reduce carbon emissions.**

4.
Protect vulnerable societies, such as island communities that depend on reefs for protection and seafood for protein.



By **2100**, the ocean will probably be **150% more acidic**



This is likely to change **entire food webs** and might lead to species going extinct.

In a worse-case scenario, ocean acidification and warming could mean our grandchildren know only **dead reefs** covered in algae and abounding with **jellyfish**. This is likely when ocean acidification is coupled with warming of the surface waters.

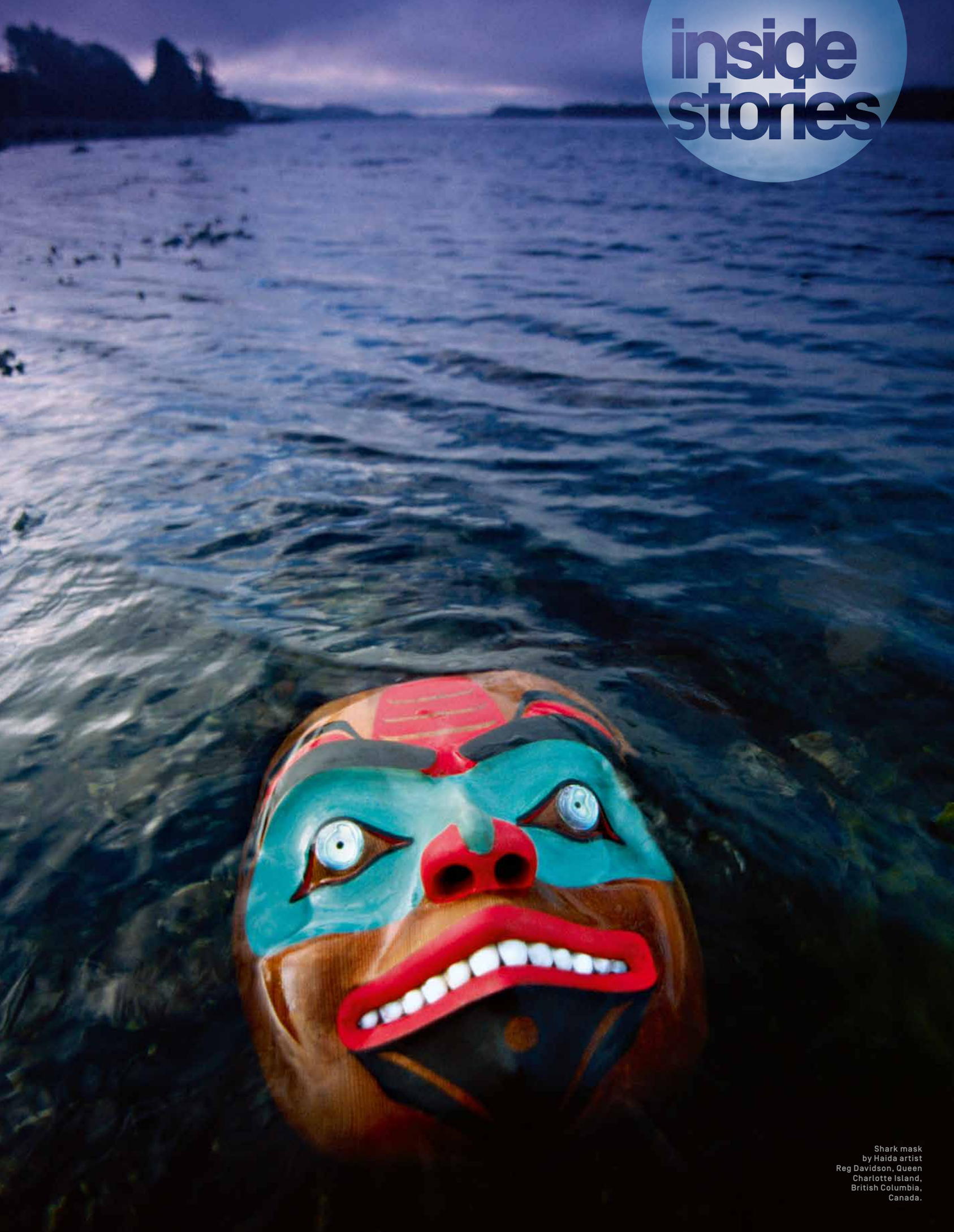
Some organisms, like certain sea grasses, might **benefit from ocean acidification**.

FIND OUT MORE:

- Cooley, S. et al. 2012. *Frequently Asked Questions about Ocean Acidification*. U.S. Ocean Carbon and Biogeochemistry Program and the UK Ocean Acidification Research Programme. Version 2.
- Laffoley, D. d'A and Baxter, J.M. (eds). 2015. *Tackling Ocean Acidification – improving prospects by planning ahead*. 16 pp.
- Doney, S.C. et al. 2009. *Ocean Acidification: the Other CO_2 problem*. *Annual Review of Marine Science*. Vol 1: 169-192.

Infographic by Elzemiek Zinkstok | Lushomo

inside stories



Shark mask by Haida artist Reg Davidson, Queen Charlotte Island, British Columbia, Canada.

There is no shortage of work to be done in the areas of ocean research, conservation and education. In addition to the projects we fund around the world, the Save Our Seas Foundation (SOSF) is proud to directly manage four centres and hold long-term relationships with four NGO partners, all of which are leading vital work to protect our marine environment and wildlife. Of the SOSF centres, two concentrate on education – the Island School Seychelles and the Shark Education Centre – and two are dedicated to research – the D'Arros Research Centre and the Shark Research Center. Located in the Seychelles, South Africa and the USA, the centres extend the on-the-ground reach of the foundation to these countries and beyond. The partnerships we hold with independent NGOs, the Bimini Biological Field Station (also known as the Shark Lab), Cetacea Lab, the Manta Trust and Shark Spotters, are mutually supportive and closer in terms of funding and communication than our regular projects. Each partner has its own area of expertise and is conducting long-term research and conservation work that goes beyond the normal project cycle length. This is one of the reasons we partner with them; the other is the passionate people who lead and drive this work – and have inspired us. The following pages are dedicated to stories from these centres and partners, and from the great people working there who are leading the charge for marine conservation.

Photo by Frans Lanting | National Geographic Creative

One of the signs that the end of the year is looming is the preparation for the December Marine Awareness Camp run by the Save Our Seas Foundation's Shark Education Centre. This three-day residential camp takes place at the Soetwater Environmental Education Centre in Kommetjie, along the shore of the wild Atlantic Ocean. During the camp, 30 Grade 5 learners from a local school are immersed in the coastal environment while they learn about all things sea, shore and sky – and, of course, have plenty of wholesome outdoor fun doing it. It's always an exciting time for the Education Centre team, as the biannual camps are a real highlight in our calendar. This time, however, something extra was added to the mix: an entirely different set of 'learners' who were there to both learn and teach!

The Save Our Seas Foundation Youth Ocean Ambassadorship Programme was developed and rolled out in 2015. Its purpose is to mentor future leaders in ocean conservation through a residential one-month survey of careers in marine science. Six young women from the Seychelles and South Africa were selected from a pool of applicants to participate in this exciting inaugural programme. Participants lived, worked and learnt together in Kalk Bay, along with programme mentors Sunnye Collins (an independent education consultant) and Abi March (project leader of the SOSF Island School Seychelles).

