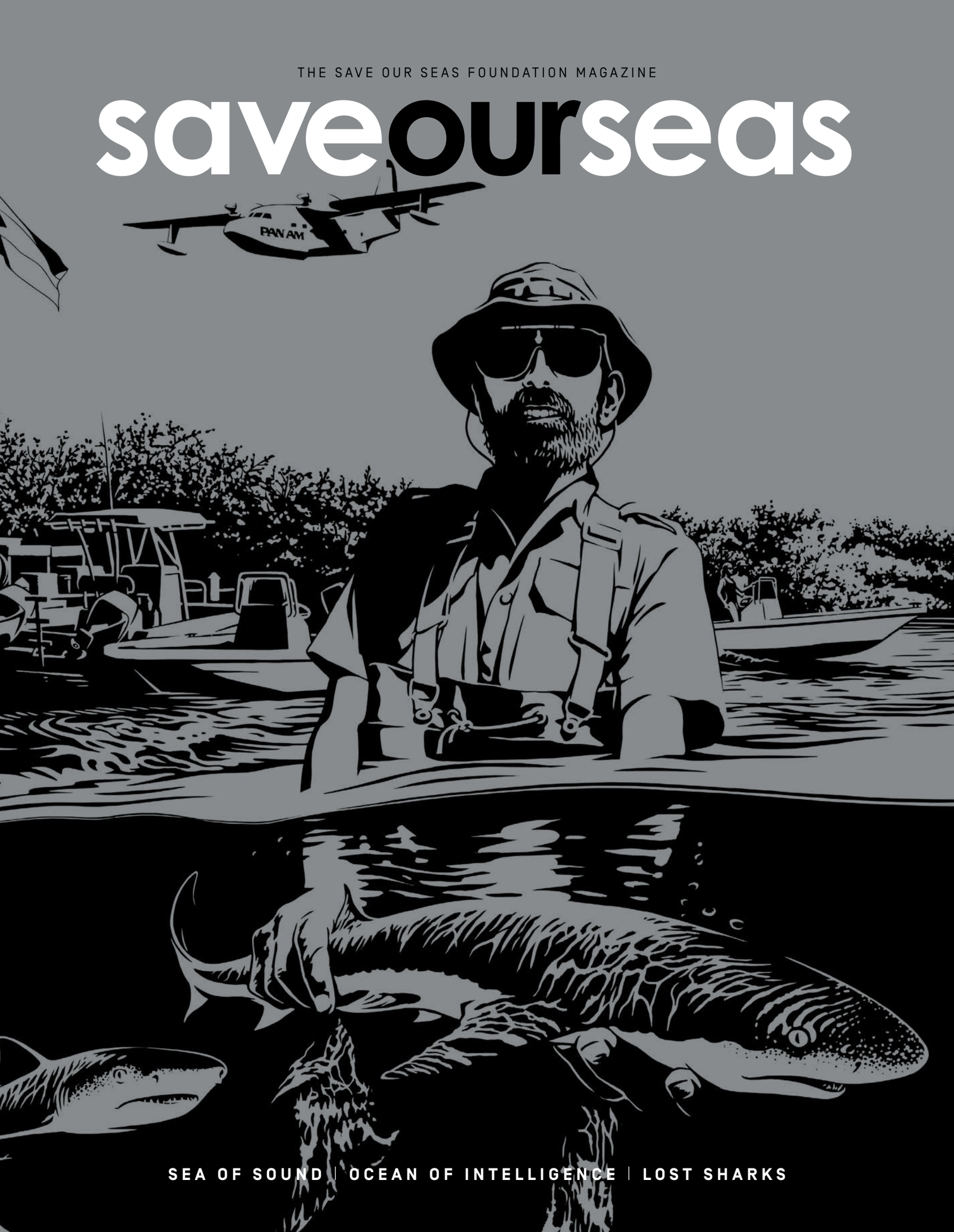
THE SAVE OUR SEAS FOUNDATION MAGAZINE

saveourseas



SEA OF SOUND | OCEAN OF INTELLIGENCE | LOST SHARKS

Alasdair Harris

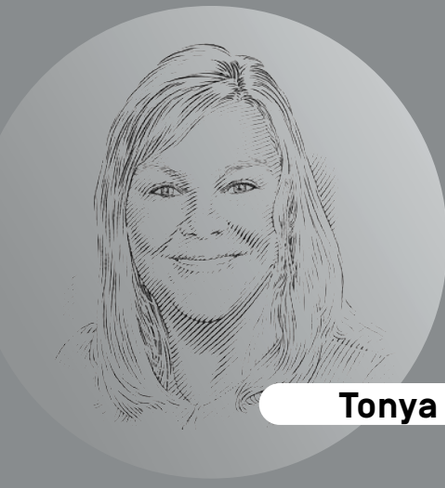
With a PhD in marine ecology and an honorary Doctorate of Sciences from the University of Edinburgh, one could have forgiven Alasdair Harris for staying in academia. Instead, the founder of Blue Ventures is motivated by making marine conservation make economic sense to coastal communities. His organisation is rooted in practical approaches to empowering communities to lead locally relevant ocean protection measures. A TED and Ashoka Fellow and the 2015 Skoll Award winner for social entrepreneurship, Alasdair oversees a team of some 230 colleagues in the world's poorest countries, where food security and economic stability underpin conservation buy-in.

Ruth Leeney

Ruth Leeney is the founder and director of Protect Africa's Sawfishes, which she established in 2012 to address the lack of information about sawfish populations in low-income countries. Since then she has conducted baseline studies on sawfishes in nine countries and has collaborated with or supported researchers and NGOs in another four countries around the globe. She is committed to the effective communication of research findings and conservation messages to diverse audiences and to developing realistic conservation approaches by engaging with communities. She is fascinated by the links between humans and the natural world in traditional cultures. Ruth is a scientific associate at the Natural History Museum, London.

Haley Pope

Haley grew up as an intercontinental child frolicking through Malaysia, Chile, South Africa and the USA, where she developed a passion for discovery and a desire to protect nature. She earned her Bachelor's degree in biology from Elon University in North Carolina, USA, and an MSc in zoology, focusing on marine ecology, from Stellenbosch University in South Africa. Currently, Haley is the president of TerraLens Photography LLC. She provides photography, photo archiving and science writing services to conservation-minded companies. She's a contributing writer for the North American Nature Photography Association and leads international trips for Habitat for Humanity's Global Village programme.



Tonya Wiley

Tonya put her passion for sawfishes into action when she founded Havenworth Coastal Conservation in 2010. Through this organisation she combines research, outreach and education to champion the protection of endangered marine life. Tonya holds a BSc in marine fisheries from Texas A&M University and has been employed by the Coastal Fisheries Division of Texas Parks and Wildlife Department as a marine finfish hatchery technician, ecosystem management technician and fisheries outreach specialist. She has also worked for the Mote Marine Laboratory's Center for Shark Research on the Sawfish Research Project. Now based in Tampa Bay, Florida, Tonya's infectious love of the ocean keeps her working as part of the Sawfish Recovery Team.

Dr Samuel H. Gruber
(May 13, 1938 – April 18, 2019)
holding one of his juvenile
lemon sharks in front of the
Bimini Biological Field Station's
Shark Lab in Bimini, Bahamas
Artwork by Gregory Gilbert-Lodge ©

Photo by Tui De Roy | Minden Pictures | BiosPhoto

CONTENTS

002 **FOUNDER'S NOTE**
004 **WHERE WE WORK**
006 **EDITORIAL**
012 **OCEAN VIEW**
020 **FROM THE FIELD**
022 **THE RAY THE WORLD FORGOT**
126 **INSIDE STORIES**
142 **IN CONVERSATION**

044 **A SEA OF SOUND -** PART 1
FINDING A VOICE IN THE OCEAN
To really understand the lives of the sea's most sophisticated singers – cetaceans – you need to listen. That's what Janie Wray from the North Coast Cetacean Society and her colleague Ben Hendricks do. Speaking to them about the Fin Island hydrophone project and the emerging field of acoustic science, Lauren De Vos discovers that much can be learned from listening to whales and that sound might connect us to a more profound appreciation of the creatures of the sea.

