THE SAVE OUR SEAS FOUNDATION MAGAZINE

save our seas

GALÁPAGOS | SAWFISH | ORCA | PIRATES

CLARE KEATING DALY

A Master's degree in commerce gives ocean-loving Clare a unique perspective on marine conservation. While her qualifications bring fresh insights into conservation, her significant ocean experience includes scuba instruction in the Philippines and Thailand and working as a research assistant on bull and tiger sharks while conducting her own studies into the sustainable financing of marine protected areas in southern Mozambique. As programme director, Clare manages the SOSF D'Arros Research Centre together with her husband Ryan.

SAMUEL GRUBER

Samuel founded the Bimini Biological Field Station (Shark Lab) and serves as its current director. 'Doc' Gruber, as he is affectionately known by students and colleagues, has been driven by a passion for sharks throughout his nearly 50-year research career. He founded the American Elasmobranch Society in 1983, and the World Conservation Union's (IUCN) Shark Specialist Group, which he led as chairperson between 1991 and 1996. Samuel now focuses on the behaviour, ecology and conservation biology of sharks.

CARL SAFINA

An ecologist with a flair for storytelling, Carl earned a PhD in ecology from Rutgers University, New Jersey, studying seabirds. His writing about the living world has won him a MacArthur Fellowship, or 'genius grant'; Pew and Guggenheim Fellowships; book awards from Lannan, Orion and the National Academies; and the John Burroughs, James Beard and George Rabb medals. Carl is now the first holder of the Endowed Chair for Nature and Humanity at Stony Brook University, New York, and is founding president of the not-for-profit Safina Center.

PELAYO SALINAS-DE LEÓN

Describing himself as a 'happy marine ecologist', Pelayo is an SOSF project leader and a marine research coordinator for the Charles Darwin Foundation in the Galápagos, having served the organisation as a senior marine scientist since 2012. A major focus of his research has been the ecology and conservation of sharks and manta rays, and his work has made serious strides towards the sustainable management of resources in the Galápagos Marine Reserve. Pelayo is also a National Geographic Pristine Seas Conservation Scientist.

A stable population of silky sharks *Carcharhinus falciformis* patrol the rich coral reefs of Gardens of the Queen in Cuba.

Cover photo by David Doubilet | National Geographic Creative

ISSUE 8

Photo by Paul Nicklen | National Geographic Creative

Photo by Thomas Peschak

"As long as there are people who care, we can and will make a difference"

THE FOUNDER
SAVE OUR SEAS
FOUNDATION

Michael C. Scholl
Chief Executive Officer
Save Our Seas Foundation

EDITORIAL

Having been born in the early 1970s, I grew up when the environmental movement was taking off. Although the plight of sharks was first highlighted in the '80s, the unfortunate timing of Steven Spielberg's *Jaws* (1975) hampered the public's empathy for the declining shark populations in those early years. Even today, the lingering effects of the film remain an obstacle to shark conservation, despite a much better understanding of these mysterious creatures of the oceans. The IUCN Red List of Threatened Species registers more than a thousand species of chondrichthyan fishes (sharks, rays and chimaeras), close to half of which are classified as Data Deficient; an estimated quarter of all chondrichthyans are listed as Threatened. And while a significant number of new species have been discovered over the past couple of decades, some of these are likely to disappear before they are even described. These 'lost sharks' are at the mercy of greater attention being paid to the more charismatic, and often less threatened, species.

In this eighth issue of the *Save Our Seas* magazine, we present a new series of exciting stories from around the world. They tell of the work, and life passion, of scientists, conservationists and educators, and some feature lesser-known chondrichthyans. For example, in June I was fortunate to join an expedition led by Dr Dean Grubbs to the West Side National Park on Andros Island in The Bahamas, one of the last healthy refuges for the smalltooth sawfish. In two weeks of intense fishing for these elusive and threatened batoids, we managed to catch only one (but close to 200 other sharks). The work done by Dr Grubbs and his colleagues in The Bahamas and in the Florida Everglades and Keys is revealing crucial new information about this enigmatic species, as well as the relevance of marine protected areas.

Last year, I joined *National Geographic* Magazine photographer Thomas Peschak on a research expedition led by Dr Pelayo Salinas-de León to Darwin and Wolf islands in the Galápagos. The Darwin and Wolf Marine Sanctuary, proclaimed in 2016, harbours one of the highest abundances of sharks on the planet, and each shark is estimated to be worth about $5.4-million over its lifetime. Known for its remote and evolutionarily unique ecosystem, the Galápagos archipelago is actually not that isolated as far as highly migratory marine species are concerned.

A decade ago, while visiting Argentina's Península Valdés, I was surprised at the similarities in terms of wildlife between it and Dyer Island in South Africa. The exception was that orcas were the dominant predator in Patagonia, whereas white sharks were number one in the Western Cape. In recent years, however, a couple of orcas have taken a liking to sharks in False Bay and at Dyer Island and have established their supremacy, effectively rearranging the ecosystem's food web.

As I write these few lines while attending the World Conference of Science Journalists, I want to recognise the significance of communicating science to a broader public audience. All scientists witness incredible observations and experiences and although their principal role lies in reporting their findings in scientific publications, their part in communicating to the public remains nonetheless essential. This magazine presents a variety of articles that will hopefully inspire readers around the world and help them to understand the importance of all the creatures that share our planet.

Michael Scholl holds a Critically Endangered hawksbill turtle in St Joseph Atoll in the Amirantes island group in the Seychelles. Soon afterwards, the turtle was tagged by the research team.

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- Southern African Shark and Ray Symposium | Hermanus, ZA
- Wavescape 2017 | Cape Town, ZA

Photo by Deron Verbeck | I Am Aquatic

2017

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 200 projects in more than 51 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*

Prestigious win for photography grant recipient

Justin Gilligan has been announced as one of the winners in *Australia Geographic's* Nature Photographer of the Year competition for 2017. A freelance photographer hailing from New South Wales, Gilligan was the recipient of an SOSF marine photography grant in 2016. Together with journalist Pippa Ehrlich, he documented the impact of encroaching human development on Florida's marine biodiversity. 'Urban Pioneers: Florida's Marine Wildlife' took him to the swamps and keys, photographing tarpon and nurse sharks, loggerhead turtles and silky sharks. He was honoured this year by the South Australian Museum and *Australia Geographic* for his photo 'Predatory pursuit'. In the image, an army of spider crabs marches in an astounding procession, tackled by a brazen Maori octopus *Macroctopus maorum*, the largest of the octopus species in Australasian waters. The unexpected encounter happened at Mercury Passage, between Maria Island and the Tasmanian coast, where Gilligan was diving with scientists from the University of Tasmania studying kelp on artificial reefs. The images that were placed in the competition are currently displayed at the South Australian Museum and at the Australian Museum in Sydney.

'Predatory pursuit' shows an incredible interaction between an octopus and spider crabs. The photo won acclaim for Justin Gilligan, a recipient of an SOSF marine photography grant, in *Australia Geographic's* Nature Photographer of the Year competition.

Photo by Thomas Peschak | National Geographic Creative

Sawfish rostra on Mahout Island, Oman.

Imperilled sharks of the Arabian Seas assessed

Just over half the chondrichthyan species found in the Arabian Sea Region are considered threatened in this range. This finding is described by Rima Jabado and her co-editors in a new report that provides an important conservation baseline for the monitoring of sharks, rays and chimaeras. *The Conservation Status of Sharks, Rays and Chimaeras in the Arabian Sea and Adjacent Waters* details the findings from a regional Red List workshop hosted in Abu Dhabi, United Arab Emirates, in February 2017.

Carried out according to the IUCN Red List categories, the assessments considered species from the Red Sea, Gulf of Aden, Arabian Sea, Sea of Oman and the Persian Gulf. Some of the world's most significant shark fishing nations fall within this area, perhaps most notably India and Pakistan. Of the 158 species of chondricthyans assessed in the report, 78 were considered threatened. Of these, 9.2% were classified as Critically Endangered, 22.2% as Endangered and 19.6% as Vulnerable. Thirty species were identified as endemic to the Arabian Sea Region, 26.6% of which were considered threatened. The Pondicherry shark *Carcharhinus hemiodon*, the Red Sea torpedo *Torpedo suessi* and the tentacled butterfly ray *Gymnura tentaculata* were highlighted as Possibly Extinct. This classification comes as a result of their absence from any verifiable records since 1979, 1898 and 1986 respectively, in spite of increased research efforts in the region.

Fishing pressure, with by-catch deemed the greatest threat, and the destruction of important habitats like coral reefs, mangroves and sea grasses as a result of coastal development, were considered key threats to chondrichthyans in the region. The report makes several recommendations to better manage chondrichthyan populations. These include implementing action to reduce the by-catch of threatened species, delineating and enforcing no-take marine protected areas and supporting research into the identification of critical habitats. The main challenge is to improve current chondricthyan monitoring so that the assessments in this report can be regularly updated and improved, since the IUCN requires re-evaluation of species threat status every decade. This significant body of work, the result of a major collaborative effort by international and regional experts, marks a major step forward in gathering sound scientific evidence to underpin governance, research and conservation in the Arabian Seas.

Historic shark seizure in Galápagos National Park

Twenty crew members of the *Fu Yuan Yu Leng 999*, a vessel sailing under the Chinese flag, were arrested in a historic illegal shark-fishing bust in the Galápagos National Park in August. Dr Pelayo Salinas-de León, a marine ecologist working with the Charles Darwin Foundation, described the event as highly unusual and a stroke of luck for law enforcement. 'Normally boats of this type are known as ghost ships because they turn off their positioning systems,' he observed in an interview with BBC World News. This particular boat, in a most perplexing lapse of subterfuge tactics, kept its Automatic Identification System (AIS) on, allowing Galápagos National Park authorities and the Ecuadorian navy to locate the vessel on their surveillance systems. The boat is what is termed a 'reefer', a mother ship of sorts that collects the catches brought to it by other, smaller vessels.

'Sharks are one of the most threatened groups of vertebrates,' continued Salinas in his interview. For this reason, the seizure of thousands of sharks, among them scalloped hammerheads and silky sharks, which are classified as Endangered and Near Threatened respectively on the IUCN Red List, is all the more troubling. Speaking to National Geographic, Salinas noted that this is undoubtedly the largest confiscation of sharks in the history of the Galápagos.

While the authorities launch a full-scale investigation into the ship's detailed movement patterns (catching, trading and transporting sharks in the Galápagos National Park is illegal, and a permit is required to cross the boundary into protected waters), the incident is a stark reminder of the challenge to adequate enforcement of marine protected areas, particularly in remote ocean regions. Salinas pointed out that a major component of this challenge is a lack of resources: funding patrol boats is an expensive business. The incident, however, presents a unique opportunity to open a discussion about improving monitoring and enforcement. 'For the first time, we will have an insight into what these vessels are catching and on what scale,' he concluded.

Citizens take to the streets of Santa Cruz Island on 25 August 2017 to raise their voices against illegal fishing in the Galápagos Islands Exclusive Economic Zone (EEZ).

Photo by Jose Jacome | Keystone

Sawfish connection adds another piece to the research puzzle

Photo by Grant Johnson

Photo by Andrea Kroetz

A surprising connection has been made between the first smalltooth sawfish *Pristis pectinata* tagged at the Bimini Biological Field Station and the pregnant female that delivered five pups in the first recorded sawfish birth in the wild on 7 December 2016. Dr Dean Grubbs, associate director of research at the Florida State University, and his team caught the female late last year. 'It was clear she had been tagged; there was a part of some sort of streamer tag under the side of her dorsal fin,' explains Grubbs in an interview. Few sawfishes of that size have been tagged in The Bahamas or Florida, but unfortunately the tag numbers were indistinguishable. However, blood and DNA samples were taken from the mother and the pups and sent to Kevin Feldheim at The Field Museum for analysis.

'When Kevin called back with the genetic results for both the mother and her pups,' continues Grubbs, 'he said to me, "Interestingly, the mom is a known sample to us. She is in our database as BIMPPE1, but I don't have any collection data on her".' So a search began that led to an old e-mail from Dr Samuel Gruber and photos of Grant Johnson holding the animal in question. The female was caught on 29 April 2002 using gill nets on South Bimini, and at 2.6 metres (eight feet six inches) total length, she was an estimated three years old. When Grubbs and his team re-caught her in 2016, she was pregnant, had grown to 4.29 metres (14 feet) and was approximately 18 years old. 'Obviously it was extremely exciting to figure out who that animal was, and of course Grant's reaction when I told him about it was fantastic!' chuckles Grubbs.

With so many basic life history parameters missing for sawfishes, the connection is an important step in decoding their lives. 'How long does it take them to reach maturity, and at what size? How often do they reproduce? Of course, when you don't start that work until they're Endangered, you can't do the standard methods of sacrificing animals to age them and look at their reproductive traits,' explains Grubbs.

It is also vital to understand how and where sawfishes move in order to inform their protection, particularly where reserves are spatially delineated. It's therefore interesting to note that this sawfish was originally caught on the Great Bahama Bank and nearly 15 years later was re-caught in the same region. 'Having these long-term records is critical, and obviously it also highlights the need to collect genetic samples, because you never know when they will be needed,' Grubbs concludes.

SHORTFIN MAKO SHARKS IN BIG TROUBLE

Traditional methods of monitoring shortfin makos *Isurus oxyrinchus* in the western North Atlantic have greatly underestimated the impact of fishing on their populations. A new study published in the *Proceedings of the Royal Society* shows that fishing mortality (the rate at which sharks are killed by fisheries) for shortfin makos is actually 10 times higher than previous assessments indicated. Michael Byrne and Mahmoud Shivji from the Nova Southeastern University's Guy Harvey Research Institute (GHRI), together with their co-authors, employed satellite telemetry data as a fisheries-independent tool for monitoring mako sharks with near real-time tracking, allowing them to see directly how many were captured.

Shortfin makos are long-lived, highly mobile sharks whose habitat overlaps with that of commercially targeted tuna and billfishes. The result is that this shark, listed as Vulnerable on the IUCN Red List, is taken as by-catch in these fisheries and often retained to be sold for its high-value meat. To manage the species adequately, its populations need to be monitored. The trouble is that the majority of current population estimates rely on data reported by fishermen themselves. These 'fisheries-dependent' data are often unreliable, being based on catch reports that may be misrepresented.

This study tracked 40 sharks tagged with satellite-linked radio tags (SLRTs) over a period of three years. The tag is attached to the shark's dorsal fin and connects to satellites to provide an estimate of the shark's location every time the fin breaks the surface. Byrne and his colleagues found that these individuals swam into the Exclusive Economic Zones of 19 countries and were harvested in fisheries belonging to five countries. This result highlights the importance of cross-border cooperation to manage mobile species. Of the sharks tagged in this project, 30% were caught and killed. This suggests that the population is experiencing a state of overfishing – critical information needed to underpin conservation management decisions. Satellite tagging programmes, according to the researchers, have the potential to generate more than just information about where and how sharks move; they can inform more accurate estimates of shark fishing mortality than the traditional fisheries-dependent methods do.

A new study has shown that mortality for shortfin mako sharks as a result of fishing is 10 times higher than previously thought.

Photo by Brian Skerry | National Geographic Creative

Protected species still on the menu, says DNA barcoding

Artwork by The Biochemist Artist | Shutterstock

DNA barcoding has revealed that more than half of the dried shark fins and gill plates being traded originate from species classified as Endangered or Vulnerable by the IUCN. The study, published in *Scientific Reports* in August, was led by Dirk Steinke from the University of Guelph, with Mahmoud Shivji from the Guy Harvey Research Institute and Save Our Seas Shark Research Center at Nova Southeastern University and colleagues. While a quarter of sharks and rays are considered threatened, the demand for products in the form of fins, meat, liver, oil and gill plates remains a significant challenge to managing their populations. Commercial trade in several species is banned. However, new evidence shows that this hasn't stopped people from buying and selling their fins and gill plates.

Understanding the population status of elasmobranch species around the world helps to inform management decisions. This requires improvements to current catch data, with one of the major challenges being the accurate identification of species that look similar, or whose body parts have already been processed. Dried fins and gill plates lack any clear features that can help researchers to confidently identify their species of origin. This study used DNA barcoding to identify species from genetic material obtained from dried fins and gill plates collected in Canada, China and Sri Lanka.

DNA barcoding is an exciting development that improves the resolution of elasmobranch identification, with special relevance for detecting whether products originate from legal or illegally imported species. Seventy-one fins and 53 gill plates were analysed and matched to 20 shark and five ray species; 56% of these species are on the IUCN Red List as Endangered or Vulnerable. The number of species considered vulnerable increased to 80% when those classified as Near Threatened were included. Twelve of these species have been approved in 2017 for listing on the Convention on International Trade in Endangered Species of Fauna and Flora (CITES) appendices: seven shark species and all five rays are banned from trade under this listing. Samples were collected in 2012, and while trade bans for most of these species came into effect between 2014 and 2017, some samples came from species like the whale shark, which had protected status and was banned from trade at the time of sampling. As the researchers write in their paper, 'This work demonstrates the importance of market surveillance as a conservation countermeasure that would benefit from large-scale and long-term monitoring.'

Are MPAs protecting sharks & rays?

Photo by Thomas Peschak

Marine protected areas (MPAs) are a popular conservation tool implemented around the world to manage marine biodiversity and protect sensitive habitats, but how do we make sure they're achieving the conservation goals we set for them? This question interests Mark Bond, a postdoctoral researcher at Florida International University, whose PhD findings led him to conduct a global review of the effects of MPAs on elasmobranchs. As he notes, ensuring that MPAs adequately protect species is important to make their designation defensible and to maintain the trust of the people involved in their implementation and enforcement. 'If we propose MPAs as a solution, we need to have empirical, long-term evidence that they work. If we can't show this, we risk losing the trust of the stakeholders.'

Researchers typically investigate changes in the biomass (total mass), density (number of individuals in a given area), diversity and abundance of species inside and outside MPAs to assess their efficacy. 'All the evidence that we have using these measures is limited to bony fishes and species like rock lobsters and conch,' says Bond. To make more informed decisions about the conservation management of sharks and rays, scientists must take into account their different life history strategies, the fact that they are highly mobile and may move in and out of MPAs, and their conservation status. 'We want to be confident that when we say MPAs work, they work for the species that we are talking about, and that we don't need to rather employ another measure, like controlling trade,' explains Bond. It's about ensuring that we match the conservation strategy best suited to a species based on its individual life history and behaviour.

To explore how well we're currently protecting elasmobranchs using MPAs, Bond trawled through the published scientific literature and reached out to scientists working around the world. An interesting preliminary note, he says, is that studies on elasmobranchs in MPAs are restricted to tropical coral reefs. 'We're very limited in terms of where we're seeing this evidence, and also only from a very small set of species within that ecoregion. So we really need to broaden that to include temperate seas, and look to deeper waters.' As his work is starting to show, identifying current gaps in the available data for sharks and rays can guide future research and collaborative efforts to help build a strong evidence base for decision-making.

From the Field A short interview with Kye Adams

In the small coastal town of Kiama, Australia, Kye Adams and the Project AIRSHIP team are testing a non-invasive alternative to shark nets. Their blimp-mounted camera system aims to provide adequate warning to beach users when sharks or other hazards are present in the water.

How would you explain your connection to the ocean and sharks?

My father has always loved the ocean, so much so that my name comes from the Hawaiian word for it: Kye, which means salt water. So it was almost inevitable that I would share the same connection. To me, the ocean is the last remaining wilderness. One of my favourite feelings is being out in deep water, where you can't see the bottom, and being aware of that sense of the unknown. It makes me feel really small – and it's good to be reminded of that. Sharks add to that feeling; without sharks the ocean becomes just a big swimming pool, it loses its attraction. Wild animals make the world more interesting. It's great to feel powerless sometimes and to be reminded that we are not in complete control. I think a lot of people are chasing that feeling when they enter the ocean. As soon as you step off the sand, you're entering a wilderness area, even if that beach is in a city.

How did you come up with the blimp concept?

As professional lifeguards, we spend a lot of time staring at the sea and although we sit in towers that are elevated, sometimes we feel that they are not elevated enough to get a complete view of the ocean. Surf Beach is a small coastal embayment that, with a headland at each end, feels quite enclosed. This makes it an ideal spot for running the programme because you have both headlands and you can spot any activity between them from the sky. Obviously, people have considered drones as a solution to this, but they have the downside of a short battery life. For the purpose of providing beach and ocean coverage for eight hours, drones aren't the most effective solution. So the blimp idea came from me watching old documentaries about the First and Second world wars, when blimps were used for surveillance.
I thought that perhaps they could work in our situation. The more I researched how they operate and what can be done with them, the more boxes they ticked.
I'm also hoping that with the project AIRSHIP blimp we can replicate that feeling of safety that shark nets give the public, but not have the downside of by-catch and unnecessary shark deaths. My end goal is to replace the shark nets with blimps.

Your job means that you work with recreational ocean-goers every day. How would you describe the public's attitude towards sharks?

Kiama is a summer destination for both local and international tourists and a lot of them don't have much understanding of the ocean and sharks. Among the locals and the surfers, though, there is more respect for the ocean, and they understand it better too. They also realise that sharks are a necessary part of the environment. It's different with tourists.
For example, mothers will often come and ask if it is safe for their children to enter the water. Once we've explained about the blimp and tell them that we haven't seen anything that day, then usually they'll go in, but only into the shallows. So sharks are definitely on their minds.
A social scientist has got involved in the project this summer and she will be conducting surveys, so we'll get a good idea of what people think about sharks and their attitude to the blimp and shark nets and the other strategies that are being used. We're looking forward to the data that will come from that.

Are there any challenges that you have encountered that need to be taken into consideration with the blimp?

We struggle if it is raining because all our equipment is not waterproof at this stage. But thankfully all the conditions that prevail when spotting potential is really good coincide with high beach visitation rates. So when the conditions are poor – when it's windy or cloudy or rainy – no one is at the beach so there aren't that many water users. When it's sunny with calm conditions, that's when we have our best capacity to spot sharks.
Our summer boasts the ideal environmental conditions for the blimp and it coincides with the most people at the beach.
Based on historical data that we've looked at, we can put the blimp up 70% of the days in summer, so five out of every seven days the conditions are suitable. In the end, the environmental factors don't pose too much of a challenge.

Besides your upcoming field work and the holiday season, is there anything else exciting in store for the programme?

The programme is evolving and that in itself is exciting. With the support of the Save Our Seas Foundation and funding from our university, we are developing an automated shark-detecting algorithm. The blimp will eventually be running that, removing the need for human observers to watch the footage. We are also going to train the algorithm to spot rip tides and swimmers in distress. So project AIRSHIP will be an integrated approach to general beach safety.
I am currently working on a preliminary paper that describes how effective the blimp can be as a shark management tool. The initial results are very promising and suggest that the blimp outperforms other forms of aerial surveillance. I'm hoping that once the blimp has proven to be effective, it will provide an alternative for politicians when they are called on to remove shark nets; rather than just take out the nets and replace them with nothing, they could theoretically take the nets out and put a blimp above the beach. And people would feel just as safe.
I'd love to see a blimp on Bondi Beach in Sydney.

Photo by Paul Jones | UOW

The sharkiest pla

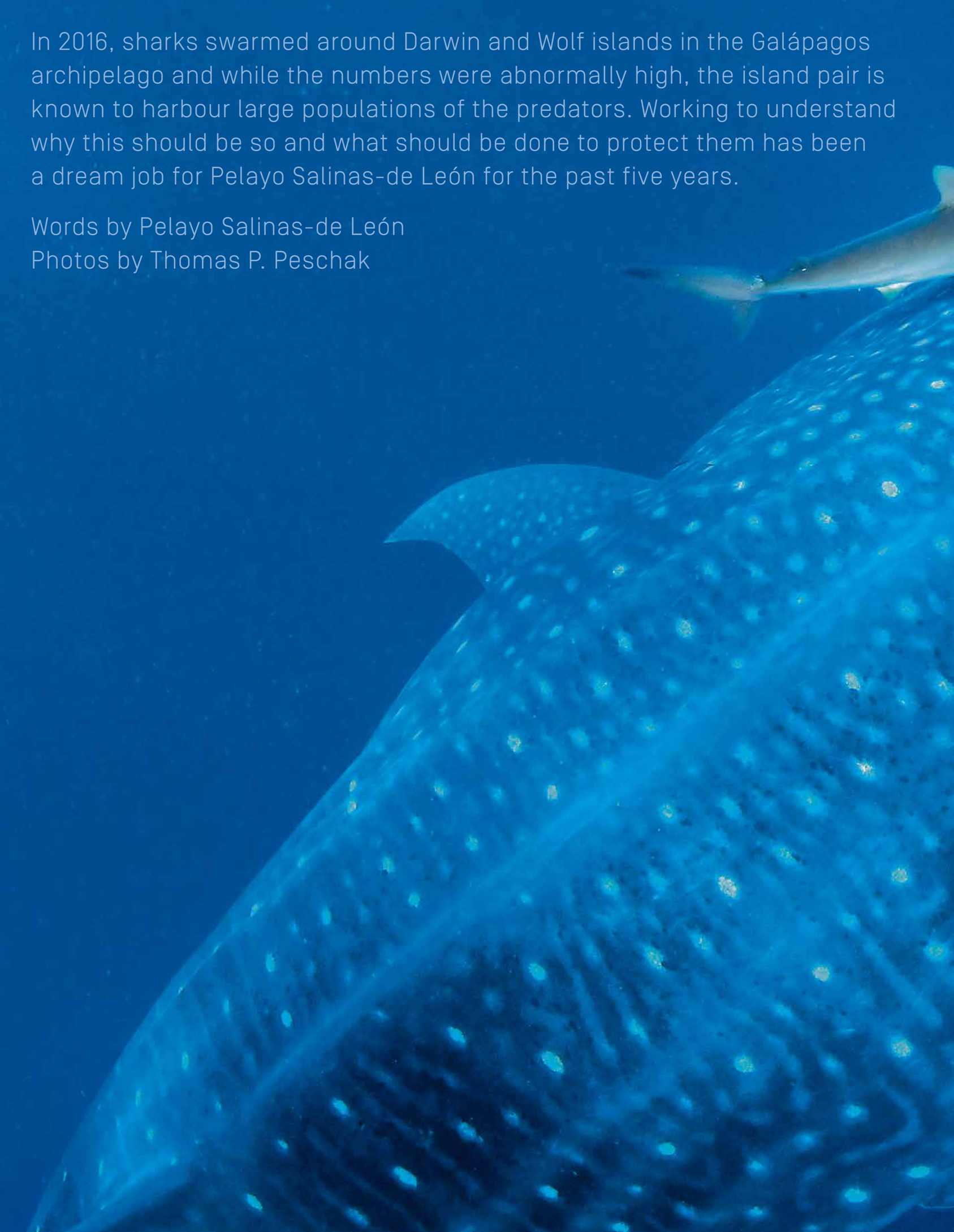
Photo by Thomas Peschak and Michael Scholl

nce on the planet

Darwin's Arch rises out of the Pacific Ocean south-east of Darwin Island. The waters around Darwin and Wolf, the smallest of the islands in the Galápagos archipelago, are home to a wide variety of different shark species.

In 2016, sharks swarmed around Darwin and Wolf islands in the Galápagos archipelago and while the numbers were abnormally high, the island pair is known to harbour large populations of the predators. Working to understand why this should be so and what should be done to protect them has been a dream job for Pelayo Salinas-de León for the past five years.

Words by Pelayo Salinas-de León
Photos by Thomas P. Peschak



A silky shark is rendered remora-like when cruising alongside a whale shark. The filter-feeding ocean giants have been documented as seasonal return visitors to Darwin Island, while silky sharks, which are actually rather large, have been observed shimmying up to whale sharks to rub irritating parasites off their skin.

Pelayo Salinas-de León and Etienne Rastoin shine a light on shark activity at a pelagic Baited Remote Underwater Video Station. A non-extractive method of assessing shark abundance and diversity, the station and its camera float in the open ocean where Galápagos and silky sharks are drawn into the camera's field of view by the scent of bait attached to the rig.

As a teenager growing up in Asturias, northern Spain, I had two things very clear in my head: I wanted to be a marine biologist and I wanted to work in the Galápagos Islands. I'm still not sure why the Galápagos Islands; I'd probably watched a Jacques Cousteau documentary or read an article about Charles Darwin's theory of natural selection. Whatever the reason, during my undergraduate and postgraduate years in Wales, New Zealand, Indonesia and Spain I had shared my obsession for Darwin's enchanted islands with pretty much everyone who crossed my path. So when the position of senior marine ecologist with the Charles Darwin Foundation was advertised in 2012, I received multiple e-mails from different corners of the globe, all with the same message: apply for this and stop daydreaming about it!

It's now been five years since I joined the CDF, a not-for-profit institution that for more than 50 years has been running the Charles Darwin Research Station, the only facility of its kind in the Galápagos. The role of the CDF, as official scientific advisor to the government of Ecuador, is to generate knowledge to inform the conservation of the fragile Galápagos ecosystems. Working for the organisation has been an amazing roller-coaster ride and, once I had completed a very steep learning curve on the job, I have been extremely lucky to have enjoyed some incredible experiences, like collaborating with one-of-a-kind people such as Bob Ballard and Enric Sala, and exploring and documenting new species aboard a manned submersible to a depth of 1,000 metres (3,280 feet). Even calling the waters around Darwin and Wolf islands – the sharkiest location on earth – my underwater office is a tremendous thrill. You could say that I have fulfilled my childhood dream, but the mission is far from over; there is still far too much to learn and do in order to protect the islands, and especially their marine environment and threatened shark populations.

When I'm diving in these shark-filled waters, as a reality check I always think back to when I was conducting research for my MSc and PhD in Indonesia and even after 700 or so dives I could still count the number of sharks I'd encountered on the fingers of one hand. For most marine biologists of my generation this is the sad baseline. But read the reports of early explorers like the great William Beebe or Thor Heyerdahl with his Kon-Tiki expedition and the baseline looks very different: healthy marine ecosystems dominated by populations of sharks and large predatory fishes.

We humans have just got too good at fishing and have fished too much for too long, with the result that we have completely altered what used to be considered a 'normal' underwater environment. Even worse, we tend to forget what a healthy marine ecosystem looks like and how it should operate. All is not lost, however. There is still hope for our oceans, since there are still some pristine places left on earth. And in September 2012, just a month after I arrived in the Galápagos, I got the opportunity to witness this at first hand.

The moment I jumped into the water at Darwin Island in the northern part of the Galápagos archipelago, I felt like one of those early explorers. Just imagine this: you're resting on a bare rock at a depth of 20 metres (65 feet) and a school of hundreds of scalloped hammerheads swims past your head, while a number of curious and rather large, frisky Galápagos sharks come up close to check you out. Minutes later, you look to your left and an apparently pregnant whale shark more than 12 metres (40 feet) long glides past. Sharks, dolphins, sea turtles, eagle rays, giant tunas, orcas – you name it. And all that in an hour's dive. I was blown away!

We surfaced from this first dive and headed back in the zodiac to our tiny research boat anchored 10 minutes away. On the way, we encountered Galápagos artisanal fishermen catching the very same fish that have attracted the dozens of tourists diving from the two liveaboard ships that were moored next to us. 'Why is fishing allowed here?' was my immediate reaction. After all, Darwin and Wolf (as the islands are simply known) are unique, forming an irreplaceable marine ecosystem.

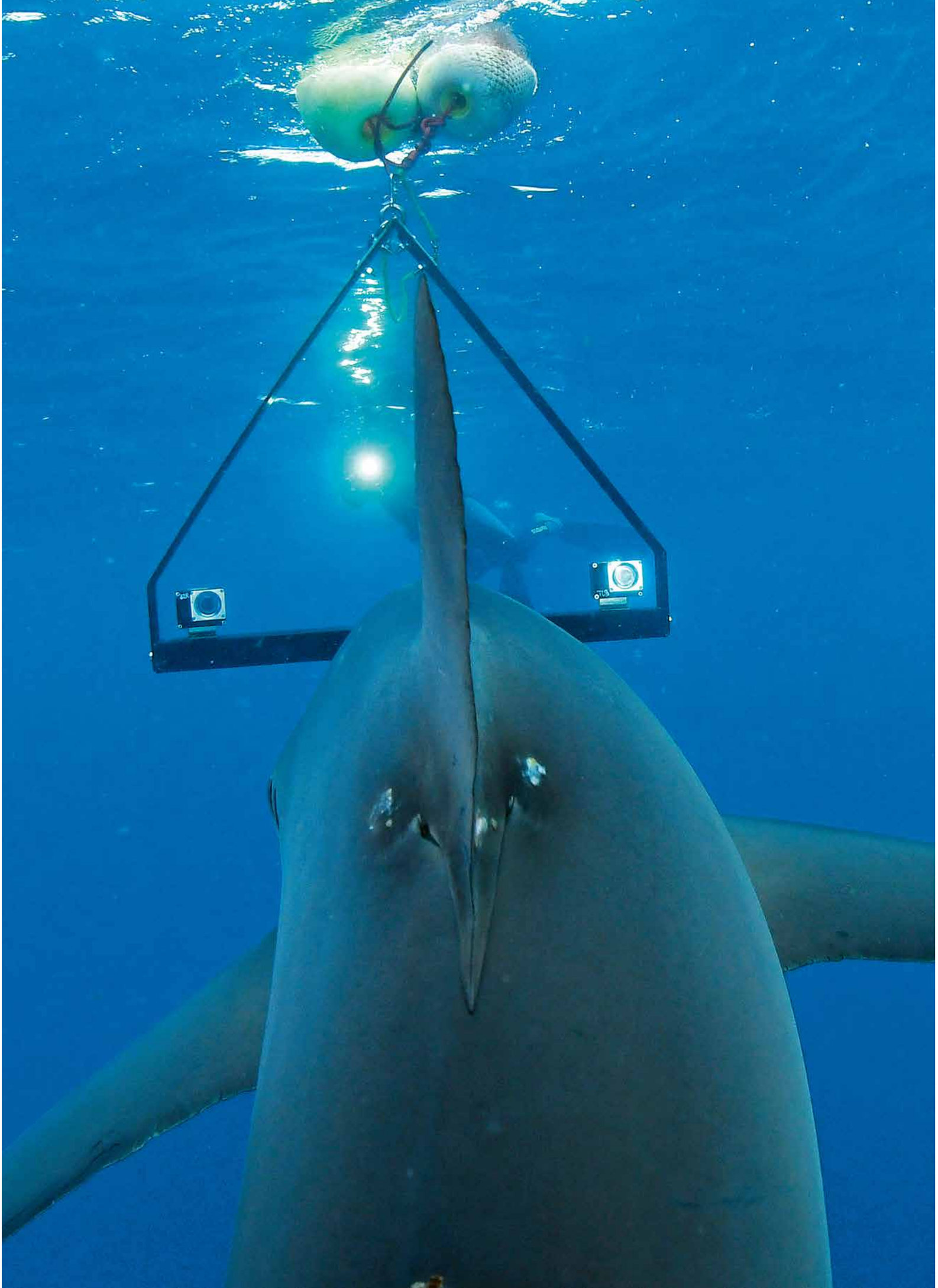
These islands have long been considered one of the best dive sites on the planet and every year they attract thousands of tourists who support a thriving shark-diving industry worth millions of dollars. They are also the most isolated islands of the Galápagos archipelago – the nearest town lies more than 300 kilometres (almost 200 miles) away – so from a safety point of view it is a mission to fish there, especially if you are in a seven-metre (23-foot) single-engine fishing skiff. Whichever way I looked at it, it didn't make sense. From that moment on, I had a new quest: Darwin and Wolf needed to be protected and we had to generate the knowledge necessary to support a fully no-take designation.