Each week they focused on a different aspect of careers in marine science: tourism, conservation, education and research. Each of these fields was explored through presentations and discussions with professionals, field work, volunteer work, observation and interviews, and by reading relevant publications and reflecting on the learning process through verbal and written work. For the environmental education section of the course, the timing was perfect for hands-on, experiential learning and the six young women, or YOAs, joined us at the camp to help lead the groups of children and to discover at first hand some of the ins and outs of in-field teaching.

During the camp, the 30 learners were split into six groups that tackled the tasks given to them over the next three days. This time, each group was also accompanied by a YOA as group mentor, which gave the children a perfect opportunity to hear all about the experiences and the education path that the YOAs had taken, as well as their passion for the ocean. And it was a plunge right into the deep end for the YOAs, who were thrust immediately into the role of hands-on educator – a task that some found easier than others! For some of the YOAs there was a language barrier to overcome, as English was not their first language. For all of them, there was the shift from 'learning' to 'teaching' (while still learning) that they had to make. But they had not been selected for this sought-after and prestigious course from a whole group of applicants for nothing. Within a very short time they were immersed in their groups and holding their own beautifully!

In addition to giving us some very welcome help in supervising and mentoring the learners, the YOAs were able to add a completely new element to the camp. For one thing, they inspired the learners with their tangible passion; for another, the fact that they were all from such varied and different backgrounds and had taken so many different routes to get to where they were opened the children's eyes to the many possibilities within the realm of marine science and conservation. They led discussions and gave presentations, giving the Grade 5s some insight into life in the Seychelles (and for most of them their first awareness that there is a country called the Seychelles, let alone where it is!). And they in turn learnt something of what it is like to have to combine safety, scheduling, lesson content, supervision, fun, learning, exploring and feedback all in one.

All in all, it was a wonderful Marine Awareness Camp. Of course they always are, but this one was especially rewarding: for us, being able to teach on so many levels and learn at the same time; for the Grade 5s from Muizenberg Junior School, who had an added degree of mentorship and example; and last but not least, hopefully also for the six amazing young women who joined us. In the words of one of them, YOA Anthea Laurence from the Seychelles, 'We were able to put ourselves in a marine educator's shoes for three days. We shared our knowledge and experience with the students in the hope that it would inspire them to become marine ambassadors like us. Thank you to Eleanor, Paul and Zanele for giving us this opportunity.'

inside stories

A LEARNING–TEACHING EXPERIENCE

SHARK EDUCATION CENTRE

WORDS BY ELEANOR YELD HUTCHINGS

False Bay's vibrant ecosystem provided the perfect living classroom where students from Cape Town and the Seychelles were exposed to different aspects of careers in marine science.

Photo by Louis Hiemstra | iStock Getty Images

A FOREST BELOW THE WAVES

D'ARROS RESEARCH CENTRE

WORDS BY KERRYN BULLOCK

Coral can tell us a lot about the environment it is found in, particularly if that environment is changing for the worse. Based at D'Arros Island and St Joseph Atoll in the Amirantes Islands of the Seychelles, Kerryn Bullock describes some of the ways in which researchers are monitoring local reefs.

Coral reefs are considered to be the most biodiverse ecosystems on earth, home to a multitude of different types of fish, invertebrates and turtles. They cover less than 1% of the sea floor, yet support an estimated 25% of all marine life. As well as providing feeding, refuge, spawning and nursery areas for a large variety of organisms, reefs are natural breakwaters that minimise the impact of waves from storms.

Defined as a marine polyp with a calcareous skeleton that lives in colonies, hard coral provides a prime example of symbiosis: *sym* meaning 'together' and *biosis* meaning 'life' – in other words, organisms living together. It also illustrates mutualistic symbiosis, as each organism in the union benefits from the presence of the other. The two organisms in question that live inside the skeleton of the coral colony are coral polyps and colourful, one-celled algae called zooxanthellae. The algae produce oxygen and nutrients through photosynthesis and these are used by the coral polyps. In return, the coral polyps produce carbon dioxide and calcium carbonate, which the algae need to thrive. The polyps then use the calcium carbonate to build a cup-shaped skeleton structure that is strong enough to withstand typical wave action. Coral grows only where the water is shallow enough for the sun to penetrate, enabling the algae to photosynthesise.

Sudden changes in water temperature can have a profound effect on coral reef ecosystems. In 1998 almost 70% of hard corals in the Seychelles region perished due to the uncharacteristically warm sea water. Coral bleaching occurs when above-average sea temperatures result in the expulsion of the zooxanthellae. The loss of these photosynthetic algae turns corals white, diminishes their energy resources and eventually results in their death. Therefore, given today's changing climate and predicted coral bleaching, it is of utmost importance to monitor the temperature of the sea surface and to integrate the resulting data into surveys of coral health.

Since 2011, the D'Arros Research Centre has been using temperature loggers to monitor at 15-minute intervals the sea temperature at 20 coral reef sites around the islands.

In addition to this, the research centre runs an extensive coral reef monitoring programme consisting of six projects whose fundamental aim is to assess trends in the structure and health of coral reef communities around D'Arros Island and St Joseph Atoll. In order to detect long-term trends in coral reef communities, our data collection methods and sampling effort are standardised and repeated consistently over the years.

One of these monitoring projects investigates the growth rate and size-specific survival and mortality rates of individual corals belonging to two genera common in the Amirantes: *Acropora* and *Pocillopora.* We use a vernier to measure the length (widest horizontal axis), width (longest horizontal axis perpendicular to the length) and height (longest vertical axis) of the 100 tagged corals (50 *Acropora* spp. and 50 *Pocillopora* spp.) and then calculate a growth index using the sum of these three measurements. We photograph and measure the corals on a monthly basis. These two types of coral are highly susceptible to bleaching and can act as indicators of ocean conditions. One tagged *Acropora* coral that was 30 x 40 x 30 millimetres when we began measuring in May 2013 was measured two and a half years later at 414 x 391 x 190 millimetres, indicating substantial growth.

Another long-term coral reef monitoring project undertaken by the D'Arros Research Centre is the annual benthic cover and composition survey. Its aim is to provide baseline data on what is growing at the base of the reefs in order to monitor potential changes. Significant changes may indicate climate change, overfishing, pollution or physical damage to the coral reefs. There are 11 survey sites and for each one 80 photo-quadrat images need to be made. Two divers are required for this exercise: one places the quadrat tool, measuring one square metre, on the reef and the other photographs it from directly above. We use special software (Coral Point Count software v.4) to analyse and compare the photos.

These are just a few components of the D'Arros Research Centre's coral monitoring programme. With the climate changing and spikes in sea temperature expected in future, such programmes are vitally important if we are to understand and protect these dynamic, sensitive and vital ecosystems.