058 **A SEA OF SOUND -** PART 2
THE CONDUCTOR'S CONUNDRUM
The sound dial is being turned up in the oceans and human activities are competing with marine life to be heard. As shipping, seismic surveys, drilling and oil exploration venture ever further, new science is needed to support conservation planning and manage sonic real estate. Lauren De Vos learns from Ben Hendricks how mathematical algorithms and a novel arrangement of underwater listening stations can help scientists identify which whales are calling, where and why. The research may help to mitigate future conflict as ships and whales share the seas' pathways.

068 **SAWFISHES IN TRADITIONAL TALES**
Understanding our present, and navigating the future, often means searching our past. There are clues about sawfishes in the cultural connections that hint at what these sharks meant to different people around the world. Ruth Leeney and Matthew McDavitt explore what the different expressions of these enigmatic, Endangered species mean in art, ceremonies and legends across the oceans.

076 **AN OCEAN OF INTELLIGENCE**
Manta rays that recognise themselves in the mirror and octopuses that use tools to disguise themselves from predators and prey... Sharks that store long-term memories and dolphins that cooperate with fishermen to net a meal... Haley Pope explores how our understanding of intelligence in the ocean is starting to change and questions what this might mean for how we view its inhabitants. To what extent does our enlightenment about the sea change how we treat it?

092 **TURNING THE TIDE FOR MANTA AND DEVIL RAYS**
A glimmer of hope in ocean conservation, The Manta Trust has seen some important achievements in the course of its eight-year existence. As head of strategy, Isabel Ender explores what's worked for the NGO and what this means for protecting manta populations around the world.

106 **WILL YOU STAY OR WILL YOU GO?**
The comings and goings of great hammerhead sharks is the subject of a publication by Tristan Guttridge, former director of the Shark Lab. Answering the question of where these sharks go and how often they return is information vital to better managing populations of this endangered species. In the waters of Bimini, The Bahamas, Lauren De Vos traces the pathways of a shark called Gaia as it helps scientists understand how to better protect it and its kind.

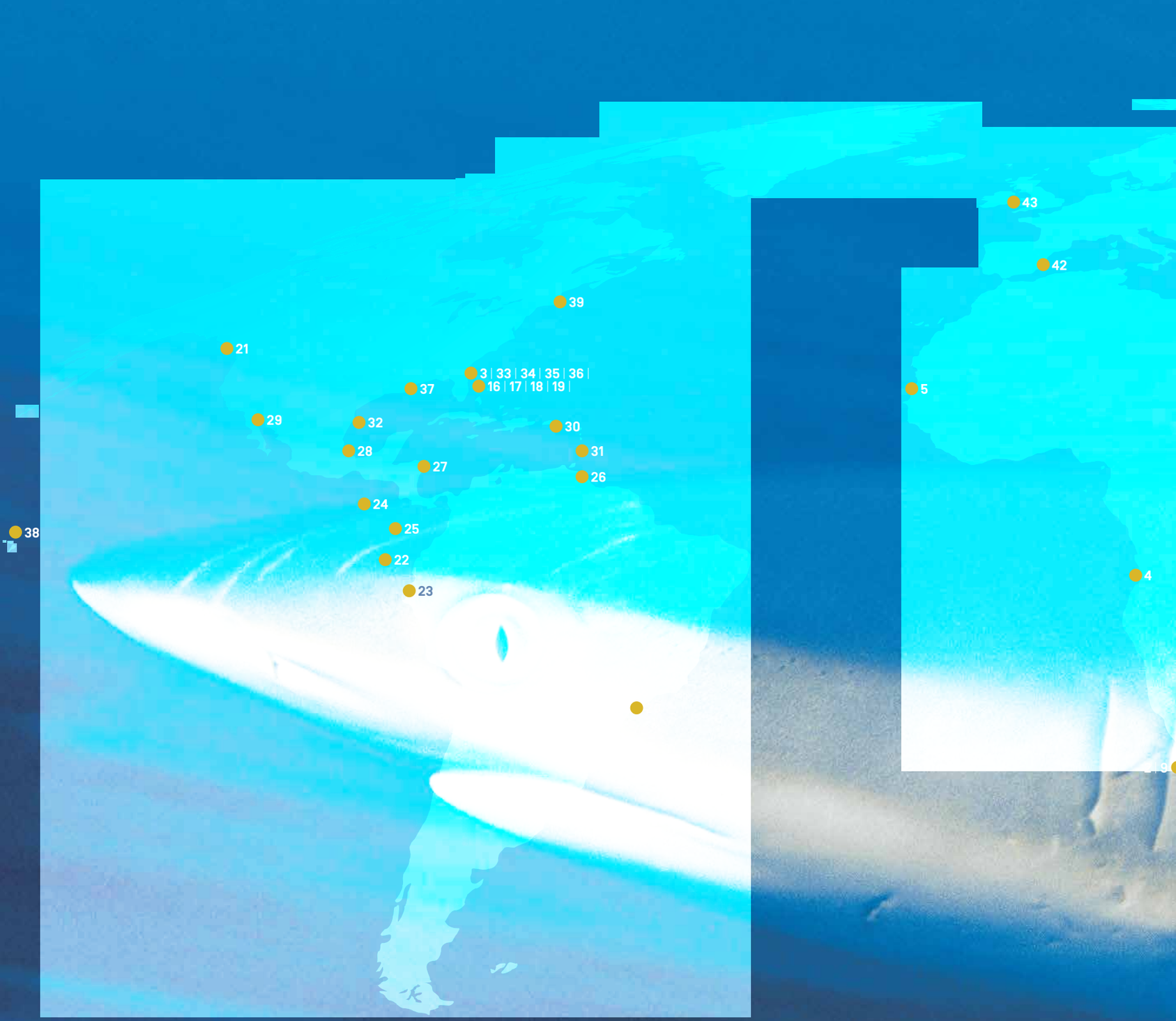
112 **CAN SOUND SCIENCE HELP REEFS?**
Tuning in to the cacophony on coral reefs gives new insights into how their different inhabitants navigate, feed, find mates – and make their way to a reef to settle in the first place. Bio-acoustics, as this field of science is called, is helping scientists to identify and understand healthy reef systems. Paul Caiger from Woods Hole Oceanographic Institution writes about the Coral Chorus project, a collaborative effort in the Virgin Islands that aims to show how the science of sound could help us protect reefs in the future.

122 **A SHARK BY ANY OTHER NAME**
The science of classifying life on earth is centuries old, but there are fears that it's a dying field. A scarcity of funding, little support and even less public interest haven't deterred Dr Dave Ebert from searching for the ocean's 'lost sharks' and he's discovered over 40 new species in his lifetime – and counting... Lauren De Vos interviews Dave about the state of shark systematics and what the future looks like for finding and describing new species.

AS LONG AS THERE ARE PEOPLE WHO CARE, WE CAN AND WILL MAKE A DIFFERENCE

THE FOUNDER
SAVE OUR SEAS
FOUNDATION

Photo by Thomas Peschak



Where we work 2019

The Save Our Seas Foundation was established in 2003 with a mission to protect our oceans by funding and supporting research, conservation and education projects around the world, focusing primarily on charismatic threatened wildlife and their habitats.