Together with my colleague and friend David Acuña, I spent the following months, even years, putting together proposals to get the funding we needed to provide the technical support for the protection of these jewels in the Galápagos crown. We were also very keen to evaluate how effective the Galápagos Marine Reserve was in protecting highly mobile shark species. We believed strongly that the Galápagos, where sharks have been protected since 1998, should be a role model for shark conservation around the world. Although other researchers had conducted several studies to understand shark migratory routes in the region, there were no data to understand how shark populations were faring after 15 years of protection. There was not even a comprehensive baseline against which change could be monitored. Finally, in 2015, and thanks to the perfect combination of hard work and good karma, the planets finally aligned and our quest got under way...

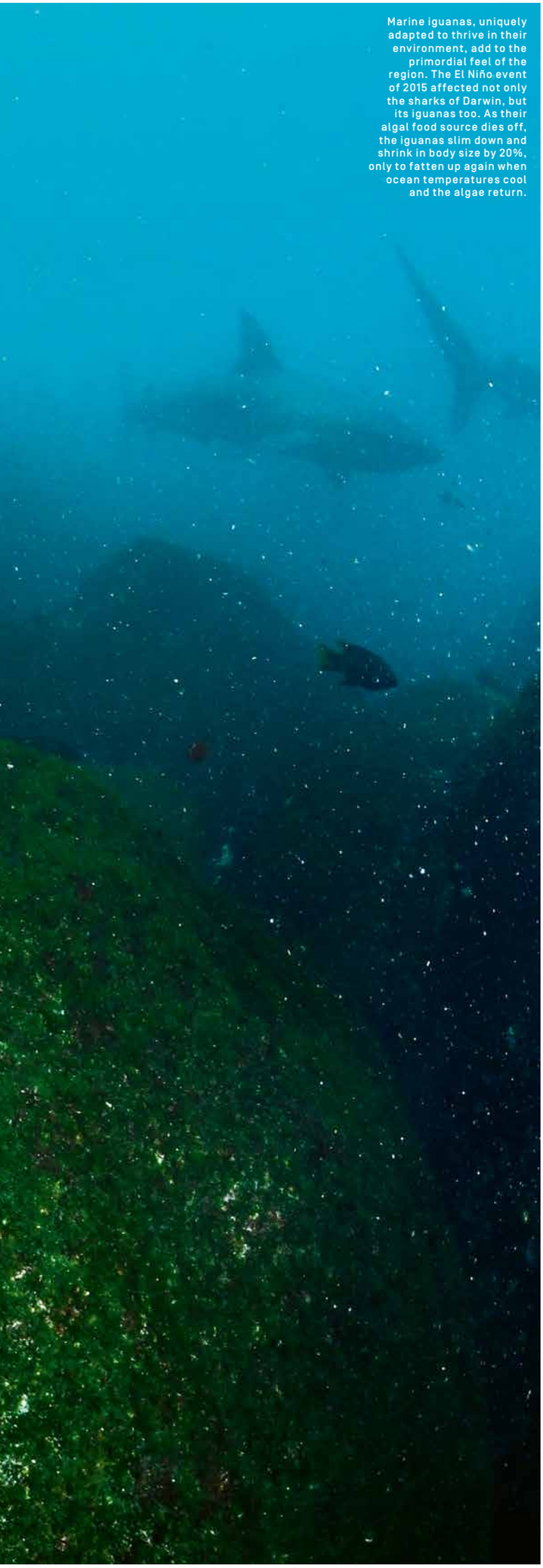
Firstly, we partnered with stereo-video guru Professor Euan Harvey at Curtin University and were awarded a Save Our Seas Foundation (SOSF) keystone grant to establish a shark abundance and diversity baseline for the Galápagos using Baited Remote Underwater Video Stations (BRUVS). This non-invasive methodology has been proved ideal to study shark populations, since some shark species are frightened off by diver bubbles. Secondly, we teamed up with Enric Sala and the National Geographic Pristine Seas Initiative to conduct a scientific expedition to fill gaps in our knowledge and highlight the uniqueness of Darwin and Wolf. Finally, Bob Ballard and his Remote Operated Vehicle (ROV) visited the islands aboard the E/V *Nautilus*, so for the first time we could explore the sea mounts in the vicinity. We were all set.

To cut a long story short, and after we had gathered plenty of evidence to support our contention that Darwin and Wolf harbour unique underwater communities (including the largest concentration of sharks in the world), in March 2016 Rafael Correa, the president of Ecuador at the time, signed an executive decree to establish a 40,000-square-kilometre (15,444-square-mile) fully no-take marine sanctuary around the islands. You can imagine our satisfaction after this conservation milestone for the oceans! My celebration buddies that day were the more than 500,000 boobies that live on Clipperton Atoll, where I was at the time on expedition with National Geographic Pristine Seas. You have to love boobies!

In addition to contributing to the acquisition of full protection for Darwin and Wolf, the SOSF-funded Galápagos shark project provided us with a unique research opportunity. While we were conducting the 2015 BRUVS field campaign to quantify the abundance and diversity of sharks around the archipelago, an El Niño event developed in the Pacific. This is a natural phenomenon that occurs when oceanic currents shift and the typically colder, nutrient-rich water masses surrounding the Galápagos are replaced by warmer, nutrient-poor



Barnacles form a crusty icing on these rocks, the result of fluctuating water temperatures during alternate El Niño and La Niña events that encourage their proliferation. The scalloped hammerheads cruising above are often at the receiving end of these crustaceans' scouring, and resultant infections show up as white patches on the sharks' skin. Pelayo and his team have been collecting skin biopsies to investigate what may be an increase in skin disease after periods of warmer waters.



Marine iguanas, uniquely adapted to thrive in their environment, add to the primordial feel of the region. The El Niño event of 2015 affected not only the sharks of Darwin, but its iguanas too. As their algal food source dies off, the iguanas slim down and shrink in body size by 20%, only to fatten up again when ocean temperatures cool and the algae return.

waters from the West Pacific. It has profound effects on Galápagos marine ecosystems, the warmer waters altering food webs and reducing food availability, with the result that populations of many Galápagos endemic and charismatic species suffer the consequences. For example, during the previous major El Niño event in 1998, massive die-offs and reproductive failures were recorded for marine iguanas, Galápagos sea lions and endemic penguins.

El Niño events share several similarities with some of the predicted extreme effects of climate change on the marine environment, so the Galápagos Islands represent an excellent natural laboratory to gain a better understanding of the impacts of climate change. This is especially true for highly mobile and top predatory species like sharks, where very little data exist to date.

The 2015 El Niño event was followed by a La Niña event, characterised by unusually colder (that is, nutrient-rich) waters that foster productivity and help marine populations to bounce back. In 2016, thanks to a continuation grant from the SOSF, we were able to conduct a new campaign to complete a before-and-after picture of the abundance and diversity of sharks in the archipelago during the turbulent El Niño–Southern Oscillation cycle. Although we are still analysing data, in the case of shark-central Darwin and Wolf we observed a severe reduction in the number of sharks during El Niño, with very few individuals recorded during the peak season.

The following year, and after water temperatures around the Tropical Eastern Pacific had remained abnormally high for a number of months, we recorded an unusually high number of hammerhead sharks around the islands. By unusual, I mean swarms and swarms of hammerheads, comparable only to the queues at an outlet for free beer at the Oktoberfest! Even National Geographic photographer and SOSF conservation director Thomas Peschak, who has travelled the world covering shark stories, supported our findings during our research cruise in late 2016. 'Pelayo,' he said, 'I thought you were full of nonsense when I read your paper about the largest global shark biomass around Darwin and Wolf, but you are right; there are a ton of sharks up here.'

In addition to the sheer number of sharks, many of the individuals we recorded in 2016 showed very large patches of skin disease and were desperately visiting the reef-fish cleaning stations around the islands. So together with project scientist and free-diving guru Etienne Rastoin, we collected skin biopsies by using a Hawaiian sling while free-diving. Now we are awaiting genetic analysis results (early evidence points to a bacterial disease). Although stereo-video analysis is still being carried out by project volunteer Ana Moya, the findings so far in relation to El Niño effects around Darwin and Wolf reflect a severe reduction in the number of sharks (we hypothesise that many seek deeper, cooler waters) and an increase in the incidence of skin disease following the period of warmer water.

As part of this SOSF-funded project, we also conducted an education and outreach campaign to share our main findings and some key shark conservation messages among the local population. The Galápagos Islands have a permanent human population of about 30,000 people, which is boosted every year by thousands of tourists visiting the archipelago to dive with sharks. Tourism is the economic engine of the region and in 2015 the annual value of a living shark was estimated at US$360,000 per year.

Despite the ecological and economic value of sharks for the Galápagos, most local residents, especially the children, barely venture to the surrounding ocean and know nothing about the importance of sharks. In 2016, during our educational campaign based on the motto 'The Galápagos: a sustainable model of co-existence between humans and sharks', our local environmental educator Daniela Vilema reached more than 1,500 local schoolchildren between the ages of seven and nine and shared key messages about the importance of sharks. This educational campaign was a total success and a great majority of the children changed their negative perception of sharks when they understood better the predators' role in the ecosystem and their socio-economic importance, as well as the current severe population declines for most shark species. The Galápagos Islands now have an amazing new generation of shark conservationists in the making!

Looking back, the past two years have been the most rewarding time of my life from a professional point of view and I have been extremely fortunate to have enjoyed the ride with an amazing team of very talented shark scientists and conservationists. But the mission is far from over. The Galápagos is definitely a global model for sustainable co-existence between humans and sharks and now it's time to export it. Let's make the planet sharky again!

Darwin's Arch haloes a free-diving Pelayo Salinas-de León as he swims with a stereo diver-operated underwater system. Using cameras to record diversity has been an important part of Pelayo's work to cement the Galápagos, and Darwin Island in particular, as one of the most shark-rich regions in the world. The data generated by this means underpin the evidence that Pelayo and the Charles Darwin Foundation use to shape protection policies in these waters.


SCUBAPRO

Photo by Thomas Peschak and Michael Scholl

Wolf Island cuts a stark contrast between gunmetal sea and sky. Named after the German geologist Theodor Wolf, this island and its neighbour Darwin Island loom from the remains of an extinct and mostly subsurface volcano that rises 1,000 metres (3,280 feet) above the sea floor. Wolf's bleak landscape belies the wealth of ocean life in the surrounding waters. While land sightseers are not permitted, dive tourism allows visitors to experience the island's marine wildlife.

The vampire tactics employed by ground finches on Wolf Island highlight how animals have adapted to survive its harsh environment. The island can be extremely dry and, with food and water sources depleted, these finches drink the blood of Nazca boobies. Using its beak to pull out a developing feather, the finch laps up the blood from the wound. The booby, however, seems unfazed.

Galápagos Islands

DARWIN & WOLF ISLANDS

New protections: accessible for scientific use and tourism only; no extraction of natural resources (including fishing) allowed

Galápagos Marine Reserve artisanal fishing permitted, along with tourism and science

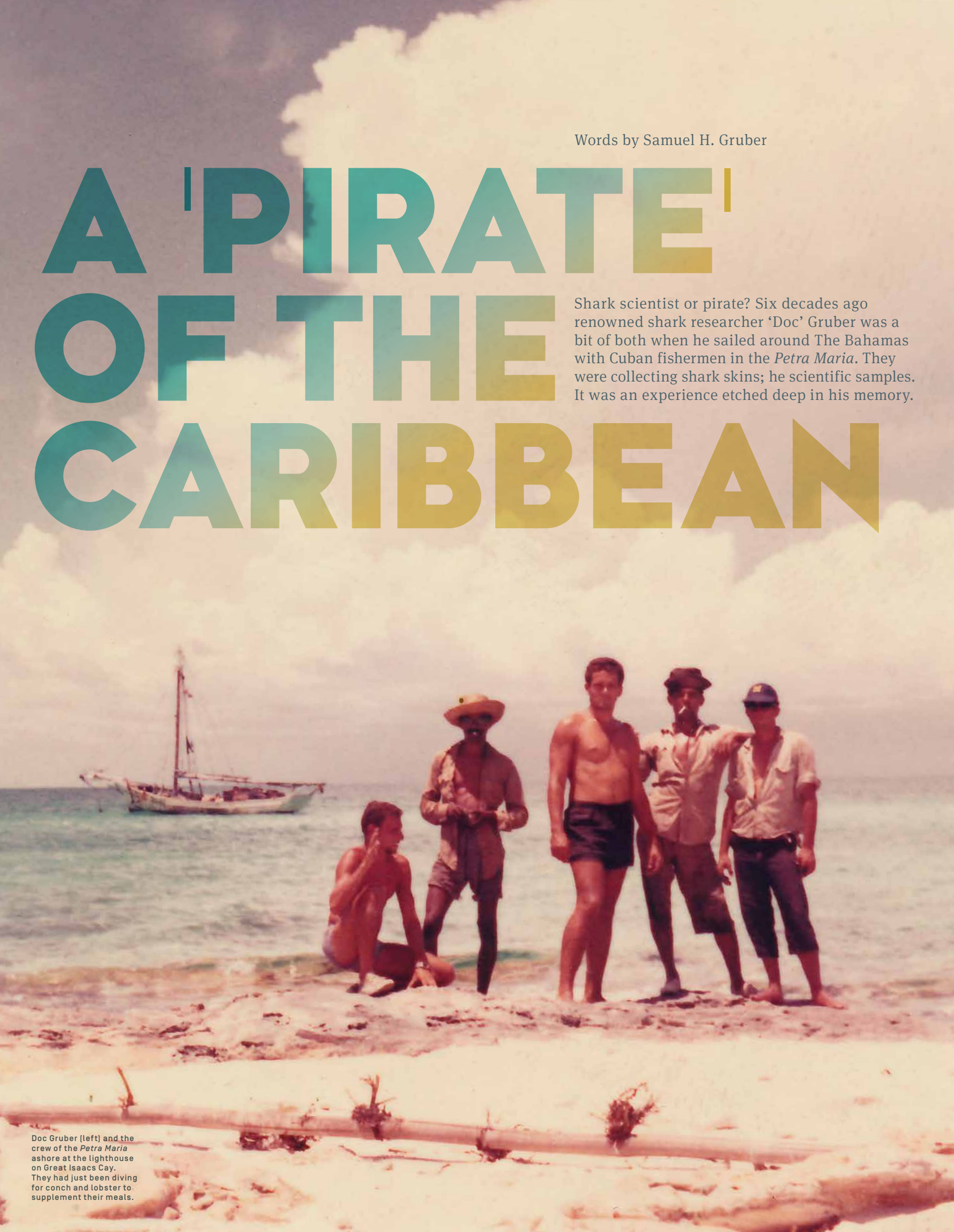
150 KM

Artwork by William Ruzek

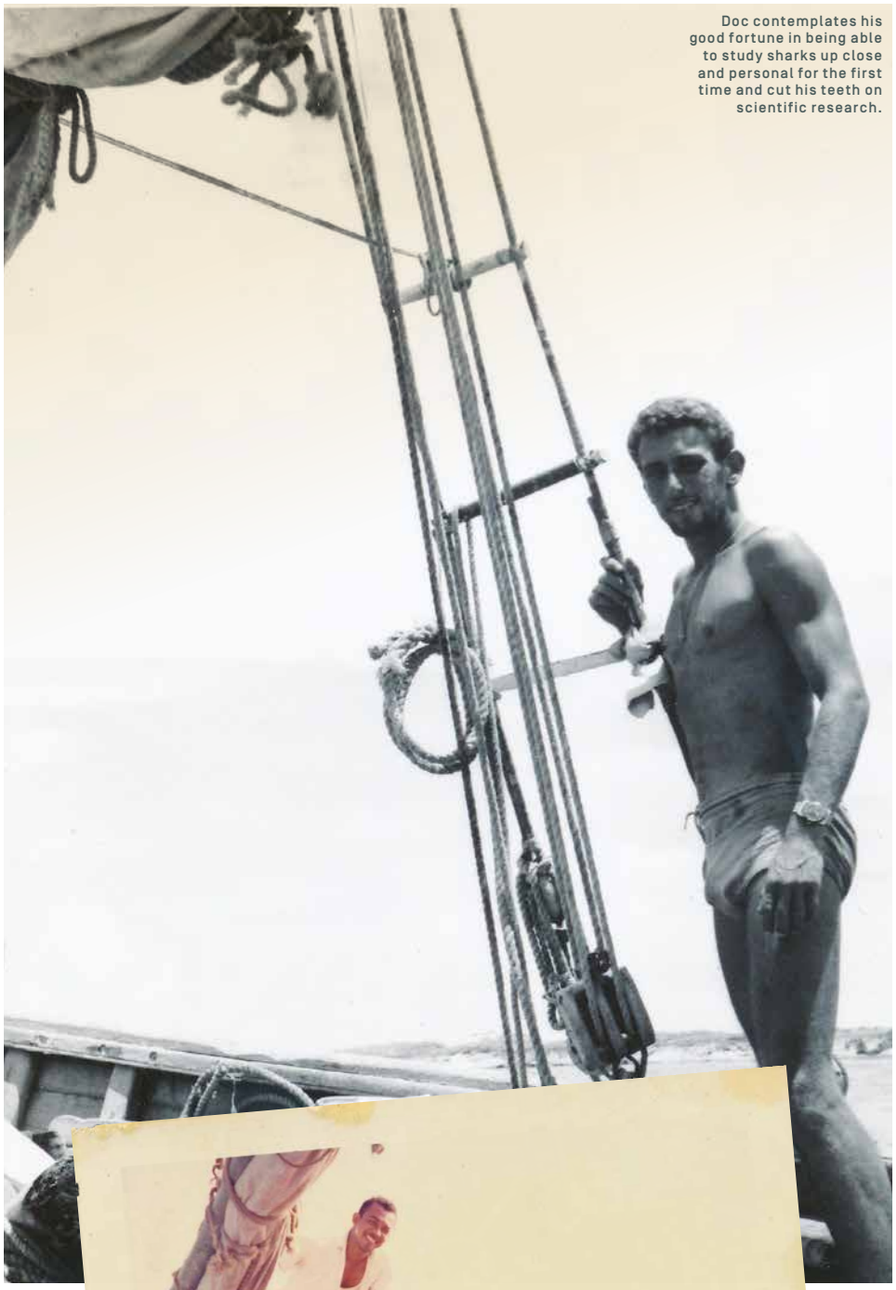
Words by Samuel H. Gruber

A 'PIRATE' OF THE CARIBBEAN

Shark scientist or pirate? Six decades ago renowned shark researcher 'Doc' Gruber was a bit of both when he sailed around The Bahamas with Cuban fishermen in the *Petra Maria*. They were collecting shark skins; he scientific samples. It was an experience etched deep in his memory.



Doc Gruber (left) and the crew of the *Petra Maria* ashore at the lighthouse on Great Isaacs Cay. They had just been diving for conch and lobster to supplement their meals.



Doc contemplates his good fortune in being able to study sharks up close and personal for the first time and cut his teeth on scientific research.

The year was 1961. I had finally made a decision to follow my life's career. Torn between Air Force jet jockey, professional ballet dancer and marine biologist, I had been persuaded by my father that the most viable and least dangerous path to follow would be the academic route to marine biology. He was a good observer and judge of character so I took him at his word, but failed to mention that my desire was to study sharks.

Even before beginning my 58-year career at the University of Miami's Rosenstiel School of Marine and Atmospheric Sciences, I decided to carry out my own little research project. I found out that many a Cuban fisherman had grabbed his boat back from Fidel Castro, who nationalised them when he took over the country in 1960. One particular vessel, the *Petra Maria* out of Caibarien, Cuba, sailed to Miami with the goal of shark fishing for hides that would be tanned into leather. The crew worked for a small company, Florida Caribbean Fisheries, which liked to employ refugee Cubans because they were excellent fishers, despite using primitive methods.

In those days, the Ocean Leather Company was buying up shark skins and tanning them into a leather that was said to be indestructible; workmen's boots tipped with shark skin would apparently 'last forever'. The company also manufactured belts, wallets and briefcases as high-end products and was doing very well. In the 1960s, though, it could not get enough of the raw product. Enter Florida Caribbean Fisheries, which agreed to sponsor the *Petra Maria's* owner-captain with shark-catching gear.

The vessel's crew comprised a captain and four deck hands. They were all Cuban and spoke no English whatsoever, having arrived in Florida only a few weeks before. Fortunately, I spoke some Spanish because my roommates in prep school were mostly from Havana. As best I can recall, the captain's name was Indio, while the most experienced fisher was Antonio, who claimed he started fishing at 12 and was about 70 at the time I met him. He actually hailed from Portugal, but spoke Spanish and had lived in Cuba for years. I have forgotten the names of the other three crew members, but they were rather young and surly.

I still remember the day I parked my little red Fiat Spyder in front of the Florida Caribbean Fisheries office and walked in. With apparent confidence, I asked the owner if I could join the next shark fishing trip. He must have been amused because he agreed instantly while the crew grumbled in the background. You can't imagine the incongruity between this crew, their vessel and me, the 23-year-old son of a wealthy banker. Nevertheless, I was ready to jump in with both feet and finally learn something about sharks, after having struggled for four years to study them on my own.

The plan was to fish for about a month at the north-western edge of the Great Bahama Bank, poaching sharks. We would be fishing from South Riding Rock to Great Isaac's Cay, a distance of about 90 kilometres (55 miles). Although I joked that the *Petra Maria* was my first research vessel, she was in fact an old, salty, 12-metre (40-foot) gaff-rigged sloop with no electrical system, no head, no galley, no lights and no radio. Our only drinking water was contained in a pair of 200-litre (52-gallon) wooden casks on the deck. We were essentially living on an 18th-century fishing boat. Her one modern amenity was a three-cylinder Buda diesel engine that was started by jamming the morning's cigarette butts into each of the three glow plugs and cranking a hand pump to get diesel fuel into the cylinders.

The captain would turn over the engine by hand crank and off she would go, reliable every time.

Once it had been agreed that I could sail with the *Petra Maria*, the next question came up: what in the world was I going to choose as a research project? I had come across a laboratory at Rutgers University called the Institute of Comparative Serology. The researchers claimed to be able to trace the evolution of a related group of species in a way similar to what we see in genetics research today, but of course this was long before such techniques were even dreamed of.

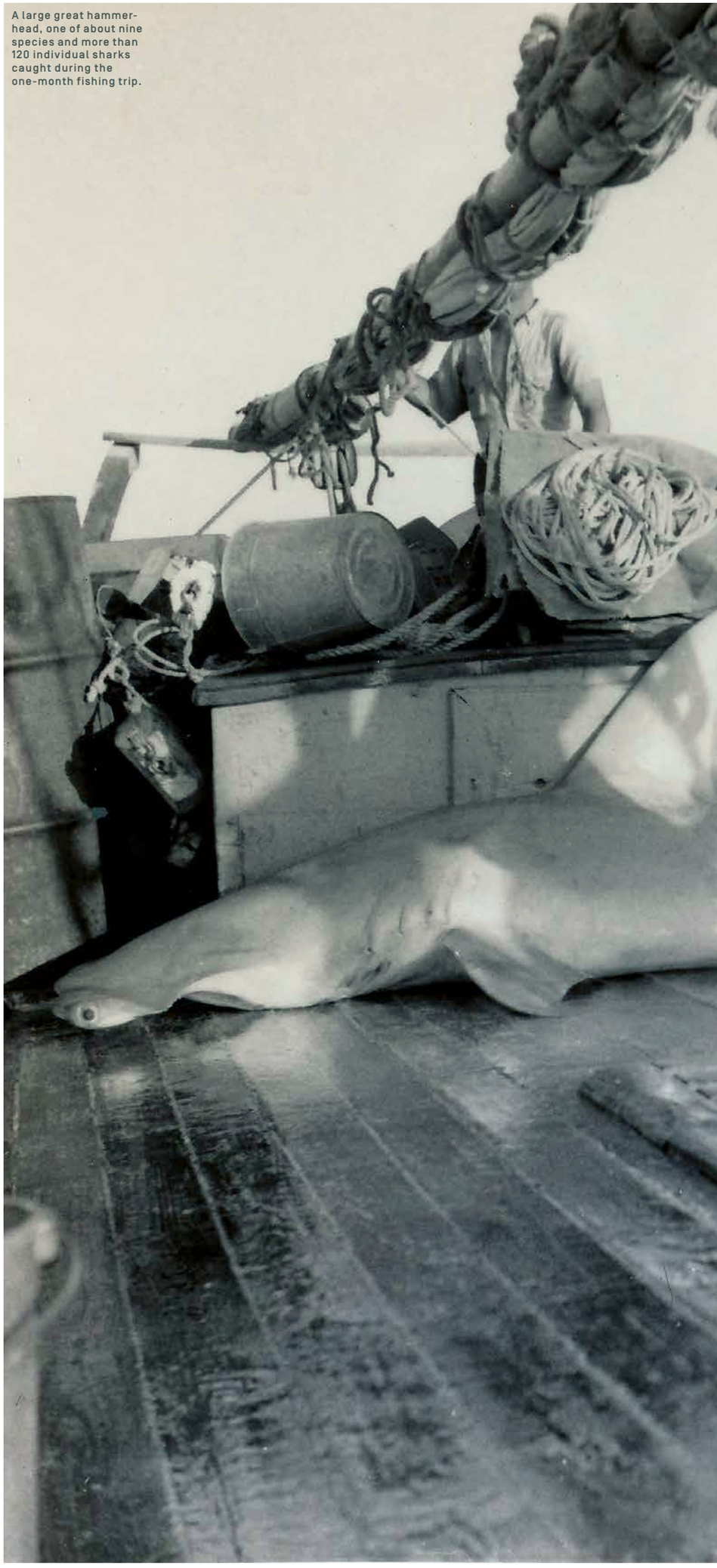
The research method then was to collect blood serum from different but related species and inject it into a test rabbit whose immune system would naturally raise antibodies to the serum antigens in the sample. I approached the Rutgers team and they enthusiastically accepted my proposal. We decided to use the blacktip shark as the baseline species. They would inject rabbits with the blacktip serum I would collect in The Bahamas. The rabbits would then react to the blacktip's serum antigens and produce antibodies specific to this shark. The trick was to test the blacktip antibodies on the antigens in the serum of related sharks.

So the plan was for me to collect serum from many shark species and send them to the Rutgers laboratory, where the blood would be processed and tested against that of the blacktip. For example, the more closely related a shark is to the blacktip, the less immune-related precipitation occurs between antibody and antigen. Thus it was possible to specify how closely a particular shark species is related to the blacktip. As the Rutgers scientists had already pioneered such research on other species, I realised it was a unique opportunity to look at shark evolution in the same way. I thought that this was an amazing technique and after communicating with the Rutgers scientists, I learned that I could collect shark blood and store it without refrigeration using a chemical preservative.

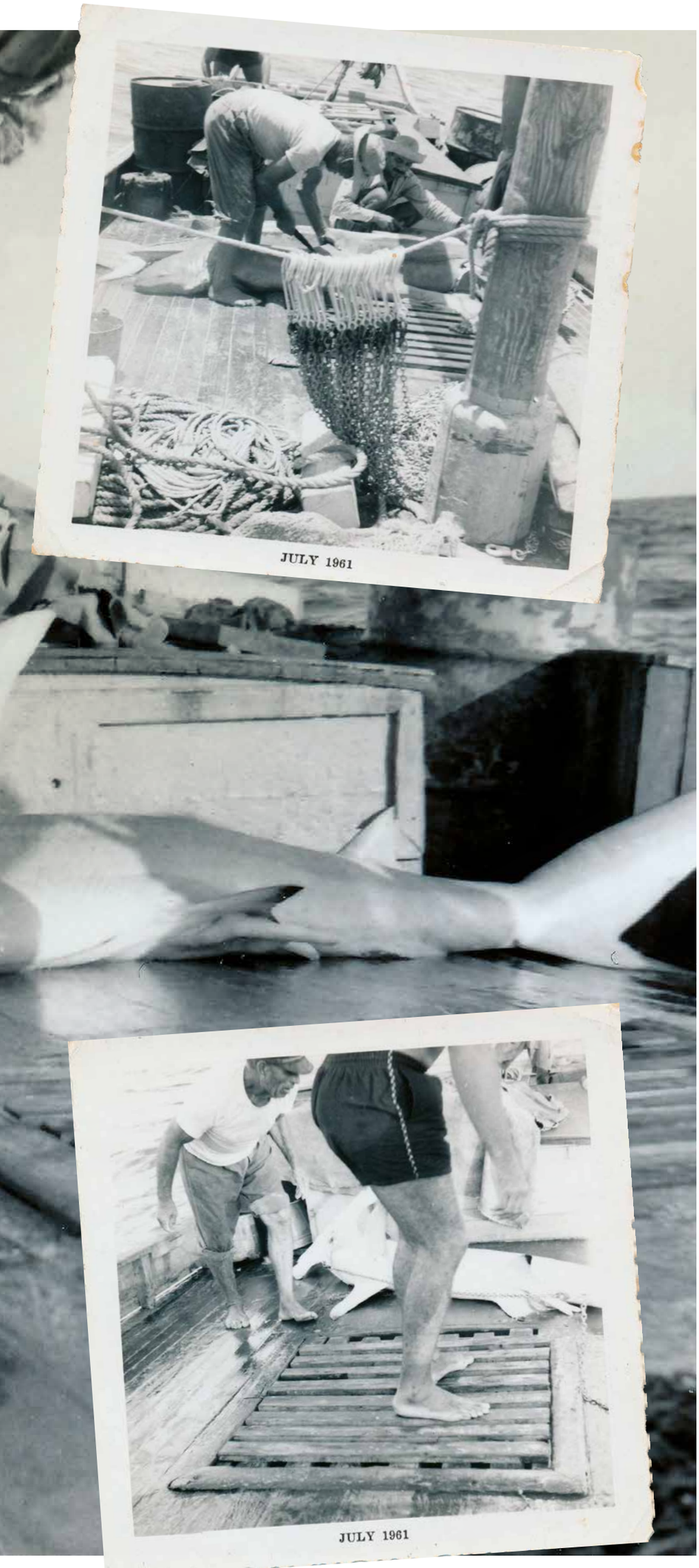
The plan seemed perfect, so in June 1961 I signed on and, with me aboard, the *Petra Maria* sailed across the Gulf Stream to The Bahamas. Once we reached Bahamian waters, we never thought to clear customs or request a commercial or export fishing permit. That's the way things were in those days. Although some of the crew were polite enough, the young ones were intent on giving me a hard time. I had the impression that they didn't really want this strange American on board. They were a team bonded by the struggle to survive and I was an outsider with a project they thought crazy.

We began our work at South Riding Rocks, 120 kilometres (75 miles) south-east of Miami as the crow flies. The crew deployed an all-chain, 250-metre (820-foot) mainline with gangions, or leader chains, tipped with huge hooks – extremely inefficient gear that had been supplied by the Ocean Leather Company. As we had no refrigeration, our first task was to troll back and forth and catch barracuda, kingfish and the occasional mahi-mahi for bait to set the long-line the next morning. Back then, there was no shortage of fish and trolling produced all we could want both for our consumption and for the sharks.

As a youngster growing up on Miami Beach I was well acquainted with fishing methods, but I had never seen anything like the way our captain fished. For trolling, he had a kind of lure made out of pigskin with double hooks attached to it. The rig was basically an all-wire hand line without any sort of rod, reel or even Cuban yo-yo reel. Indio would troll his bait about 10 metres (33 feet) behind the vessel, which was constantly under sail. It is hard to believe that the strike of, say, a 15-kilogram (33-pound) kingfish would not rip his fingers off as he gripped the wire, but he knew just how to handle the fish in such a way that he tired it out without ever slowing down or striking the sails. Eventually he hauled that kingfish in and cut it up for bait for the next day's shark fishing. Our work done and the sun having just set, we anchored that first evening off South Riding Rocks.



A large great hammerhead, one of about nine species and more than 120 individual sharks caught during the one-month fishing trip.



Dinner was as far-fetched an experience as trolling. One of the crew had put a pot of rice on to boil even though there was no stove or other mechanical cooking device. All our meals were prepared in a large, tin-lined wooden box open at the front and the fuel was charcoal homemade from driftwood. Typically, we would eat fish, either canned or fresh, along with rice and highly sweetened Cuban coffee, lightened with evaporated milk from a can.