Photo by Rainer von Brandis

FIJI LEADS THE

The Manta Trust
Words by Isabel Ender

Historically sidelined compared to manta rays, mobula rays are no less threatened than their larger relatives, notably by the unregulated trade in their gill plates. Fiji is the first country to take up their cause.

inside stories

Can a small island nation in a remote location in the Pacific Ocean change the world of marine conservation? A silly idea, you might think. Surely that's not possible? Well, we challenge you to reconsider this assumption, as we introduce to you the extraordinary work that the nation of Fiji has done, quietly standing up to become the world's champion for mobula conservation.

The government of Fiji took the first step towards global protection of these amazing animals in 2014 when it proposed that mobula rays and the reef manta be listed on Appendix I and Appendix II of the Convention on the Conservation of Migratory Species of Wild Animals (CMS). The proposal was approved at the 11th Conference of the Parties in Quito, Ecuador, and marks a significant success, particularly as the listing represented the first-ever protection for mobula rays at international level.

In December 2015 Fiji stepped up again, giving us an early Christmas present: a proposal to list all species of mobula rays on Appendix II of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) at the next Conference of the Parties in 2016. Both the reef and the oceanic mantas were listed on CITES Appendix II in 2013, but no such protection is in place for their smaller cousins.

'Mobula rays are facing global population declines due to

WAY FOR RAYS

growing and unregulated international trade,' says Eleni Tokaduadua, the principal environment officer and head of the Fijian CITES Management Authority. 'We recognise their economic value through sustainable means such as ecotourism and encourage countries to support this proposal to ensure the survival of these species for generations to come.'

Mobula rays, like their close cousins the manta rays, grow slowly, mature late and produce few offspring over their long lifetimes. This life-history strategy, coupled with their migratory nature and schooling behaviour, makes them extremely vulnerable to overexploitation.

Escalating demand for the dried gill plates of mobulas, which are used in Chinese medicine, as well as for their meat and cartilage, has led to these vulnerable species being targeted by fisheries that are largely unregulated and unmonitored. Significant declines in mobula catches have been observed in a number of locations in the Indo-Pacific, Eastern Pacific and Indian Ocean regions, often despite evidence of increased fishing effort. Population declines are likely to be occurring in other locations but have gone unnoticed.

'As a small island nation, Fiji greatly values all marine resources and we recognise the need to improve protection for slow-growing and vulnerable species such as mobula rays,' highlights Aisake Batibasaga, the director of fisheries at the Fijian Ministry of Fisheries and Forest. 'A CITES Appendix II listing will ensure that all international trade in these species is managed sustainably.'

The CITES listing would not only build upon the existing CMS Appendix I and Appendix II listings, but would also mean that trade in mobula body parts would have to be managed through science-based export limits. In addition, it would bolster national and regional protection; complement the CITES measures in place for manta species and the CMS listing of all manta and mobula rays; encourage sustainable international trade; help determine trends in populations; and contribute to the implementation of the United Nations FAO International Plan of Action for the Conservation and Management of Sharks.

The Manta Trust congratulates the government of Fiji for taking these decisive steps to protect mobula rays. Now it's time for the rest of the world to take action and follow Fiji's bold move by supporting its proposal to conserve these vulnerable and valuable species. With endorsement from several international NGOs, the Manta Trust has produced a document entitled 'Devils in distress', which presents more information about mobula rays and provides insight into the threats they face. The Manta Trust is fully committed to supporting Fiji in order to ensure the success of this proposal and assisting all nations with the implementation of such a listing.

Photo by Shawn Heinrichs | Blue Sphere Media

SHARK SPOTTERS

WORDS BY TAMLYN ENGELBRECHT

SECRETIVE SEVENGILL

UNRAVELLING THE MYS OF ENIGMATIC PREDATO

The water is murky and I can't see more than five metres (16 feet) in front of me. I sigh into my regulator and navigate my way awkwardly through the thick kelp, my bulky scuba kit making my movements cumbersome. After what seems like an endless dive battling through this dense underwater forest, there is still no sign of any broadnose sevengill sharks (more fancily termed *Notorynchus cepedianus)*. As I start to lose faith in this so-called shark aggregation site, my dive buddy and I break through the kelp into a sandy channel. There, cruising placidly in languid circles, are three of the strangest looking sharks I have ever seen: seven gills instead of the usual five, one dorsal fin instead of two, and a broad, almost smiling face. I do a small underwater victory dance and sink to my knees on the sand as the sharks meander over to investigate this clumsy two-legged creature that is watching them so avidly.

To be able to get so up close and personal with one's study species and observe it unobtrusively in its natural environment is a rare privilege. Broadnose sevengill sharks (or simply sevengills) are apex predators found in temperate seas worldwide. Because they occupy shallow coastal waters, they are vulnerable to human-induced threats that range from overfishing to pollution and habitat loss. Despite this, there are limited management and conservation strategies for these sharks throughout their range, primarily due to large gaps in our understanding of their behaviour, ecology and life history. Miller's Point in False Bay, South Africa, is a popular dive site that hosts one of the largest known aggregations of sevengills in the world: as many as 70 sharks can be seen on a single one-hour dive. But why these sharks aggregate here, how they move around the rest of False Bay – and more broadly along the South African coast – and what influences the timing, scale and direction of their movements are all questions that remain to be answered. In fact, research conducted globally on the sevengill's behaviour and ecology is so limited that the species is classified as Data Deficient on the IUCN Red List of Threatened Species™.

This is where I come in! I am completing a Master's degree at the University of Cape Town with the support of Shark Spotters. I aim to investigate the distribution, behaviour and spatial ecology of