In that time, the foundation has sponsored over 300 projects in more than 50 countries, proudly supporting outstanding researchers, educators and conservationists who have contributed to the continued existence of more than 60 of our planet's precious marine species.

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

SOSF Centres

1 D'Arros Research Centre | Seychelles
2 Shark Education Centre | Clova Mabin
3 Shark Research Center | Mahmood Shivji

AFRICA

ANGOLA
4 Sharks and Rays | Ana Lucia Furtado Soares

SENEGAL
5 Sawfish Expedition in the Casamance River | Nigel Downing

SEYCHELLES
6 Turtles | Jeanne Mortimer
7 University of Seychelles | Terence Vel

SOUTH AFRICA
8 ATAP | Paul Cowley
9 Shark Spotters | Sarah Waries
10 White Shark Population | Dylan Irion

WESTERN INDIAN OCEAN
11 Guitarfishes and Wedgefishes | Dave Ebert

OCEANIA

AUSTRALIA
12 Rays | Kevin Crook
13 Sawsharks | Jane Williamson & Paddy Burke

PAPUA NEW GUINEA
14 Sawfishes | William White
15 Education Center | Jonas Müller

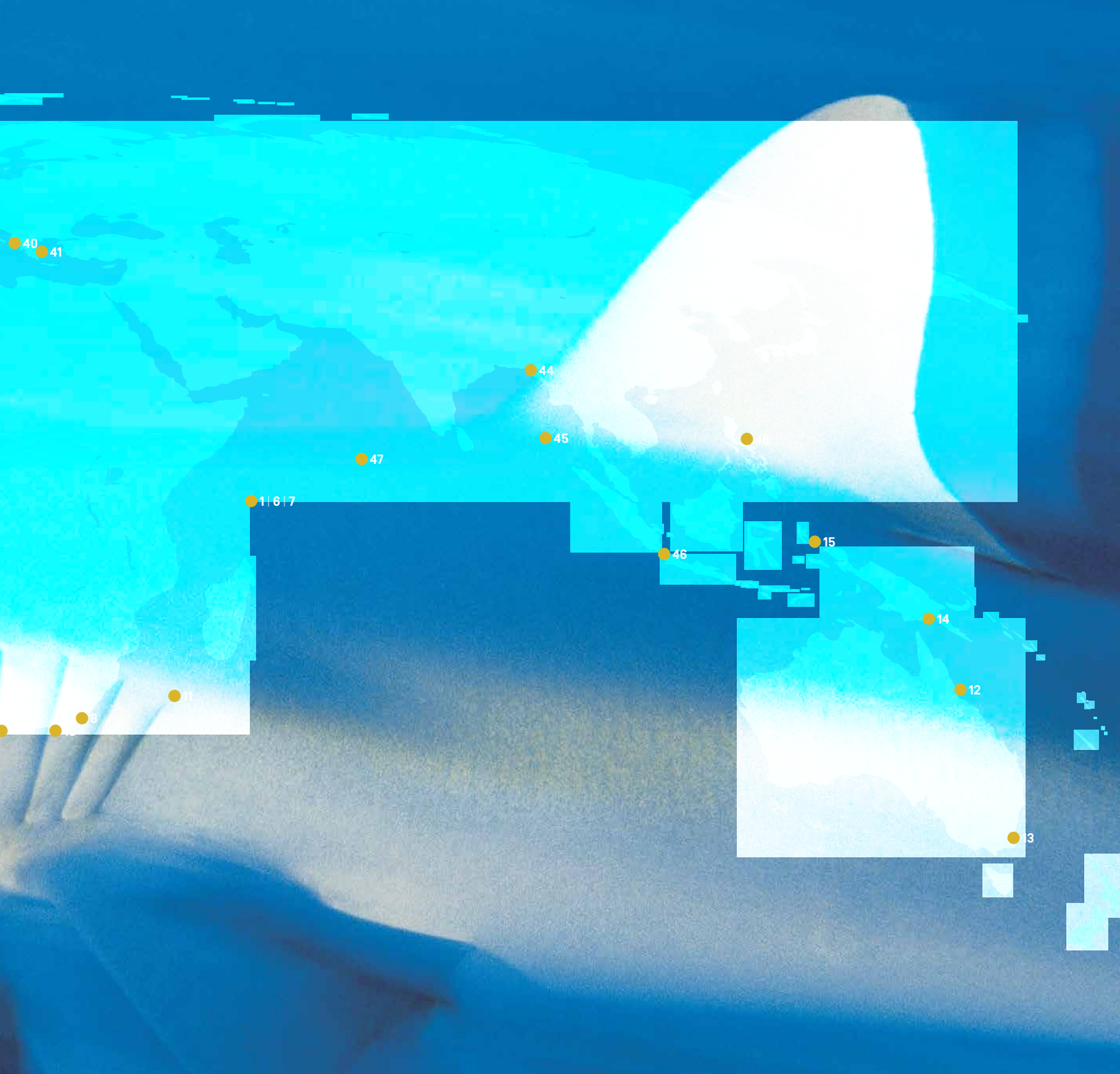
AMERICAS

BAHAMAS
16 Bimini Biological Field Station | Matt Smukall
17 Lemon Shark | Andria Beal
18 Lemon Shark | Evan Byrnes
19 Tiger Shark | Matt Smukall

BRAZIL
20 Guitarfishes and Angel Shark | Mariana Martins

CANADA
21 North Coast Cetacean Society | Janie Wray

ECUADOR
22 Darwin and Wolf Marine Sanctuary | Pelayo Salinas
23 Hammerhead Sharks | Kristy Shaw



EASTERN TROPICAL PACIFIC
24 Mobulids | Don Croll & Melissa Cronin
25 Mobulids | Josh Stewart

GUYANA
26 Sharks | Diego Cardeñosa

HONDURAS
27 Sharks | Gaby Ochoa

MEXICO
28 Sawfishes | Ramón Bonfil
29 Sharks and Rays | Luz Saldaña-Ruiz

PUERTO RICO
30 Sharks | Glorimar Franqui Rivera

SAINT VINCENT & THE GRENADINES
31 Sharks | Catherine Macdonald

USA
32 Blacktip Shark | Dominic Swift
33 Bonnethead and Bull Shark | Cheston Peterson
34 Great Hammerhead | Jill Brooks & Hannah Medd
35 Sawfishes | Tonya Wiley
36 Sawfishes | Gregg Poulakis
37 Sawfish Population Genetics | Nicole Phillips
38 Silky Shark | Derek Kraft
39 White Shark | Greg Skomal

EUROPE

ALBANIA
40 Sharks | Rigers Bakiu

GREECE
41 Batoids | Chrysoula Gubili

SPAIN
42 Spiny Butterfly Ray | Jaime Penadés-Suay

UNITED KINGDOM
43 Angel Shark | Jake Davies

ASIA

BANGLADESH
44 Sawfishes | Alifa B. Haque

INDIA
45 Sharks and Rays | Ravi Kumar

INDONESIA
46 Sawfishes | Dharmadi Dharmadi

MALDIVES
47 Microplastics | Alina Wieczorek & Giulia Donati

PHILIPPINES
48 Wedgefishes | AA Yaptinchay

WORLDWIDE

- Sawfish eDNA | Colin Simpfendorfer
- The Manta Trust | Guy Stevens
- White Shark Finprinting System | Michael Scholl & Benjamin Hughes