There were no state rooms or bunks below deck; you just found a spot in the hold, lay down and went to sleep among the sacks of salt for preserving the shark skins. The entire centre of the vessel was a large well into which we threw fresh lobster, conch and finfish when we got a chance to dive or spearfish on the reef. The animals we collected were kept alive with water that flowed directly in through about 50 small holes in the bottom of the boat. The walls on four sides were waterproof to keep the boat from sinking.

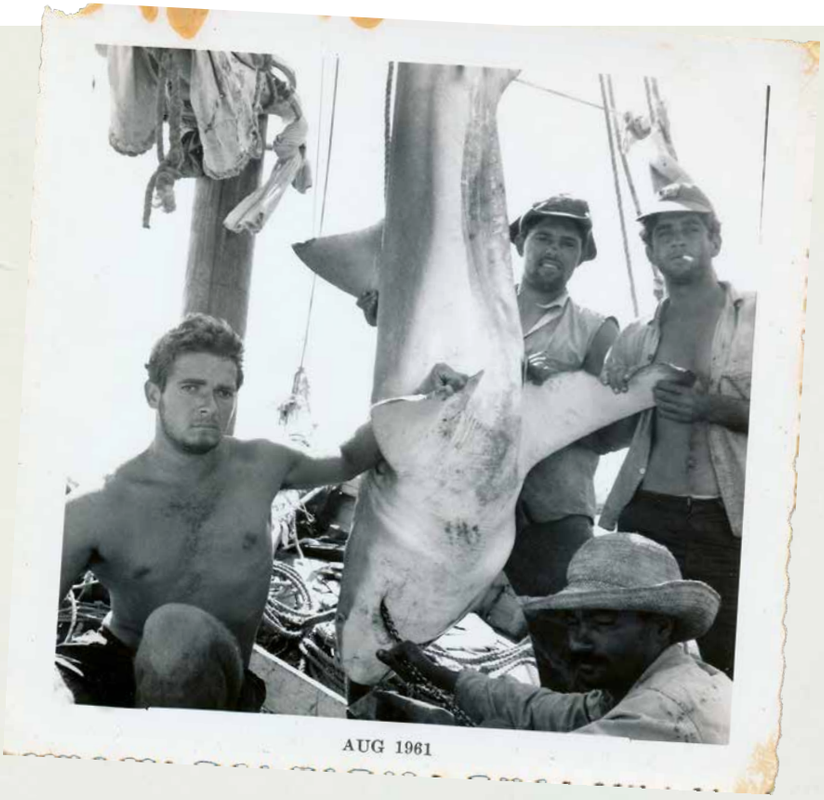
Imagine my excitement that first evening. Here I was in The Bahamas on a shark-fishing vessel. It was my first opportunity to come face to face with sharks I had only read about or seen tossed up to the sport-fishing docks in Miami. Anticipation kept me awake as I wondered what species of shark we would catch in these virgin, shark-rich waters. And would tomorrow be the dawn of my research career? Yet for the snoring crew, it would be just another tedious and exhausting day at sea.

On our first long-line set, we caught plenty of sharks. Over the month there were 103 'keepers' of various species while many others were released, being too small to provide a saleable skin. The keeper sharks comprised mainly Caribbean reef and lemon sharks, but there were also bull, great hammerhead, nurse, blacktip and tiger sharks. Every morning, after a breakfast of little more than sweet, strong Cuban coffee, the crew pulled in the ridiculously heavy long-line. After hauling back, removing any sharks and stowing the gear, the ritual of shark skinning began. Each shark was skinned in a particular way, as demanded by Ocean Leather, and the skins were carefully inspected for blemishes and mating scars, which lowered the price. The crew usually finished the skinning around noon, when we took a lunch break of canned sardines and yet more sweet Cuban coffee. After lunch, the hides were scraped, salted, folded up into neat squares and stacked in the hold.

During the skinning, I collected and prepared my blood samples, having identified and measured each shark. Afterwards, I removed, cleaned and dried a selection of jaws. The crew then cut up enough shark meat to bait all the hooks for the next day and from then on we used no other fish for bait. If we wanted fresh fish we would troll, but that was only for our personal meals.

About a week after our arrival in The Bahamas, we found ourselves off Ocean Cay, about 35 kilometres (21 miles) south of the Biminis, where we caught our first tiger shark. It was a big fish, about three metres (10 feet) long. After working up and skinning the animal, Antonio opened the body cavity and, to my bemusement, removed a large piece of liver that he cut it into tiny cubes. He filled a glass jug with the tissue, then tied it to the roof of the cabin. In my best broken Spanglish I asked him what on earth he was doing. He explained that if you leave the liver pieces in the sun for a few days, the oil renders out and floats to the top. Sure enough, after three days, the jug was full of clear amber oil, with a layer of rendered liver debris at the bottom. Every morning thereafter, I watched the crew members take a swig of tiger shark oil before their breakfast coffee.

As a budding marine biologist, I knew that shark liver oil contains large amounts of vitamin A. In fact, during World War II, when much of the cod fishery was impacted by the Battle of the Atlantic, shark liver oil became the preferred daily medicine for every child in the USA. I clearly remember every morning during the war, my mother gave me a tablespoon of so-called cod liver oil. I literally had to hold my nose and gulp down this nasty fluid. Sure enough, the oil in Antonio's jug was exactly what I



AUG 1961

AUG 19

(Left) The crew with a 3.5-metre (11.5-foot) dusky shark. Although we caught several duskies on our trip in 1961, they have since become victims of over-fishing and are now rare in Gulf Stream waters.

remembered from the 1940s as a kid – and there was no way I was going to have any!

There was another thing about the tiger shark oil. Captain Indio once poured a small sample of oil into a glass vial. He explained that this was how he could predict the weather. He claimed that as the atmospheric pressure fell and storms approached, the clear amber fluid would turn a bit cloudy and then he knew it was time to hunker down behind one of the small cays. If you find this theory far-fetched, I recommend that you Google an article called 'Predicting the weather with shark liver oil'. Sometimes truth is stranger than fiction.

After a few days, the island of Bimini hove into view, which at that time was a British crown colony. At my insistence, and as if we were a ship of the Royal Navy, we jauntily sailed up the harbour to what was then the Lerner Marine Laboratory – right past customs house and never clearing customs or immigration! I knew that Dr Perry Gilbert, the great shark scientist, was visiting as he did every summer, and I was anxious to meet him. Furthermore, we had caught and skinned a big nurse shark a few days earlier and I had found viable eggs in her oviduct, which I had placed in the well in anticipation of this hoped-for meeting. We moored at the Lerner laboratory dock and I jumped off, looking like a pirate. When I found Dr Gilbert, I explained that I had these viable nurse shark eggs and I wanted him to have them. He was dumbfounded that we had had the audacity to sail straight to the lab's dock, and when he came out to retrieve the eggs, he advised us to leave immediately as we had not been cleared to enter The Bahamas and would probably be arrested, along with everyone else at the lab. Years later, after I had presented a paper, Dr Gilbert came up to me with a smile and recalled our first meeting, admitting that he knew then that the budding scientist-pirate would become an effective researcher.

For the next week, we fished our way towards Great Isaacs Cay and its famous old lighthouse. Although the crew provided food, I had brought along a few edible items of my own. Earlier that year I had met my future wife, Mari Hirata, and learnt about Japanese food. One very convenient item is *ochazuki nori*, which comprises a packet of tea, bonito powder, seaweed and spices. The contents are poured over a bowl of rice and mixed together with hot water: simple, lightweight, delicious and filling. One evening, Antonio asked me what my meal was. I answered that it was a seaweed powder *(algas marinas)* with tea. For the next three days, every time we sailed past a piece of floating seaweed, the crew would net it and call out *'Gringo, algas para comer!'* (Yankee, seaweed to eat!). Then they would double over laughing and toss it at me.

Eventually, the crew and I settled into our routines. Day after day, we set that chain long-line and hauled in shark after shark. They would skin, scrape and salt their catch while I gleefully collected and preserved my precious blood samples and updated my records. The hold began to reek, but by this time we were used to it. I slept on a stack of salted hides and was none the worse for wear, at least by the standards of a pirate ship.

In due course we arrived at Great Isaacs. Constructed in 1859, the lighthouse was manned until 1969, when both keepers mysteriously disappeared and it was closed down. When we visited the keepers in 1961, they were happy to see us. One thing I recall was the turtle meat that was kept in a huge container of bloody brine. It looked repulsive, but the keepers said it was the best meat they could get.

We fished around the Isaacs for a couple of days, when one morning we arose to the sight of a 35-metre (115-foot) luxury yacht named the *Black Hawk*, which was out of Chicago. Wanting to make contact with another American, I swam over. As I got close, an impeccably dressed man appeared on deck with a big chrome pistol. Pointing it at me, he demanded that I return to the *Petra Maria*. I beat a hasty retreat – but never forgot. I managed payback years later when I was on the marine school dock one afternoon as the *Black Hawk* chugged up. The impeccably dressed captain asked me the way to the Seaquarium. 'Sure,' I replied. 'Just stay close to the shore and make your way around the point for a few hundred yards.' As I walked back to class, I was delighted to see them hard aground on the flat where I knew they would get stuck.

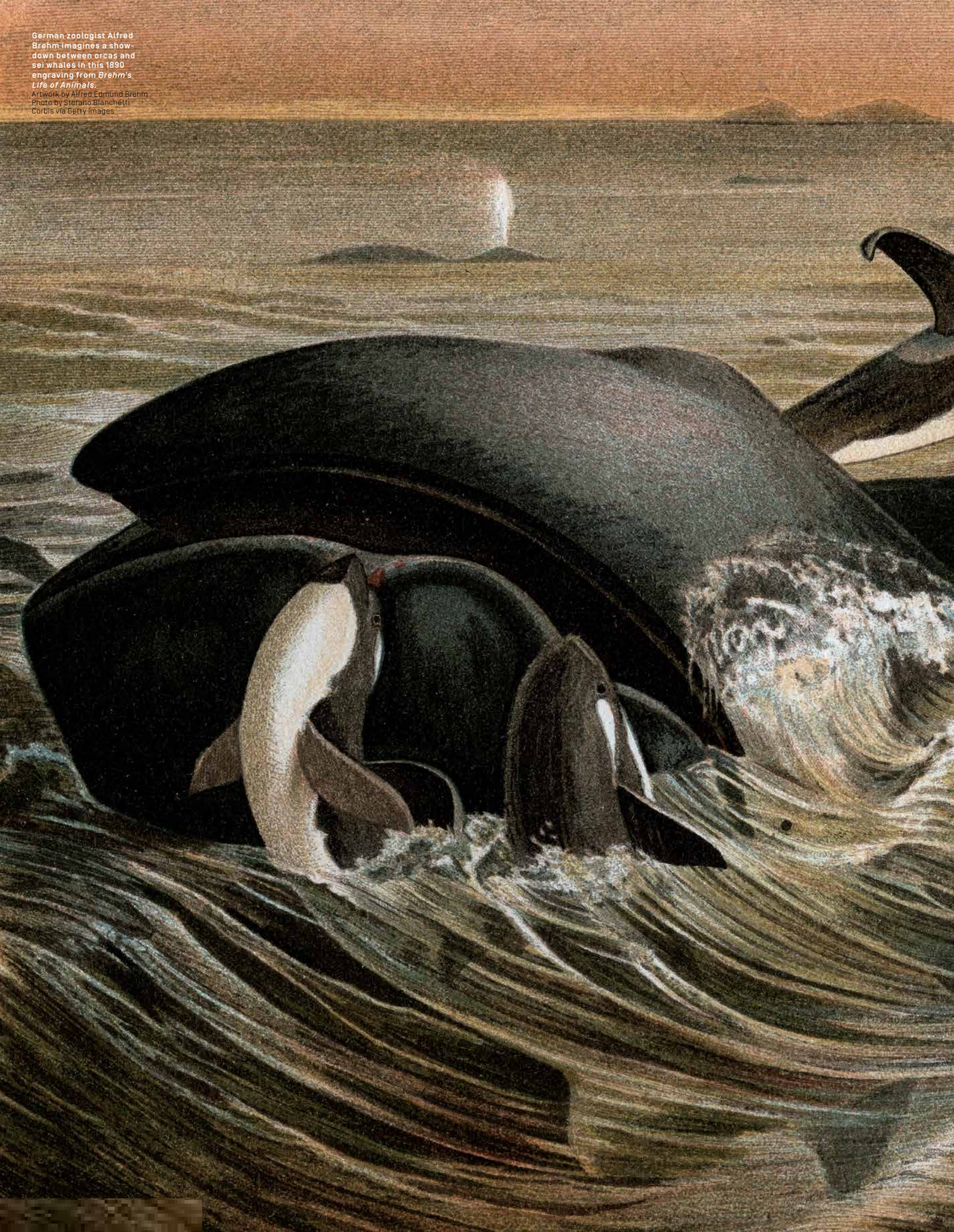
The rest of the cruise was fairly uneventful. After 30 days in The Bahamas, we returned to Miami and, again without bothering with US customs formalities, motored up the Miami River to unload our 103 top-quality shark hides. I thanked the crew, bid farewell to the *Petra Maria* and carried my sets of jaws and preserved blood to the fish museum at the University of Miami marine school.

Clearly, this scientific, cultural, even dangerous expedition affected me in a major and positive way. Living at sea for a month, barely speaking the crew's language and trying to fit in socially was an experience not to be forgotten. Indeed, my recollections of a trip that occurred some 60 years ago are so clear that the adventure must have been seared into my brain. My goal of meeting sharks up close and personal greatly helped to kick-start my graduate career. Eventually becoming close and respected friends with the crew was a real breakthrough for me and it would not be repeated until some 20 years later, when I had the privilege of going to sea as a chief scientist directing a dozen young scientist-students. Thus ended my first scientific cruise. In the end, though, the memories are bittersweet, for the *Petra Maria* and her crew were lost in 1964 during hurricane Cleo.

As a postscript, after all the planning, effort and excitement of my expedition, I got a stiff reality check. I had sent my samples to the Rutgers researchers, but heard nothing for several months. I tried to contact them to find out what had happened to my material, but couldn't get a straight answer. About a year later, while doing the school's mandatory literature surveys, I came across a publication about all the shark research I had done in The Bahamas. The Rutgers group had stolen my data and published it as their own. There was not even a grateful acknowledgement for my research material. It was then that I realised that scientists are human beings and share the same foibles as everyone else.

I would like to conclude my little reminiscence with some observations. Long gone are the attitudes that 'the only good shark is a dead shark' or 'sharks are the death fish from hell'. Today, some six decades later, many lay people realise the importance of sharks and the role they play in the sea. Yes, the media hype up the gory aspects of shark attack, but they still seem to convey the conservation message. Consequently, I never cease to be amazed by the knowledge people have about the importance of shark conservation. Coming from a time when there was not a single photograph of a living great white shark, I am astounded at the changes I have seen. Just think, in the 1980s the National Oceanic and Atmospheric Administration was still exhorting fishers to mortgage their boats and buy shark-fishing gear. Sharks were euphemistically called an 'under-utilised resource'.

Today there are major efforts to protect sharks, including the shark sanctuaries that have been organised by the Pew Global Shark Conservation Initiative. These days, more and more NGOs like the Save Our Seas Foundation are putting their money where their mouth is and funding important, conservation-oriented research. The role and positive impact of such NGOs on marine conservation cannot be underestimated. Such are the changes that I have witnessed during my long and enchanting career in marine biology. My dear old dad was right after all to point me in that direction!



German zoologist Alfred Brehm imagines a showdown between orcas and sei whales in this 1890 engraving from *Brehm's Life of Animals*.
Artwork by Alfred Edmund Brehm
Photo by Stefano Bianchetti
Corbis via Getty Images

Winter is coming

For South Africa's most southerly white sharks, winter has come in the form of two floppy-finned cetaceans known as Port and Starboard.

Words by Philippa Ehrlich

The infamous orcas Starboard (left) and Port (right) – prime suspects in the cases of shark predation along the South African coast – cruise the waters off Gansbaai.
Photo by Alison Towner | Dyer Island Conservation Trust

Artwork by Marc Dando

A broadnose sevengill shark flees killer whales hunting together in the kelp.

I'm in mid-water, surrounded by a vast undersea forest. I move to the edge of the kelp, wrap both hands around a thick stipe and hang like an amphibious monkey, staring out into the great blue-green abyss of False Bay. It's winter, so the visibility is good, but I am on my own and I don't feel safe outside the kelp. For most surfers and divers along South Africa's most southerly coast, going into the water holds a certain edge, and visions of black fins and torpedo-shaped shadows dance menacingly at the fringes of one's imagination. This is the kingdom of one of the largest populations of white sharks on the planet and even after 10 years of regular diving, for me primal terrors die hard. But somehow, on this particular dive, the ocean feels more benign. Perhaps it's because my rational mind is in on a not-so-secret secret: there's a new ruler in the bay and multiple rows of razor-sharp teeth don't scare it.

For decades, this part of the coast has been an energy-rich haven for white sharks. In winter they feed on healthy populations of naive Cape fur seal pups and in summer they move inshore to feast on shoals of migrating yellowtail fish. Similar patterns have been observed 100 kilometres (62 miles) away at the 'sharkdom' of Gansbaai on the Overberg coast. For cage-diving operators, winter should be the season of plenty with good visibility, an abundance of white sharks and boatfuls of clients, but this season there was hardly a shark to be seen and one company was forced to close down.

What would cause the uncontested king of South Africa's marine food chain to vanish from his well-established territory? To answer that we need to return to the scene of a series of grisly discoveries made by shark researchers along the Overberg coast.

The first clue that something was amiss for the white sharks at Gansbaai was the carcass of a 2.7-metre (9-foot) female that washed ashore on 9 February 2017. Researcher Alison Towner and a team from the Dyer Island Conservation Trust (DICT) found nothing conclusive. The animal was completely intact, with just a couple of scratches around its head, and there were no obvious signs of what might have killed it. Even more extraordinary was the fact that every other shark in the area left the bay and did not return for more than three weeks. South African officials refused to grant permission for a more in-depth necropsy and for the next three months the death of the small female and the departure of the others from their kingdom remained a mystery.

Then, at 8 am on 3 May 2017, Towner and the DICT team responded to a call about a large white shark that had washed up dead during high tide. When they reached the shore they were saddened by the sight of a massive female shark that had visited their research boat on multiple occasions and been named 'Khaleesi', after the Game of Thrones character. She was almost five metres (16 feet) long and weighed more than a ton – a very dominant female shark. Shark scientists travelled from around the country and the next day the shark was autopsied in front of the public. As external measurements were being taken, nothing seemed out of the ordinary with Khaleesi, but when they rolled her mammoth body onto its back, a huge gaping wound was revealed. They opened her stomach cavity and waited for her liver to slide out – but the liver wasn't there.

No sooner had Towner arrived home that evening after the nine-hour necropsy when she received another call. She and her team rushed down to a different part of the coast, where they found the remains of a smaller, male white shark that had been documented at a cage-diving boat just four days earlier. 'His torso was completely twisted. The head was there and the lower end of the abdomen towards the tail, but then there were huge gaping chunks out of both sides of his flanks. His liver, testes and heart were missing,' explains Towner. Apart from the missing organs, the mutilated shark showed another clue: his pectoral fins were covered in rake marks and tooth impressions that looked very much as if they had been made by an orca. By 25 June, five white sharks had washed up dead and in all of them, apart from the animal discovered in February, the livers were missing.

These were not the first sharks with missing livers to be found by South African biologists. About 100 kilometres down the coast, in the south-western corner of False Bay, lies Castle Rock Reserve, a tiny kingdom that is ruled not by great whites, but rather by some of the most prehistoric fish in the sea: sevengill cowsharks. These animals grow up to three metres (10 feet) long and aggregate in large groups; up to 70 animals have been observed at this particular spot. Since 2014, local scuba divers have been sending in reports of dead sevengills that have come to the attention of Dr Alison Kock, a marine biologist now with South African National Parks who has been researching sharks in False Bay for almost a decade. She could tell very little from most of the images and videos received, as most of the carcasses were severely decayed,

but one photograph showed a shark lying on the bottom with just a single injury between its pectoral fins. 'It looked as if someone had sliced it open, and so clinically it seemed to have been done by human hands. Everybody assumed a fisherman had done it,' recalls Kock.

Castle Rock is a protected area and Kock and her team were concerned about the possibility of humans killing sharks, so on 13 April 2016 they went to investigate. When they found the carcass it was very decomposed. On examination, they realised that both of the shark's pectoral fins showed tooth impressions and its liver was missing. All its other organs were intact. Over the next few weeks more sevengills were discovered and all had lost their livers. The other sharks fled and Kock concluded that they were being predated on by orcas. 'It looks like at least two orcas had to have worked together. We saw the bite marks on the pectoral fins and then the shark was torn open to the pectoral girdle. Based on that examination, it seems the orcas are biting on the pectorals, ripping the shark apart and then taking its liver out,' she explains.

The necropsy was not the only clue that pointed to killer whales. About four months earlier, Kock and her team had been diving at Castle Rock to collect some data from a receiver. As they returned to the boat, someone shouted 'Whale!' Bryde's and southern right whales are common in the bay, but this was a different kind – and there were two of them. 'We had two killer whales that must have been swimming around us in the kelp forest without us knowing. They were right on the boat and they both had floppy dorsal fins,' exclaims Kock.

Orcas have always been seen off the coast of southern Africa, but prior to 2009 they had never been recorded inside False Bay. Dave Hurwitz is an avid naturalist based in Simon's Town. For the past 20 years he has run a whale-watching company from the local marina and he was one of the first people to see orcas here. 'It was almost surreal,' he says. 'I had read a lot about them and seen some of the reports about them off our coast. The first time I saw them was only briefly and that was right inside the harbour here. We were coming along and suddenly there were two killer whales right in front of the boat. I thought I was dreaming. They swam up and around the boat a couple of times and then went off. I had goose bumps for the rest of the day. That was the first time I registered that there is a possibility of seeing killer whales in the bay here.' Since then Hurwitz has collected records of more than 160 sightings in and around False Bay and witnessed incredible scenes of killer whales hunting large pods of dolphins that swim in during summer. But scientists know that orcas are fussy eaters and mammal hunters are highly unlikely to attack sharks.

Then, in 2015, Hurwitz saw two floppy-finned orcas swimming alone half a mile from Seal Island, the fabled home of breaching white sharks. 'I named them "Port" and "Starboard". The fin of one of them flops over to the left and the fin of the other to the right, so I named them so that it would be easy to re-identify them,' he explains.

Two years later, Port and Starboard have become the prime suspects in the case of the 'eliverated' sharks. Recorded sightings of the pair correlate exactly with the discovery of the shark carcasses at Gansbaai, starting with the small female that washed up in February. Researchers suspect she beached herself while being chased by the orcas. Because of their distinctive fins, Port and Starboard are easy to recognise and have been seen at numerous points along the southern tip of Africa, from Walvis Bay in Namibia to Langebaan on South Africa's West Coast and to Gansbaai in the east – a total distance of more than 1,400 kilometres (870 miles).

Although the recovery of shark carcasses without livers is a world first, incidents of orcas predating on sharks have been reported in California, Australia, New Zealand and Canada, and for some time experts have suspected that South Africa could also be home to shark-eating orcas. Dr John Ford has been studying orca populations in British Columbia since the late 1970s. Several years ago he was asked to review a paper by Dr Peter Best, South Africa's top cetacean researcher at the time. 'The report mentioned one or two stranded animals that showed profound wear of their teeth. In the manuscript he commented that this must be a sign of old age,' Ford remembers. 'I wrote back immediately and said, "Don't jump to that conclusion because we have a whole population on the West Coast of Canada (from California to Alaska) that have profound tooth wear of the same kind and for many years we hypothesised that it was due to something they were eating,"' he continues.

After almost four decades of research, British Columbian researchers have uncovered a vast body of knowledge about Canada's resident and transient killer whales, but it was only in the late 1980s that they first observed a group of orcas that they called 'offshores'. 'They often travel in really big groups of 100 or more, but sometimes they also occur as a pair and sometimes they are on their own. We didn't even know this population existed for the first 20 years of our field work on this coast,' explains Ford.

Port and Starboard chase down a great white shark. The orcas were named for the direction in which their fins flop: Port to the left, Starboard to the right.

Artwork by Marc Dando

Apart from a subtle difference in fin shape and being slightly smaller, offshores appear to be identical to other types of orca. In the orca kingdom, it is culture rather than morphology that separates. The killer whales are divided into three groups, or 'ecotypes', and although their ranges can overlap, they are very xenophobic. Resident killer whales, which we know the most about, are highly vocal, tend to live in stable matrilineal family groups in inshore waters and feed on salmon. Mammal-eating transient killer whales are silent and have a more dynamic social structure. The offshores are also highly vocal, presumably because they target a prey that is not sensitive to sound. Ultimately, it was not the whales' voices that alerted Ford to their dietary choice, but their teeth. 'Both the transients and the residents have perfectly healthy teeth, but pretty much all the offshores have teeth that have worn flat to the gums,' he says. 'We reasoned that it was because of the abrasive qualities of the sharks' dermal denticles. Offshores don't have very useful teeth for piercing, but their flat teeth would still be fine for grasping, especially onto an animal with a very rough skin.'

Ford and his colleagues speculated about this for 20 years and then, once in 2008 and again in 2009, they witnessed events that confirmed their suspicions. They were running surveys in very deep water (200–350 metres, or 650–1,150 feet) when they came across a titanic deep-water battle between two great predators. The first incident involved five offshore orcas, the second a group of about 100. The animals were diving in unison for up to 10 minutes at a time. The researchers could see from their behaviour that they were feeding, but they had no way of telling what was going on at that incredible depth. Then, as the orcas surfaced, large pieces of soft, oily tissue floated to the surface with them. The researchers watched as the animals picked up the chunks and shared them with one another just beneath the surface – a cultural practice that helps to maintain harmony within orca pods. Ford and his team collected some of the floating tissue and tests later revealed that it was the liver of Pacific sleeper sharks and that orcas had killed at least 11 sharks during the first event and seven during the second.

Sleeper sharks can grow to more than four metres (13 feet) long and are found at depths of up to 2,000 metres (6,560 feet). Their flesh is toxic, but this does not appear to be the case with their livers and somehow the orcas know that. 'Of course, shark livers are wonderfully rich and killer whales love lipids. They are really driven by high lipid content – lots of oil or fat – and that is why they selectively remove the tongue and the skin as well as the blubber of large whales that they kill because these parts have the highest energetic punch. Some sharks can be up to 30% liver and of that liver, up to 80% can be lipids,' explains Ford. So far, the research suggests that more than 93% of the offshores' diet is shark and includes blue sharks, sleeper sharks and spiny dogfishes. Ford has also discovered that wear on the teeth starts very early in the animals' lives, but does not appear to affect their general lifespan.

But why would the top predators in the ocean be so picky about their prey and does it serve them to have such limited diets? 'I think it's basically because by being specialists, they can actually out-compete generalists. If they get really good at a particular foraging tactic, and there is sufficient prey abundance over time, they can become sort of culturally specialised on that particular food resource,' explains Ford. 'It's not necessarily a good thing, because as we have seen over the past few decades, when Chinook salmon abundance fails, the mortality rate in resident orca populations shoots right up and the numbers decline. Once they attain these cultural blinkers that have them focusing on a particular prey, they don't seem to be able to switch quickly to an alternative.'

This might provide a clue as to what is happening in South Africa. In all likelihood, the shark-eating orcas have always existed in offshore waters and Port and Starboard are probably part of a larger pod that we have not seen yet. But what has motivated them to start hunting great whites? Ford can only speculate, but it appears that the floppy-finned animals are colonising new territory. They may have discovered the abundant source of shark liver by chance, but given the general decline in pelagic shark numbers, this new behaviour could also be driven by a need for new resources.

After the grisly spate of killings, the great whites were not seen again in Gansbaai for almost three months, despite the tantalising smell of a deceased sperm whale. In the meantime, shark researchers further east reported record numbers of sightings. Alison Kock is not surprised that the sharks fled after the death of their kin, but what fascinates her is why they were gone for so long. 'I think there are a lot of really interesting theories, but you can imagine that when two orcas start predating on such a small aggregation, all the other sharks will hear and see the commotion, which could cause an immediate flight response. And if dead sharks are sinking to the bottom and being left there to decompose, the chemicals released by the decaying shark could also create a deterrent,' she speculates. The animals have since trickled back and cage-diving operations have resumed, but it is impossible to predict how long peace will reign in the sharkdom of Gansbaai – or when the orcas might return. As Dave Hurwitz says, 'They don't follow a set path like other whales or cetaceans. They are such good predators because they are so unpredictable.'

The question is, given that white sharks are already vulnerable, what will this mean for the sharkdoms of the Cape? And will there be consequences for the local ecosystem? 'Top predators are vital in that they shape the entire ecosystem from the top down. If you have an imbalance at the top, then the next trophic level is going to become too numerous,' says Alison Towner. 'We already have too many Cape fur seals on Geyser Rock. That affects us at Dyer Island because they start to predate on our penguins and the penguin colony is incredibly threatened. In fact, the species itself is under major threat. It cascades right down to the bottom. So we don't really know what the effect will be, but we have to assume that there will be one of some sort or another,' she continues.

A new study funded by the Save Our Seas Foundation will use sophisticated population models to combine data collected from all of South Africa's white shark aggregation sites over the past two decades (including previously unpublished data) to assess how trends have shifted during that time. Currently, we do not have an accurate number for South Africa's white shark population. Between 2007 and 2013, Towner observed about 1,000 individual sharks at Gansbaai and over a similar time period, Kock estimated that there were just over 700 in False Bay. Her sightings data show a steady decline in great white sightings from 2005 to now. While Port and Starboard are almost certainly responsible for the sudden disappearance of sharks at Gansbaai, the reason behind the overall decline in great whites is harder to pinpoint and for Kock that is the greater mystery. 'We work in a dynamic environment. Sometimes it might be orcas. Sometimes it might be extreme water temperatures. These animals are adapted to move to where conditions are favourable. They can leave an area and move somewhere that is better for a short while and then they might come back. It's really hard to say what is going to happen because these interactions are so complex. We just don't know enough and that is the bottom line,' she concludes.

A few months later I am swimming through a cave in the kelp forest when I hear what sounds like a conversation between two underwater sirens. I fly up to the surface to breathe and the sound disappears. I descend again and hover in the cave. The submarine chamber seems to amplify the noise. I hold my breath, suspended in awe. There are many whale species in False Bay and I don't know enough about them to identify their voices, but I try to feel out into the ocean around me and picture what the sound is coming from. My mind stretches across the bay to Seal Island and I think of the sharks and wonder what they are picking up on and whether it fills them with fear.

Killer whales coordinate an attack, aiming at the underbelly of a great white shark.

Artwork by Marc Dando

A bottlenose dolphin motors away from a hunting orca that is bearing down on it. The wide variety of prey taken by orcas has long fascinated biologists, who have identified groups that specialise in marine mammals or in fish.

Photo by François Gohier | Biosphoto

A killer whale grasps a big-eye thresher shark off Hawaii. The shark is itself an efficient hunter, using its whip-like tail to stun prey, but has now been recorded as one of several shark species that fall prey to orcas. The first reported incidents of killer whales feeding on thresher and smooth hammerhead sharks came from New Zealand.

Photo by Deron Verbeck | I Am Aquatic

Photo by Marine Dynamics | Dyer Island Conservation Trust

Alison Towner from the Dyer Island Conservation Trust and her colleagues prepare to move Khaleesi, a female white shark, from the beach to perform a necropsy.

Dr John Ford has noted that whereas resident and transient killer whales have healthy teeth, the teeth of offshore killer whales are worn down almost to the gums. This, he surmises, may be an indication that offshore orcas prey on sharks. The photographs show the teeth of a female resident orca (top); a male transient (centre) and a female offshore (bottom). All the orcas pictured are adults.

Mel, a male killer whale, launches himself onto the beach at Punta Norte in Argentina. Southern sea lions give birth here in January and February and it has been reported that killer whales deliberately strand themselves to take advantage of the hapless pups on the pebble beaches.