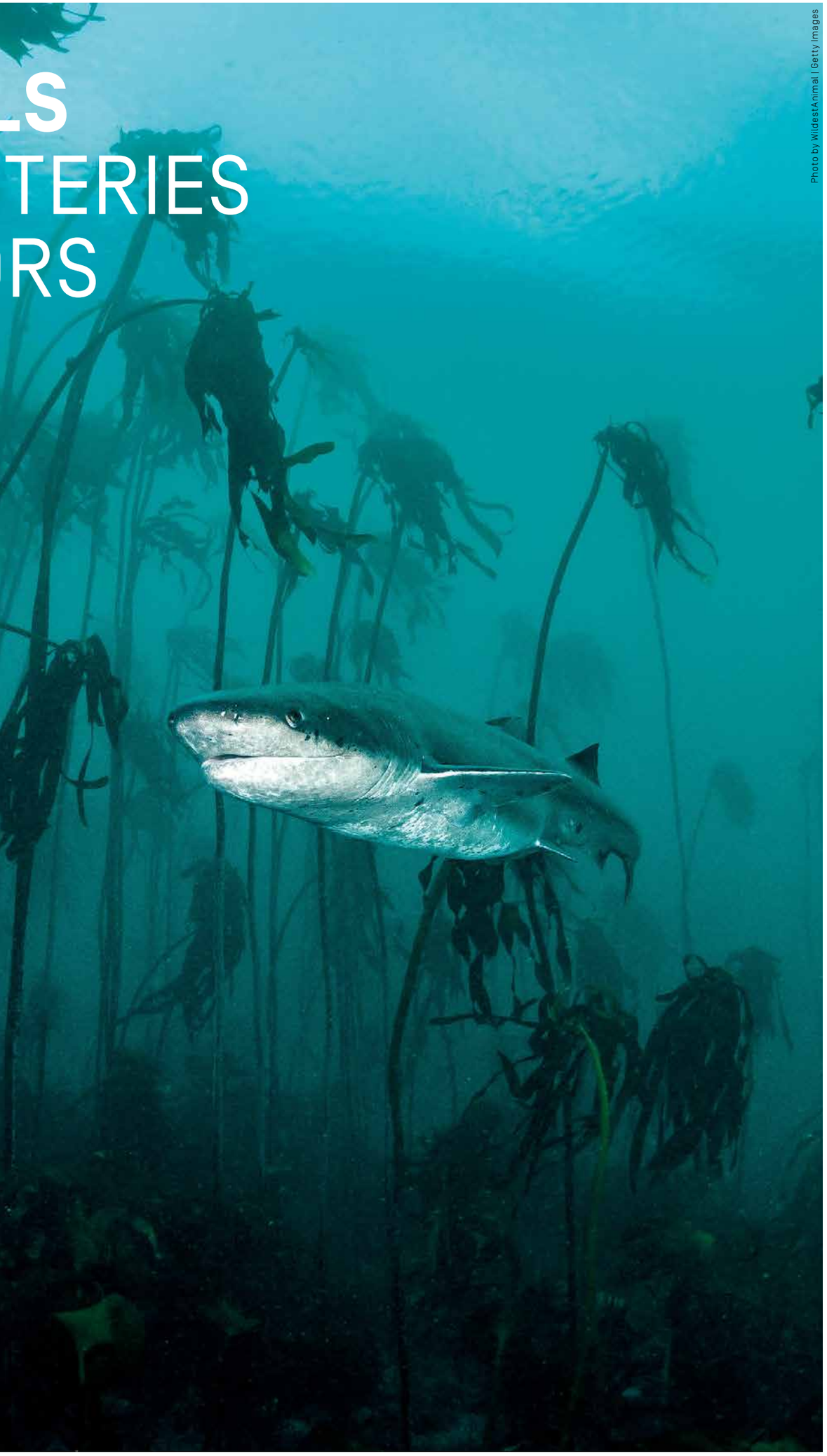


Photo by WildestAnimal | Getty Images

A broadnose sevengill shark glides through the kelp forest at Miller's Point in False Bay.

sevengills in southern Africa and to do so I am using data derived from fisheries combined with acoustic and satellite telemetry. My project has only recently started, but already I have made some interesting discoveries.

Long-term tag-and-recapture data for sevengills from recreational angling in southern Africa has shown them to be wide-ranging, capable of large-scale migrations of up to 600 kilometres (370 miles)! Yet even though they can travel long distances, sevengills commonly return to specific coastal areas seasonally, a characteristic known as site fidelity. In one particular case a sevengill tagged by an angler in Namibia was recaptured in the exact same fishing spot more than four years later. Furthermore, despite the species' wide-ranging capability, no sevengills tagged in Namibia were reported recaptured in South African waters (or vice versa), which may indicate that populations are regionally segregated. These preliminary findings provide a glimpse into the complexities of sevengill behaviour and show that we have a long way to go before we understand this enigmatic species. In the next phase of my research I will use acoustic and satellite telemetry to dig more deeply into the mysterious movements of sevengills and investigate what drives these patterns – on a fine scale in False Bay and more broadly along the South African coastline.

So, how does my research fit into the mandate of Shark Spotters? Over the past 10 years Shark Spotters, with the support of the Save Our Seas Foundation, have focused research on the well-known white sharks of False Bay. Through this work we have gained an understanding of the white shark presence and how this varies over space and time, but we still have limited insight into the greater role of large, predatory sharks in coastal ecosystems and what drives their behaviour. The Shark Spotters' research programme has therefore expanded from studying a single species in isolation to investigating the interactions between white sharks, other predatory sharks like the sevengills, their prey and the environment. This will enable us to improve our understanding not only of the apex predators that live in False Bay, but also of the complex and dynamic ecosystem that these sharks are a pivotal part of. Through this research, we can gain the necessary knowledge to foster a balance between the needs of people and sharks in the bay.

inside stories

CETACEA LAB

THE SINGING SEA

WORDS BY SAMANTHA PHILLIPS

It's dark by the time our dinner dishes are cleaned and put away. Not wanting to zip our tents closed quite yet, we stay up in the dimly lit house and play cards, breathing in yet another whale-filled day. Sounds of the calm Canadian Pacific creep in through the wooden cracks of the cabin. Inside, the fire pops in the wood stove, adding percussion to the steady static of the speaker behind me.

Twenty minutes in, a sequence of pings flows out of the speaker. Goosebumps, like it's the first time I've heard that sound. Our laughter stops in its tracks. I look at Hermann. 'Is that...?' But he doesn't have to answer because the four of us are already running in the light of our headlamps through the small patch of forest towards the lab.

In 2001, the Gitga'at First Nations gave Hermann Meuter and Janie Wray permission to build on their land on Gil Island in British Columbia where they founded and built Cetacea Lab. Sixty to 80 feet (18–24 metres) underwater, directly in front of the lab, rests an underwater microphone. A radio transmitter broadcasts all the whale vocalisations that this hydrophone – and a network of nine others – picks up, so that Janie and Hermann can carry out a critical component of their ground-breaking marine mammal research.

Hermann puts on headphones to isolate the sounds while we step out onto the observation deck and peer into the darkness. Seconds later we hear the quick blows and tail-slapping of the transient orca pod right in front of us. Even when they're out of sight, you can feel the presence of a whale.

Cetacea Lab is deriving so much meaning from such beauty. Day and night, Janie, Hermann and their troop of interns monitor and record humpback and orca vocalisations to learn more about the social bonds, feeding methods and abundance of these whales. With this data, the pair hopes to answer the most essential question: what is so important about this area for whales? They already know part of the answer. Recently dubbed the Great Whale Sea, the area boasts a network of fjords that locals deem to be the quietest segment of ocean on the planet. Whales depend on peaceful waterways to communicate, feed and thrive. Hermann and Janie strive to gather the proof they need to lead the charge to establish the Great Whale Sea as a marine protected area.

With thousands of recorded hours of whale calls, the Cetacea Lab team has observed a huge spike in vocalisations since it first arrived on Gil Island. Both the humpback and the fin whale populations in the area are today more than seven times as large as they were in 2004. Many believe that after whale hunting ended in the 1980s, these marine mammals were finally given the chance to make a recovery. Today, a different form of human disruption threatens to erase that progress. The oil and natural gas industry proposes to transform the aptly named Whale Channel into a shipping lane.

Photo by Samantha Phillips

Janie cautions, 'There will be a decline in this area's whale population. These vessels will strike whales. The ambient noise will inhibit the whales' ability to find food.'

Listening to whale calls is a moving experience, whereas boat noise underwater is a screech worse than nails on a chalkboard. I can never lower the volume fast enough; whales, on the other hand, cannot simply turn down the volume of an obnoxious boat buzz.