CONFERENCES, EVENTS & SPONSORSHIPS

- American Elasmobranch Society (AES) Conference | Snowbird, USA
- Eugenie Clark Award | American Elasmobranch Society (AES) | Snowbird, USA
- European Elasmobranch Association (EEA) Conference | Rende, Italy
- First Latin American Conference of Sharks, Rays and Chimaeras | Playa del Carmen, Mexico
- Musée de Zoologie – Exposition Disparus! | Lausanne, Switzerland
- Museum of Discovery & Science (MODS) - Great Bear Rainforest IMAX Film & Distinguished Speaker Series | Fort Lauderdale, USA
- Ocean 19 | Bristol, United Kingdom
- Oceania Chondrichthyan Society (OCS) Conference | Dunedin, New Zealand
- Southern African Shark and Ray Symposium | Cape Town, South Africa
- Swiss Long Distance Swimmer – Renato Munz | Switzerland
- World Conference of Science Journalists (WCSJ) | Lausanne, Switzerland

Photo by Paul Nicklen | National Geographic Image Collection

EDITORIAL

Photo by Michael Scholl

The Bahamas boldly proclaimed its territorial waters a shark sanctuary in 2011, after having pronounced a ban on long-lining in 1992. Tourism underpins the island nation's economy, generating about 60% of its gross domestic product and employing roughly 50% of its population. Shark diving contributes approximately US$114-million annually to the Bahamian economy, the majority of which is based on shark and ray tourism. With its continued stewardship and conservation measures targeted on sharks, The Bahamas, it seems, is a good place for these species. Unfortunately, the same can't necessarily be said for their cousins the rays, or for the important mangrove habitats that act as a natural barrier against erosion and hurricanes and represent crucial nursery grounds for many species of fish – they remain unprotected to this day. Yet although we see The Bahamas' bold action mirrored globally – the world's first national shark sanctuary was declared in 2009 by Palau, followed by 10 other nations in the past decade – only 7.59% of the world's oceans and 14.9% of the earth's land surface are protected to date. We have committed to many international conservation and sustainable development targets, but each and every one of us still needs to ask a more deeply personal question of ourselves: what world do we want to live in tomorrow and, more importantly, pass on to future generations?

As I am writing these lines on the small Bahamian island of Bimini, I have just learned of the passing of my mentor and dear friend Dr Samuel 'Doc' Gruber. Doc's life was one lived in an earnest interrogation of what kind of world he'd like to see: he spent his scientific career contributing to the ideal of tomorrow and empowering a generation of shark conservationists. This is evident in his actions: a pioneer in the field of shark research and conservation, he co-founded the American Elasmobranch Society in 1983 and founded the IUCN Shark Specialist Group in 1991. He dedicated his life to the better understanding of sharks through his research and he nurtured new cohorts of students through the establishment of the Bimini Biological Field Station's Shark Lab. This is where my own life with sharks started in 1995, 24 years ago to the day, on a course that was followed by an internship. Doc had two passions in his life: sharks and his family – his wife Marie and his daughters Meegan and Aya. He fought various cancers over the past 40 years, winning many of these battles against all odds, and I have looked up to him for most of my adult life. I will sorely miss our close friendship and lively discussions. The legacy of Dr Samuel H. Gruber will live on through all the people he has taught, with whom he shared his passion and who he empowered to lead as the next generation of shark conservationists.

Doc's passing is a reminder that while our lives might be fleeting, each of us has the capacity within our lifetime to create a world we're proud to leave behind. Shaping what that world might look like requires us to know more and act decisively, based on the best available evidence. The diverse stories collected in this issue represent just how much we're learning, and what we need to know to empower ourselves to make better decisions. We explore the complex world of sound in the marine ecosystem and the ever-growing impact our human activities have on its sensitive balance. We examine the cultural interpretations of sawfish around the world, contest that consciousness and intelligence aren't limited to human beings, search for undiscovered shark species and showcase the rays the world forgot.

Michael C. Scholl
Chief Executive Officer
Save Our Seas Foundation

A tribute to

Dr Samuel 'Sonny' H.

1938–2019

Dr Samuel ('Sonny') Harvey Gruber passed away at his home with his family by his side on Thursday, 18 April 2019 at the age of 80. A true pioneer and one of the most influential figures in shark science, Dr Gruber made contributions to elasmobranch research that cannot be overstated. Called simply 'Doc' by most who knew him, he broke new ground in the study of sensory physiology in sharks and over the course of a career lasting more than 50 years he published over 190 peer-reviewed papers on shark biology, ecology and behaviour, greatly advancing our understanding of these enigmatic creatures.

One of his greatest contributions to the field was the co-founding of the American Elasmobranch Society (AES) in 1983, along with California State University Long Beach professor Dr Don Nelson. The AES has become the largest professional society of elasmobranch scientists on the planet. Another major achievement, and the one that Doc was most proud of, was the establishment of the Bimini Biological Field Station (aka the 'Shark Lab') in 1990, which moved shark research forward through novel scientific findings and by serving as a conveyor belt of competent and passionate shark researchers.

Doc was born in 1938 in Brooklyn, New York, to Claire and Sidney Gruber. His love for the ocean and sense of connection to it emerged strongly when the family moved to South Beach in Miami, Florida, shortly after the end of the Second World War. He quickly became an avid swimmer and high board diver, feeling very at home in and under the water. Doc would have the family driver take him to the shore as often as possible, where he would spend hours at the beach or fishing docks, fascinated by the weird and wonderful creatures the boats would bring in at the end of the day. On one such day he was so enthralled by his surroundings that he left a brand-new pair of shoes on the dock. This was the final straw for his parents, whose patience was already strained by frequent instances of misbehaviour. They decided that enough was enough and in 1953 they sent him to military school.

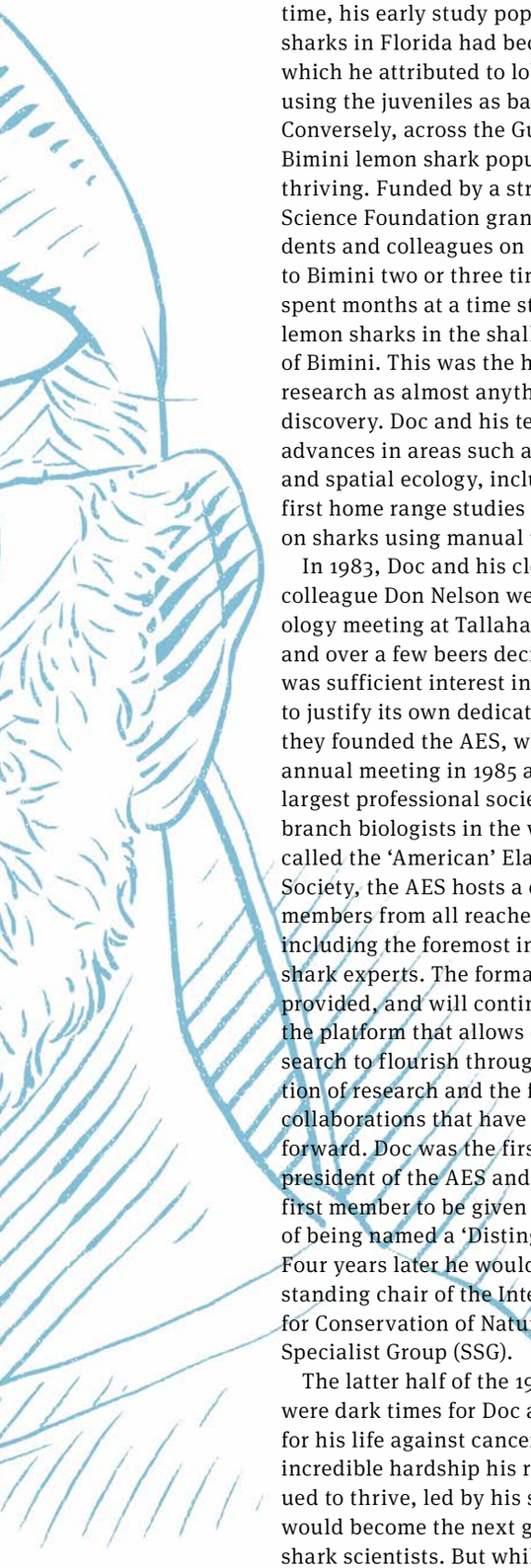
Doc's time at Riverside Military Academy was split between two campuses, one in Miami and the other in northern Georgia. His tenure at military school was plagued by abuse from his classmates that was fuelled by the anti-Semitic culture of the period. When Doc spoke of this in later years, he was often asked why he didn't leave. His response was always the same: 'I just refused to let those bastards beat me.' That mentality, even at an early age, will come as no surprise to anyone who ever knew Doc. It reflected the perseverance and tenacity that would later enable him to become a leader in his field and beat all the odds to survive cancer for decades.