Photo by Paul Nicklen | National Geographic Creative

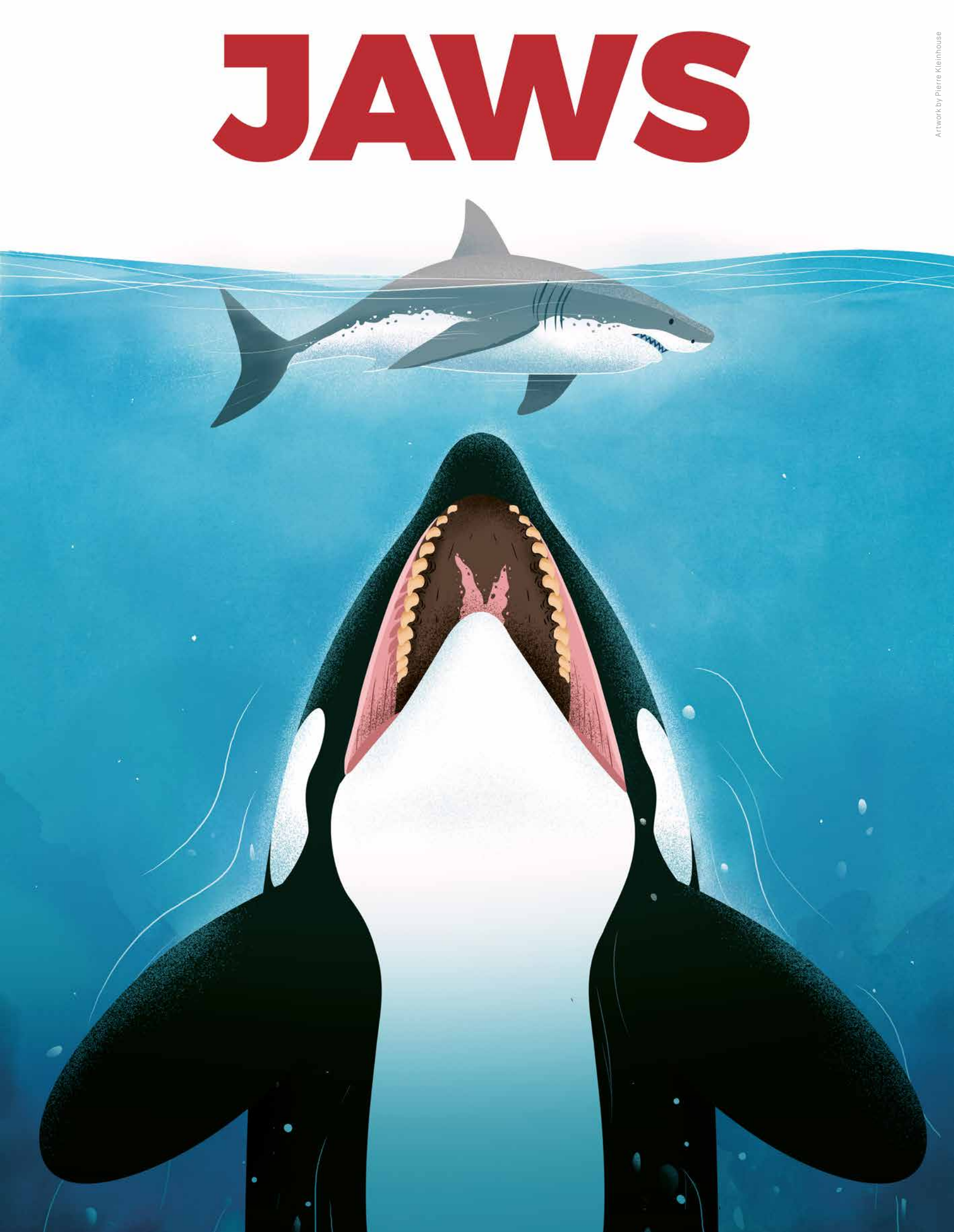
Efficient communication and sophisticated teamwork give orcas the edge as they corral herrings in Norway. Calls, whistles and echolocation clicks keep the group in close contact in this cooperative hunting behaviour known as carousel feeding.

In Patagonia, killer whales hunt by deliberately stranding on a beach or patrolling the shoreline. Adult sea lions watch from the safety of the sand as the orcas search for pups that, more naive, have entered the water.

When a group of about 17 orcas was seen attacking a grey whale and her calf in Monterey Bay on 2 May 1992, the event nearly doubled the previous known range for these killer whales. Previous attacks on grey whales by orcas had been recorded in Glacier Bay, Alaska.

In a life-and-death ballet, a killer whale and a bottlenose dolphin mirror one another in an athletic showdown in the Gulf of California. The orca emerged the victor, swimming away with the dolphin clamped in its jaws.

1 Photo by D. Parer and E. Parer-Cook | Minden Pictures | Biosphoto
All other photos by François Gohier | Biosphoto


JAWS
Artwork by Pierre Kleinhouse

ORCINUS ORCA E

SOUTHERN HEMISPHERE

1

Antarctic Killer Whale (type A)

A large (perhaps to 9.5 m/31 ft) black and white form; it migrates to Antarctica during the austral (southern) summer where it forages in open (ice-free) waters and feeds mainly on minke whales and occasionally elephant seals. During the winter, it probably migrates to lower latitudes, perhaps to the tropics.

2

Pack Ice Killer Whale (large type B)

A large, two-toned grey and white form with a dark cape pattern and very large eye patch. Often has yellowish cast due to diatoms. Circumpolar, it forages mainly in loose pack ice where it preys on ice seals (prefers Weddell seals), which groups wave-wash off ice floes by creating waves with their tails. Occasionally takes minke whales.

3

Gerlache Killer Whale (small type B)

A medium-sized, two-toned grey and white form with a dark cape pattern and large white eye patch. Often appears yellowish due to diatom infestation. Common around Antarctic Peninsula, especially in the Gerlache Strait. Preferred prey unknown, but has been seen feeding on penguins on numerous occasions.

4

Ross Sea Killer Whale (type C)

The smallest killer whale known – adult males reach only 6 m (20 ft). A two-toned grey and white form with a dark grey cape; often coloured yellowish by diatom film. Eye patch is distinctively narrow and slanted. Occurs deep in the pack ice in eastern Antarctica and feeds on fish; especially common in the Ross Sea.

5

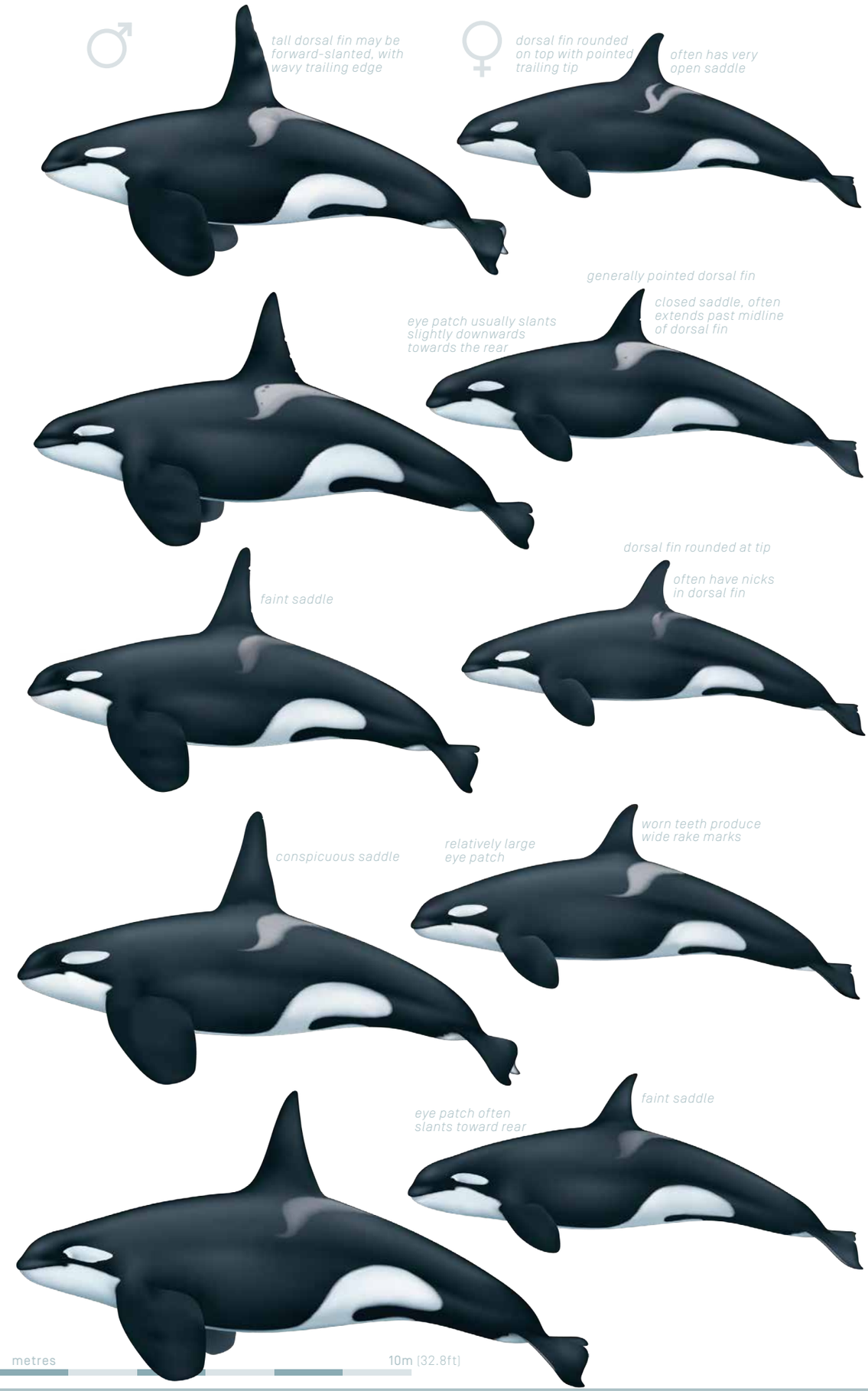
Subantarctic Killer Whale (type D)

Recently described form, known from perhaps a dozen sightings. Easily recognised by its tiny eye patch (all ages); head is rounded, dorsal fin often swept back and pointed. Distribution circumglobal in subantarctic waters (north of 60°S); sometimes associated with islands. Preferred prey unknown, but reportedly steals fish off long-lines.

The killer whale, or orca, *Orcinus orca,* occurs in all the world's oceans, where it is the top marine predator and perhaps the most widespread vertebrate on earth. Although currently considered to be a single, worldwide species, recent research has revealed that there are at least 10 recognisable forms (or ecotypes) of killer whales, which are shown here drawn to scale. For the most part, these forms have different prey preferences, distributions, social structures, foraging behaviours, acoustics, physical

COTYPES & FORMS

NORTHERN HEMISPHERE



6

Resident Killer Whale

The best-known killer whale. A medium-large (to 7.2 m/23.6 ft), black and white form that lives in coastal waters of the North Pacific. Saddle patch often has a large black intrusion ('open' saddle) not found in other killer whales. A fish specialist – some populations feed almost exclusively on salmon. Females may live to 80–90 years.

7

Bigg's Killer Whale (transient)

A large (perhaps 8 m/26 ft), black and white form – similar to resident killer whale except it lacks an open saddle. Occurs in coastal and offshore waters of the North Pacific. A mammal eater, it feeds mostly on harbour seals and minke whales but will also take sea lions, otters, calves of large whales, etc. Named after pioneer killer whale researcher Michael Bigg.

8

Offshore Killer Whale

A smaller form (to 6.7 m/22 ft) rarely observed because it occurs mainly over the outer continental shelf of the eastern North Pacific. Group size usually large (100–200); ranges widely: some groups travel between Alaska and southern California. Apparently feeds extensively on sharks and teeth are often worn to gum line due to rough skin of sharks.

9

Type 1 Eastern North Atlantic

A smaller (6.6 m/21.6 ft), black and white form, currently known only from the North Atlantic. Off Norway, feeds on herring and mackerel, which are cooperatively herded into dense schools; some individuals have also been seen to take seals. Teeth of this form are often worn smooth to the gum line, perhaps from feeding on sharks.

10

Type 2 Eastern North Atlantic

A large (8.5 m/28 ft), black and white form (only recently recognised), but with a distinctive back-sloping white eye patch. Few recorded observations; currently known only from the North Atlantic where it preys on other cetaceans, especially minke whales.

features and genetics. This has led some researchers to suggest that there is more than one species of killer whale, and perhaps several. Our research seeks to understand the taxonomy and role of these predators in marine ecosystems. Illustrations by Uko Gorter | www.ukogorter.com - Text by Robert L. Pitman | Southwest Fisheries Science Center | NOAA Fisheries Service,

Marine protect

Words by Doris Neubauer

Photo by Brendon O'Hagan | Bloomberg via Getty Images

ion Māori style

A surfer walks past cargo containers washed ashore from the stricken Rena, which ran aground off the island of Motiti, New Zealand, in October 2011. Four years later, the wreckage had still not been removed.

The indigenous population of a small island in New Zealand's Bay of Plenty is fighting the national government for the right to protect the sea around it. These Māori could change history – and be a model for other coastal communities around the world.

Motiti, a small island lying just 10 kilometres (six miles) off the coast of New Zealand's North Island, is usually a tranquil spot. Inhabited by only 40 people, it lies close to the Astrolabe Reef, where scuba-divers congregate to marvel at the abundance and diversity of reef fishes and other marine life. On 5 October 2011, though, the island made headlines for a different reason: the 236-metre (775-foot) container ship MV *Rena* had run aground on the reef. It was the most serious environmental disaster in the Pacific nation's history.

Oil and waste estimated at more than 230 tonnes contaminated the waters around the reef and another 350 tonnes of oil was scraped off the island's beaches. More than 2,000 seabirds fell victim to the spill. But, as so often happens, something positive emerged from the disaster. In order to avoid further damage to the reef, a fishing and diving ban was imposed within a radius of two nautical miles. Four years later, the fishes and other sea creatures were back and abundant once more. In the absence of harmful human impacts, the local marine life was again flourishing.

All's well that ends well? Far from it. Emboldened by the recovery, in April 2016 the Astrolabe Reef – including the wreck of the *Rena* – was reopened to divers. At the same time, the New Zealand authorities refused to ban fishing within three nautical miles of the reef for the next two years. Māori living on Motiti, including the Motiti Rohe Moana Trust (MRMT), protested fiercely but to no avail.

'Since then, every man and his dog have been fishing on those rocks,' complains Umuhuri Matehaere of the MRMT. 'The reef is now in the same state as it was before.' Refusing to remain silent, he and the others in the trust engaged in an expensive legal battle. 'We, the local communities, know our environment best,' they argued. 'We should be able to co-decide what should be protected and how.'

Taking responsibility for the environment is in the Māori DNA. These indigenous locals call themselves *tangata whenua*, or 'people of the land', consider themselves managers of the environment and do all they can to preserve their *mauri*, or 'life force', for future generations. 'While the Western approach is to take advantage of the "stock" of a particular species for the benefit of humans, for the Māori protecting the ocean means protecting our environment so that our cultural and spiritual relationship with the life force of the ocean can continue,' explains marine biologist Te Atarangi (T.A.) Sayers, whose family has been linked to Motiti Island for 15 generations. He continues, 'In contrast to the existing system, we ensure ecologically sustainable management.' For him, long-term usability instead of exploitation is the motto. And the Environment Court of Tauranga, Bay of Plenty, under whose jurisdiction Motiti falls, agreed.

On 5 December 2016, a new legal declaration set a precedent: within the regulations of the Resource Management Act, protection zones could be established at a regional level and fishing-related activities could be restricted, with the aim of protecting biodiversity and preserving both the ecological and the cultural value of the habitat.

Such a pronouncement flew in the face of regulations such as the Fisheries Act promulgated by the New Zealand government, and indeed the government appealed against the ruling. But during the austral summer of 2017 the legality of the Environment Court's decision was confirmed by the High Court. Justice Christian Whata ruled in principle that the Resource Management Act empowers regional councils to regulate fishing in order to preserve marine biodiversity, significant habitats and Māori relationships with the ocean and *taonga* (treasured) species.

With the support of New Zealand's largest conservation NGO, Forest & Bird, the Motiti Rohe Moana Trust prevailed and it was decided that regional councils throughout the country have the power to draw up policies, objectives and fishing regulations in order to prevent damage to the ecosystem and promote a non-commercial relationship with the sea. 'This decision confirms that the duties of regional authorities extend to coastal and marine areas,' explains Sayers. And it's a decision that has been welcomed throughout the country, but particularly in Marlborough, South Island, where demands for it have been expressed for some time; and in Omaha at the northern tip of North Island, where swimmers get caught up in abandoned fishing nets. The declaration opens the door for local communities like these, as well as for environmental advocacy groups such as Forest & Bird, to pursue conservation in New Zealand's territorial waters.

'It's good to have clarity that the Resources Management Act charges local councils with managing the effects of fishing on the environment,' continues Sayers. 'But councils cannot make the rules that impact on the sustainability of fishing resources – this comes under the Fisheries Act. Now we know where the line is drawn, and on what grounds.' The decision also clarifies that the Fisheries Act covers Māori interests in traditional fishing, whereas the Resources Management Act embraces wider cultural and spiritual connections with the sea.

Photo by Robert Harding Picture | National Geographic

For the Māori, protecting the environment, including the ocean, enables them to maintain a cultural and spiritual relationship with the life force of the world around them.

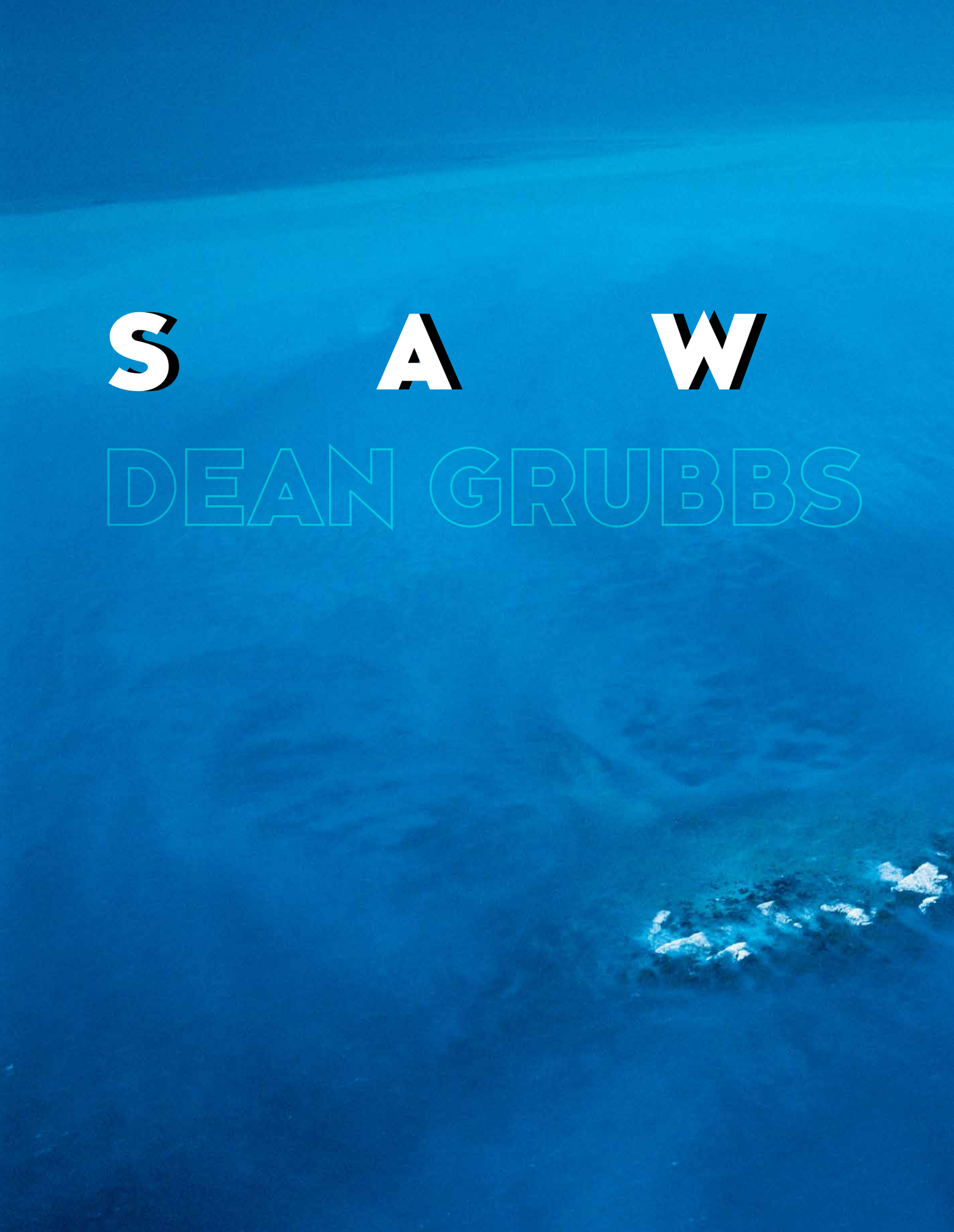
This important decision may have ramifications far beyond the Motiti model and even beyond the shores of New Zealand; it could encourage other nations to rethink their strategies with regard to local coastal populations that face similar challenges. And it's not the first time that New Zealand has set an example. In March 2017, in response to demands by the local Māori, the Whanganui River was given its own legal identity, becoming the first river in the world to be accorded such status. This means that anyone

harming it, directly or indirectly, can be prosecuted. The concept is already being emulated, with similar efforts taking place in Ecuador, Bolivia and India. Forward-thinking scientists such as Daniel Hikuroa of the University of Auckland would like to take it a step further, advocating that the sea be recognised as a legal person.

In the meantime, protective measures need to be put in place that cater for the cultural and community, as well as the environmental, value of the ocean. 'That is, the intrinsic, landscape, Māori, non-economic value,' elaborates Sayers. 'In each region, communities will have to consider cases on their individual merits. They need to realise the importance of the decisions they make and will have to pinpoint the values, connections and relationships that must be protected, restored and preserved.'

The Māori of Motiti have already done this. But whether they will be able to act as the stewards of their piece of ocean remains in doubt – an appeal against the High Court's decision has been lodged... Clearly, the little island of Motiti will continue to rewrite history.

To support coastal communities, marine biologist Te Atarangi Sayers has created the Nomad Ocean Project, a series of talks and workshops about community-led marine protection. He will conduct these events as he sails around New Zealand in the Kahu *between October 2017 and February 2018. The voyage will be documented by freelance journalist Doris Neubauer. Please join this journey and support the Nomad Ocean Project* (www.patreon.com/nomadocean)*; find out more at* www.NomadOcean.org


SAW
DEAN GRUBBS

F I S H

Photo by David Doubilet | National Geographic Creative

Research into the smalltooth sawfish in Florida and The Bahamas is gr
Perhaps the biggest question of all is whether marine national pa

Photo by Michael Scholl

Lifeboats for sawfishes?

adually revealing important information about this mysterious species.
arks can provide sanctuaries in which its population can recover.

Photo by Michael Scholl

Dean Grubbs hooks a smalltooth sawfish in the shallow waters
success: Charles Bethell expertly skippers while And

of Andros in The Bahamas. Teamwork is key to the researchers'
rea Kotze reaches to catch the sawfish with a dip net.

Wild tales have been concocted about sawfishes and their toothed ros

The sawfishes (family Pristidae) are a small but highly charismatic group of very large batoids, or rays. They are the only living batoids that possess a toothed rostrum, which they use for defence and to catch prey – imagine a shark-like ray up to five metres (16 feet) long that has a giant hedge trimmer at the end of its snout! Worldwide, there are five living species of sawfishes[1] and although they all reach a length of at least three metres (10 feet), these unusual creatures often go unnoticed, spending much of their lives lying on the bottom in the murky coastal and estuarine waters of the tropics. For decades, sawfishes didn't receive the attention they deserved from scientists – or the conservation community either. That has changed over the past 15 years or so, as it became apparent that populations around the globe had collapsed.

Impressive predators

In view of their imposing size, it is not surprising that, as adults, sawfishes are among the top predators in the ecosystems they inhabit. As we go about our research, it isn't unusual to find the scales of large bony fishes impaled on the ends of their needle-sharp rostral teeth. And on multiple occasions we have caught an adult sawfish on our line that was not even hooked, but had swallowed a whole metre-long (three-foot) shark that had been caught on the line first! In attempting to remove the hook, I have been able to reach into the sawfish's mouth and pull out the shark, hook and all, by the tail, removing it completely from the sawfish.

A study recently published by our research team has demonstrated that in Florida juvenile to adult smalltooth sawfishes occupy essentially the same position in the food web as bull sharks of the same life stage[2]. Like many species of sharks, sawfishes have been the subject of myths, fear and misunderstanding. This is summed up in an article by Erwin Bauer titled 'Mystery Monster' that appeared in a 1959 issue of the US outdoor magazine *Field & Stream*. Bauer wrote, 'Like an axe murderer, he's been in the headlines… There have been assertions that sawfish stalk bathers… and cut them in two. According to old whaling journals, the saws hunted whales in packs and sliced them up like so much salami. There are even accounts of sawfish attacking men in dories after reducing the boats to driftwood.'

Of course, none of this is true. While I can attest that sawfishes are incredibly defensive when captured, and a large one can certainly inflict serious injury, there are no records of sawfishes attacking bathers, whales or men in boats!

Conservation concern

The *Field & Stream* article went on to state that 'Marine researchers are finding [sawfish] wholesale almost everywhere. It's hard to predict where [they] will poke their lethal noses next.' Oh, how we wish that were true today!

Sawfishes occur in tropical coastal waters where their large toothed rostrum renders them highly susceptible to entanglement in all types of fishing gear. Targeted commercial fishing in some regions, sport fishing, the collection of rostra for the curio trade and personal memorabilia, and by-catch in net and long-line fisheries have all led to declines

Photo by Matthew Pottenski

tra, but only recently have scientists started deciphering sawfish lives.

in sawfish populations the world over. Like most large sharks, sawfishes have conservative life histories that limit how quickly they can recover if threats should abate. By 1996, four of the seven species of sawfish recognised at the time were designated as Critically Endangered or Endangered by the International Union for the Conservation of Nature (IUCN). All five of the currently recognised species[3] are now listed as Critically Endangered or Endangered, distinguishing the Pristidae as the most imperilled family of elasmobranch species, if not the most endangered of all marine fishes[4,5].

The smalltooth sawfish *Pristis pectinata* is endemic to the Atlantic Ocean and is the only sawfish species native to the USA and the islands of the Greater Caribbean Basin. In the United States, its range contracted during the second half of the 20th century and its population was estimated to have been reduced by perhaps as much as 95%. The primary stronghold for the smalltooth sawfish in the western Atlantic is, and always has been, south-western Florida. Population declines in this region became apparent in the early 1990s, resulting primarily from the capture of the sawfishes in gill-net and trawl fisheries. This led to legislation listing the smalltooth sawfish as a protected species in Florida's waters in 1992, and in 2003 it became the first native marine fish to be registered as Endangered under the US Endangered Species Act. In addition, all sawfish species are now listed on Appendix I of the Convention on International Trade of Endangered Species (CITES), which prohibits international commercial trade.

Research in Florida and The Bahamas

Since 2010, my colleagues, graduate students and I have been conducting research aimed at promoting the recovery of the smalltooth sawfish in the USA and assessing its status in The Bahamas. It's a species that typifies the challenges of assessing population status, not to mention recovery, in widely distributed marine fishes. Its baseline population sizes are unknown and long-term relative abundance surveys do not exist, so we are unable to track declines. However, significant range contraction and regional extirpations suggest that drastic population declines occurred throughout this sawfish's range during the second half of the 20th century. In the western North Atlantic, a large majority of the recent confirmed smalltooth sawfish records are from the USA, where the current range is restricted primarily to south-western Florida. At the time we began our work in 2010, research into juvenile sawfishes had been ongoing in Florida for a decade. It was hypothesised then that Florida could be the only region remaining with a reproducing population.

The Bahamas is the only other country with relatively frequent records of smalltooth sawfish and the research we have conducted since 2010 suggests that a viable population also exists here, mainly on the western side of the island of Andros[6,7]. Lying in one of the most remote and unspoiled parts of the Greater Caribbean Basin, Andros harbours as much mangrove habitat as Everglades National Park in Florida. Working here is logistically challenging, which is precisely why the

The smalltooth sawfish is found only in the Atlantic Ocean and is th
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e only sawfish species native to the USA and islands of the Greater
n Basin.

Photo by Matthew Pottenski

island's ecosystems remain intact. In 2015, we assembled data from a variety of sources, including biologists, fishing guides and divers, throughout The Bahamas in order to assess the probable distribution of the smalltooth sawfish among the more than 700 islands and cays that make up the archipelago. Not surprisingly, a large majority of the records were from the island of Andros. Bimini was the second most popular location, and together these islands on the Great Bahama Bank accounted for more than 80% of The Bahamas' records of smalltooth sawfishes between 2002 and 2015[7].

Juvenile sawfishes and their nursery habitat

Nearly all of the initial sawfish research in Florida has been on juveniles. Although a sawfish giving birth had never been observed, the areas of parturition in Florida are well documented by the occurrence of cohorts of newborn sawfishes from Florida Bay to Charlotte Harbor on the south-western coast. Our group and colleagues have conducted a lot of research on the patterns of habitat use by juvenile sawfishes in these nurseries and much of it suggests that they have a strong affinity for the shallow water along red mangrove shorelines and islands in bays, rivers and backcountry creeks for at least the first year of life[8,9]. Critical habitat for the species, designated in Florida in accordance with the US Endangered Species Act, is based on these patterns of juvenile habitat use[10].

In the Everglades, we often observe that small juvenile smalltooth sawfishes associate with very specific mangrove islands, ignoring others. They are generally found only among red mangroves, probably because the dense pneumatophores of black mangroves deter them. The density of red mangrove prop roots and the water depth appear to be critical factors influencing which red mangrove islands are inhabited. Small sawfishes are vulnerable to predation not only by bull and lemon sharks, but potentially also by American alligators and American crocodiles in this region. Prop roots need to be spaced so that the juvenile sawfishes can move between them for cover at high tide, but dense enough to exclude predators. When the tide falls and the sawfishes are forced from the mangroves, the adjacent mud flats or channels must be deep enough that they don't dry out, but shallow enough to exclude larger sharks.

Active tracking in the remote Everglades backcountry by graduate student Lisa Hollensead showed that these young-of-the-year sawfishes have incredibly small daily activity spaces (0.07–0.17 square kilometres; 0.027–0.06 square miles) that aren't static, but move slightly from day to day[8]. Interestingly, we found that the space occupied by a juvenile sawfish is larger during the day than during the night, but the rate of movement is higher during the night than by day. We hypothesise that the higher rates of movement in a more confined area at night may be related to hunting and feeding. High prey densities in these nurseries enable smalltooth sawfishes to grow incredibly fast as juveniles, more than doubling in length from 0.7 metres (2 feet 3 inches) to 1.5 metres (4 feet 11 inches) in the first year and reaching more than two metres (6 feet 7 inches) by two years of age. Rapid growth leads to lower predation risk, thus allowing juvenile sawfishes to begin exploring other habitats such as deeper rivers, creeks and bays[9].

When we began our work in The Bahamas, there were no known parturition sites or nurseries for smalltooth sawfishes outside Florida. We could find no records of small juveniles anywhere in the region, leading to speculation that perhaps sawfishes in The Bahamas were born in Florida. During our initial trips to Andros, we developed a strong relationship with the Flamingo Cay Lodge, the only establishment on west Andros, and its fishing guides. The guides reported seeing small juvenile sawfishes and with them we observed sawfishes that were probably young-of-the-year, assuming that Bahamian sawfishes grow at the same rates as their Florida counterparts. This assumption may not be valid, however, in view of research having shown that lemon sharks in The Bahamas grow much more slowly than those in Florida. Nevertheless, the occurrence of such small sawfishes suggested to us that Andros may be a pupping area.

We have made numerous expeditions to Andros since 2010, supported by multiple foundations and grants, with the Save Our Seas Foundation playing the dominant role. Although working in such a pristine place has been rewarding, the research was also frustrating. By the end of 2015 we had tagged nearly 50 adult sawfishes in Florida, yet over seven expeditions to Andros during the same period we had only managed to capture four sawfishes.

Finally in December 2016, during an SOSF-funded expedition based on the R/V *Garvin* operated by The Field School, we were rewarded with proof that sawfishes do indeed give birth in The Bahamas. We captured the largest sawfish we have caught to date in The Bahamas: a 4.29-metre (14-foot) female – and she was giving birth! This was the first time this has ever been observed in the wild and it provided the only evidence to date of pupping in the western Atlantic outside the USA.

The female delivered five pups, though more were still in the uteri when we released her. All the pups emerged rostrum first, with the rostral teeth covered in thick connective tissue.

At approximately 0.7 metres, these pups were the same length as the newborn sawfishes we frequently capture in Florida. All five of the newborns were tagged with microchips similar to those used on dogs and cats and we hope that future recaptures of them will provide data on juvenile growth that may be compared to data from Florida.

Are sawfishes in Florida and The Bahamas distinct populations?

A critical determinant of whether the smalltooth sawfish is likely to recover across its range is the amount of exchange (or degree of isolation) between population segments. The fact that the species has been extirpated from large parts of its range suggests that recovery throughout the range requires populations to be connected. If there is mixing of adult sawfishes from multiple population segments, then putting significant effort into promoting revival in the core population may lead to range-wide recovery. However, if populations are isolated, then serial depletion may put the species at greater risk of extinction unless recovery efforts are spread across all extant populations.

Pop-off archival satellite tagging is a valuable tool in determining whether adult and large juvenile sawfishes undertake seasonal migrations and if there is movement between the USA and The Bahamas. As part of a large research effort, we deployed more than 70 satellite tags on Florida sawfishes between 2002 and 2016, although data were collected from only about half of these. In addition, since 2010 we have successfully satellite tagged six large juvenile or adult sawfishes on Andros.

In Florida, our ongoing surveys and telemetry data show that adult male and female sawfishes use both the backcountry mangrove habitat and the deeper waters (40–70 metres; 130–230 feet) along the edge of the continental shelf. These deeper habitats are buffered from temperature regimes and appear to offer thermal refuge in winter and summer, as well as increased foraging opportunities for large sawfishes. Data from the only adult sawfish tagged in Andros to date suggest that Bahamian adult sawfishes may use similar habitats at the edge of the Great Bahama Bank. Importantly, these deeper shelf-edge habitats would be the start-off point for sawfishes that may cross between Florida and The Bahamas.

Analyses of the satellite telemetry data[11] suggest, however, that sawfishes tagged in Florida stayed in Florida and those tagged in The Bahamas stayed in The Bahamas. The sawfishes in both regions spent most of their time in waters shallower than 10 metres (33 feet). The deepest depth recorded by any tagged sawfish was 68 metres (223 feet) and they

rarely ventured into waters below 20 °C (68 °F; the coldest experienced was 18 °C, or 64.4 °F). Crossing from Florida to The Bahamas requires crossing depths of more than 800 metres (2,625 feet) in the Florida Straits, where the bottom temperatures are less than 6 °C (42.8 °F). Therefore, movements between Florida and The Bahamas would require about 80 kilometres (50 miles) of pelagic swimming by a batoid that spends its life on the bottom.