In response to the oil industry's proposals, Cetacea Lab is working closely with the Gitga'at to launch a new addition to the hydrophone network along the proposed tanker route in Squally Channel. Its state-of-the-art, four-hydrophone array will deliver the exact coordinates of a vocalising whale in real time. The acoustic data created through triangulation will be received by a PhD student and interns stationed at a land-based out-camp and will be confirmed by means of a theodolite station that will visually locate the whale. The Squally out-camp will also provide data for non-vocal whales – invisible to a hydrophone – and thus contribute to a more complete representation of the marine mammal behaviour in the area. This will establish a baseline of ambient noise and measure the effects of noise on the ability of whales to communicate and locate prey. Ultimately, it will help Cetacea Lab to mitigate the impact of shipping noise on marine mammal populations in the region.

In spite of the shipping traffic that is trickling into the area, Janie and Hermann never lose sight of what they are working to protect. Hermann smiles when he describes hearing a call through the speaker, 'You put the headphones on and you listen to the whales as long as they're vocal. That's an excitement that will never go away. That's why we're here. That's part of the passion of the job.'

The fleeting night ends with twinkling specks in the dark waters below. Looking up, we see an overcast sky that rules out any notion of a reflection. The specks are bioluminescence, and between them and the faint howls of a wolf pack it's as though the entire coast is reacting to the whale calls.

Cetacea Lab, along with fellow non-profit organisations in the area as well as First Nations, has been listening to the sea for a long time. It's now our turn to listen: they all are telling us that we must urgently protect the Great Bear Rainforest and the waterways that hug its shores.

Prime Minister Trudeau's recent mandate letter directing Canada's transport minister to implement a moratorium on tankers in this region suggests we are off to a positive start, but there is much more work to be done to safeguard the Kitimat Fjord system. You can share in these efforts by following Whale Point on Facebook to listen LIVE to the Great Whale Sea and to get notifications of the next steps being taken to make British Columbia's northern coast a marine protected area.

Hermann Meuter listens in on the voices of Great Bear's whales.

A lemon shark pup swims away from its mother a moment after birth. The remoras (suckerfishes) in front of the pup will clean up the afterbirth.

LEMON SHARK

BIMINI BIOLOGICAL FIELD STATION

WORDS BY JILL BROOKS

ARE HOW OLD

How old is that shark?

The story – and implications – of new research led by Jill Brooks that extends the age of lemon sharks using genetic information from 25 years of research.

As the saying goes, age is just a number. But when managing sharks, it can be a very important number. In Bimini, The Bahamas, we have found lemon sharks that are as old as 37 years – almost twice as old as previously thought. For some perspective, that's like finding out people – which we've known previously to live to a maximum of 122 years – can live to be 205!

But how do you 'age' a shark? One way is to look at its vertebrae. A shark 'lays down' new layers of cartilage as it grows, just like the rings of a tree, and these give a basic idea of how old it is. Unfortunately, the shark has to be dead before you can age it in this way and these growth rings are difficult to see. Furthermore, different species of sharks grow and lay down rings at different rates and the rings can be blurry and impossible to interpret.

There is, however, another way to age a shark. You capture it, tag it, inject it with a dye, release it – and then hope to catch it again one day in the future. The dye marks the shark's vertebrae at the time of capture, so if it is caught again scientists can count the number of rings that have formed in a known amount of time. They can then compare against growth curves how much the shark has grown in that time period. Normally sharks grow a little bit less each year as they get older, until they barely grow at all towards the end of their lives.

And why is it important that we know for how long lemon sharks live? Well, it helps to answer a pretty impossible question: how many lemon sharks are there in the ocean? With some complicated mathematical models and biological data (like the maximum lifespan of lemon sharks), fisheries scientists can make pretty good guesses. If we know how many pups a female shark has each year and for how many years they can live, we can estimate the rate at which sharks die from natural causes and the time required for local populations to rebound from declines. However, if any of this information is wrong when scientists define how many sharks fishermen can catch, collapses in shark populations could be the result – as has happened in the past.

Having accurate life-history data is important for the sustainable management of any fish species, but for sharks, with their slow reproductive rate and late age of maturity, it is even more important. In the only growth study ever conducted on lemon sharks, Dr Craig Brown and Dr Samuel Gruber captured and injected dye into 2,300 lemon sharks; out of the 55 recaptured individuals, the oldest was 22 years. Until recently, this had been the oldest lemon shark ever recorded and its lifespan has been used as the maximum for the species in fisheries models.

In Bimini's lagoon, we are fortunate to catch shark pups within weeks of their day of birth. Their navels (umbilical scars) have yet to heal, so we know they are less than six weeks old. We measure them, tag them with a barcode-like PIT (Passive Integrated Transponder) tag and then keep catching them over and over again throughout their first six to eight years. We take a small fin clip from each shark and send it to a genetics lab in Chicago, where a big family tree is created by working out which of the sharks previously sampled are related to this individual. This means we can know what year they were born in, their size at birth, who their brothers and sisters are, and who their mother and father is.

Scientists at Bimini Biological Field Station Foundation (also known as the Shark Lab) have been catching and tagging lemon sharks for 25 years, which adds up to a lot of shark pups and a lot of DNA. Young sharks that were caught in 1990 are now 25 years old. And because we have their DNA and we know when their pups were born, we also know when they started to give birth at about 14 to 17 years old. We don't even need to catch them to know they are alive; we just keep finding their pups every other year and can age them that way.