Doc studied pre-medicine at Emory University in Atlanta, but in 1958 took a summer course in anatomy at the University of Miami. For extra cash, he would spear fish and sell his catch to local restaurants; Burger King, whose fish sandwiches were popular, was his best customer. While spearfishing on the reef one day he was, as he would always put it, 'menaced by a big hammerhead'. He credits that moment for defining the direction of his life. He was terrified by the experience, but equally fascinated. Seeking counsel from his anatomy professor at the University of Miami, he asked the dean if he thought it would be possible to make a career out of studying sharks. The professor believed that such a career could be feasible and pointed out that very little was known about this group of animals that Doc found so fascinating. And the rest, as they say, is history. Doc abandoned his ambitions of becoming a fighter pilot (although he retained a passion for vintage aircraft and spent much of his 'retirement' flying in Second World War planes) or a professional ballet dancer (he had taken up ballet to meet women, but turned out to be a real natural) and transferred to the University of Miami full time.

After finishing his undergraduate degree in zoology, Doc began his graduate studies in marine science, focusing on shark sensory systems initially under the tutelage of Dr Warren Wisby. Following Dr Wisby's departure from the University of Miami, Doc continued his sensory biology line of work under the advisement of well-known fish ethologist Dr Arthur Myrberg. The students in Dr Myrberg's lab included Don Nelson, who would become Doc's long-time friend and colleague. Much of the work conducted by Dr Myrberg and his students was funded by the United States Office of Naval Research with the motivation of preventing shark attacks on downed pilots. Dr Myrberg was also conducting work out of the Lerner Marine Laboratory on North Bimini, The Bahamas, which gave Doc his first exposure to the islands that would eventually become his research home.

For his PhD research Doc focused on the visual systems of sharks, using the lemon shark as a model species. His reasoning, that lemon sharks were locally accessible and did well in captivity, developed into a long relationship between Doc and his favourite species and he often professed that he owed everything to it – life, career and notability. It can be argued that today the lemon shark is the most comprehensively studied of all the shark species, and in turn that fact correlates directly to Doc's connection with it.

Following the completion of his PhD, Doc took up a professorship at the University of Miami, where he continued his studies using the lemon shark as the



Doc Gruber

core species but, in collaboration with Dr Myrberg, he expanded the research focus into shark ecology and behaviour. At this time, his early study population of lemon sharks in Florida had become depleted, which he attributed to lobster fishermen using the juveniles as bait in their traps. Conversely, across the Gulf Stream in Bimini lemon shark populations were thriving. Funded by a string of National Science Foundation grants, Doc took students and colleagues on research cruises to Bimini two or three times a year and spent months at a time studying the lemon sharks in the shallow North Sound of Bimini. This was the heyday of shark research as almost anything was a new discovery. Doc and his team made great advances in areas such as bio-energetics and spatial ecology, including one of the first home range studies to be conducted on sharks using manual tracking.

In 1983, Doc and his close friend and colleague Don Nelson were at an ichthyology meeting at Tallahassee, Florida, and over a few beers decided that there was sufficient interest in shark research to justify its own dedicated society. Thus they founded the AES, which held its first annual meeting in 1985 and is now the largest professional society of elasmobranch biologists in the world. Although called the 'American' Elasmobranch Society, the AES hosts a diverse group of members from all reaches of the planet, including the foremost international shark experts. The formation of AES provided, and will continue to provide, the platform that allows elasmobranch research to flourish through the dissemination of research and the forging of fruitful collaborations that have driven the field forward. Doc was the first standing president of the AES and in 1987 was the first member to be given the great honour of being named a 'Distinguished Fellow'. Four years later he would become the first standing chair of the International Union for Conservation of Nature (IUCN) Shark Specialist Group (SSG).

The latter half of the 1980s, however, were dark times for Doc as he battled for his life against cancer. Despite this incredible hardship his research continued to thrive, led by his students who would become the next generation of shark scientists. But while his outlook was bleak – he was completely written off by many people many times – betting against Doc was never a smart move and he himself never gave up. He was told by his doctors that there was nothing more they could do and that he should get his affairs in order and say goodbye to his family. Instead, Doc burrowed deep into the medical literature and found a paper about an experimental drug. The drug was designed for a different type of cancer, but a small footnote in the paper stated that it had produced some positive results with the cancer he had. He demanded to be prescribed this drug and, much to everyone's amazement, it eventually cured him. From then on, nobody ever wrote Dr Gruber off again.

During his battle to live Doc made a promise to himself: if he could beat the cancer, he would open his own dedicated research station at Bimini. Once he had recovered, there was no chance that he wouldn't follow through and realise his dream. With blood, sweat and tears, in 1989 Doc and his wife Marie, with a team of students, built a field laboratory that was officially established as the Bimini Biological Field Station (Shark Lab) the following year.

Doc created not only a permanent research facility where world-class shark research has been conducted for the past three decades, but also a place where aspiring young scientists could gain crucial hands-on field experience. The number of opportunities the Shark Lab has provided to graduate students and volunteers over the years is unrivalled in the field. There are not too many places where a shark enthusiast with no prior practical experience can work and leave with the skill sets they gain at the Shark Lab. Doc and Marie always took great pride in the lives that were touched at Bimini and the thousands of perceptions about sharks that were forever changed for the better. In the Shark Lab, Doc's legacy and passion will live on for decades to come.

Although Doc enjoyed a stellar professional career, it was his family that he took most pride in. He and Marie recently celebrated 50 years of marriage and throughout those years Marie was his rock, often the only one who could calm Doc's sometimes irascible tendencies. A true example of commitment through sickness and health, their union supported Doc through his life and career; indeed Marie, 'the Lab Mother', was as responsible for establishing and sustaining the Shark Lab as Doc himself was. In the field of elasmobranch research, Doc and Marie were always known as a single entity, a true team. Together they had two wonderful daughters, Meegan and Aya. Brilliant like their parents, these two are both successful professionals, Meegan as a plastic surgeon and Aya as a lawyer turned law professor. There's no doubt that Doc passed a healthy dose of his determination on to his daughters, and between them they have given Doc and Marie three amazing grandchildren: Mia, Max and Misa, whom Doc loved dearly and will forever be proud of.

It is worth saying again that Dr Gruber's contribution to and influence on the field of elasmobranch research cannot be overstated. Many people associate Doc's legacy directly with the Bimini Shark Lab, but it began long before that with the groundbreaking research of his PhD, the early students under his tutelage at the University of Miami through the 1970s and '80s, and his co-founding of the AES. No other individual is directly connected to the success and development of so many established elasmobranch scientists today. Those of us who were privileged to benefit from the time we spent with Doc will miss him dearly.