Over the past several years, large arrays of acoustic receivers have been deployed by collaborative groups of researchers all over the world. Hundreds of receivers are currently deployed along the US Atlantic and Gulf coasts and throughout The Bahamas. We have added receivers to arrays in the Florida Everglades and on the west side of Andros. In 2016, we began implanting long-term acoustic transmitters in sawfishes in both regions. Since these tags will remain active for 10 years, this technology promises to provide a wealth of information about sawfish movements and habitat use.

In a little over one year, we have received thousands of detections of our tagged sawfishes on more than 80 receivers in the USA. These preliminary data indicate that adult sawfishes in Florida move frequently between Florida Bay in Everglades National Park and the Florida Keys reef tract. Many tagged sawfishes appear to use the deeper shelf edge habitats in this region throughout the year, although in summer some adults migrated 500–900 kilometres (310–560 miles) north from the Florida Keys. Importantly, no sawfishes tagged in Florida have been detected in The Bahamas.

Similarly, data from our first year in The Bahamas suggest that sawfishes are probably resident year round in the mangrove backcountry and creeks of north-western Andros until they approach maturity. The only adult sawfish tagged to date at Andros was the pregnant female from December 2016. Interestingly, when our colleague Kevin Feldheim analysed her genetics, he discovered that he already had a sample from her in the database. She had been caught and sampled in Bimini in 2002, nearly 15 years before we captured her at Andros, and had grown from 2.6 metres (8 feet 6 inches) to 4.29 metres (14 feet), providing an important indication of growth rates.

Taken together, our data suggest that The Bahamas and the USA contain isolated populations of the Critically Endangered smalltooth sawfish. The large collaborative receiver arrays and long-term transmitters will enable us to determine this with more certainty in the next few years.

Adult sawfishes: movements, habitat use, fisheries interactions

One of the major goals of our work to investigate the habitat use and migration of adult sawfishes was to delineate the areas with highest potential interactions with different fisheries, particularly commercial fisheries where most mortality occurs. If these habitats are discrete and sawfishes aggregate to them predictably, time-area closures for specific fisheries could be effective measures to decrease mortality.

Our findings suggest that adult sawfishes do aggregate. We have captured nearly 60 adults in Florida on scientific long-line sets. Of the one-hour sets, 30% caught more than one sawfish, often on successive hooks. On two occasions, six sawfishes were caught together on the same set. One aggregation area is the northern part of Florida Bay in Everglades National Park. Adults occur in this region year round, but large numbers of adult males aggregate here from March until August[12]. Large sawfishes are frequently caught by recreational and charter fishers in this region, but mortality is believed to be low.

We also discovered that adult sawfishes aggregate in shelf-edge habitats 40–70 metres (130–230 feet) deep along the entire Florida Keys. Divers have reported similar aggregations along Florida's east coast at shallower depths (15–25 metres; 50–82 feet). In the USA, these shelf-edge habitats are where most sawfish by-catch mortality occurs in shrimp trawl and demersal long-line fisheries.

The sawfish aggregations comprise both males and females and, based on our surveys and telemetry data, they do not appear to be seasonal. In fact, we captured seven adult sawfishes (five females and two males) together in this region in January and six adults (four females and two males) together in July. Our satellite telemetry data suggest that use of these deeper habitats is ephemeral, as sawfishes move back and forth from shallower creeks and backcountry regions to the deep shelf edge. The function of these movements is unknown, but may be related to foraging and thermoregulation.

Reproduction

Much of the basic biology and ecology of sawfishes was a mystery when we began our research, and unfortunately much of it remains a mystery. There are still so many questions: at what age and size do sawfishes reach sexual maturity? Where does mating take place? Does mating occur in aggregations or in solitary pairs? How often do female sawfishes give birth? How many sawfish pups are born in each litter?

Over the past few years we have begun to answer some of these questions, though often our findings only spawn new questions. My colleague Jim Gelsleichter has been examining the cycling of sex steroid concentrations in the blood plasma of the large sawfishes we capture to determine at what size they reach maturity as well as when, where and how often mating and parturition take place. We couple this with ultrasonography of females to assess pregnancy. Males appear to reach sexual maturity at about 3.6 metres (11 feet 9 inches) total length and females at about 3.8 metres (12 feet 6 inches).

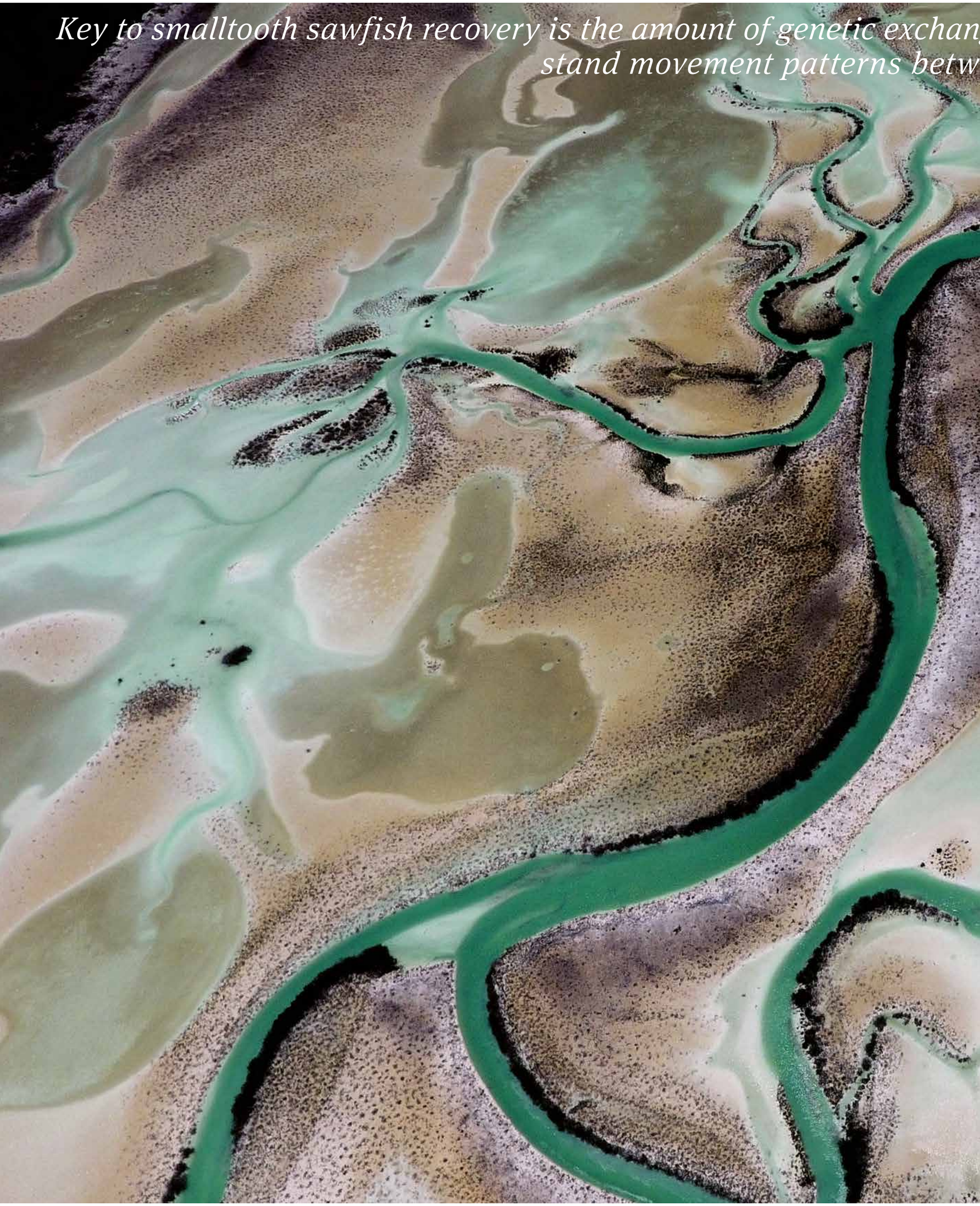
No one has observed sawfishes mating, but given the toothed weapon on the rostrum, we predict it is a raucous affair resulting in scars in the form of parallel scrapes and punctures. Such scars are not seen on the aggregated sawfishes we encounter in the deeper habitats and we confirmed that some of the females were already pregnant. However, we hit a string of sampling luck in April 2017 when, in two different regions, we captured adult males and females together with fresh mating scars on both sexes! These were in the far backcountry of Everglades National Park and in a creek in the lower Florida Keys National Marine Sanctuary, and hormone analyses confirmed that mating had probably been taking place.

Interestingly, the potential mating aggregation in the backcountry occurred in the same habitat where parturition is known to occur; in fact, newborns were caught there the day the adults were seen. This would be expected in a species where the females undergo vitellogenesis during pregnancy and are ready to mate following parturition. Many small coastal sharks with annual reproductive cycles as well as many deep-sea sharks do this. In most large elasmobranchs with multi-year reproductive cycles, vitellogenesis takes place during the resting year, so mating and parturition don't occur in the same habitat. Multiple lines of evidence indicate that sawfish gestation is one year and mating takes place every two years. The observation of apparent mating in the primary nursery habitat is therefore surprising and begs additional work.

National parks as 'lifeboats'?

Habitat loss from urban development, agriculture, dredging and the diversion of freshwater has exacerbated the declines in sawfish populations worldwide and in some cases may be the greatest hindrance to recovery. For smalltooth sawfish in The Bahamas and the USA, there are large tracts of primary habitat that are protected from development. Unfortunately, there are also large areas of sawfish habitat that are heavily altered by development in both countries.

In The Bahamas, the west side of Andros Island is one of the most remote and


Key to smalltooth sawfish recovery is the amount of genetic exchan
stand movement patterns betw

ge between populations. Satellite tagging helps researchers under-
een the USA and The Bahamas.

Photo by Michael Scholl

hey feed, or mate, or pup, informs effective protection policies.

Photo by Michael Scholl

unaltered tropical systems in the Atlantic Ocean. Recently proclaimed the Andros West Side National Park, it has the potential to protect these pristine habitats in a country where a tourism-based economy has traditionally led to gross overdevelopment and habitat degradation. Indeed, large sections of mangrove habitat on the island of Bimini, which once supported at least transient sawfishes, have been destroyed to build a large marina, casino and resort, and further development is planned.

In Florida, large tracts of sawfish habitat are protected in the remote and relatively pristine Everglades National Park and the Ten Thousand Islands National Wildlife Refuge, but Charlotte Harbor and the Caloosahatchee River, the other major sawfish nursery region, is heavily urbanised. Graduate student Bianca Prohaska has shown that juvenile sawfishes living in the heavily degraded nursery region in Florida may suffer from chronic physiological stress compared to those residing in the pristine habitat[13].

Nick Dulvy and his colleagues[5] have coined the term 'lifeboats' for regions such as Florida and northern Australia, where there is hope that sawfish populations may recover and their extinction be prevented. In the western Atlantic, the Everglades National Park in the USA and the Andros West Side National Park in The Bahamas potentially represent 6,070-square-kilometre (1.5 million-acre) and 5,260-square-kilometre (1.3 million-acre) 'lifeboats' respectively for smalltooth sawfish recovery. In Florida, due to the protection of sawfishes instituted in 1992 and a 1994 ban on entanglement (gill) nets that decreased by-catch mortality, several lines of evidence, including our survey data, suggest that the US population of sawfishes is slowly increasing. The status of the sawfish population in The Bahamas is unknown and currently sawfishes are not protected in that country. Fortunately, no targeted fishery or large-scale commercial fishery that would take sawfish as by-catch exists there.

One of the challenges to assessing recovery in an endangered species is developing recovery criteria that can be assessed and are biologically meaningful. Often, baseline densities and environmental carrying capacities are unknown. Such is the case with the smalltooth sawfish in Florida and The Bahamas. We don't know how many sawfishes were in the population when it was at carrying capacity before the decline began. Due to deterioration in available habitat, prey resources and the populations of predators and competitors, the current carrying capacity for sawfishes in these regions is probably very different from what it was a century ago, so recovery to pre-decline numbers or densities is unrealistic.

Evidence of a population increase

The smalltooth sawfish is one of five species of living sawfish,

like the one we are seeing in Florida is very encouraging. Should that increase halt, indicating that the population had reached a plateau, the challenge would be to distinguish a stop in recovery from a population reaching its new carrying capacity. The former would call for stronger conservation actions, whereas the latter would indicate the species could be downlisted to a less threatened category. Assessments of range expansion and spill-over, or increased abundance in areas outside the core, will help distinguish between these possibilities.

Everglades National Park and Andros West Side National Park have similar areas of available mangrove habitat for sawfishes, but the characteristics of the habitat – abiotic fluctuations, relative primary productivity and the available prey resources – are very different. These two important areas are likely to have different sawfish carrying capacities, which must be considered when assessing conservation success. There are probably other areas that may be important to the recovery and maintenance of genetic diversity in the western Atlantic smalltooth sawfish. We have received photographs of small sawfishes on the Little Bahama Bank, which suggests there may be a second Bahamas 'population' there. We also know there are contemporary records of sawfishes in Cuba. As movement between any of these four regions (Florida, Great Bahama Bank, Little Bahama Bank and Cuba) requires crossing water deeper than 600 metres (1,700 feet), exchange between them may be limited. However, whereas the distance between Florida and the Great Bahama Bank is 85 kilometres (53 miles), only 25 kilometres (15 miles) separate the Great Bahama Bank from Cuba. Perhaps in the future we will find these are additional 'lifeboats' to sawfish recovery.

Acknowledgements

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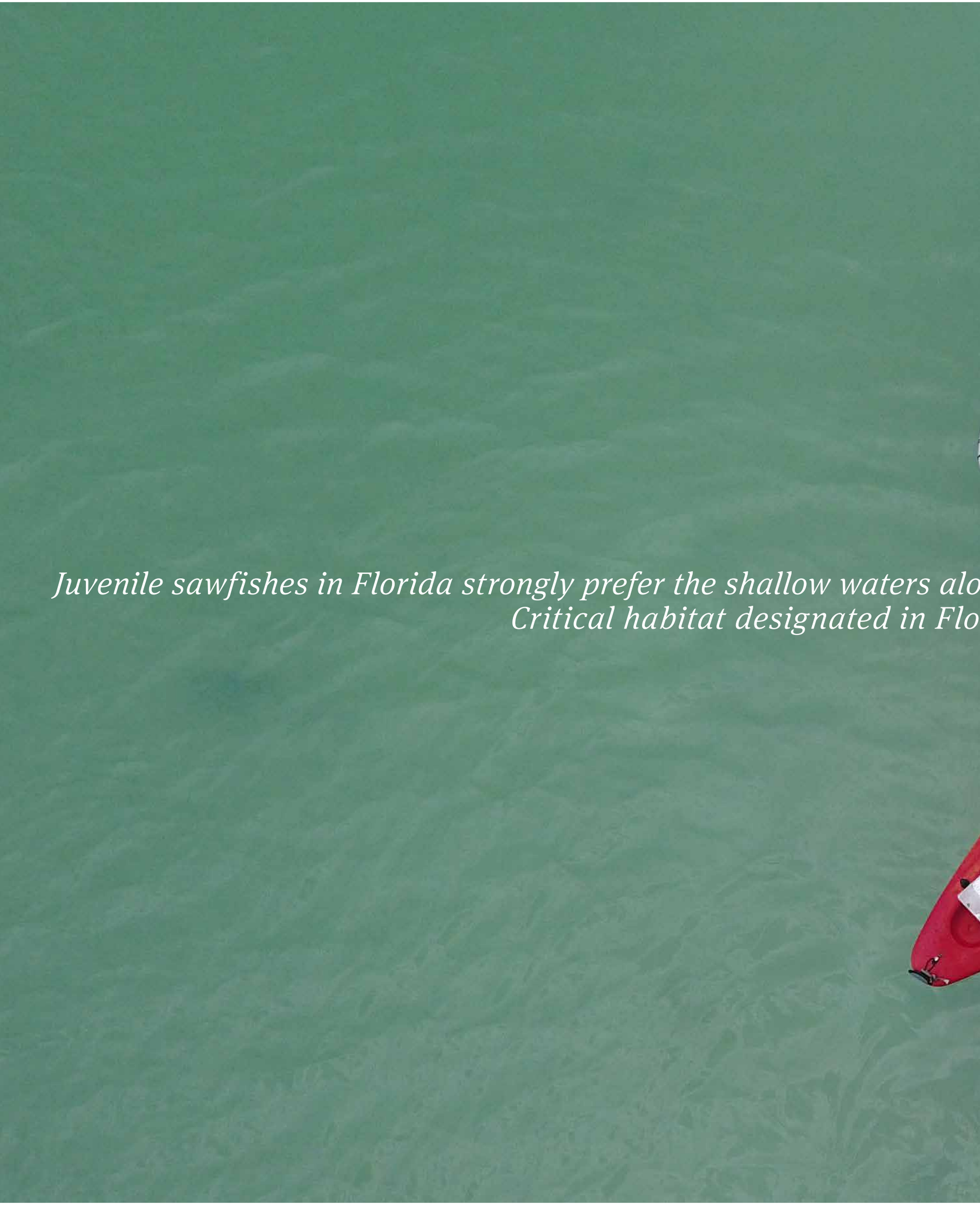
Photo by Matthew Pottenski

all of which can reach up to three metres (10 feet) in length.



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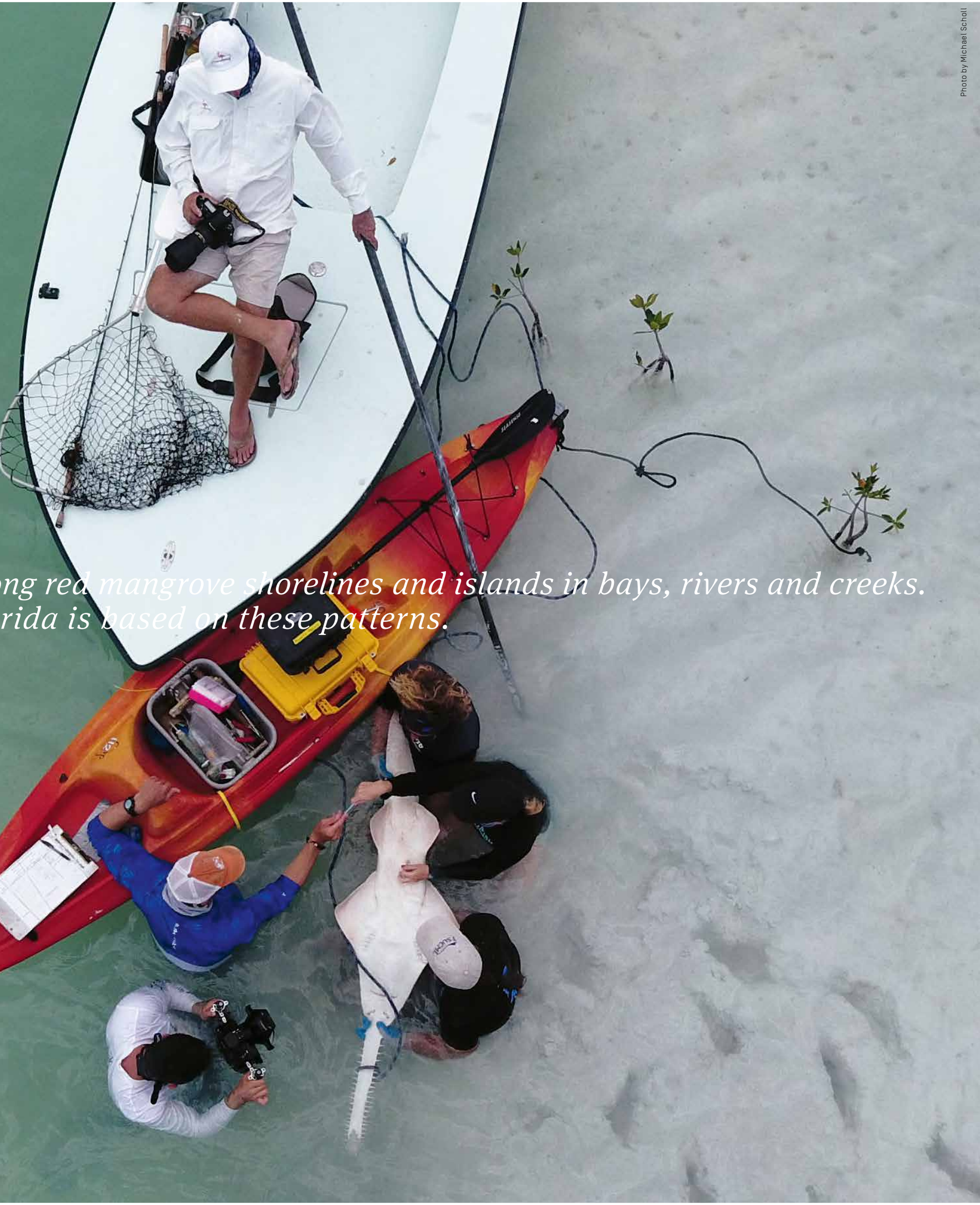

Photo by Michael Scholl

ng red mangrove shorelines and islands in bays, rivers and creeks.
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Concerted research efforts are perhaps the last chance for threaten
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Photo by Matthew Pottenski

ed smalltooth sawfishes: a better understanding of their lives and conservation strategies.

Photo by Matthew Pottenski

The Everglades National Park and the Andros West Side National P
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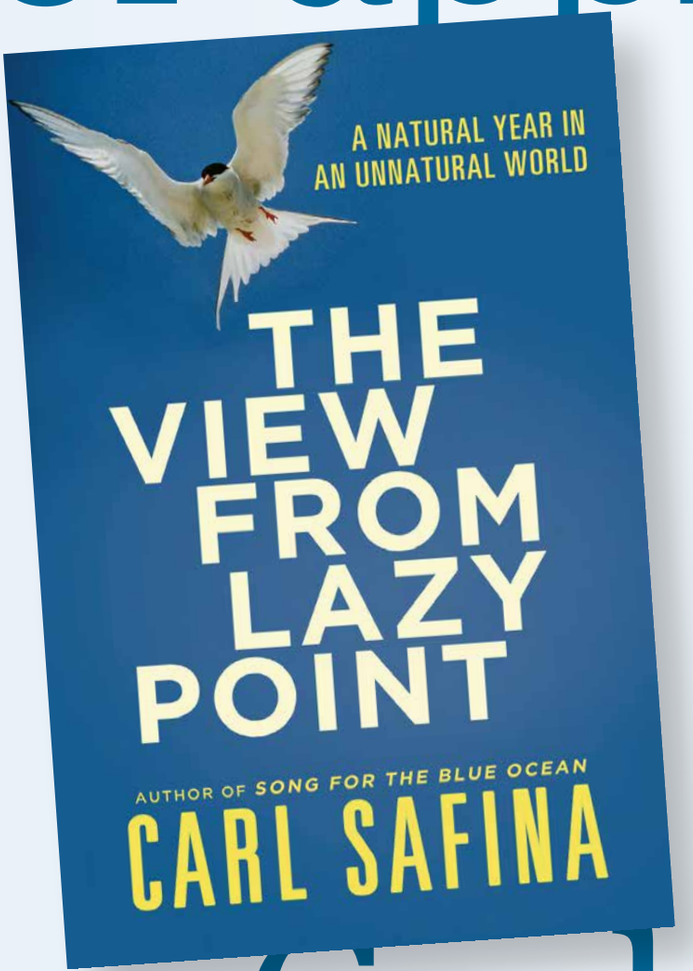
ark might be 'lifeboats' for smalltooth sawfish recovery, giving hope out their future.

Fishing for approval

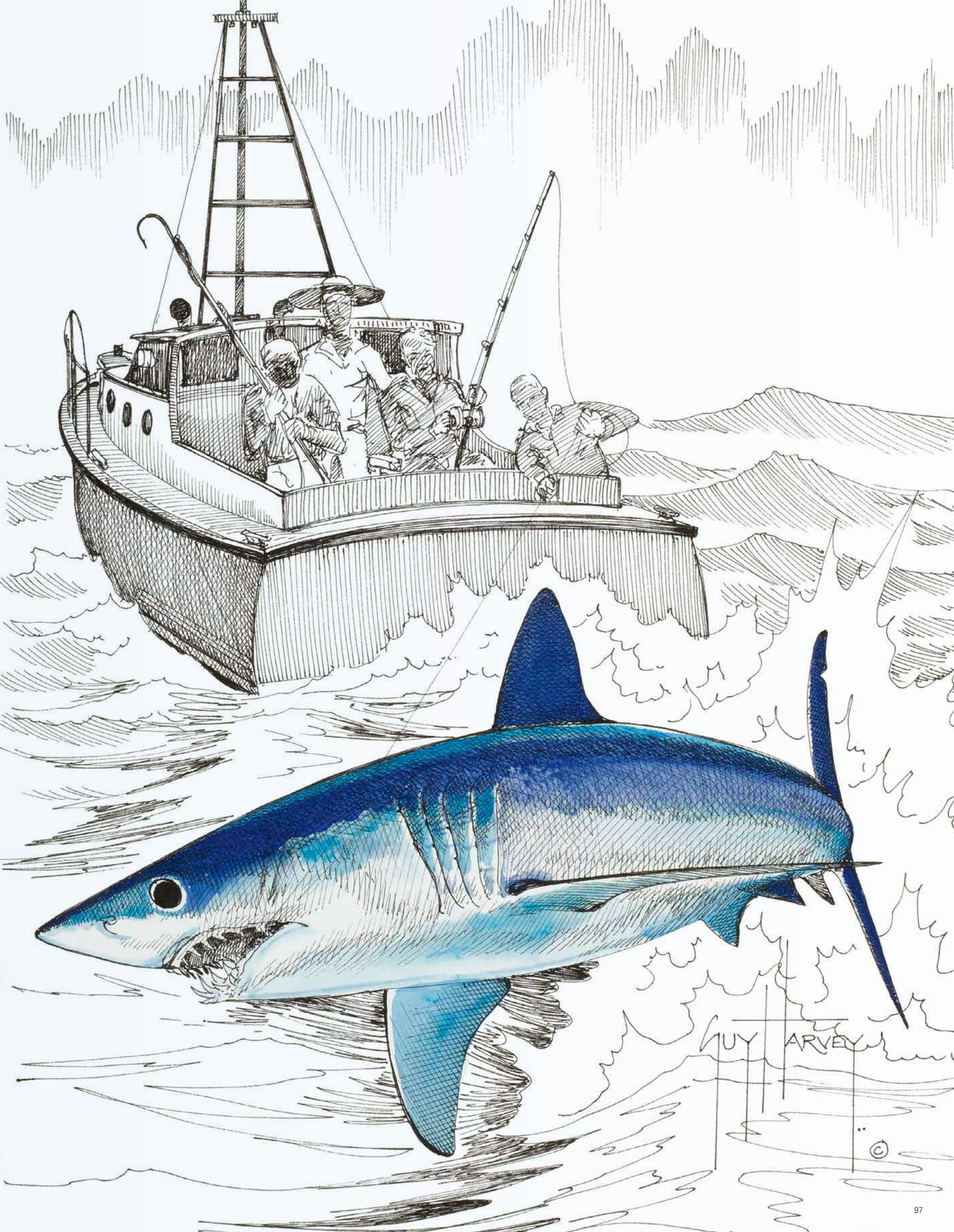


by Carl Safina

August used to mean a lot of time spent offshore. Who needed air conditioning when one had the whole Atlantic? I believed that during summer one wasted a day if one untied a boat and planned to be back to the dock in under 15 hours. And I did a lot of shark fishing.

In the mid 1990s, during a short spell of fine weather, I had the urge to go offshore but could locate no one who could join me on a weekday. I left the harbor in the dark and the sun rose to find *First Light* already on the ocean, running southeast. About twelve miles offshore I noticed a change in the water color. Its greenish tint changed suddenly to a clearer blue. The temperature jumped several degrees in half a mile. This was a pretty distinct edge. The terns I'd seen inshore were now replaced by several shearwaters. The floating weed was different here too; drifting rockweed and eelgrass from the bays was replaced by a yellowish weed called sargassum that originates far offshore. I had crossed into new water. This drifting oceanic border area was a reasonable place to look for sharks. I cut the engine and set up, putting a perforated bucket full of ground fish over the side and, hoping for a mako, I baited a hook with a whole mackerel, attached a float, and drifted it out about 150 feet, letting the float bob in the blue swells. Then for a few hours I worked pleasurably on edits to a manuscript, drifting and dreaming.

During late morning I heard a splash, saw a swirl, and watched the line come tight and the rod lunge downward. I got to my feet as the line began slipping under the tight drag and I struggled to snap my back-harness to the reel and follow the fish around the boat's stern.


GUY HARVEY
©

Virtually no one goes shark fishing alone. A shark fishing crew usually has 3 people: one for the rod, one to grab and hold the leader, and one to gaff or release the shark. I had a plan to be all three: If I worked a fish to the boat, I'd put the rod in a holder, grab the leader with one hand, and deal with the fish with the other hand.

This plan might work well with sharks like medium-sized summer Blue Sharks that always stay submerged, and roll slowly, if at all, at boatside. But it could be trickier if this was a mako. Makos can be fast, erratic, liable to high-jump unpredictably (hooked makos have jumped into boats), and prone to rapid spinning at boatside. A wildly thrashing shark could throw a loop of leader-wire around your hand—it's happened to me—and might pull you over. Things can happen out in big water with big fish. I would have preferred company.

Now I had company—on the other end of the line hissing through the surface.

The shark came up and thrashed. And I saw that cobalt back and those reflective flanks; I saw the bullet snout and a stiff strong tail and glimpsed a black pit of an eye. Mako.

To my mind the shark of all sharks, the Short-finned Mako is a sleek streak of sapphire, a gemstone cut from the sea itself. To say it is fearless and cunning seems like cheap anthropomorphism, so let's just say I have known excellent fishermen who consider the Short-finned Mako demonically clever. Even among sharks, it is big (the largest females approach a ton), unusually fast, exceptionally aerial when hunting or hooked. It is the only known predator of adult Swordfish. It is warm-blooded. Also unusually among sharks, its flesh tastes delicious.

I always released all the sharks I caught, except that in those days I'd sometimes—once every two or three years—keep a mako for the grill. It had been 7 years since I'd killed my first good-sized mako, a shark just over 200 pounds. That was the last time I'd felt thoroughly excited about a big fish, but even then I'd felt, for the first time, remorse afterwards. That surge of buck-fever, that trembling adrenalin thrill I'd so often felt as a teenager and even well into my 20s, was now replaced with conflicting thoughts. These big, dangerous animals had come to seem somehow so vulnerable. In the intervening years I'd caught and released a lot of sharks. I'd seen the Smooth Hammerheads and Sandbar Sharks and Duskies and Tigers virtually disappear, and even the formerly abundant Blue Sharks decline, killed mainly by commercial longliners for their fins. I'd watched the makos grow scarce, killed by both sport and commercial fishermen for meat. Each time a happy crew in a victory mood hoisted a big mako or thresher onto the marina's scales, I felt a new sadness.

But now, alone and with this shark hooked, I knew one thing: I wanted this mako.

Finding a mako is difficult enough. Tempting it to bite isn't always easy. Subduing and securing one is tricky even for experienced crews. Most people wouldn't consider trying it alone, and couldn't imagine how it could be managed. I knew that if I did all these things solo, there would be congratulations and status at the marina. I would be respected as a skilled fisherman. My ego was captaining this trip.

Understand please that I was the product of two cultures. I had fished since I was 3 years old. Fishing had its rules and community values. Anyone would understand why an athlete is thrilled to win, and millions of sports spectators share that tense thrill of competition and the honor and prestige that follow victory. Fishing is much more personal, but one facet is competitive, and prestige still accompanies big fish. As a kid, I thought there could be no better compliment than for someone to gesture with their chin and whisper, "He's a good fisherman."

Now, youth's wolf was howling me back to the pack. I was back to wanting to prove something. I didn't ask why or intellectualize. This connection to the shark was direct and personal. Adrenaline was returning me to my emotional roots. Indeed, back to the emotional roots of humanity, locked in direct battle with a large, dangerous beast. No witnesses or referee presided, no photos could record a skilled release. I wanted this animal for meat and I wanted status as a skilled hunter. I wanted to drag it into my village and have the other hunters dance around it.

We all do the same almost daily, of course. The corporate climber seeks to be a tribal chief. The necktied, starch-shirted businessman seeks respect as a maker of killings. It's all the same: Bring down the quarry, tell the harrowing tale around the fire, howl in victory, sleep off the full belly, and hunt again. The rawness is masked, the corpse deodorized, but we still, simply for status, strive to excel among peers. Beneath the suits, the bulk of business consists of cave dwellers on commuter trains.

All ashore was elaborate convention. Here was a truer enduring reality: a risky hunt, a stuggle to make food, the promise of praise. But if I had thought of those things earlier, all thought now was narrowed to a point. In the heat of the moment, the shark was neither allegory, parable, nor metaphor. My knees were shaking. I wanted to kill this fish.

It was a hot, calm day, the August sun stabbing the sea to depth. The shark went deep to fight in cooler shadows. Bowed like a bonsai over the arced rod, I broke a sweat. I rocked and cranked. I raised the fish a few inches at a time, so slowly, so sleightly, that the mako began to rise as if lulled, as if it had gotten over its alarm.

Its glowing color appeared below, its body turned against the pressure, hanging hard and hardly moving.

I reached for my glove. I rehearsed the end-game in my mind: When the 10-foot wire leader broke the surface I'd unclip the harness from the reel. When the leader reached the rod tip I would put the rod in the boat's rod-holder. While grasping the leader—smoothly so as not to alarm the shark—I would lift the readied harpoon. I would delay the thrust until the shark broke the water and hesitated. I would wait until I had a clear shot to the wide of its body behind the dorsal fin. Then I would visualize darting the shaft clear through the other side, and would ram it with all the thrust one arm could muster.

The shark loomed up. It was tired and stayed calm. It seemed large. A hundred and eighty pounds? All fish look bigger under water. Pay attention. There's the leader. Unclip the harness. Here it is. Rod into holder. Leader in hand. Be smooth. Harpoon seems heavy; arm's tired.