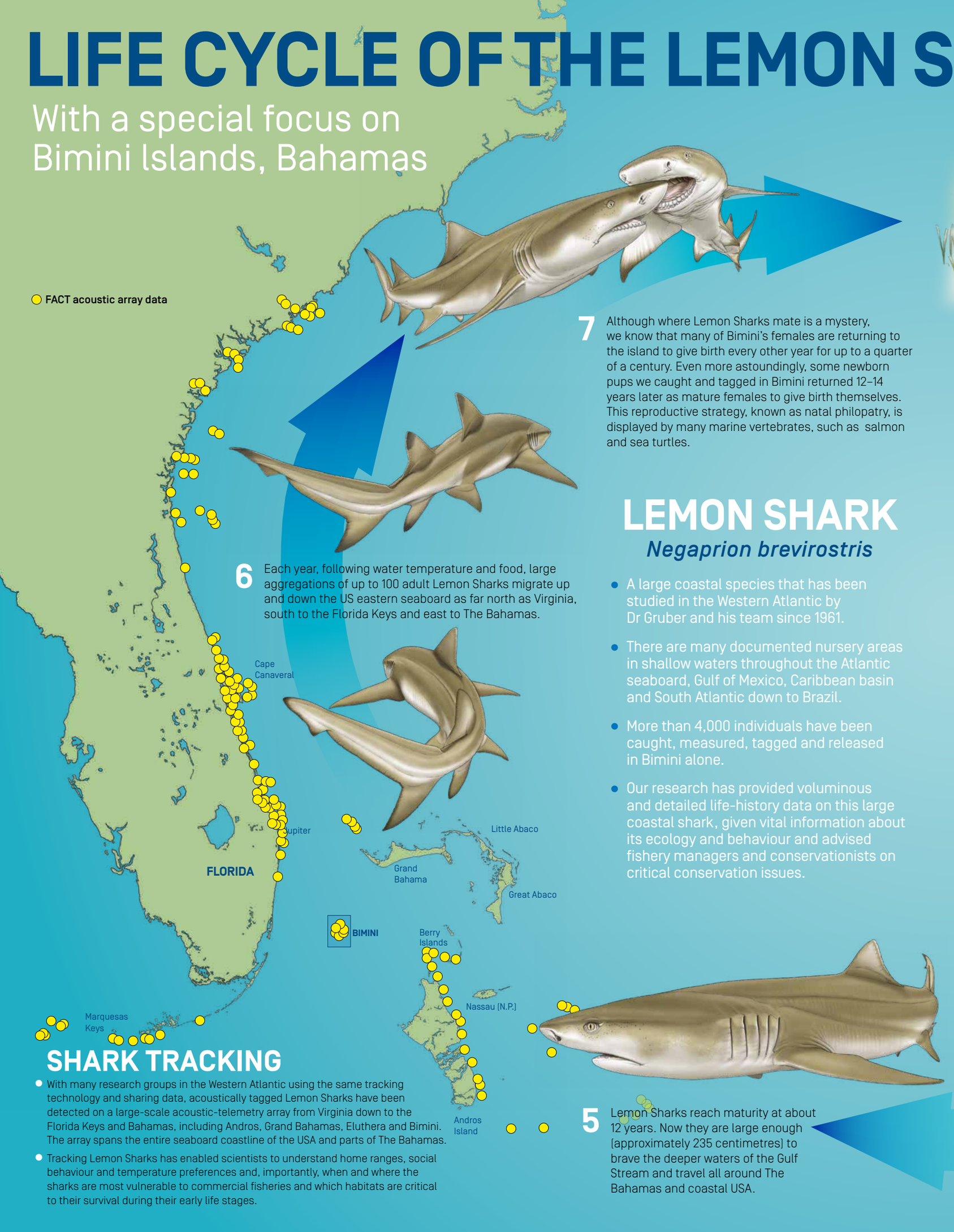
One female lemon shark that we like to call Lucy has been coming to Bimini for 32 years. The Shark Lab caught her on a long-line in 1997 while she was pregnant. She was PIT-tagged, measured, sampled for DNA and released. Her pups showed up in the genetic family tree that year, confirming that she had indeed been pregnant. They were also sampled in 1999, 2001 and 2003 – and we caught her again on our monthly long-lines in 2005! Her pups were caught that year, too, and every other year until 2013, when she was captured while we were filming for the BBC documentary series *Shark*. Lucy isn't the oldest lemon shark we have, though. 'B-Female-12' has been pupping in Bimini's nurseries since 1989, making her at least 37 years old.

We will be keeping our eyes out for Lucy and B-Female-12 (along with about 20 other mothers) and will continue to celebrate their April birth date with each spring-time receiver download and genetic processing. The Shark Lab will also continue its June census project at Bimini. Maybe we will start to see some grand-pups from our mommas.

Photo by David Doubilet | National Geographic Creative

LIFE CYCLE OF THE LEMON S

With a special focus on Bimini Islands, Bahamas



7 Although where Lemon Sharks mate is a mystery, we know that many of Bimini's females are returning to the island to give birth every other year for up to a quarter of a century. Even more astoundingly, some newborn pups we caught and tagged in Bimini returned 12–14 years later as mature females to give birth themselves. This reproductive strategy, known as natal philopatry, is displayed by many marine vertebrates, such as salmon and sea turtles.

LEMON SHARK

Negaprion brevirostris

- A large coastal species that has been studied in the Western Atlantic by Dr Gruber and his team since 1961.
- There are many documented nursery areas in shallow waters throughout the Atlantic seaboard, Gulf of Mexico, Caribbean basin and South Atlantic down to Brazil.
- More than 4,000 individuals have been caught, measured, tagged and released in Bimini alone.
- Our research has provided voluminous and detailed life-history data on this large coastal shark, given vital information about its ecology and behaviour and advised fishery managers and conservationists on critical conservation issues.

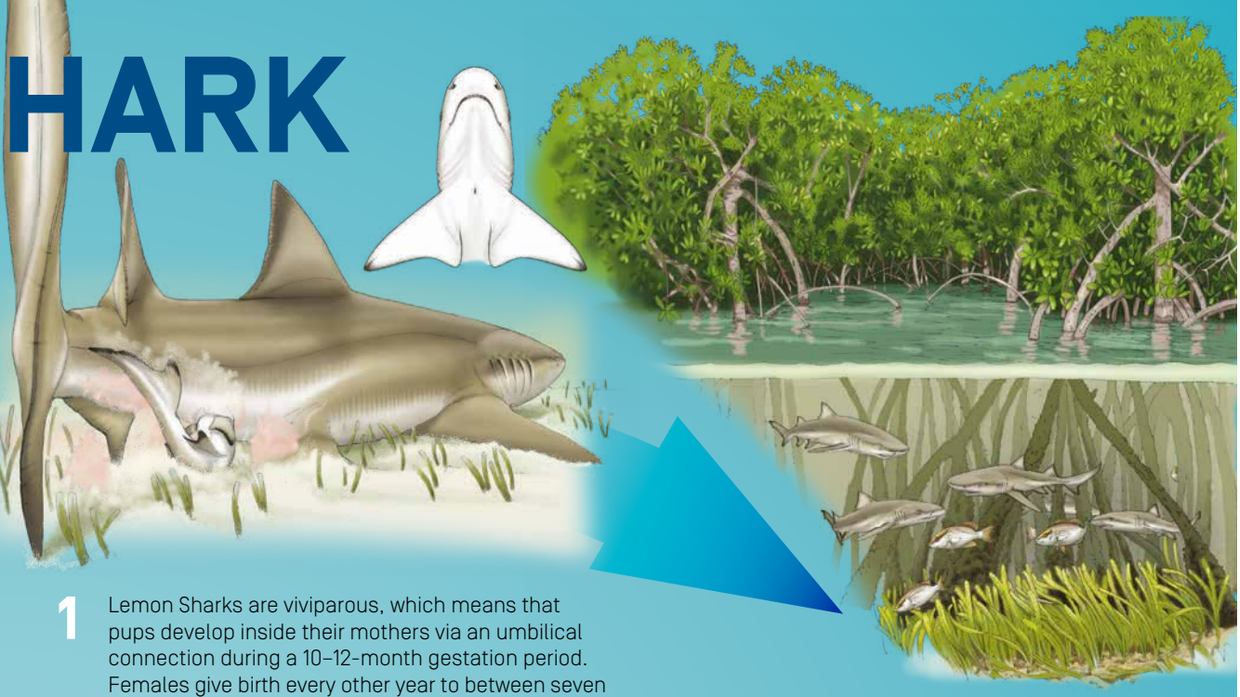
6 Each year, following water temperature and food, large aggregations of up to 100 adult Lemon Sharks migrate up and down the US eastern seaboard as far north as Virginia, south to the Florida Keys and east to The Bahamas.