His personality was notoriously strong and often cantankerous, but this simply reflected his incredible tenacity, and his dedication and passion for life and sharks had tremendous influence on those within his sphere. If you worked with Doc, you will know how hard his demands on you could be, but we all were willing to rise to the challenge and it made us better for it. How could you not be willing, when in his 50s, 60s and even 70s he would be right there beside you and working even harder than you were? And not only was he there, but he had an inspiring sense of how lucky he was to be there. To every shark he encountered, Doc would react with a sense of amazement as if it were his first, even after five decades of working with these animals. His passion for sharks was truly infectious and it was impossible for it not to rub off onto you, even through all the yelling and chastising you would often receive as his excitement boiled over – a process that we all affectionately refer to as being 'Gruberised'.

Doc had a presence that would command respect whenever he entered a room; no matter whom he met or how senior they were, they would give him the utmost attention and listen to what he had to say. Yet somehow he had time for everyone. At the lab, when new volunteers arrived, or at society meetings, he would delight in speaking to aspiring young scientists, listening to their stories and discussing their interests with an encyclopaedic level of detail. Doc's larger-than-life personality drew the focus of many a television documentary in which he will be forever immortalised. Even more so, and more importantly, his legacy will live on in the Shark Lab, with his beloved family, and in the lives and achievements of all of us who had the distinct privilege of working with, or even just spending some time in the presence of, Dr Samuel H. Gruber, a true legend in our field.

Steven T. Kessel, PhD
Chairman | Bimini Biological Field Station Foundation (BBFSF)
Director of Marine Research | Daniel P. Haerther Center for Conservation and Research | John G. Shedd Aquarium

R. Dean Grubbs, PhD
Member of the Board of Directors | Bimini Biological Field Station Foundation (BBFSF)
Associate Director of Research | Florida State University Coastal and Marine Laboratory


1
2
3
4
9
10
11
12
13
14
21
22
23
24
25
28
29
30
31
37
38
39
40
41
42
43
44

BIMINI *Biological Field Station*

1. Bimini Ameiva *Pholidoscelis auberi*
2. Curly-tailed Lizard *Leiocephalus carinatus*
3. Giant Hermit Crab *Petrochirus diogenes*
4. Brown Pelican *Pelecanus occidentalis*
5. Common Bottlenose Dolphin *Tursiops truncatus*
6. Magnificent Frigatebird *Fregata magnificens*
7. Bimini Boa *Chilabothrus strigilatus fosteri*
8. Great Blue Heron *Ardea herodias*
9. Green Sea Turtle *Chelonia mydas*
10. Caribbean Reef Shark *Carcharhinus perezi*
11. Lemon Shark *Negaprion brevirostris*
12. Mutton Snapper *Lutjanus analis*
13. Wahoo *Acanthocybium solandri*
14. Mahi Mahi *Coryphaena hippurus*
15. Tiger Shark *Galeocerdo cuvier*
16. Atlantic Spotted Dolphin *Stenella frontalis*
17. Mangrove Gray Snapper *Lutjanus griseus*
18. Rock Beauty Angelfish *Holacanthus tricolor*
19. Atlantic Bluefin Tuna *Thunnus thynnus*
20. Lemon Sharks (juvenile) *Negaprion brevirostris*
21. Great Hammerhead Shark *Sphyrna mokkaran*
22. Spotted Moray Eel *Gymnothorax moringa*
23. Spot-fin Porcupinefish *Diodon hystrix*
24. Shortjaw Bonefish *Albula vulpes*
25. Loggerhead Sea Turtle *Caretta caretta*
26. Bull Shark *Carcharhinus leucas*
27. Hogfish *Lachnolaimus maximus*
28. Spotted Eagle Ray *Aetobatus narinari*
29. Yellowtail Damselfish *Microspathodon chrysurus*
30. Caribbean Reef Octopus *Octopus briareus*
31. Nassau Grouper *Epinephelus striatus*
32. Caribbean Reef Squid *Sepioteuthis sepioidea*
33. Smalltooth Sawfish *Pristis pectinata*
34. Yellow Stingray *Urobatis jamaicensis*
35. Black Triggerfish Durgon *Melichthys niger*
36. Green Moray Eel *Gymnothorax funebris*
37. Queen Conch *Lobatus gigas*
38. Caribbean Spiny Lobster *Panulirus argus*
39. Elkhorn Coral *Acropora palmata*
40. Great Star Coral *Montastrea cavernosa*
41. Mustard Hill Coral *Porites astreoides*
42. West Indian Topshell *Cittarium pica*
43. Long-spined Sea Urchin *Diadema antillarum*
44. Pineapple Coral *Dichocoenia stokesi*
45. Pillar Coral *Dendrogyra cylindrus*
46. Red Cushion Sea Star *Oreaster reticulatus*
47. Grooved Brain Coral *Diploria labyrinthiformis*
48. Finger Hump Coral *Porites porites*
49. Southern Stingray *Hypanus americanus*
50. Rose Coral *Manicina areolata*

© Illustrations by Rohan Chakravarty
Save Our Seas Foundation © 2019
www.SaveOurSeas.com
www.BiminiSharkLab.com
www.GreenHumour.com

Photo by David Doubilet | National Geographic Image Collection

How to heal the sea

One of the biggest conundrums facing us today is this: we rely on the ocean for all the services it provides for us – from the food we eat and the oxygen we breathe to the climate system that makes the earth habitable for us – and yet our collective actions threaten the health of this life-support system. It's undeniably a challenge: to figure out how to continue using the ocean sustainably while at the same time allowing those regions to recover where ocean health has declined the most.

Kurt Ingeman from the University of California (Santa Barbara), together with Jameal Samhouri and Adrian Stier, tackles this precise issue in a recent paper in *Science*. They interrogate why it might be that, despite more scientific insight, stronger policies and regulations, and management strategies that have in many cases catalysed a process of ocean recovery, we're still not succeeding in some areas. One reason, they say, is because marine ecosystems and human societies change: they are 'moving targets' that keep conservationists chasing solutions. Their review looks at several different approaches we can adopt in the coming years to overcome some of the main issues that stifle our successes. Their first principle is to widen our definition of recovery to embrace a range of outcomes. Secondly, research should improve its predictive capacity, anticipating what recovery dynamics might look like and charting a path forward. Finally, policy-makers need to navigate more adaptable approaches to keep up with the rate of change, so that communication and coordination across institutions and stakeholders is more 'fluid'. The authors also point out that local knowledge and traditional cultural practices need to be better integrated into what we consider recovery and how we best achieve it. Their conclusions are certainly ambitious, but conflicting approaches to ocean recovery hinder our progress. A framework that wrangles some of the biggest concepts in ocean conservation into a philosophical format is useful to guide where we might aim to head in future.

Reference
Ingeman KE, Samhouri JF and Stier AC. 2019. Ocean recoveries for tomorrow's Earth: Hitting a moving target. *Science* 363(6425).

OCEAN VIEW

Rising temperatures, melting sea ice and ... colder winters?

The misconceptions about climate change are many and varied, and it's not uncommon to hear confusion about its impacts being uniform across the planet. 'Global warming' means we're going to get hotter, right? That's great if you're living in icy climes, surely! That snowy Scandinavian real estate you own might be a balmy, tropical retreat in future? Bring it on... In reality, we understand that climate change is complex: its impacts are nuanced and there is much variation in what it will mean for different regions across the planet. Add to that the fact that climate science is complicated by nature and is fraught with careful interpretation, and we understandably need to proceed with caution in the face of sweeping statements and generalisations. In fact, some of the ways in which climate change is impacting the planet are bringing surprising trends to light.