I had the weight of the fish on the leader in one hand, the weight of the long wooden harpoon shaft overhead. A man with a spear, face to face with a large, dangerous animal—an old, old scene.

I pressured the leader and the shark's bullet of a snout rose through the surface, pointing at me. Bad angle. The hesitation made my tired arm weaken.

I relaxed the leader a little and the shark rotated slowly onto its side and turned to dive.

I struck and the fish exploded, spinning crazily and diving, ripping the dart from its side and stripping line from my humming reel.

I had not lunged hard enough; my arm was too tired from the fight and holding the heavy harpoon overhead.

Amazingly, the violence did not break the line or throw a weakening kink into the leader. In a few minutes I again drew the shark close. I decided that this time I would try for a shot through the gills. A gill shot is more decisive, but riskier. The head, rather than the tail, comes up as you pull the harpoon line, making it harder to place the securing tail-rope, increasing the probability that the shark will bite and perhaps simply sever the harpoon line—and raising the possibility that a sudden leap will propel the animal straight at you.

The mako came up again. I was ready. But when the shark presented the perfect shot, I hesitated.

The shark waited.

I looked deep into that black eye. Undefiant, matter-of-factly, the mako informed me this was no game, not a "sport." That eye rolled forward just a bit then back to me—and inquired what next.

I reconsidered, then thrust.

The mako blurred into lashing froth and blood. I reached for the gaff and sank it and swept him toward me and cinched the tail rope.

Now I had my prize. Each subsequent thrash pumped a new pillow of blood into the sea. For a few more minutes, the black eye queried: What next? Then the creature drained away into the sea, and all I had left was a dead carcass tied to the boat, and myself. And something had gone from me in that same billowing blood that took the shark and left the carcass. I'd sought to prove my place among others. The shark taught me that everything has its place, and I had overstepped mine. I knew then it was the last time I would ever feel that trembling buck-fever.

I had loved the sleek motion, the speed and agility, the gliding vitality and ocean-bursting power. And all these things, I had just destroyed. I had sought connection, but beyond connection, possession. And beyond possession, ego. That left my motives open to question. It is one thing to catch a fish and eat it. But there is in these equations a matter of scale, and such a thing as too much. And sometimes, why one does something is more important than what one does.

Now I'd have my steaks. Grills would sizzle. At the dock came the expected congratulations, the admiring onlookers male and female, the incredulous head-shakes that I had conquered this fish alone. My name found its way into the weekly fishing columns. I had distinguished myself. Perhaps people would say, "He's a good fisherman." But with sharks declining, I could not duck the fact that I was still drawing blood from such magnificent creatures. And that made the sought-after admiration feel hollow.

A few days later I repeated the offshore solo venture and located another mako. This time, after its leaping fight subsided and I drew the creature close, I leaned overboard not with harpoon but with hook remover. In those days virtually no one released sizable makos. But at the dock no one who asked what I'd caught questioned my tale of solo catch and solo release—because I'd proven my prowess with the earlier carcass. Now I was proving—if only to myself—that the next step in prowess was to relinquish the prize. But as it turned out, I again made the fishing columns, this time as a kind of mako liberator.

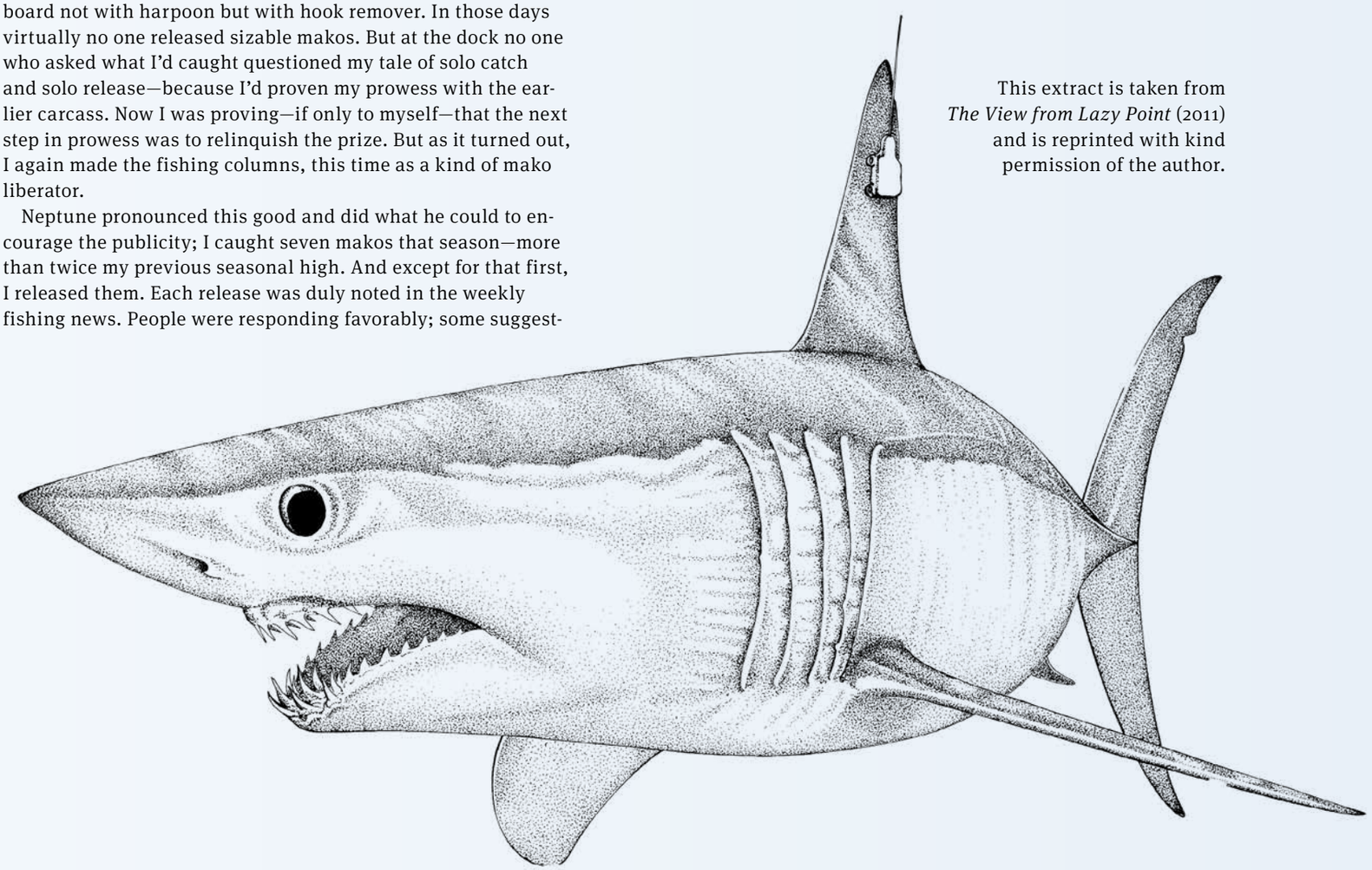
Neptune pronounced this good and did what he could to encourage the publicity; I caught seven makos that season—more than twice my previous seasonal high. And except for that first, I released them. Each release was duly noted in the weekly fishing news. People were responding favorably; some suggested that I was setting an example. Maybe I would become a good fisherman after all.

People are hungry to make their mark in the world. Every shark would understand. Or would they? The shark has a hunter's attitude, but there's nothing social in its killing. It gains only nutrition, knows no pride. The shark does only what it needs, and needs only what it does. Of the burden of needing to make an impression, the shark is free. Yet we cause the whole world, even the sharks of the blue ocean, to bear the burden of our ego. Certainly I had.

We must all kill to live, and scarcely a vegetarian would try denying it. Some measure of good resides in getting one's food from nature, for the connections it brings, the sense of place and the community it gathers. But two forks exist in the decision tree: One is whether the killing is humane. The other, whether we can we keep doing this. Shark hunting fails both counts. If a course of action simply cannot last, we must admit to ourselves that it's wrong. I knew that whether I killed one mako shark a year—or released them all—would not decide the future of the species. I wasn't the problem, but we're all always only part of the problem. At some point one confronts the question of right and wrong in private, with the door closed. We can do the right thing. Right things maintain a community. I prefer a community that includes, among many things, sharks.

We each make our solo voyages to deep, expansive waters. Alone in our contest with the wider world, we test our mettle and seek our trophies, promotions, compliments, and accolades. We strive to be needed and to thereby know there is a reason for us. We seek to be told we are good because we're too unsure of ourselves to know. Yet often we remain so focused on our neediness that we forget the creatures—human and otherwise—we're drawing into the vortex of our own passion play. All of us have compulsive loves we must forebear. We forget to see that we can engage the world without harming it. While we fish for approval, the challenge is to capture our prizes while bringing more to the world than we take.

This extract is taken from *The View from Lazy Point* (2011) and is reprinted with kind permission of the author.



Artworks by Guy Harvey | Guy Harvey Ocean Foundation

Finding a pla

Dr Ryan Daly sinks onto a bed of sea grass to photograph an anemone fish as part of a rapid biodiversity assessment around D'Arros Island and St Joseph Atoll.

anon

ce g the fishes

Photo by Guy Stevens

Words by
Clare Keating Daly

A rapid biodiversity assessment of fish communities in the waters surrounding the Save Our Seas Foundation–D'Arros Research Centre provided more than just a list of fish species. It revealed an essence of place. Writing from D'Arros Island, Clare Keating Daly reports on the findings and the place.

Place is a slippery thing. Read a guidebook, zoom in on a map, search a tag or a keyword, walk its shores or its roads – there are many ways to feel as though we know a place. And yet, a place's essence, its contents and components remain concealed, unknown. As wilderness, wildness and the ability to find solitude in the natural world disappear before our eyes, it can feel as though there is little left to discover, that the book on nature can be closed. But there is still so much to learn, to record, to preserve. There is so much at risk of slipping away, of remaining unknown.

Our planet harbours unimaginable biodiversity, an estimated 8.7 million species. Today, researchers believe that roughly 85% of these species have not yet been described. Which is to say, we still have a long way to go. We have much to learn about what kind of place this planet is, and the best way to begin to understand this is to act locally.

A constellation of islands scattered some 1,500 kilometres (930 miles) off the coast of eastern Africa, the Seychelles is, in a way, surrounded by fishes. Nonetheless, marine fishes are not a hot topic of study in the country and even less so in the Outer Islands of the Amirantes Archipelago, home of the SOSF-D'Arros Research Centre. There is wilderness here, wildness under the waves. There is much that remains unknown. Thus to understand more about the biodiversity of the Seychelles, what better place to start than with its fishes.

Although the research centre's reef fish monitoring programme is entering its eighth year, knowledge of the local fishes was limited to a record of the species encountered during general research activities, a list containing approximately 220 names. Suspecting that more fish species could be found in the diverse range of marine habitats, in May 2017 a team of three researchers set out to establish a benchmark.

The team consisted of SOSF-D'Arros Research Centre's research director Dr Ryan Daly, consultant Dr Guy Stevens and research assistant Justin Blake. Free diving and on scuba, they armed themselves with cameras and clipboards in the field and *Fishbase.org* and identification guides in the lab. Over 19 days, spending 84 hours underwater, they undertook a rapid biodiversity assessment of the coral reefs and associated habitats found around D'Arros Island and St Joseph Atoll.

Roving through meadows of sea grass and across sand flats, shining a light into the darkest caves and exploring the murky waters of the atoll lagoon, the team more than doubled the number of known fish species in the waters surrounding the island and the atoll. They recorded 514 reef-associated fish species in 71 families, photographing 73% of these records for positive identification.

Fishbase, the global biodiversity information system on fishes, currently lists 887 native or endemic reef-associated fish species in the Seychelles. Based on these numbers, the waters surrounding D'Arros and St Joseph support 58% of known reef-associated species recorded in the Seychelles to date. Thus, in under three weeks, the rapid biodiversity assessment team quantified the importance of D'Arros Island and St Joseph Atoll for fish life in the Seychelles. At the start, they thought they were asking the question, 'What fishes are here?' By the end, the question they had answered was, 'What kind of place is this?'

This is a place of refuge. Of the 29 vulnerable or endangered fish species on the IUCN Red List of Threatened Species for the Seychelles, more than half (15) find sanctuary in the diverse habitats that the island–atoll complex provides. For these vulnerable and endangered species, two features stand out as particularly important – in fact, unique in the Amirantes and potentially unique in the Seychelles as a whole.

The first is the system of habitats within St Joseph Atoll. At every low tide, the inner habitats of the atoll are entirely cut off from the surrounding ocean, creating a sort of marine island. The lagoon and flats within this system shape an irreplaceable nursery and foraging area for at least 10 of the 15 Red Listed species recorded during the assessment.

The second is the deep channel that separates D'Arros Island and St Joseph Atoll, the slopes of which plunge to depths of more than 70 metres (230 feet) in less than one kilometre (half a mile). Currents scour the divide, creating some of the deepest waters on the Amirantes Bank. Both the reef manta ray *Manta alfredi* and the Napoleon wrasse *Cheilinus undulatus*, two of the four CITES Appendix II-listed species recorded during the assessment, rely on the structure of this distinct channel. The combination of an upwelling of zooplankton and favourable currents to concentrate the zooplankton in the shallows may be one of the reasons manta rays congregate here nearly year-round (read more about the manta rays of D'Arros on page 114). Meanwhile, the caverns and caves lining the steep slopes of the channel provide important habitat for Napoleon wrasse. During the assessment, the team watched as up to 11 individuals of this species gathered in the channel before each slipped into a cave to roost safely for the night.

Of course, a place of refuge means a home for Seychelles endemics as well. The black-eye emperor *Lethrinus enigmaticus*, one of the most abundant species found in the survey, is also commonly sighted in the channel as well as along its slopes and in deep sea-grass meadows.

It's also a place of discovery. The waters surrounding the D'Arros and St Joseph complex are a marine frontier. Spending the equivalent of three and a half days underwater, the rapid biodiversity assessment team often encountered a species thought to be rare and recognised at least three others that were far from home, translating to significant range expansions for these species.

The green sea-grass wrasse *Pseudojuloides argyreogaster*, a shy, schooling species, was one such discovery. Until this assessment, this low-key wrasse was thought to be rare in its known locations, which were limited to scattered localities in the Seychelles and coastal Tanzania, and photos of it were exceedingly rare. To their delight, the team members often saw – and photographed – the green sea-grass wrasse in the thick meadows of its namesake along reef crests of D'Arros and St Joseph. What's more, they recorded this understated wrasse at a depth of 25 metres (82 feet), expanding its known depth range from its previous record of a mere six metres (20 feet).

The team made further discoveries at the depths where the green sea-grass wrasse had been thought not to venture. Another rare fish, the blue-lined flasher wrasse *Paracheilinus attenuatus* was previously known only from St François Island in the Amirantes and through the aquarium trade in Kenya. Here it was present on deep sandy slopes.

There are rare fish and then there are lost fish. Or perhaps not lost, only never noticed. The sightings of three species contributed to significant range extensions during the assessment, collectively adding 11,000 kilometres (6,850 miles) to the recorded range of these species. Diving along the steep reef slopes of the channel between D'Arros and St Joseph, the team recorded a glitter of purple-cheek wrasse *Pseudocoris petila* during the assessment. Photographed and confirmed, this species was previously known only from the Andaman Islands, some 5,000 kilometres (3,100 miles) away from the Amirantes.

Also known previously only from the Andamans, the blemished razorfish *Iniistius naevus* was reliably recorded on the deep sand flats just off the D'Arros Island dive centre, adding another 5,000 kilometres of range extension. The frequency at which we've sighted these razorfish after the assessment suggests that indeed they are not lost, and that their range may be much larger than originally thought. The final range extension, of 1,000 kilometres (620 miles), was courtesy of a single blue-lined triggerfish *Xanthichthys caeruleolineatus* making its way along the deep channel between D'Arros and St Joseph. Although it gave

Photo by Justin Blake

Delving into the wealth of life secreted away in D'Arros waters means spending significant time submerged. Dr Ryan Daly photographs marine life in what amounted to 84 hours underwater.

only a fleeting view, the fish was photographed and added to the ID catalogue.

Like any wild place, the D'Arros–St Joseph complex is one that keeps its secrets well. The assessment team uncovered treasure in the form of four cryptic fish species, all new records for the Seychelles. These tiny gems, tucked away in caves and coral, are potentially common, but their cryptic nature, rather than actual rarity, is probably what accounts for the lack of previous records for them in the Seychelles. In a place so full of life, looking just a little closer reaps great rewards.

A single cave concealed three of the four cryptic species recorded during the assessment. Each was subsequently found in other caves and reef overhangs, but coming upon them in one cave gave the divers the feeling that they'd stumbled into a secret lair. The species in question were the broad-banded pipefish *Dunckerocampus boylei*, the cave pygmy goby *Trimma anaima* and the flame pygmy goby *T. macrophthalmum*. The fourth cryptic species new to Seychelles was positively identified as the blue eye-lined coral goby *Gobiodon bilineatus*. Once its hiding spot had been found, the team often encountered this brilliant goby crouching in colonies of *Acropora* corals.

D'Arros Island and St Joseph Atoll are without doubt a place of refuge, discovery and secrets and their ecosystems still leave much to the imagination. However, the results from the SOSF-D'Arros Research Centre's rapid biodiversity assessment of fish communities have not only established the intended benchmark, but also developed the largest reef-associated fish species list for the Seychelles, a country surrounded by fish. Detailed, quantifiable data on fish biodiversity such as these provide the backbone for qualitative interpretation; together, D'Arros and St Joseph are truly a special place.

Like many rapid biodiversity assessments, this undertaking answered more than it set out to achieve. The sheer diversity of fishes – 514 species in 71 families – is astounding. In particular, the final number of species found during the assessment is 182 more than a recent fish survey recorded at World Heritage Site Aldabra Atoll, which is famous for its biodiversity. And yet the team members share a feeling that there is still much to discover here in the habitats of D'Arros Island and St Joseph Atoll. Besides the opportunity to expand known ranges and perhaps find fish that are new to science, there is also the chance to increase our limited knowledge about the Seychelles' coral and invertebrate species; a reef-wide assessment of qualitative data to add weight to the feeling of wonder that this place already inspires.

Photo by Ryan Daly

The green sea-grass wrasse was thought to be rare and limited in its range. The D'Arros teamdiscovered this shy fish in the sea-grass meadows of D'Arros Island and St Joseph Atoll, sometimes at a depth of 25 metres – four times deeper than previously recorded.

A rapid biodiversity assessment is...

Rapid

A traditional scientific study can take years to produce results. After data collection and analysis, the publication process can push the timeline even further as papers go into review and revision. Yet decisions about conservation and protected areas happen on a different time scale; politicians and policymakers don't always have the patience of scientists. They need relevant information yesterday, not next year. The timeframe of a rapid biodiversity assessment usually aims to have a detailed report of the assessment findings within six weeks of completion and a publication submitted within six months.

Biodiversity

Biodiversity refers to the richness of species. The numbers vary, but estimates suggest that there are somewhere between 1.2 and 1.65 million described species on the planet. Of the entire complement of the earth's species, scientists guesstimate that probably 85% have not yet been found. While it's unlikely that we'll ever know all the species on earth, there is plenty of room for discovery and clearly scientists and taxonomists have some catching up to do.

Assessment

There is a reason for it being called an assessment and not an inventory. The process of a rapid biodiversity assessment asks a specific question: what can we discover about the nature or makeup of this place in this amount of time? It is a roll-call of sorts, adding species to a list and identifying what is present.

Knowing better doesn't mean doing better

The world's biodiversity is facing its greatest challenges today, despite a long history of conservation programmes. I, along with many other conservationists, am driven to understand how we can create more effective programmes to address the urgent global issues facing our wildlife. I am frequently in discussion with conservation practitioners, researchers, NGOs, advocates and even the general public and I often hear people say that we need to educate people if we are to solve our conservation problems. At the very least, education programmes are often considered an essential adjunct to every other conservation strategy, whether that comprises alternative livelihoods, incentives or prohibitions and fines, to name just a few. The educational component itself can range from providing opportunities to view wildlife films to organising classroom presentations, pamphlet deliveries, media campaigns, tourist visitor centres and community workshops, among others.

We've been led to believe that when people know better, they do better. But as a researcher with a background in psychology and a purpose to provide guidance on how to promote environmental conservation behaviour, I sought to find evidence for how we can achieve this. In doing so, I came across a worrying and persistent theme: education programmes without evidence of impact.

In 2016, my co-authors and I published a paper in *Biological Conservation* showing that a review of community-based conservation programmes that quantitatively measured conservation behaviour in developing countries frequently reported the use of conservation education as an additional strategy to other primary community-based conservation strategies. The overall goal of this paper was to understand how community-based conservation programmes in these developing countries change human behaviour. The issue, however, was the very limited research into, and evidence of, the impact of the educational components of these programmes on people and their direct or indirect actions to conserve. Therefore, we could only speculate – as did the original authors of the reviewed papers – about the reasons why, and if, education can promote change in the behaviour of individuals.

These findings should be of concern to conservation researchers and practitioners who are under extreme pressure to deliver measurable conservation outcomes. Significant time and resources are invested in conservation education, even though there is very limited evidence of its success. Without understanding how these programmes are influencing people, it is impossible to learn from them and alter future projects to work more effectively. Increasingly scarce resources in conservation mean that practitioners have to prioritise where money is spent – and this is invariably on strategies that are likely to achieve the most impact. However, without evidence of the impact of such education programmes in these developing contexts, we cannot know if, and when, they are important and required, or whether money could be better spent on other conservation strategies.

The information deficit model has largely dominated behaviour change campaigns, both within and outside the conservation sphere. This model implies that people lack knowledge about a certain topic and if they are provided with information that fills this gap, they will change their behaviour. For instance, we assume that communities may not be aware that a species is critically endangered or is crucial to the ecosystem and that if they are given this key information, they will be more likely to act in ways that conserve the species and the ecosystem. Unfortunately, this simplistic thinking about human behaviour has been ineffective at facilitating progressive change in the conservation movement around the world.

Another pivotal assumption within many of these education campaigns is that changing attitudes is important for conservation. For instance, in 2015 Rakotonmamonjy et al published research in *Animal Conservation* on the efficacy of environmental education in rural Madagascar, but focused on knowledge and attitudes as outcomes rather than on behaviour. However, the psychological and conservation social science literature demonstrates a strong need to move away from a focus on purely attitude-based outcomes, as they are not a proxy for behaviour. Instead it is now argued, and quite well accepted, that successful conservation ultimately relies on changing human behaviour. After all, the problems facing wildlife and the natural environment are a result of human actions.

Researchers Kling and Hopkins investigated the effect of education programmes in primate conservation, publishing their results in the *American Journal of Primatology* in 2015. They too found a greater need for the thorough reporting of participants' behaviour rather than outcomes relating to their attitude or knowledge. Psychological research demonstrates the importance of focusing on investigating attitudes and knowledge as potential influential variables and cautions against viewing them as outcome variables, as in the past. Instead it is behaviour, or people's actions, that we need to focus on now.

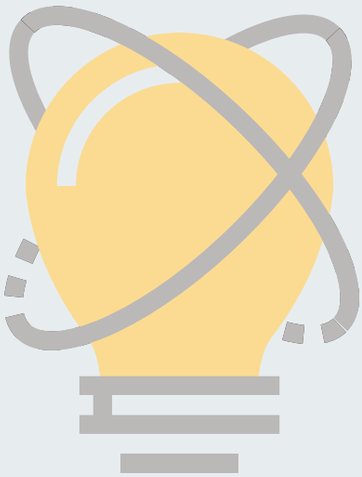
Words by Danielle Nilsson

For instance, a programme designed by Proyecto Titi to conserve the critically endangered cotton-top tamarin in Colombia included extensive educational programmes that were reported to have created knowledgeable individuals who were concerned for the environment. However, focus group data suggested that economic constraints meant that people still struggled to align their actions with these concerns or knowledge.

Projeto TAMAR-IBAMA, a programme designed in Brazil for the conservation of sea turtles, had a range of educational initiatives: school presentations; pamphlets with information on how to save turtles caught accidentally by fishermen; community outreach to increase local awareness of the importance of healthy marine ecosystems; and tourism-based campaigns. These education efforts existed alongside the employment of former egg poachers to patrol the beaches and protect turtle nests. However, there was no direct evidence to suggest what impact these strategies were having on the programme or to what extent each component was important.

Perhaps the strongest reasoning brought to light by our review for people engaging in conservation behaviour as a result of education related to teaching people conservation techniques. This could imply a mechanism of 'self-efficacy' or 'skill'. For example, it seems that a tree planting initiative in Nepal that provided technical support such as free seedlings and advice on planting methods led to an increase in trees planted on private land.

Furthermore, in the Proyecto Titi programme in Colombia, education was provided in the form of instructions on how to use *bindes* (small cooking stoves made from clay) as well as how they benefit tamarin conservation efforts. This has reduced the number of trees used for firewood. However, it was not clear to what extent the education provided about how using *bindes* benefits the conservation of tamarins influenced an individual's decision to make use of them. Nevertheless, this kind of result suggests that it may be better to spend money on teaching people new skills and techniques that have a direct conservation value rather than on providing knowledge about species or ecosystems in general.



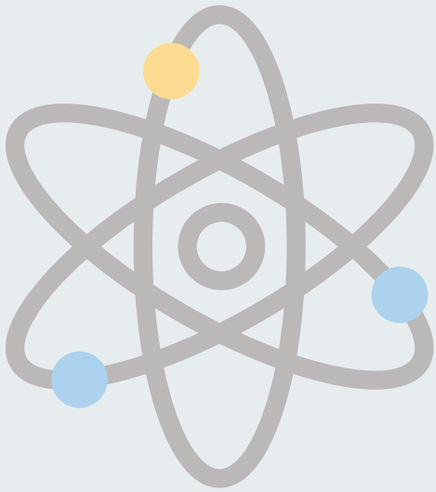
Cartwright et al, who investigated the effect of conservation education in great ape reintroduction programmes in the Republic of Congo in *Environmental Education* in 2012, highlight that conservation education programmes are often created on an ad hoc basis and managed in an impromptu and intuitive manner that lacks priority, expertise and funding. In effect, they would benefit from systematic evaluation during all stages of their development. The researchers' objectives should be commended but, as they note themselves, since the research methodology was naturalistic and qualitative, the findings should be treated with caution.

Moving forward, we therefore need to focus on strengthening investigation into the effect of education on the reasoning of individuals to engage in various conservation actions. Ideally, this would be through quantitative measures of behaviour change. The notion that education is essential to any conservation programme to overcome our environmental problems is too simplistic for the complexity of these problems. That is not to say that education is not potentially important, or that it does not have a role, but without the scientific research to guide us, we are simply continuing to act in an impromptu and intuitive manner.

Overall, there is a strong need for scientific research into the impact of these education programmes. Past research and lessons demonstrate that education programmes based on shifting people's attitudes and filling gaps in information are in themselves largely ineffective when it comes to prompting changes in behaviour. As conservationists, we need to move past the intuitive thinking that has shaped the approach to designing conservation programmes, particularly those with social science requirements. We need evidence to guide our decisions – and that requires investigation, through rigorous social science, into the impact that education has on people and their decisions to engage (or otherwise) in conservation actions.

This raises another important issue: the need for closer working relationships between conservation practitioners and researchers. It is essential that we work together if we want to create the changes that we desire. Researchers have a responsibility to conduct impact-oriented research that is up to date, interdisciplinary and can be applied to real world contexts. Practitioners have a responsibility to utilise this research and not spend money on 'gut feelings' or outdated notions.

Most importantly, we must move forward and not fall into the trap that if we know better, we do better. Human behaviour isn't as simple as we like to think it is. But there is hope. By conducting scientific research, and drawing on it, we can guide a more effective use of time and resources. To do this, researchers and practitioners should work together so that conservation education programmes can be designed and implemented through evidence-based approaches. Only then can scarce funding and resources be used most effectively to generate the greatest conservation impact.



In conversation with Sarah Fowler

Sarah Fowler is one of the Save Our Seas Foundation's scientific advisers and also a founding member of the IUCN's Shark Specialist Group, the Shark Trust and the European Elasmobranch Association. She has been a part of the evolution of shark conservation for almost 30 years. Philippa Ehrlich spoke to her about where it all started, how far it's come and what she looks for when choosing new projects to fund.

How did you become interested in sharks?

When I was a small child I spent summers on the Isle of Wight, off England's southern coast. My father and I used to set a little net overnight and occasionally we would catch tope sharks, sometimes quite big ones, which would just end up inside a big sausage of net. So I spent a lot of time trying to untangle them on the beach – those were my first sharks. I also remember, when I was probably about 11 or 12, seeing a basking shark for the first time, just swimming around in a little harbour in Cornwall early one morning. It was mind-blowing! So I have always been interested in marine biology.

And how did you get involved with the Shark Specialist Group?

I had a conversation with a colleague of mine in Nature Bureau, which was the consultancy where I used to work. We were talking about the problems of the lack of management for sharks and the fact that there were extraordinary unregulated fisheries all over the world. This was in about 1990 or 1991, when the growing demand for shark fins had become an issue. Nothing was being done about it, you know; we couldn't get anyone to take any notice.

Anyway, I went back to my desk and about half an hour later my colleague, Paul Goriup, showed me a fax that he had just sent to the IUCN saying, 'You clearly need a Shark Specialist Group and there is someone here who will help you set one up.' (I had been working a bit with the IUCN already.) Then my phone rang and it was Simon Stuart, who was then running the Species Programme for the IUCN in Switzerland. He said, 'Well, you know I just got this fax and in fact we are setting up a Shark Specialist Group. We've already got the chair, Dr Sonny Gruber, but you're going to be the deputy chair.' And that was it.

What did shark conservation look like back then?

At that time, shark conservation didn't exist. Sharks and rays were very much fisheries species and the whole concept

of having protected shark species and treating them as wildlife biodiversity was just not seen to be necessary or important – or, indeed, desirable. So in the early days we spent a lot of time trying to improve the synergy between marine conservation, wildlife management and fisheries management because they were separated by a huge gulf.

When it came to the relationship between the Food and Agricultural Organization (FAO) and the Convention on International Trade in Endangered Species (CITES), there was quite a bit of conflict because many fisheries managers just did not believe that wildlife conservation was relevant to sharks. Sharks, they said, were fish and should therefore come under fisheries management rules, although in reality sharks were not important enough to receive much attention from fisheries managers. That is understandable because sharks and rays made up about one per cent of world fisheries landings, so they were simply not sufficiently important in terms of cash volume, food security or hard cash for developing countries. Sharks and rays were sort of falling between the two stools of fisheries management and wildlife conservation, and what we have done since the 1990s is bridge that gap. There is now far greater interest and enthusiasm for working together for these animals, which have a 'fin in both camps', as it were.

How did marine biologists see shark conservation at the time?

Ah ... that was interesting because many researchers in the 1980s were not really thinking about conservation. In fact, conservation was seen as a bit of an embarrassment. It was not research. It was not scientific. And that has changed completely over the intervening decades because in order to achieve conservation management, research is important; you have to know a lot about the biology of the species. Back in the early days, when many fisheries departments were saying 'Come on! Sharks are just fish and they are managed like all the other fish', there was very little awareness of the fact that sharks are actually more like mammals in their biology. You can't manage them in the same way that you would manage tuna or plaice or cod because their biology imposes completely different constraints. I think many researchers, such as Sonny Gruber, really got into conservation when they realised that their study animals were disappearing or were not as abundant as they used to be. Slowly, conservation as a profession became seen as valuable, important and respectable.

What motivated that shift?

There were all sorts of reasons for that. One is the proliferation of NGOs of all different shades of green. On one side you've got, say, the IUCN, which has governments as members and is very science-based, with a lot of emphasis on sustainable use for commercially important species. But then we also have dark green organisations that are almost militant in their defence of wildlife. They feel that no animal should be killed. So there's a whole spectrum there, and what the dark green organisations have done is shift the balance of debate more to the centre.

Do you feel there is a place for those more militant conservationists?

I believe so, yes. While I do not agree with some of the policies of those organisations, they definitely play an important role, particularly in raising awareness and getting members of the public engaged in causes.

Shark conservation has come a long way since the 1990s, but where are the gaps today?

There are still huge gaps in the capacity of many countries to monitor sharks and to manage fisheries. We have more than 80 countries sending shark fins to Singapore, Hong Kong and China, but only a very small proportion of those countries can actually manage their fisheries well. The crisis is not so much out on the high seas. The big challenges now are really in the biodiversity-rich fisheries in coastal waters, where sharks are primarily taken as part of multi-species fisheries, which are much, much harder to manage.

When looking at funding proposals, how do you choose a project for the SOSF to support?

The question inside my head is always 'So what?' We get a proposal to support a piece of research or a survey and I am always thinking 'What happens next? What will this do? What is the spin-off going to be? How will this help us to improve management? How is this going to save sharks?'

Once a project is complete, how do you measure its success?

Well, there are two ways to answer that. One is, did it do what it said it was going to do? Has it met its objectives? But I also like to see something else happening beyond that. In the case of the devil ray project in Gaza, for example, it did its work on devil rays and achieved its goal. However, it also created an advocate for sharks and rays, someone who now lives and breathes sharks and rays and is getting lots and lots of students interested in them too. That would never have happened had it not been for that small project that was looking into devil rays. We can't always tell if we're going to ignite something in a person, but when we do, it's brilliant!

Is there still an important role for biological science in marine conservation?

Of course! You can't save things if you don't know what they are, where they live, how they breed, what their life history constraints are. You have to have that basic information. If it doesn't have a name, you can't save it.