SHARK TRACKING

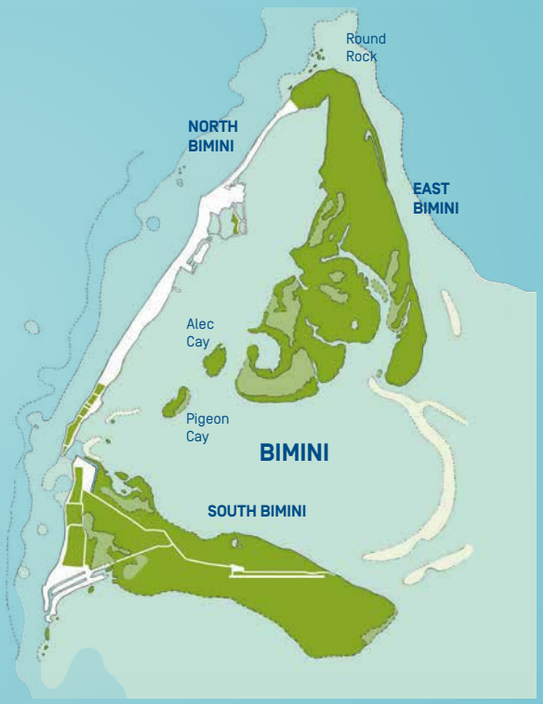
- With many research groups in the Western Atlantic using the same tracking technology and sharing data, acoustically tagged Lemon Sharks have been detected on a large-scale acoustic-telemetry array from Virginia down to the Florida Keys and Bahamas, including Andros, Grand Bahamas, Eluthera and Bimini. The array spans the entire seaboard coastline of the USA and parts of The Bahamas.
- Tracking Lemon Sharks has enabled scientists to understand home ranges, social behaviour and temperature preferences and, importantly, when and where the sharks are most vulnerable to commercial fisheries and which habitats are critical to their survival during their early life stages.

5 Lemon Sharks reach maturity at about 12 years. Now they are large enough (approximately 235 centimetres) to brave the deeper waters of the Gulf Stream and travel all around The Bahamas and coastal USA.

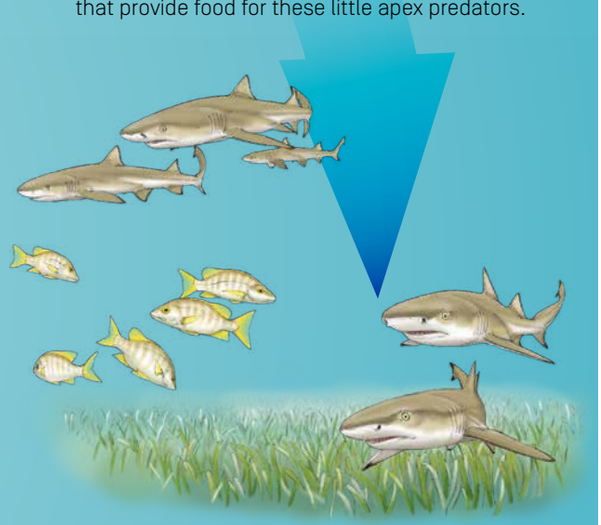
HARK



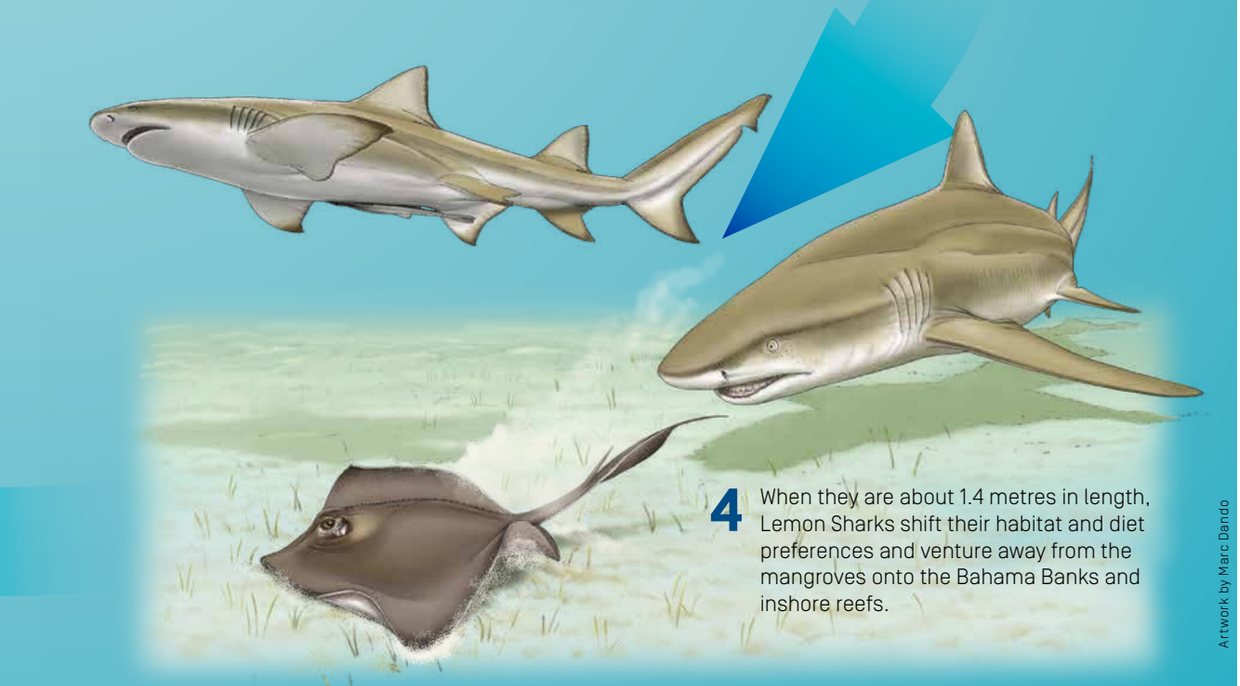
1 Lemon Sharks are viviparous, which means that pups develop inside their mothers via an umbilical connection during a 10–12-month gestation period. Females give birth every other year to between seven and 17 pups. A newborn pup is easily recognised by its open 'belly button', which takes several weeks to heal.



2 Lemon Shark pubs are miniatures of their parents and born 'ready to go', with no further parental care. They take up residence among mangrove roots, where they find protection from large predators. Here they join lots of young fish and invertebrates that provide food for these little apex predators.



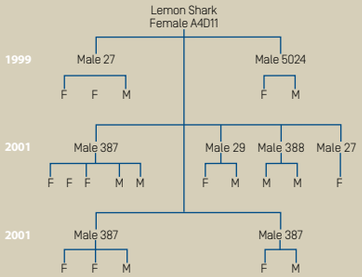
3 At Bimini, as the tide goes out and water levels drop, sharks brave the open flats and sea-grass beds to hunt for food, probably learning the best locations from other Lemon Sharks.



4 When they are about 1.4 metres in length, Lemon Sharks shift their habitat and diet preferences and venture away from the mangroves onto the Bahama Banks and inshore reefs.