A recent publication in *Nature Climate Change* showed that melting Arctic sea ice has led to increasingly harsh winters across Eurasia. Lead author Masato Mori from the University of Tokyo, together with co-authors from the university's Research Centre for Advanced Science and Technology, and the Atmosphere and Ocean Research Institute, looked at what might be causing cooling over northern mid-latitudes (particularly over central Eurasia). Their findings point to the same thing: 44% of the cooling of Eurasia between 1995 and 2014 was the result of melting sea ice in the Barents and Kara seas. Not only this, their research also shows that all the models that have linked these two phenomena have underestimated the magnitude of this trend. The paper suggests that the links here are clear: human-induced climate change (what scientists dub 'anthropogenic forcing') has increased the likelihood of freezing winter temperatures in Eurasia because warming Arctic temperatures are amplifying the loss of sea ice. The researchers note how important it is to design carefully experiments that explore regional climate change effects and highlight how our understanding of what climate change means for one part of an ocean might result in surprising trends elsewhere on our planet.

Reference
Mori M, Kosaka Y, Watanabe M, Nakamura H and Kimoto M. 2019. A reconciled estimate of the influence of Arctic sea-ice loss on recent Eurasian cooling. *Nature Climate Change* 9(2): 123–129.

Photo by Paul Souders | BiosPhoto

Brittlestars provide clues about life in the deep sea

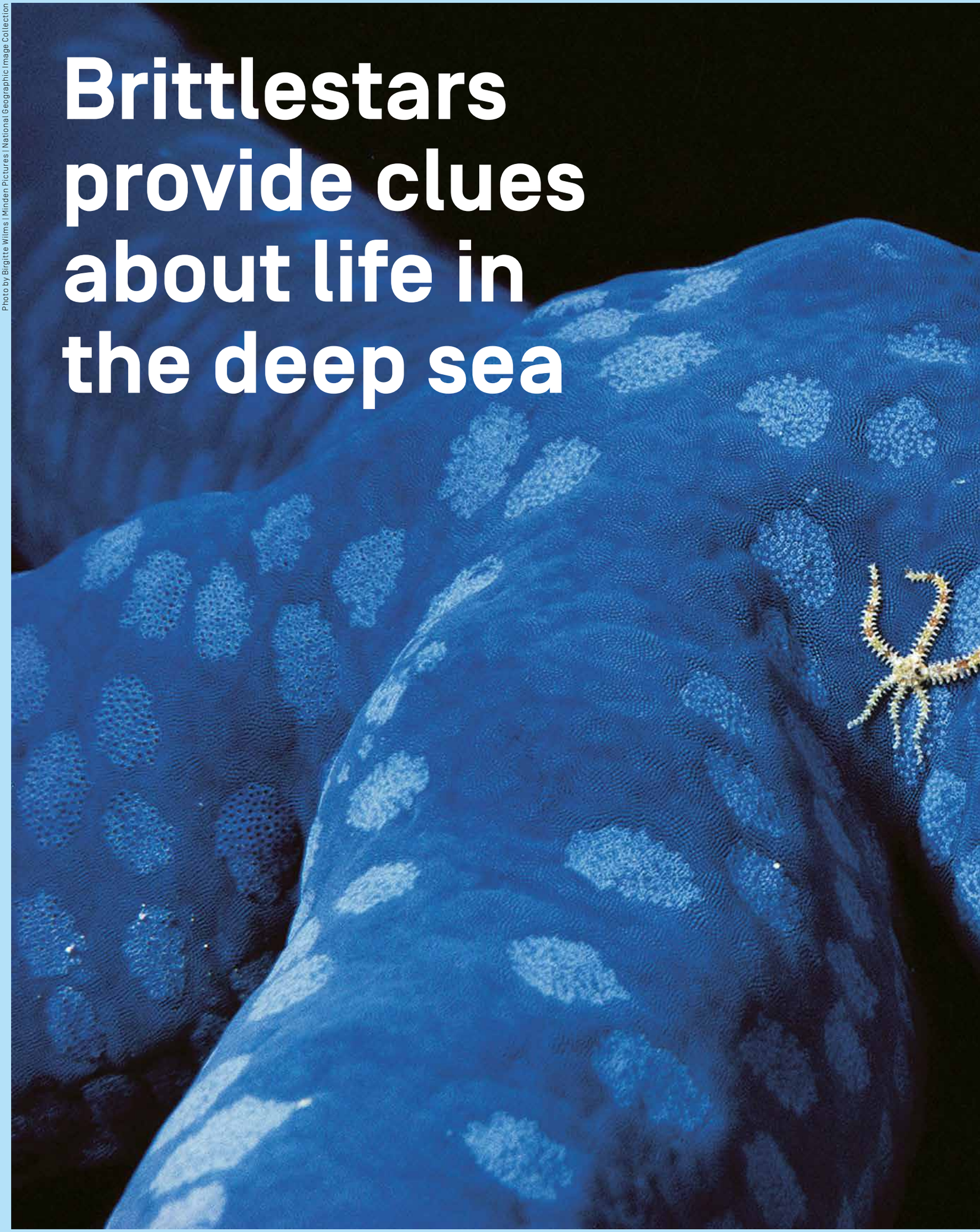


Photo by Birgitte Wilms | Minden Pictures | National Geographic Image Collection

OCEAN VIEW

Brittlestars – those scraggly-legged cousins of sea stars and urchins – have helped scientists to explore which processes might be driving evolutionary diversity from the equator to the Antarctic, from the sea surface right down to the deepest ocean abyss. A study published in *Nature* earlier this year collated data from 160,000 brittlestars representing 596 different species that were collected over the course of 1,500 research cruises in the southern hemisphere. Lead researcher Tim O'Hara from Museums Victoria showed that evolutionary processes were different in shallow and deep seas, from the tropics to the poles. Brittlestars are commonly found in all regions of the ocean, so they were an excellent choice for scientists to compare and contrast patterns over such wide areas and varying ocean realms. The scientists identified a 'museum zone' in the tropical upper bathyl (water 200–700 metres, or 660–2,300 feet, deep in tropical seas). Here, many species represent ancient lineages that have experienced little change over time – relics, if you will, that have previously been little understood or talked about from a conservation perspective.

Species richness – the total number of different species – was highest overall in tropical seas at all depths and declined towards the poles. How that high diversity came about, however, differs markedly in shallow and deep tropical seas. Scientists found that the turnover of new species was high in shallow tropical seas, describing them as a 'cradle' of life. By contrast, deep tropical seas were the 'museums', where rates of extinction had been lower through time, so that many ancient species have accumulated there – the dinosaur realm of the ocean. In his paper, O'Harris calls these the 'rainforests of the sea' because they are archives of abundant ancient life and he cautions readers to consider what this means for fishing activity in these little-understood regions. Also characterising evolutionary diversity in temperate seas and the Antarctic, the paper forms the basis of what the researchers hope will help them ultimately to tell the history of our seas.

Reference
O'Hara TD, Hugall AF, Woolley SN, Bribiesca-Contreras G and Bax NJ. 2019. Contrasting processes drive ophiuroid phylodiversity across shallow and deep seafloors. *Nature* 565: 636–639.