While the individual projects supported by the Save Our Seas Foundation (SOSF) come and go over the years, there are several relationships that we have maintained for some time and will continue to maintain for the foreseeable future. Three centres – two focusing on research and one on education – are managed directly by the SOSF, and four independent NGOs have engaged in mutually supportive partnerships with the foundation. All these organisations are dedicated to tackling, in one way or another, the huge amount of work involved in protecting the marine environment and the diverse creatures within it. Research and education are kingpins in this work and through the Shark Research Center in the USA, the D'Arros Research Centre in the Seychelles and the Shark Education Centre in South

Photo by Thomas Peschak | National Geographic Creative

Two whale sharks mirror one another in the warm India Ocean waters that fill the Gulf of Tadjoura. The coastline of this gulf in the Horn of Africa is shared between Djibouti and Somalia.

Africa, the SOSF can extend its on-the-ground reach to these countries and beyond. The NGOs Bimini Biological Field Station (also known as the Shark Lab), Cetacea Lab, the Manta Trust and Shark Spotters are carrying out long-term research and conservation work and, in terms of funding and communication, the foundation's partnership with them, as well as with the Acoustic Tracking Array Platform (ATAP), is closer than its relationship with our individual, shorter-term projects. We rely heavily on our partners' respective areas of expertise as we reach for shared conservation goals and are inspired by the passion of the individuals involved. In the following pages are accounts of the invaluable work carried out by these centres and partners.

INSIDE STORIES

INSIDE STORIES

Claire joined us at the Shark Education Centre in May 2016 as the new facilities manager. Before coming to us she worked in financial administration for a big insurance company, specialising in long-term investment and insurance, so her day-to-day working life has changed dramatically! We sat down to have a chat about what her first year with us has been like.

What are your favourite things about your new role?

There are so many! But I would say that it's the interesting things that pop up on a daily basis. I think it was during my first week at the Shark Education Centre that I got to put on a wetsuit and rearrange aquarium rocks and anemones in the big fish tank. It was freezing! But fun. We really get to be hands-on during our work here, which is definitely one of my favourite things about working at the Shark Education Centre.

What are some of the (best) things you've learnt?

I've learnt a lot about sharks and rays, both from the staff here and from interacting with the public and our exhibits and displays. The biggest, the smallest, the fastest, the weirdest, the most common, the rarest, the oldest... There are so many things to learn and so many species of sharks. But most importantly, I've learnt how these animals form part of a much bigger picture in the marine ecosystem and that without them we would most likely see a collapse in the healthy functioning of the sea, which is of global importance. I have also learnt so many interesting things about marine life and conservation. I feel like I'm constantly discovering new things – the latest was just a few days ago when I found out about the existence of limpet flatworms.

Another thing that I've had to learn is that there are more than 101 things that can and will go wrong with an aquarium – and how to go about trouble-shooting them!

Was there anything about this job that really surprised you?

The amount of resources, time and energy that it takes to run a non-profit is astounding! And also, all the work that goes on in the background to arrange what seems like a straightforward school outing. When you see a group of excited schoolchildren being shown around the centre or happily exploring the rock pools of the Dalebrook Marine Sanctuary, what you don't realise is that weeks of planning, paperwork, permissions and coordinated effort on the part of the centre's education team, the school and the parents have gone into making this happen.

What do you think of the work that the Shark Education Centre does?

People tend to be fascinated by sharks, although they don't always know much about them, but they often have entirely the wrong impression of them as scary, dangerous, people-eating machines! One of the best things that we do here is to teach people more about sharks and also about how important they are in regulating the ocean ecosystems of planet earth. In general, people are so unaware of conservation, or how their daily actions affect the natural world, that it is vitally important to teach them how they can contribute to conservation simply by acting responsibly. I think the education team really tries to convey that ultimately it's the responsibility of humans to ensure the healthy functioning of the marine ecosystem through environmentally responsible actions. I'm impressed by how much effort and time goes into making sure that the school groups and visitors are given the most positive experience the education team can provide. This is especially important given how little connection many of the children who visit have to the ocean to start with – even though they live in a coastal city! I'm really proud to be part of something that is teaching and inspiring children to be young conservationists, and that is giving them information they can use to pass on to their families and communities.

How do you see yourself developing in this role?

I am really excited about the opportunity to work with a marine conservation organisation and I'm looking forward to working with the centre for a long time. Now that most of the major internal exhibit renovations are done, I would like to focus on ensuring that the most streamlined systems are in place so that the facility is being used to its maximum capacity.

The education team has also encouraged me to assist with school outings, holiday clubs and the Marine Explorers surf and snorkel experiences. I really enjoy being able to engage with the kids and am hoping to continue to be involved with this in the future.

What are some of the challenges that you've experienced during your time here?

Part of my job as the facilities administrator is to make sure that the building and its facilities are all functioning well. This can be particularly difficult when faced with external challenges such as the extreme drought that Cape Town is currently undergoing. It's the worst drought in the Western Cape for more than 100 years. As an environmental organisation – and as citizens of Cape Town – we need to adapt to the water scarcity and the latest water restrictions (less than 80 litres per person per day). This means no use of potable water for the garden or for washing the building or windows; it means monitoring the ablution facilities, checking for leaks and reducing the toilet wastage; it means catching rain water to use for washing wetsuits; it means all sorts of things that we need to stay on top of! As an education centre, it is imperative that we educate our visitors about the importance of water and of the critical need to conserve it, and it is very important that we lead by example. However, as a public-facing facility we also need to ensure that we remain presentable and that we are able to cater for all our visitors. This can be a tricky balancing act!

An ongoing challenge is making sure that the facility remains safe and secure for the visits of schoolchildren and the public (and the legalities surrounding that, which can be a huge amount of work). But it is all so worth it in the end, when you see those beaming faces just bursting with excitement!

Shark Education Centre
Words by Eleanor Yeld Hutchings & Claire-Frances Metcalf

One year in...

Photo by Grant Atkinson | Fresh Air Crew


Space In-ray

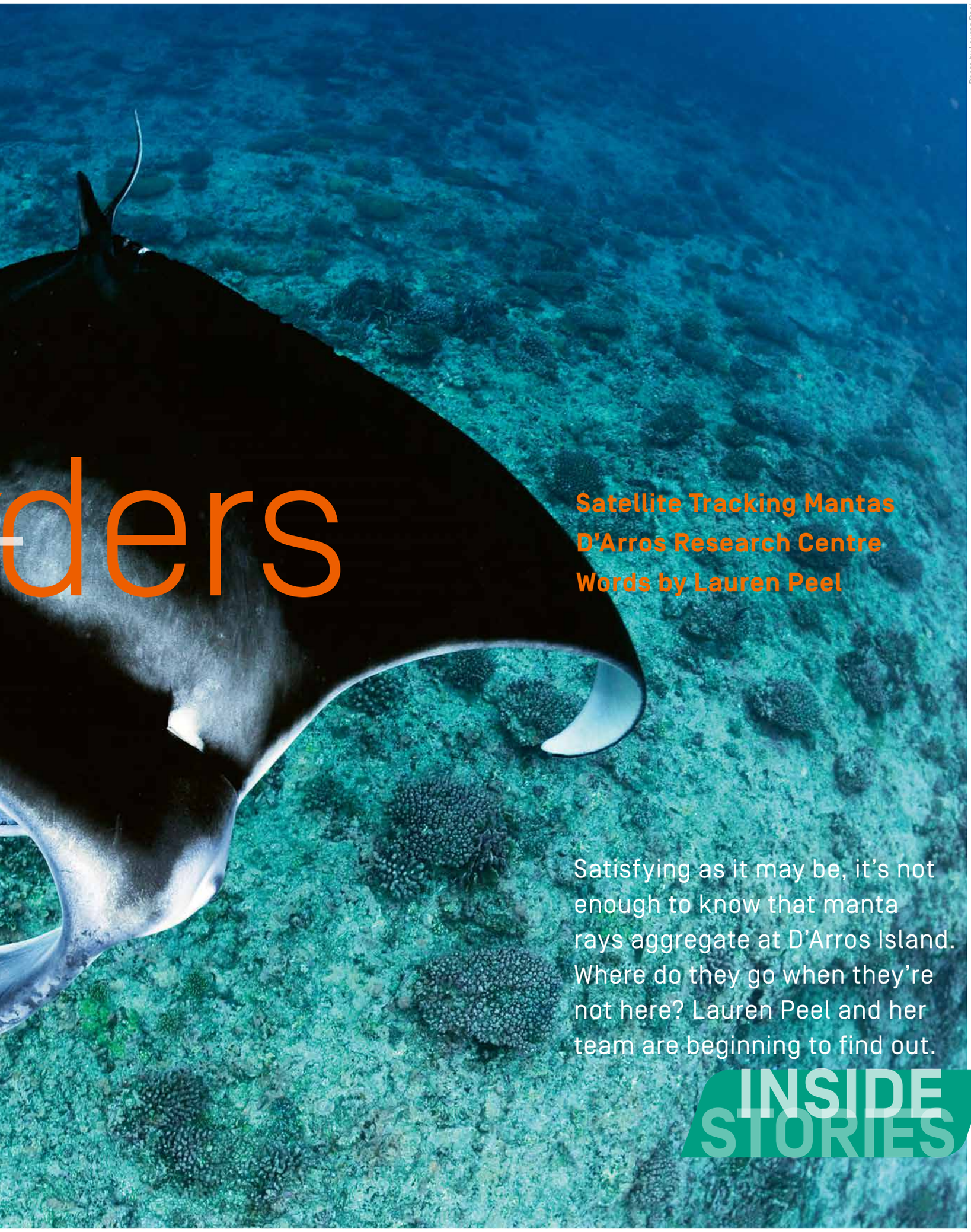


Photo by Lauren Peel

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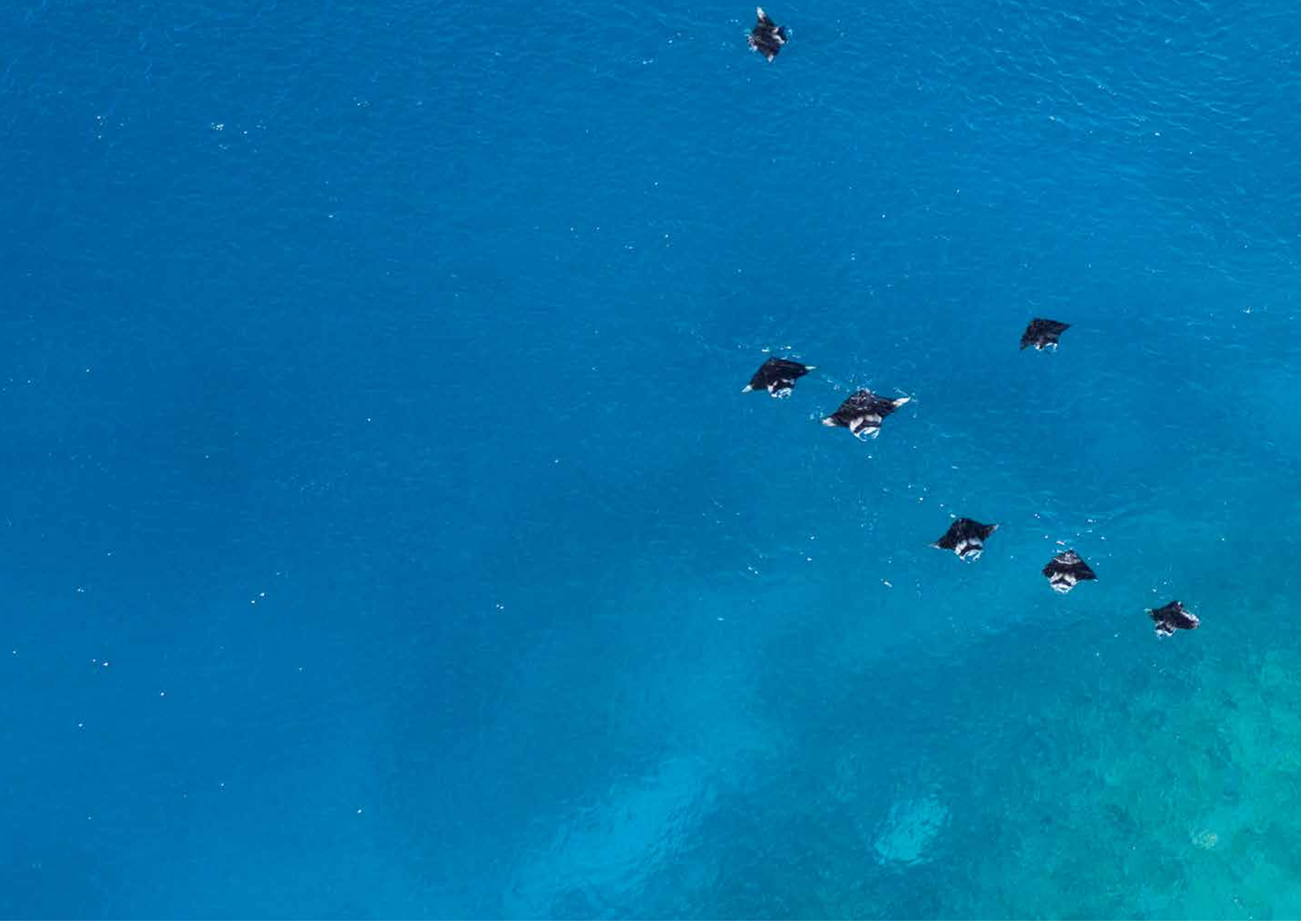
Satellite Tracking Mantas
D'Arros Research Centre
Words by Lauren Peel

Satisfying as it may be, it's not enough to know that manta rays aggregate at D'Arros Island. Where do they go when they're not here? Lauren Peel and her team are beginning to find out.

INSIDE STORIES



When people think of the Seychelles they often imagine white sandy beaches and bright green palm fronds on small islands, not the millions of square kilometres of Indian Ocean that surround the island nation. But that is all I think of: the ocean and the incredible marine life in it – and the little-studied manta ray population that lives beneath the turquoise waves of the Seychelles. Researchers have spent more than 10 years studying the manta ray populations in other parts of the world, but next to nothing is known about this one. As the leader of the Save Our Seas Foundation and the Manta Trust's Seychelles Manta Ray Project, I hope to change this by determining not only how many manta rays live in this part of the Western Indian Ocean, but also how frequently they visit the shores of the 115 islands comprising the archipelago.

As recently as six years ago, divers noted that manta rays aggregate almost year-round at D'Arros Island, a small coralline island on the Seychelles' Amirantes Bank. Work soon began to photograph the unique spot patterns on the bellies of these animals so that individuals could be identified and counted. These same manta rays would soon become the focus of my PhD and while to this very day we are still monitoring their presence at D'Arros Island by means of photo-ID, our efforts were leaving a major question unanswered. Standing in front of the Save Our Seas Foundation–D'Arros Research Centre (SOSF-DRC, the home of the Seychelles Manta Ray Project) and looking out over the shoreline towards the seemingly endless horizon, I couldn't help asking myself, 'With so much room to move, where do the manta rays go when they aren't here?'

Unlike animals that live on land and move through a two-dimensional landscape, manta rays move through a three-dimensional environment, and if I were to track their movements at first hand I would need to grow gills. Fortunately, major technological advances over the past two decades have meant that I don't need to start looking at getting a gill transplant just yet! Instead, to answer my question the SOSF-DRC team and I decided that we would use satellite tags to record and monitor remotely the movement patterns of the manta rays from D'Arros Island. There was only one downside; satellite tags are expensive! We'd be able to purchase the new technology, but only two tags. With little room for error, we knew that the field work ahead would be a challenge. But considering that this would be the first time a satellite tag would be deployed on a manta ray in the Seychelles, the excitement in the team was contagious.

The first hurdle was getting the tags to D'Arros Island. When I ordered them, the company warned that my required delivery date would be cutting it fine. Given the remoteness of D'Arros Island, flights can be spaced up to three weeks apart and if the tags weren't with me when I got on that plane, there was a chance that we wouldn't have them at all. The countdown was on. Five days to go … four days … three days – still no tags. Before I knew it, it was the day before I was meant to leave for the Seychelles and the tags still hadn't been delivered. We were indeed cutting it fine! Thankfully though – just when I thought I would break the refresh button on my e-mail inbox – the notification came through. The tags had arrived! I got on the plane less than 18 hours later with two brand-new satellite tags packed safely in my luggage.

As with any field work, time was a precious commodity. In early November 2016, the Manta Trust's Guy Stevens and I had 25 days on D'Arros Island and we wasted none of them; we'd barely touched down on the grassy runway before we were jumping into the water to photograph the mantas. After months of planning and countless hours on the plane, nothing could compare to being in the water with these mesmerising elasmobranchs. All the waiting and hurdles were forgotten every time I dove for an ID shot and turned to look back at an approaching manta. The rays' curious nature and grace left me in awe, and as they passed overhead I took as many photographs as I could. Over the next few weeks we would become familiar with some of the smaller mantas that we saw almost every day, whereas other individuals we would see only once before they left the shallow waters surrounding the island. Our sur-

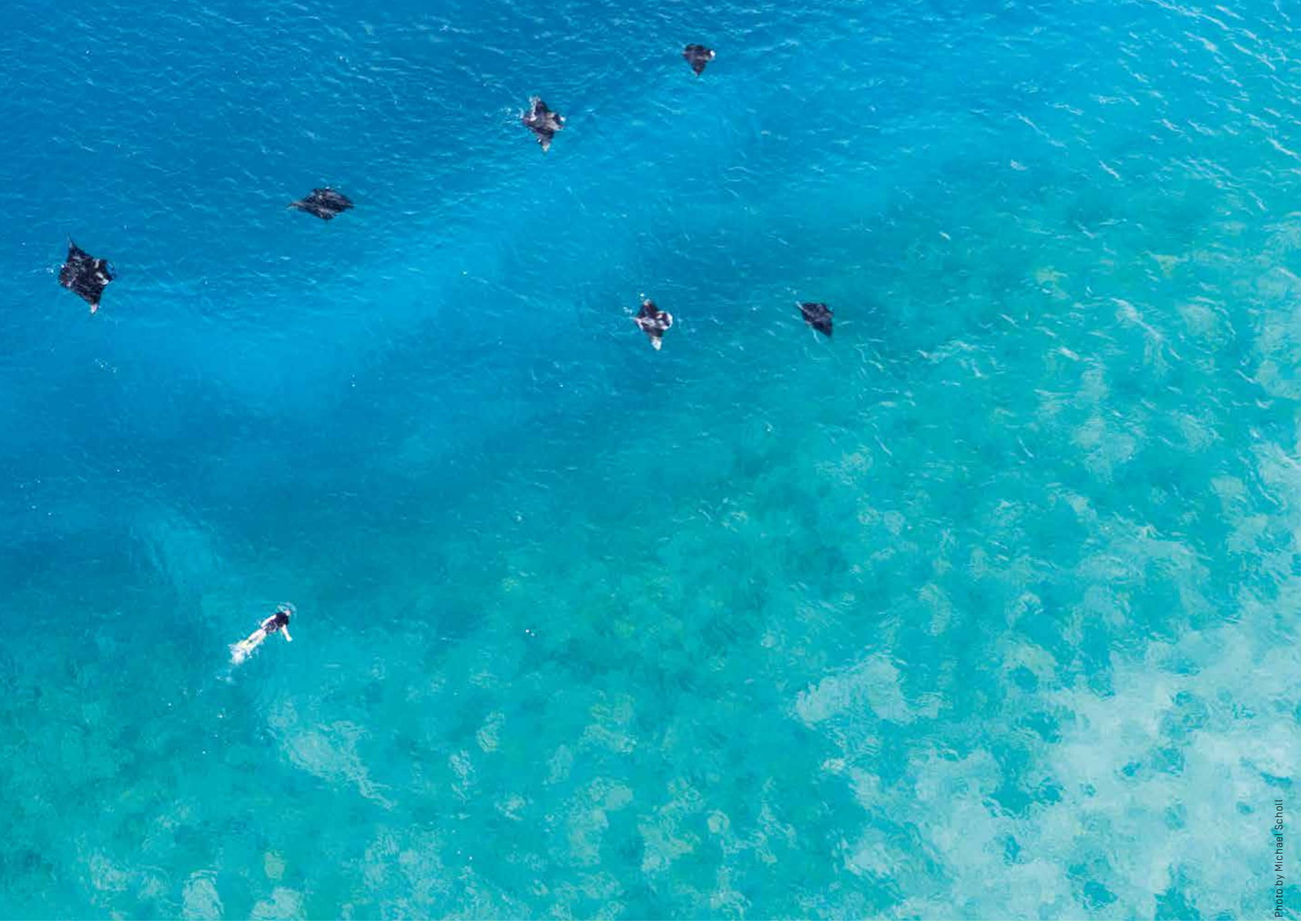


Photo by Michael Scholl

veys formed a critical component of our understanding of which mantas appeared to be resident and which were likely to travel away from the island, so we watched and waited. The timing – and the mantas – needed to be right for our tags.

Studying the photographs we'd taken, we decided that deploying our satellite tags on large female manta rays would be most beneficial. Because we saw these individuals less frequently, and rarely on consecutive days, we believed that they would be the most likely to travel widely from D'Arros Island and reveal the full distribution of this population. Armed with these insights, in our last week on the island we calibrated the satellite tags and donned our dive gear. We would deploy the tags while scuba diving at the cleaning station just 200 metres (660 feet) offshore from the SOSF-DRC lab; at this patchy reef, which the rays frequently visit to have parasites removed by small fish, we would wait for the right manta to come to us.

It didn't take long. Our time spent surveying the population had paid off and after only 30 minutes a large female manta ray, 'Shadow', descended on the cleaning station. With a wingspan of three metres (10 feet), she was perfect for a satellite tag. As she hovered over the reef to be cleaned, SOSF-DRC lab manager Ryan Daly approached her cautiously, satellite tag at the ready. I held my breath; we were so close to deploying the first tag! Then, with a single movement, Ryan carefully released the tag. Before she swam out over the drop-off and into the deep blue water I caught a glimpse of the tag perfectly placed on her back.

One down, one to go! We were nervous; would we be successful again? Returning to the cleaning station the next day, we deployed the second satellite tag just 24 hours after the first when we encountered 'Medusa', a female with a 3.6-metre (12-foot) wingspan. We watched her glide over the reef crest and approach the cleaning station. As the cleaner fish tended to her gills and cephalic fins, the second tag was attached and immediately began collecting data about Medusa's movements.

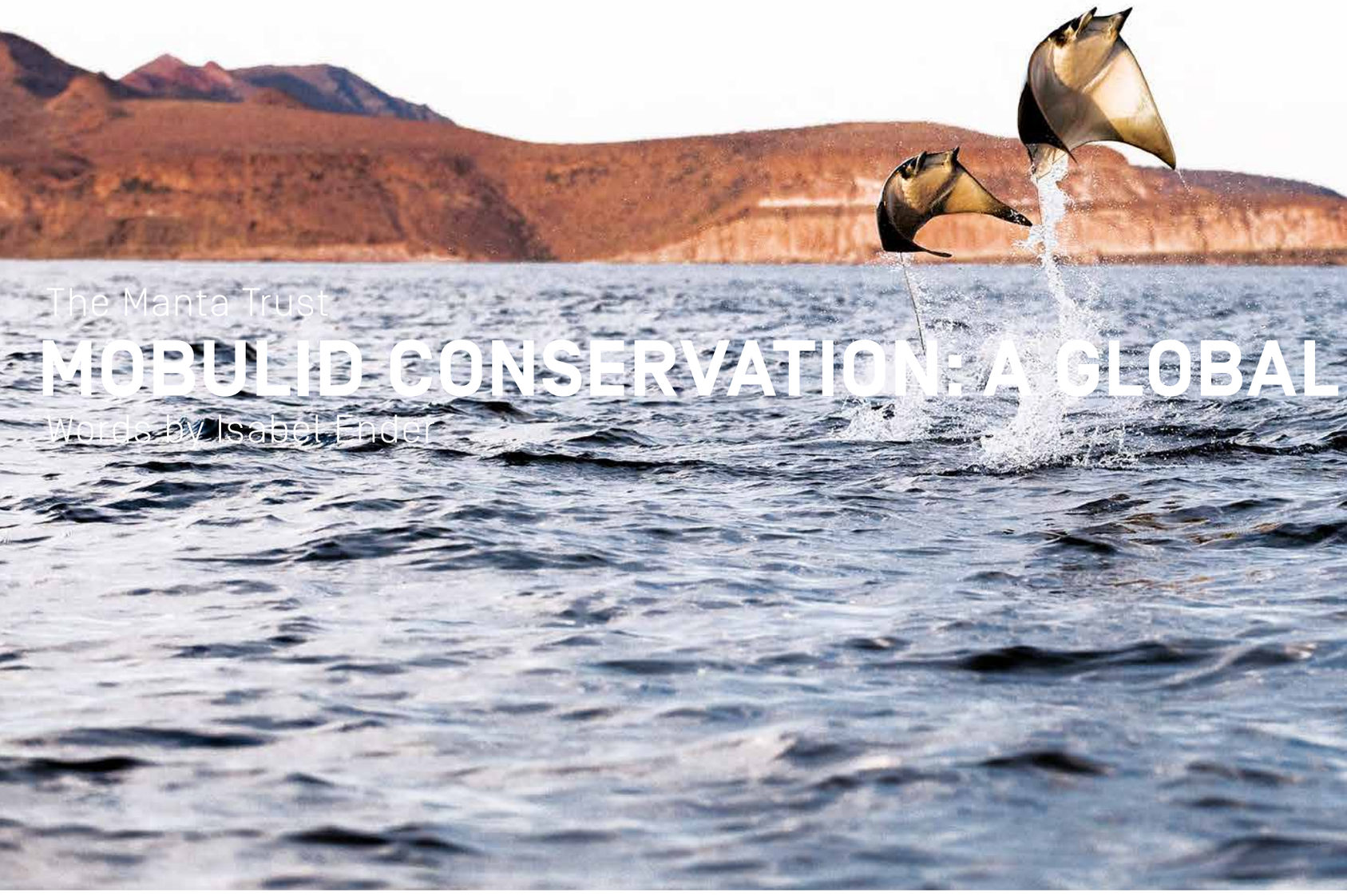
Celebrations erupted underwater. But deploying these tags had opened a floodgate of new questions. Once again, excitement was met with nervousness. Would the sensors on the tags work properly? Would the tags stay on for long enough? Would the batteries have enough power to transmit the collected data back to us? Only time would tell. Two days later, as the plane left D'Arros and my view of the palm trees and sandy beaches faded away over the horizon, I smiled as I thought of Medusa and Shadow swimming through the blue water below and taking us along with them on every step of their journey.

Three months passed and by March 2017 both tags had released from the mantas. They had worked! We were finally getting an insight into the movement patterns of these charismatic animals. Our initial observations revealed that the Seychelles' first satellite-tagged mantas seemed to remain relatively resident to the Amirantes Bank as a whole, completing offshore trips to the east and the north of the bank before returning to the shallow waters of the island chain. Shadow and Medusa spent most of their time in the relative shallows of the water column, both appearing closer to the surface during daylight hours and descending deeper in the water column at night. For the first time ever, we were seeing how these animals move through the Seychelles.

As well as bringing us closer to answering my initial question, the tracking of these manta rays with the SOSF-DRC and Manta Trust represents an important first step in the process of establishing an appropriately scaled protective strategy for these vulnerable species in this part of the Western Indian Ocean. Only by understanding their distribution and by identifying the areas of habitat that are important to them will we be able to develop targeted management strategies to monitor and conserve their populations long into the future. In the coming years, the Seychelles Manta Ray Project will continue to work towards this goal. I can't wait to find out what we will discover from the next satellite tag deployments at D'Arros Island in November 2017!

Initiated by the Manta Trust, the Global Mobulid Conservation Programme is taking a four-pronged approach to protecting manta and mobula rays around the world.

INSIDE STORIES



The Manta Trust

MOBULID CONSERVATION: A GLOBAL

Words by Isabel Ender

STRATEGY

Photo by Christopher Swann | Biosphoto

Sharks and rays are some of the most enigmatic creatures in our oceans, yet there are few that are more fascinating and mysterious than manta and mobula rays. Known collectively as the mobulids, these inquisitive creatures range throughout the tropical and subtropical oceans of our world in search of the patches of zooplankton on which they feed. Mobulid rays are distinguished from other rays by their highly specialised filter-feeding behaviour: using their enlarged mouths and modified gill plates, they strain zooplankton, fish spawn and small fishes from the water around them.

These large-bodied and slow-growing animals have one of the lowest fecundity rates of all elasmobranchs. Their populations are small, highly fragmented and sparsely distributed around the world, and in fact no-one knows with any certainty just how large – or small – the global mobulid population really is. Collectively, their low fecundity, the small size of their local populations and their migratory and aggregating behaviour make mobulids extremely vulnerable to overexploitation and their populations slow to recover from any losses.

The greatest threat to mobulid rays is excessive take – both targeted and incidental – by fisheries, a take that increasingly is being driven by the international trade in gill plates for use in an Asian health tonic purported to treat a wide variety of ailments. As a result, some mobulid populations in South-East Asia, the Indian Ocean and Africa are showing declines of more than 80%. Of particular concern is the exploitation of these species in their critical habitats, where numerous individuals can be targeted with relatively high catch-per-unit effort. For such intrinsically vulnerable species, even small negative pressures on a population are likely to have severe consequences for its survival.

In view of their vulnerable life history traits and in response to the growing threat from the gill plate trade, several significant steps have been taken in recent years to improve the conservation status of mobulids. In 2011, the oceanic manta ray *Manta birostris* was listed on the Convention for the Conservation of Migratory Species (CMS). At the same time, both it and the reef manta ray *M. alfredi* were reclassified on the IUCN Red List of Threatened Species as Vulnerable. In 2013 collaborative efforts between researchers and NGOs saw the genus *Manta* listed on Appendix II of the Convention on International Trade in Endangered Species (CITES) and the following year the reef manta ray and all mobula ray species were listed on CMS. More recently, in 2016 the genus *Mobula* joined manta rays on CITES Appendix II, driven by an impressive number of proposing governments, supporters and NGOs. Yet these growing protective measures notwithstanding, manta and mobula rays remain extremely vulnerable to exploitation.

A comprehensive approach and a strategic plan are required to ensure the long-term conservation and sustainable use of mobulid rays. Crucially, this plan needs to address the levels of targeted and incidental catches that threaten these rays. In the first place, relevant and comprehensive policies to regulate the fishing of and trade in mobulids have to be put in place, at both national and international levels. Such policies must be informed by robust and accurate scientific data, and governments should be advised by mobulid experts as they develop and implement them. Secondly, government officials and customs officers must be provided with the skills, knowledge and tools to enforce effectively the legislation designed to protect mobulids. Thirdly, communities that rely on mobulid fisheries should be encouraged to take up more sustainable livelihoods as alternatives to fishing. This requires capacity building, education and support to help them negotiate the transition. And finally, consumer demand for mobulid products, in particular gill plates, has to be reduced. This can be achieved through education and public awareness campaigns.

Since 2011, the Manta Trust has been coordinating global efforts to conserve mobulid rays and their habitat. In 2014 it launched its Global Mobulid Conservation Programme (GMCP) to carry out a strategic action plan for mobulid conservation based on the comprehensive approach described above. During its first three years, the GMCP led exciting advances in our scientific understanding of mobulid rays and played a significant role in achieving the current conservation status of these species at local and global levels. The programme orchestrated the collection of data on mobulid fisheries and trade in 22 countries, which was essential for the successful listing of mobulids on CITES and CMS. A series of government workshops were organised in key mobulid fishing nations, including Sri Lanka, India, Indonesia and the Philippines, to support the effective implementation of legislation and provide technical training for trade monitoring. Other achievements include delivering national protection for manta rays in the Maldives and Peru and conducting outreach activities with fishing communities in half a dozen countries.

The GMCP also played a significant part in developing the IUCN Shark Specialist Group's Global Conservation Strategy for Manta and Devil Rays, and its objectives and activities are intricately linked to this strategy. By taking a collaborative and multi-faceted approach, the GMCP is turning this 'paper' strategy into coordinated activities and effective conservation outcomes. With the support of our generous funders, the Save Our Seas Foundation and the Global Partnership for Sharks and Rays, we are excited to continue the work of the GMCP over the next two years and advance ever closer to our vision of a world in which stable and recovering mobulid populations thrive in a healthy and diverse marine ecosystem.

Cetacea Lab
Words by Hermann Meuter

INSIDE STORIES

The remark

Springer (A73) is an orca of the northern resident community that inhabits the waters off the coast of British Columbia, Canada. She was born in 2000 and is the daughter of Sutley (A45), a member of the A4 pod.

In the summer of 2001, Sutley and her young calf were not seen with the rest of her pod in its summer feeding grounds off northern Vancouver Island. Since we know that northern resident orcas don't travel away from their pod at any time, we presumed that both mother and daughter had perished during the previous winter.

Then, in January 2002, a young female orca was found alone in Puget Sound near Seattle in the USA. She was in a poor condition: emaciated and with skin parasites as well as ketosis, a sign of starvation. It took some time, but eventually researchers were able to identify her as Springer. So this young orca was all by herself, 400 kilometres (250 miles) from the rest of her family, in waters unfamiliar to her and becoming habituated to boats and humans. She was also sick and unlikely to survive on her own. What was to be done with this orphan that, if reunited with her family, could become an important member of a threatened species?

After weeks of consultation between US and Canadian authorities, the captive whale industry, NGOs and concerned members of the public, including First Nations, a rescue plan was put forward to the US National Marine Fisheries Service. Its aim was to try to reunite Springer with her family. She was transported from the harbour where she was found to a floating pen in the ocean, where she was kept away from the public and fed live fish to gain weight. The young orca turned out to be willing to play her part in the plan, fighting for her chance to get back to health. She ate between 18 and 23 kilograms (40 and 50 pounds) of fish a day and her health improved rapidly.

In line with the rescue plan, Springer spent a month getting stronger in the pen before being loaded into a small pool atop a catamaran and transported hundreds of kilometres up north to a holding pen in her family's home waters in Blackfish Sound, British Columbia. The timing could not have been better: on 14 July 2002, after she'd been there only one day, her family arrived in the area and she made acoustic contact with them. Now she knew that her relatives were nearby.