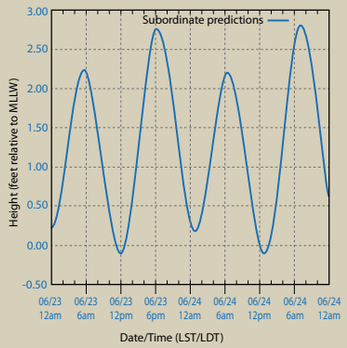
Artwork by Marc Dando

SHARK DNA



Molecular ecologists have analysed genetic samples from every Lemon Shark caught in Bimini and mapped a complete pedigree or family tree showing the relationships between Bimini's parents, offspring and siblings. As this tree for one adult female (A4D11) shows, female lemon sharks frequently mate with more than one male shark during a season. This strategy, called multiple paternity, leads to half siblings within one litter. In this particular tree, Male 27 happened to mate with the same female in two separate years.

MANGROVE REFUGES



Intertwined mangrove roots provide a perfect hiding place for juvenile Lemon Sharks, fish, conch and lobsters, enabling them to avoid large predators such as barracuda and bigger sharks. Our research has shown that juvenile Lemon Sharks use the roots as refuges at high tide and when larger Lemon Sharks are nearby.

DIET

Analysis of the stomach contents of more than 350 juvenile Lemon Sharks in Bimini shows that newborns have relatively broad diets, eating a dozen species of fishes as well as a few invertebrates such as shrimp, crab and octopus. By two years of age they become more selective, preying on fishes such as the Yellowfin Mojarra that moves in shoals throughout the mangroves and sea-grass beds. On reaching maturity, Lemon Sharks will eat other sharks (sometimes their own species), stingrays and many species of bigger fishes like jacks.

AGE AND GROWTH

Knowing growth rates and life spans of fishes is important when calculating sustainable limits in commercial fisheries. Calculating the age of an individual shark may require removing a vertebra from its spine and counting the growth rings, similar to ageing trees. In Bimini, we have been able to catch many lemon sharks within days or weeks of birth, so we can track their age and growth for decades through long-term recaptures combined with genetic fingerprinting. The oldest lemon shark we caught in Bimini was 37 years of age and had been giving birth in Bimini since 1989.

NEXT issue

In issue six we invite you to join us for some present-day time travel. Our journey begins in the near-pristine ecosystem of Bimini in The Bahamas, where sharks and rays continue to thrive in diverse habitats. Despite increasing human activities, biodiversity abounds. Just 60 miles to the west is a harsh juxtaposition, where marine life exists on the fringes of heavily populated beaches and thriving cities. Our photo grantees will showcase the natural world at both these locations and explore how marine life prevails in the context of differing scales of human development.

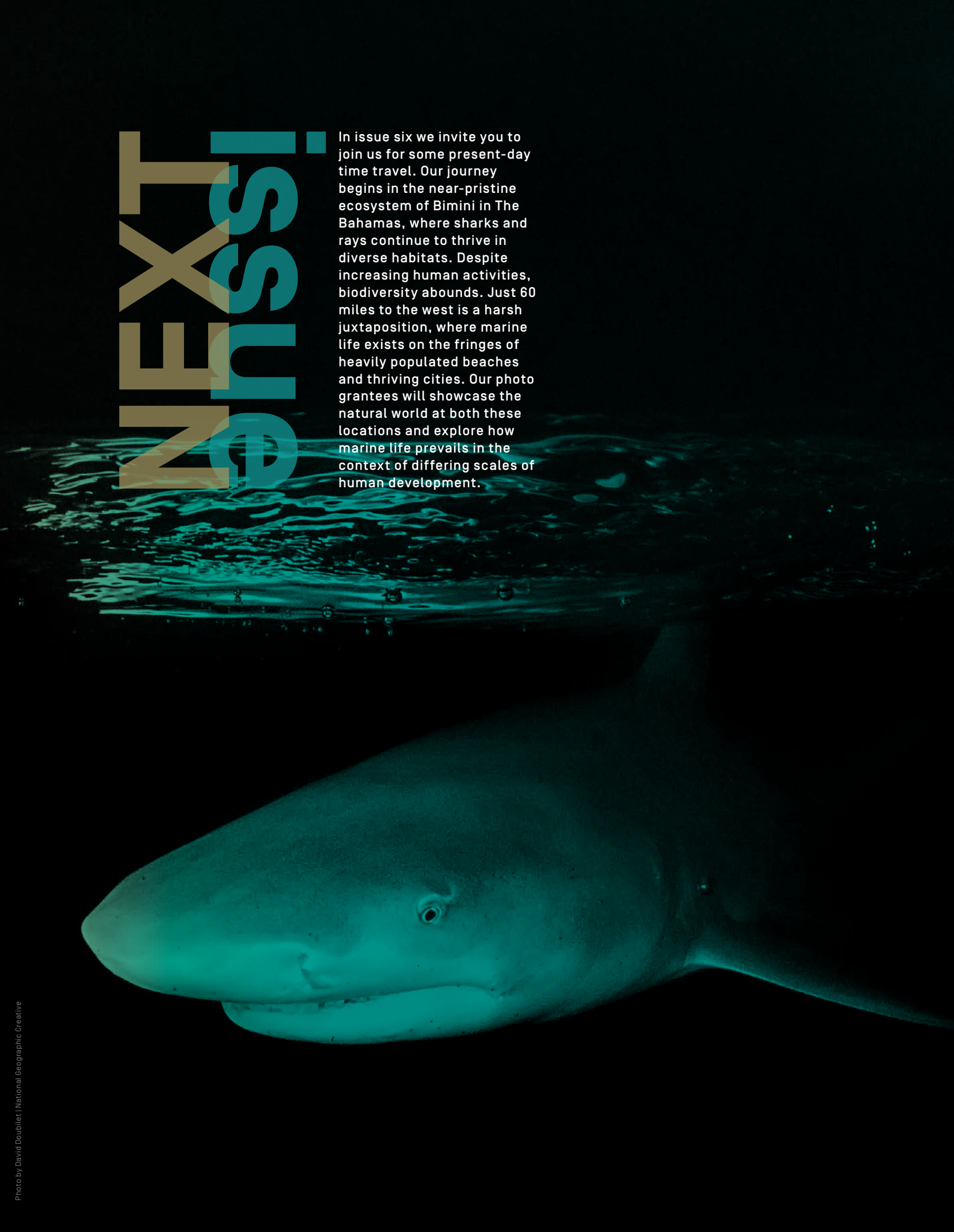


Photo by David Doubilet | National Geographic Creative

The Save Our Seas magazine has a new, dedicated website! Now you can explore the world's oceans with us, discover what's new in marine science, and read and share all the magazine's fascinating articles at *www.SaveOurSeasMagazine.com*
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ABOUT THE FOUNDATION

In the effort to protect our oceans, the Save Our Seas Foundation (SOSF) funds and supports research, conservation and education projects worldwide, focusing primarily on charismatic threatened wildlife and their habitats. From a small not-for-profit organisation funding just five projects, in just over 10 years the Save Our Seas Foundation has grown to become a major player in the fight to save the world's oceans and the wealth of marine life they contain. While the SOSF itself is not a research institute, its generous contributions of financial, practical and scientific support have, to date, facilitated more than 200 marine research and conservation projects around the world.

To find out more about the foundation, visit: saveourseas.com

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