The two-year-old became very excited and it was clear to everyone involved in her rescue that Springer had to be released immediately. As soon as the net was opened, she headed straight for her family. Although it took them a few weeks to determine just where she would best fit into its ranks, the reunion was a big success! At first the young orca was still drawn to boats and humans, but after a while her family taught her to keep her distance.

Winter months can be very harsh for young orcas, even within the strong embrace of family, and it is known that almost 50% of them will not survive the first two years of life. Researchers and public alike were concerned that Springer would not make it through the winter of 2002. But she did!

In the summer of 2003 she was first sighted in the waters around Cetacea Lab and she was in the company of her aunt's family, the A35s. We were thrilled, and very happy to share the news with the people of British Columbia who had become so fond of this young whale.

In the years that followed, Springer became an important member of her community and we at Cetacea Lab always looked forward to her return to the coast of British Columbia in early spring, when she and her family would feed on Chinook salmon as their primary source of nutrition.

Then, in May 2013, Springer arrived in Whale Channel with her own offspring. We couldn't believe our eyes when we first saw the tiny whale next to her, but felt incredibly happy for the young mother and the rest of her strong family. We decided that 'Spirit' would be a fitting name for that newborn miracle. Once again, the people of British Columbia responded very happily, with media reports about the birth of Springer's first calf making it onto the evening news on almost every television channel.

From then on we observed Springer very closely and watched as she proved to be an incredible mother, making sure that her young calf was at her side at all times. The calf is now a healthy young orca – and since early this year has been blessed with a sibling! Yes, Springer arrived this season with her second calf, proving beyond doubt that a wild whale can be reunited successfully with its family.

Perhaps one day, if she continues to produce calves, Springer might distance herself a little from the rest of her family to form her own matriline, adding to her acoustic repertoire a personal note that will identify her and her offspring and starting a new acoustic tradition within the northern resident community of orcas along the coast of British Columbia.

We at Cetacea Lab will certainly continue to follow the amazing success story of Springer and her young family for years to come and we will always be thrilled to give updates about her life within the community of wild orcas.

xable story of Springer

Photo by Lisa Spaven | Fisheries and Oceans Canada

When an orca calf loses its mother and is stranded 400 kilometres from its family, few would predict a good outcome. One particular such calf proved to be more resilient than most, however – and that helping human hands can turn a potential tragedy into a success story.

Rethinking False Bay's top predators

So you think you know which shark sits at the top of the food chain? No doubt when you hear the phrase 'the ocean's apex predator' one species rises to the top of your mind above the rest: the white shark *Carcharodon carcharias* – and deservedly so. There is, however, another species of shark, humbly lurking in temperate kelp forests worldwide, that is emerging as a rival to the charismatic white shark for the crown of top predatory shark in the waters of False Bay.

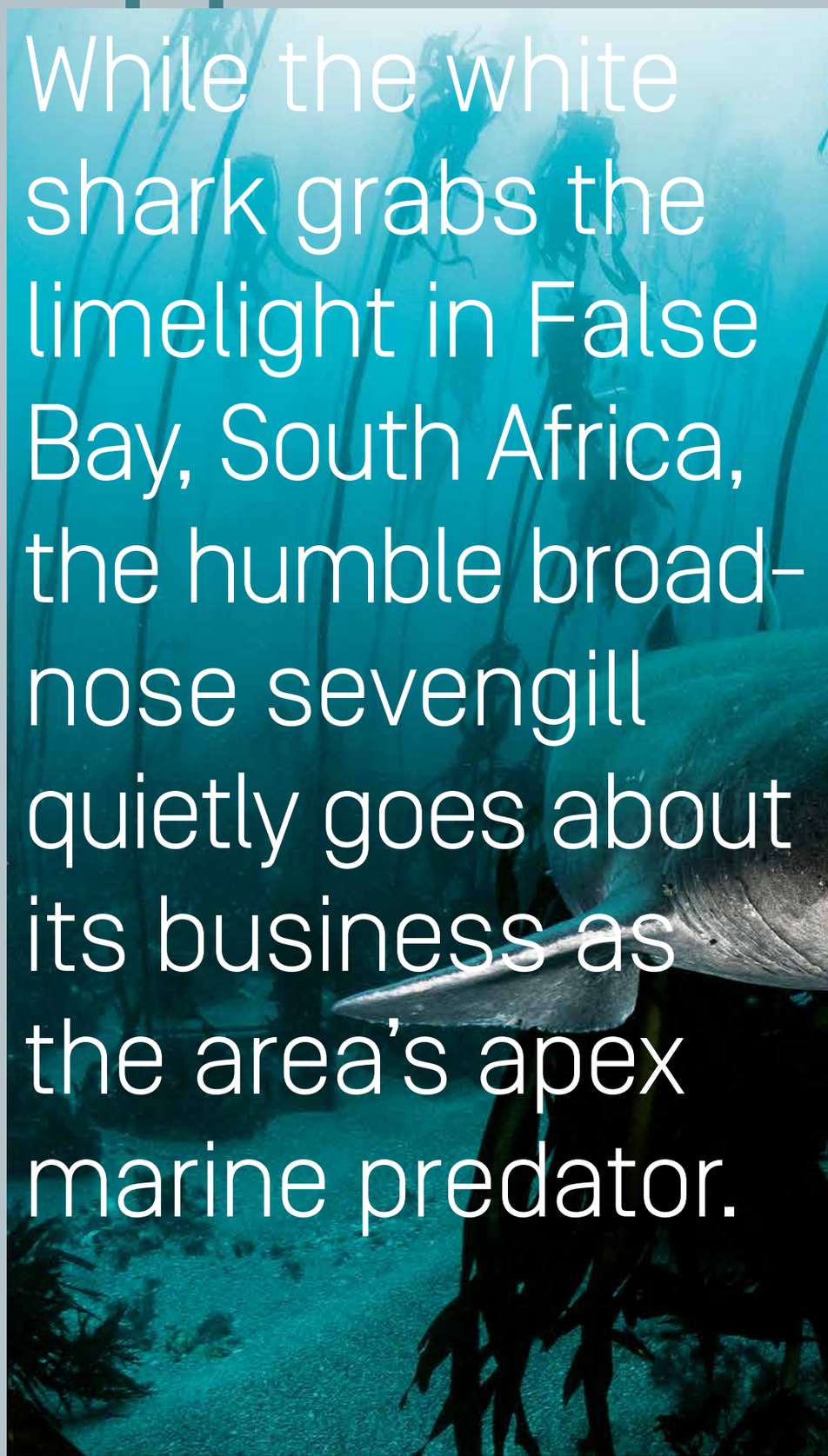
The broadnose sevengill shark *Notorynchus cepedianus*, also known simply as the sevengill or the cowshark, aggregates seasonally in the shallow water off Miller's Point, on the eastern side of False Bay. Its secretive and mysterious nature, coupled with its low conservation priority, means that there is little information about its ecology and it is therefore classified as Data Deficient on the IUCN Red List. For the past few years I have been studying sevengills in False Bay as part of my Masters degree. By investigating their diet and feeding dynamics, I hope to contribute valuable dietary data to the conservation and management of these enigmatic sharks.

Traditionally, stomach content analysis has been the most popular method used in research into the diet of sharks. It does, however, have a number of limitations, foremost of which is the difficulty of sampling large, living predators and getting out of their stomachs whatever may be inside them. Consequently, most stomach content studies have relied on lethal sampling methods – dead sharks – although they provide only a snapshot of an individual's diet. In addition, many sharks are captured with empty stomachs or unidentifiable prey items, which means that large numbers of sharks have to be caught to provide a representative diet for a given species. For threatened and protected species in particular, lethal sampling is not ideal.

An alternative, or complementary, method that addresses many of the limitations of stomach content investigation is stable isotope analysis, which is based on the premise that you are what you eat. A predator's stable isotope values reflect those of the prey it has consumed, so by comparing small tissue samples (no larger than the size of a little fingernail) from sevengills with those of their potential prey species, I was able to determine the sharks' prey preferences and the relative quantities of each prey species in their diet. This method also enabled me to gather integrated information about the long-term diet of sevengills (what they had been eating for the two to 24 months before the sample was taken), as well as reveal the position the sevengill holds in the food web relative to other predators, the white shark in particular, and relative to their various prey species.

My study analysed a total of 39 muscle samples (33 female, six male) and 28 blood plasma samples (25 female, three male) collected from sevengill sharks between 2013 and 2015, all of which were safely sampled, tagged and released alive. These were compared with muscle samples from 161 prey samples from 32 different marine species. Additionally, seven white shark samples were analysed for further comparisons with those of sevengills in order to understand the feeding dynamics between the two top predatory sharks in False Bay.

My research found that sevengills in False Bay appear to feed predominantly on a variety of coastal prey species. Inshore



While the white shark grabs the limelight in False Bay, South Africa, the humble broadnose sevengill quietly goes about its business as the area's apex marine predator.

Shark Spotters
Words by Leigh de Necker

Photo by WildestAnimal | Shutterstock

INSIDE STORIES

chondrichthyans (sharks, skates and rays) were found to be their favourite food items, with Cape fur seals and inshore teleost (bony fish) species also being important. The sevengill is therefore considered to be a generalist species, as individuals consume a variety of prey items from a variety of habitats. Diet is often regarded as a species' trait, but as apex predators that occupy areas with abundant prey resources, sevengills may be 'picky' when deciding what they eat. We identified variability in the feeding patterns of these sharks, suggesting that individual specialisation may take place to some extent, whereby certain individual sevengills will choose preferred prey items from the False Bay menu that are different from the selection of others.

Interestingly – and unexpectedly – there was significant variation in diet between mature and immature female sevengills, with the smaller sharks having a higher proportion of Cape fur seals in their diet relative to the mature females. This was in contrast to previous studies conducted on the stomach contents of sevengills (Ebert 1991), which found that larger and more mature sevengills ate more mammal prey than their smaller, immature counterparts. It is possible that the abundant opportunities to scavenge on seal pups around Seal Island in False Bay provide immature sharks with access to this resource, whereas mature sharks may be restricted to coastal waters away from seal colonies for reasons that are related to reproduction.

Overall, however, the proportion of seal in the diet of sevengills is too high to be attributed solely to scavenging. Little is known about the species' ability to actively catch live seals – sevengills are thought to feed at night, which makes it challenging to observe their hunting behaviour. It is especially difficult to compare its ability to that of a species like the white shark, which is known to hunt live mammal prey successfully. However, there is no doubt that the sevengill is a top predator and therefore its importance in the False Bay ecosystem cannot be disputed. In fact, my research puts the sevengill in a higher position than the white shark in the food web. This result mirrors that of a previous study (Cortés, 1999), which placed the sevengill in the highest position in the food web relative to the 149 shark species compared in the study, including the white shark. This may be due to the fact that sevengills consistently feed on seals, possibly all year round, whereas white sharks move between habitats and only feed on seals seasonally.

This is the first study to use stable isotopes from the muscle tissue and blood plasma of sevengills to gain insight into the species' diet and relative position in the food web within False Bay. The results confirm that the sevengill shark is an apex predator and a generalist that feeds on a variety of prey items across diverse habitat types. Stable isotope research such as this provides a better understanding of a species' role within the ecosystem, which is vital for determining conservation and management strategies for sharks.

When this work is mirrored by efforts on the sympatric white shark, the opportunity to explore the trophic and ecological role of top predatory sharks in a coastal bay will become an important milestone in shark ecology.

Nursery grounds are important habitat for nearly all species. Locating such areas for wide-ranging animals can be difficult, especially in the marine environment where observing individuals is challenging. Within that environment, elasmobranchs form a group of approximately 1,000 members, which is relatively small compared to the more than 28,000 species of bony fish. Yet small though it may be, this group displays the most diverse means of reproduction: some members lay eggs, others give birth to live young – some even produce offspring by a combination of both. Skates deposit egg cases on the sea floor, sand tiger *Carcharias taurus* pups consume other embryos within the uterus, and lemon sharks *Negaprion brevirostris* are born with a placental connection to the mother similar to that of humans. Significantly, though, elasmobranchs produce relatively low numbers of offspring, which can be problematic for conservation efforts. Therefore it is important to understand their reproduction and the role it plays in their daily lives.

Advances in technology are providing non-invasive methods for assessing pregnancy; ultrasonography, for example, has been used for decades with humans. Incorporating this technology into shark research enables scientists to learn more about the reproductive attributes of individuals. This new information can be included in movement studies, population assessments and estimates of rebound potential.

Since the inception of the Bimini Biological Field Station (also known as Shark Lab) in 1990, our team has periodically encountered large female sharks with distended, rounded bellies. Most have been in the shallow-water long-line survey that we conduct each month, but some we have come across while scuba diving. Whenever these exciting moments occur, there's one question that pops up in everyone's mind and it quickly turns into a conversation on the boat or back at the lab: 'Was that big female shark pregnant?' 'She must have been,' comes the reply. 'She was huge and her belly was prominent, possibly even moving. I'm sure she was shaped differently to a shark that has just fed!' At least sharks are not offended by our suggestions!

Yet although our team was quietly confident that many of the big momma sharks it had encountered in the past were indeed pregnant, we had no way of confirming or proving it. This is, of course, a major problem for scientists, as we typically rely on several lines of evidence to convince colleagues and journals of our findings.

By a stroke of good fortune, in 2007 an expert in animal ultrasonography, who was working on a TV series called *Into the Womb*, visited the Shark Lab and used a field ultrasound to confirm the pregnancy of a huge adult lemon shark. This was a fascinating experience for the team and an important first insight into this developing technology. But it took another decade – in fact, until earlier this year – before we finally got our hands on a unit for daily use in our research. E.I. Medical, a leading manufacturer of ultrasound equipment, generously donated one of its machines for our use. This past year has been a steep learning curve with some exciting moments, one of which is described by the Shark Lab's director, Dr Tristan Guttridge.

In the field with tiger sharks

From tadpoles to giants: each year our team catches tiger sharks that range from newborns to huge adult females with war wounds aplenty. It is this combination of captures at both ends

Bimini Biological Field Station

Is it a boy, is it a girl?

Written by Matthew Smukall and Tristan Guttridge

Sharks tend to keep their reproductive secrets close to their belly, which is why giving a tiger shark an ultrasound examination was such an amazing experience for the Shark Lab team.

of the life spectrum that has often made our team wonder whether tiger sharks give birth in the shallow flats that surround Bimini's islands. Could this habitat be an important nursery area for young pups, or perhaps a feeding ground for gestating mums? Although we've often been convinced that we've caught a pregnant tiger shark, we've never been able to produce the evidence – until one calm, humid dead of night in May this year. The shadow was distinctive, with a broad, thick back and head, and the powerful tugs on the line were characteristically slow, yet purposeful.

'She's huge!' I exclaimed, the nerves setting in. 'She looks pregnant!' The moments between knowing that you have a very special animal to work with and making it secure always last an age. But this time, to my surprise, we placed our ropes on her tail and pectoral fins with minimal fuss and finally that moment we had all been waiting for arrived: our team got to ultrasound a huge female tiger shark!

My eyes were glued to the portable ultrasound screen while Matt began our pre-determined recordings, starting at the centre of the pectoral fins and slowly moving the probe towards the pelvic fins. He completed five passes, one down the centre and two along either side, giving us an important overview of the shark's reproductive tract.

I desperately wanted to say, 'Yes, she's pregnant', but my untrained eyes and the relatively fast passes made it tricky for me to discern the outline of a tiger pup or see any distinctive structures that would indicate pregnancy. Unlike other viviparous species like blacktip and lemon sharks, in which the pups lie in the same direction as the mother, tiger shark pups lie perpendicular to her in the uterine horns. This means that in theory one of the pups could be facing outward and have its mouth close to the female's body wall. Having completed the standard passes for later review, Matt focused his attention on finding a pup to obtain a close-up. By carefully moving the probe while keeping an eye on the ultrasound, he managed to locate one opening and closing its mouth – wow!

It is almost impossible to describe the team's feelings at seeing an unborn shark for the first time: there was great elation and delight, and a little relief that our long-time hypothesis had finally been confirmed. There was, however, also a sudden and very real sense of urgency and responsibility that swept across us all. Attached to the side of our 20-foot (six-metre) skiff in the middle of the ocean was a 15-foot (4.5-metre) tiger shark, probably only days away from giving birth to perhaps more than 60 next-generation pups ready to see the outside world.

Excitement and emotion aside, the scientist in us came to the rescue and took control. In record time we took measurements (length and girth) and samples (such as blood and fin clip) before finally inserting an acoustic tracking device to monitor her local and broad-scale movements. Within a few minutes she had swum off into the dark to cheers, whoops and applause! It was a truly remarkable experience for our team, but more importantly, our success marked the start of an exciting new journey for us as we learn more about the reproductive secrets of these highly mobile and threatened animals.

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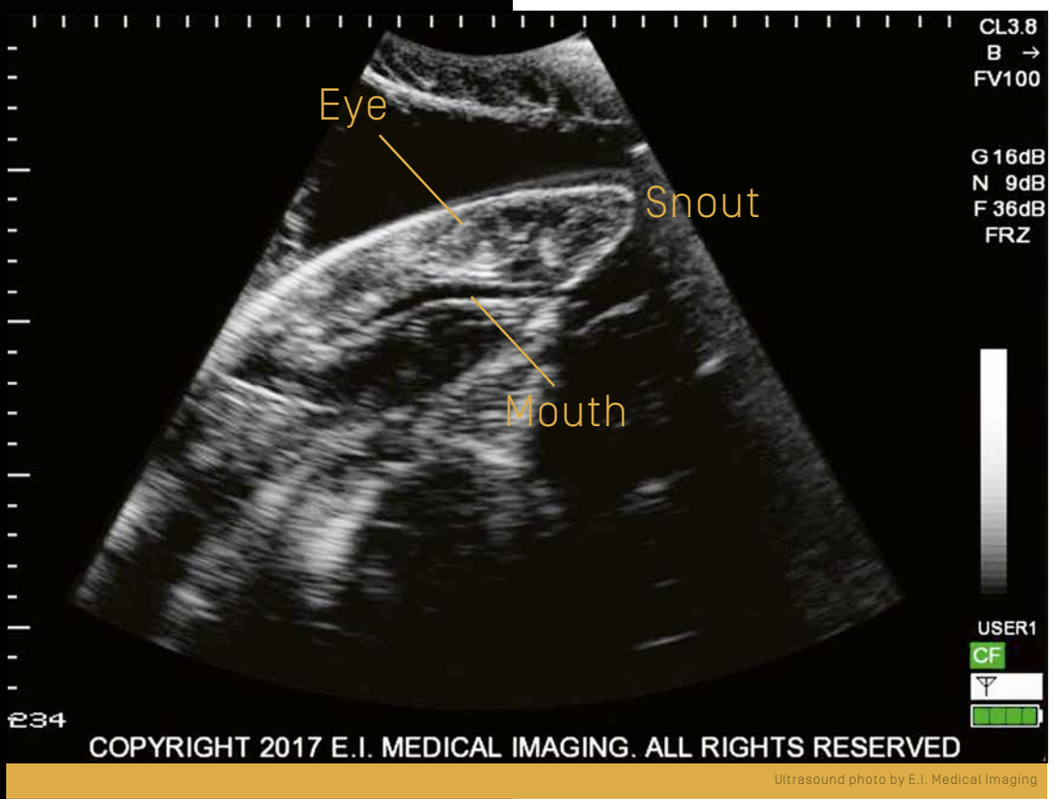

Ultrasound photo by E.I. Medical Imaging

Photo by the Bimini Biological Field Station

Save Our Seas Shark Research Center

Shark tracking and fisheries-independent assessments

Words by Jeremy Vaudo

Satellite tracking has, quite literally, opened up a new world for shark scientists, enabling them to achieve independence from data supplied by fisheries – data whose value, for a number of reasons, is limited.

Where do sharks go and when? What areas do they use? These are important questions for understanding the role of sharks in ecosystems because the answers will tell us when and where sharks are going to influence their prey populations. Answering these questions is also important to the conservation and management of sharks because it allows for the designation of critical habitats, such as nursery grounds, that can be protected.

But how do we figure out where the sharks are and where they go? It turns out fishers can be very helpful in this respect. Let's face it, fishers on the whole, whether commercial or recreational, are very good at catching fish. In fact, fishers often know the hotspots for a given species before biologists do, and we biologists often use this information to pick our study sites and species. So by working with fishers, we can learn where, when and how often they catch sharks, and then design appropriate studies to research the movements of the sharks and their encounters with fisheries. Talk to enough fishers over a large enough area and get enough conventional identification tag recaptures and there's a good chance that you can piece together a general migration picture. For example, in shortfin mako sharks in the western Atlantic Ocean, we see a northward progression of fisheries captures from the mid-Atlantic Bight in the USA to the Grand Banks off Canada as the seasons change from spring to autumn. Presumably, the sharks are following the warm waters north.

Data of this type are called fishery-dependent data because they are collected directly from commercial and recreational fisheries. Although they are extremely useful to biologists, they do have some drawbacks. Not only are we are at the mercy of the fisheries, but data collected in this manner are not standardised. Many fisheries are not targeting sharks, so depending on their target and local regulations, the gear, bait types and time of year spent fishing can differ between fisheries. The fishing locations also reflect the best places to catch the target species, not necessarily where the sharks we are studying are. So when it comes to shark movements and habitat use, fishery-dependent data can tell us that sharks are in an area where they are being caught, but the lack of capture information for an area during a given time of year doesn't necessarily mean the sharks are not there. The lack of captures for an area could be because no one was fishing there. And even if sharks are being captured in a certain area, that may not be the best place to catch them for studies.

Although fishery-dependent data are certainly useful and can provide broad insights into potential fish movements, the biases that come with them make it difficult to answer fully questions about the details of shark movements and habitat use. What we need are additional sources of data that are not dependent on fisheries – we need, in fact, fisheries-independent data. One way for scientists to collect such data directly is to conduct fishing surveys themselves in a standardised scientific format. But because of all the fishing effort needed, these methods can be very labour intensive and therefore costly. And it is still possible that sharks, being highly mobile, may leave the survey area.

So how can we figure out where wide-ranging shark species are going in a way that is independent of fisheries and yet also provides the detailed information we need? If only the sharks could tell us! But it turns out that they can – by using a technique called satellite telemetry. This method makes use of specialised tags that can 'talk' to satellites, essentially saying, 'Hey, I'm over here!' The location of the shark can then be relayed back to researchers sitting in front of their computers in their comfy offices. It's just like a tracking device you'd see in a spy movie. After the shark has been tagged, it will tell us where it is for as long as the tag's battery lasts;

we don't have to recapture the shark, so we have achieved fisheries-independence!

At the Save Our Seas Shark Research Center in Florida, USA, in collaboration with the Guy Harvey Research Institute, we've been using satellite telemetry to study the movements and habitat use of several highly mobile shark species. As a result, we've observed a lot of really neat behaviour that could not be perceived using fisheries-dependent methods. We have learnt that some tiger sharks, which were thought to be a coastal species, actually spend half the year swimming out in the open ocean. Why did it take so long for scientists to realise that this species, which is large and well known, spends so much time far out to sea? There were limited records of tiger sharks caught offshore in fisheries, but really it comes down to the fact that no one was looking for tiger sharks in the open ocean – which just goes to show the importance of fisheries-independent data.

But it was during our shortfin mako satellite telemetry project that we found a new use for our fishery-independent data. The study started off as expected: mako sharks were moving out into the international waters of the open ocean and ultimately passed through the management jurisdictions of 19 countries. But it wasn't long before sharks started telling us they were on land – they had been caught. Overall, 12 of our 40 satellite-tagged mako sharks (30%) were caught. Mako shark meat is valuable and although these sharks are not typically targeted by commercial fisheries, they are kept when they are caught. We had come across a fishery-independent way of determining a very important piece of information critical for improving stock assessments: the fishery mortality rate for mako sharks. The bottom line is that with this satellite tracking approach, we could tell which of our sharks had been caught without depending on the fishers to let us know.

Estimating fishery mortality is a key part of fisheries management. It tells us how much of the stock is being caught, which we need to know to determine whether it is growing or shrinking. Up to now, these estimates were always based on fishery-dependent data, which are largely reliant on self-reporting by fishers. We now had an independent assessment of mako fishery mortality rates – and it was striking. We calculated that a mako shark had a 72% chance of not being harvested in a fishery per year. Additionally, our estimate of fishery mortality was about 10 times higher than the previous estimate from 2012, which was based on fishery-dependent data. This new estimate suggested that mako sharks, which currently lack international protection in the western Atlantic, are being overfished. Since the publication of our work earlier this year, a new fishery-dependent stock assessment conducted by the International Commission for the Conservation of Atlantic Tunas (ICCAT) has corroborated our fishery-independent assessment. Our study and this example demonstrate the usefulness of satellite telemetry for independently assessing fishery mortality, especially in shark fisheries where it is difficult to get accurate fishery-dependent data.

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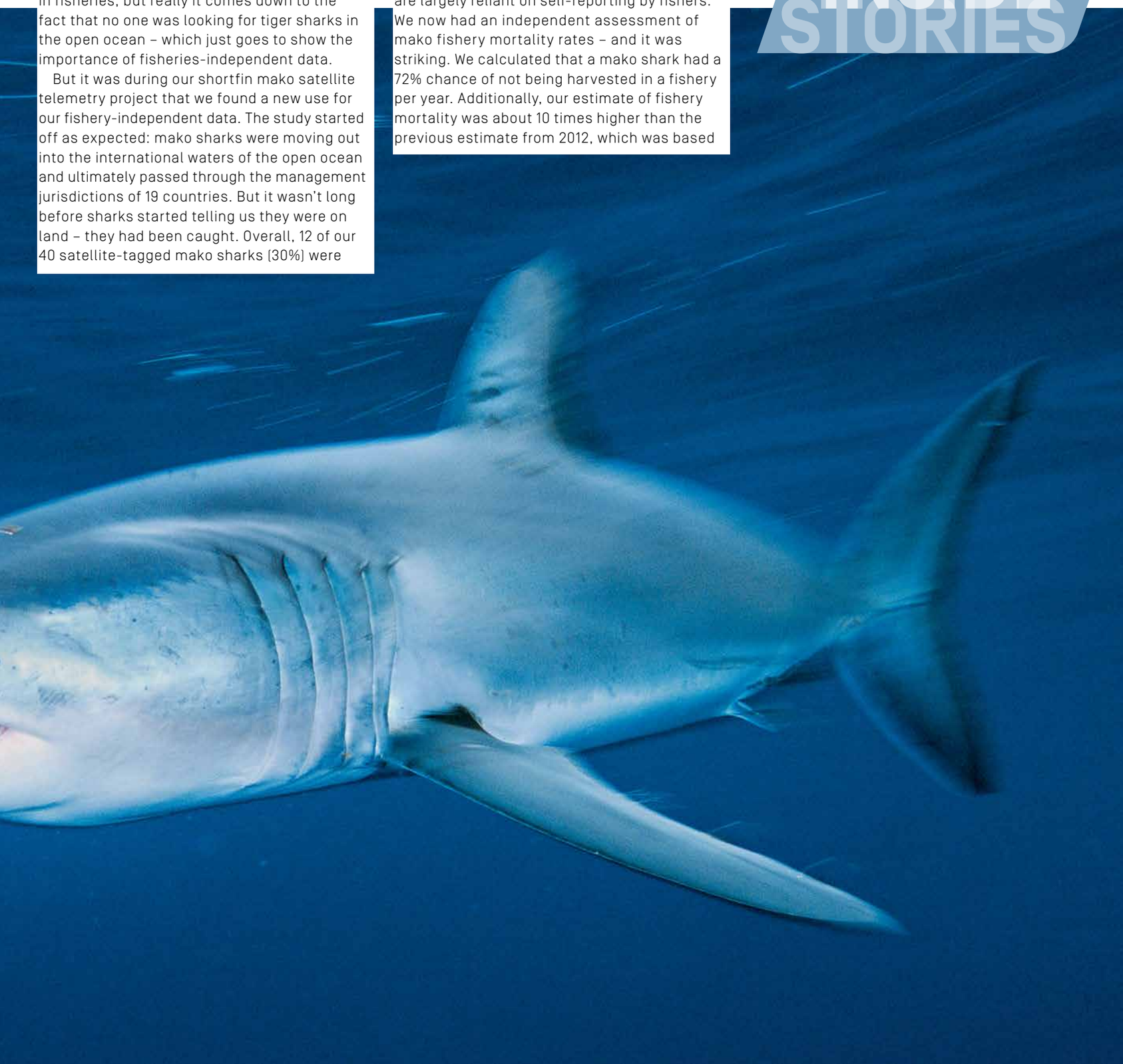

Photo by Brian Skerry | National Geographic Creative

next issue

Being invisible may be an angel shark's most prominent talent. But unseen by predators and prey, it has also to a large extent been invisible to researchers and conservationists – except in the Canary Islands. In this issue we showcase the Angel Shark Project and its efforts to conserve these species across their wider range.

Photo by Michael J Sealey

Dive in with the *Save Our Seas* magazine on a digital exploration of the world's oceans, voyaging with marine scientists and conservationists who share the latest insights, news and innovations. You can find all our magazine stories on our dedicated website, *SaveOurSeasMagazine.com*, as well as access to exclusive web content that includes interactive features, videos and unpublished images. Catch up on the latest in shark science on the go, with handy access to the magazine from your tablet or phone on *issuu.com* or *zinio.com*.

ABOUT THE SAVE OUR SEAS FOUNDATION

A commitment to protecting our oceans and their rich biodiversity is at the heart of the Save Our Seas Foundation's (SOSF) work. In a bid to achieve this, the foundation offers funding and support to research, conservation and education projects around the world that focus primarily on charismatic, threatened marine wildlife and its habitats. From its origins as a small not-for-profit organisation, in less than 15 years the SOSF has grown from funding just five projects to supporting more than 300 worldwide. It functions not as a research institute itself, but strives to sustain the many and varied efforts of scientists, conservationists and educators through generous contributions of financial, practical and scientific support. The SOSF is proud to form part of a growing and committed community of ocean stewards and, through its work, to help shape a sustainable future for our seas.

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

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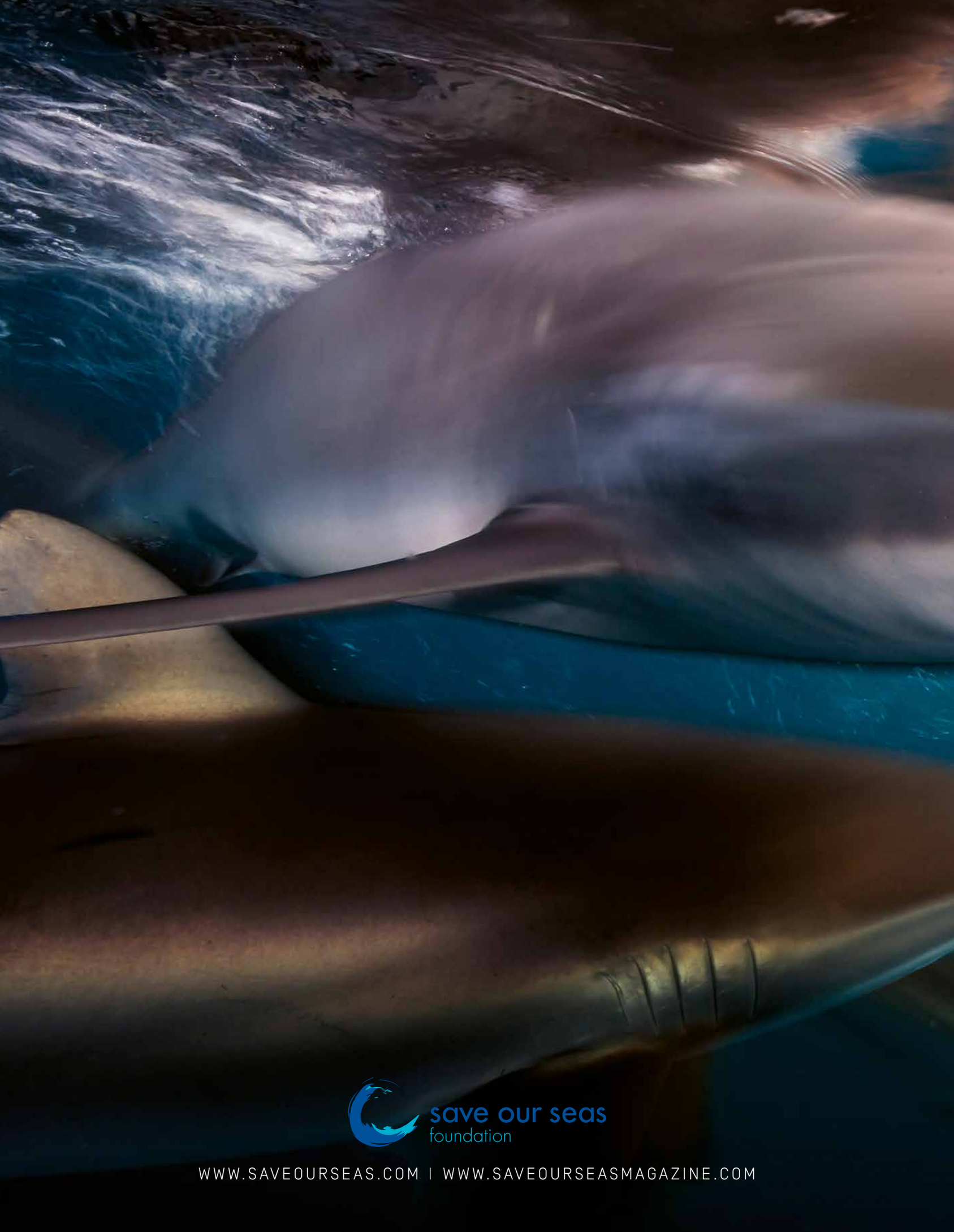

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