The puzzling patterns of predators

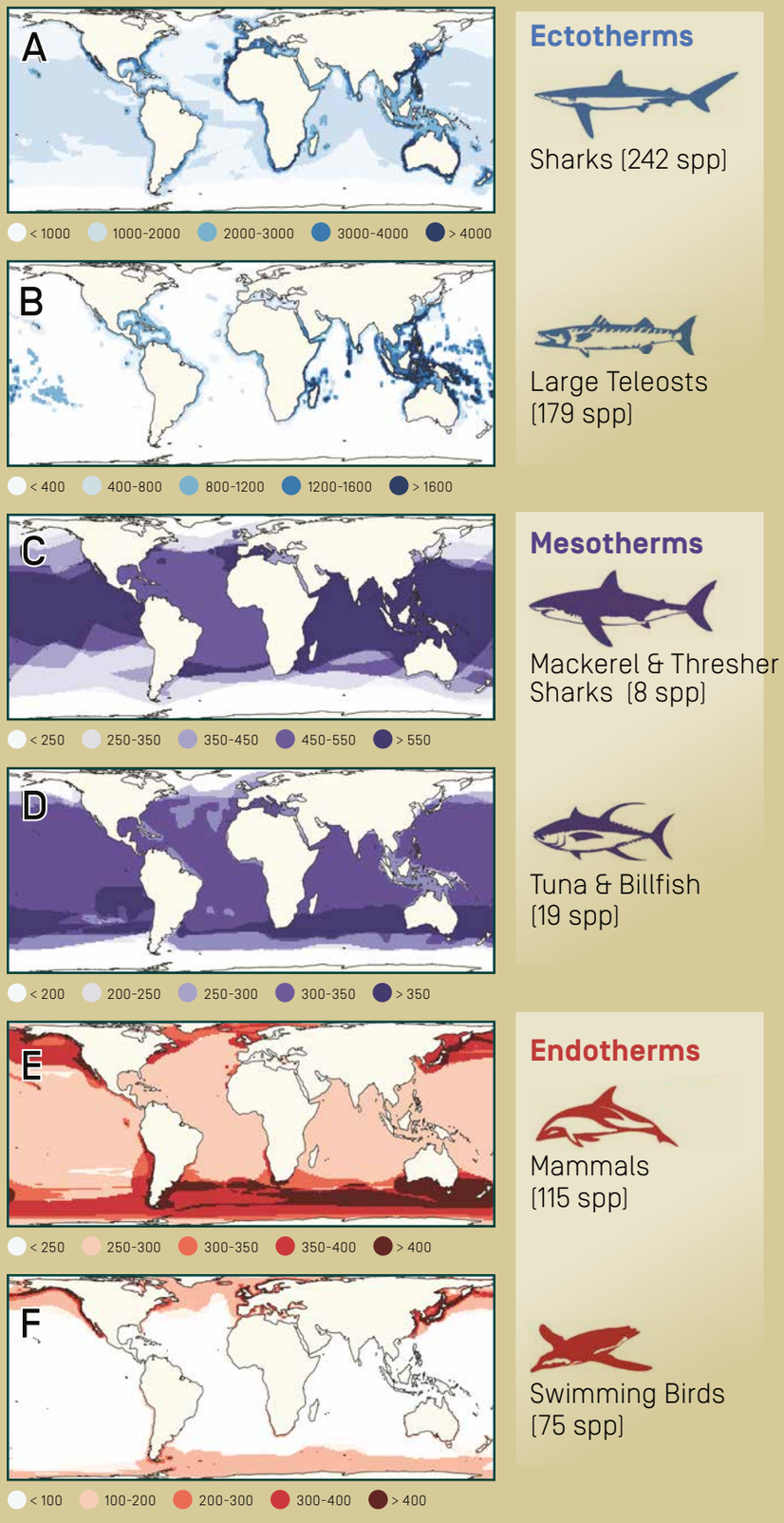
Marine ecologists love to make sense of the patterns they observe in nature and one of the most intriguing of these is how different species are distributed across our global oceans. Which animals live where – and why? A well-accepted observation is that diversity generally increases as one moves from the poles towards the equator. It has been supposed that a reason for this pattern is that the warmer waters support lots of cold-blooded fish that rely on their surroundings to regulate their internal temperature. However, birds and marine mammals (seals, whales, dolphins and other ocean species that, like us, breathe air and nurse their young with milk) throw a spanner in the ecological works: their diversity is highest in colder, temperate waters.

A new study published in *Science* collated maps showing the ranges of 998 marine species, from sharks to sea snakes, and from mammals and birds to fish. Lead author John Grady from Michigan State University wanted to explore these patterns in diversity and then link them to thermal physiology. In other words, how is it that different animals regulate their body temperature? And does this have anything to do with where they live? The researchers' findings are interesting: most warm-blooded mammals and birds are most diverse in cooler, temperate seas, whereas there are more species of cold-blooded fish and sharks in tropical waters. Their reasoning for this trend? Cold-blooded fish are often prey and rely on moving fast to avoid predation – their bodies are better able to do this in warm water. In colder seas fish move more sluggishly, which makes them easier prey for the marine mammals that hunt them! The authors of the paper then checked their theory against data that showed where seals and dolphins are most abundant and where in the oceans they feed most. As it turns out, marine mammals eat more as one moves from the equator towards the poles, increasing the amount by a factor of 80.

This is an interesting ecological observation, but what's the point? Knowing what drives patterns in diversity helps scientists better monitor what may happen when ocean temperatures rise, which will have implications for this delicate balance of predators and prey in the sea.

Reference
Grady JM, Maitner BS, Winter AS, Kaschner K, Tittensor DP, Record S, Smith FA, Wilson AM, Dell AI, Zarnetske PL and Wearing HJ. 2019. Metabolic asymmetry and the global diversity of marine predators. *Science* 363(6425).

Phylogenetic diversity of large marine predators



Phylogenetic diversity, expressed as the sum of evolutionary times of divergence (in millions of years [Ma]) between co-occurring species, is largely tropical or subtropical for ectothermic sharks and teleost fish, cosmopolitan for mesotherms (excluding poles), and peaks in cold, temperate waters for endothermic mammals and birds. Spatial cells are 110 km × 110 km; cells lacking species are unshaded.

New protection for South African waters

At the end of 2018, South Africa advanced its ocean protection goals by approving 20 new marine protected areas (MPAs) for declaration. The proposed network of MPAs would increase the country's protected waters from 0.4% to 5%, an area of about 50,000 square kilometres (19,305 square miles) according to the South African National Biodiversity Insititute (SANBI). For anyone who has visited the country's parks on land, that's twice the size of the Kruger National Park! The move is a bid to safeguard a sustainable future for South Africa's citizens, protecting threatened ocean habitats and biodiversity so that the country's fisheries and marine ecotourism sectors are secured.

From canyons in the depths to submarine mountains and deep-water corals, many of the proposed MPAs are located offshore. It is these regions of the deep ocean that scientists have identified as being the least protected in South Africa. From institutions across the country, they worked for over a decade to determine which areas would make up the proposed network. The resulting map of MPAs drew on research from a five-year-long Offshore MPA project led by Dr Kerry Sink from SANBI, while an MPA technical team aligned ocean protection goals with South Africa's planned focus on developing its ocean-based economy. Anyone interested in the MPAs can now browse an interactive website (*marineprotectedareas.org.za/*), diving into realms seldom visited to look through the lens of ocean science at some extraordinary ecosystems. The Agulhas Mud MPA, for instance, would protect the Agulhas sole, a flatfish targeted by trawlers (and beloved by seafood connoisseurs).

At 2,200–4,100 metres (7,218–13,451 feet) deep, the Agulhas Front MPA would be one of the deepest, and furthest offshore, playing host to the Endangered leatherback turtle. Where yellowwood forests stood tall a hundred million years ago, the Namaqua Fossil Forest MPA now incorporates the coral-encrusted remains of trees that have fossilised on the sea floor. Research into the country's existing MPA network has shown that MPAs can protect ocean life; one of these studies, in the Goukamma MPA on the country's southern Cape coastline, featured in *Save Our Seas* #5 for its success in protecting the brightly coloured roman seabream. A host of research projects are already under way in the new, proposed network and their insights are documented on the website.

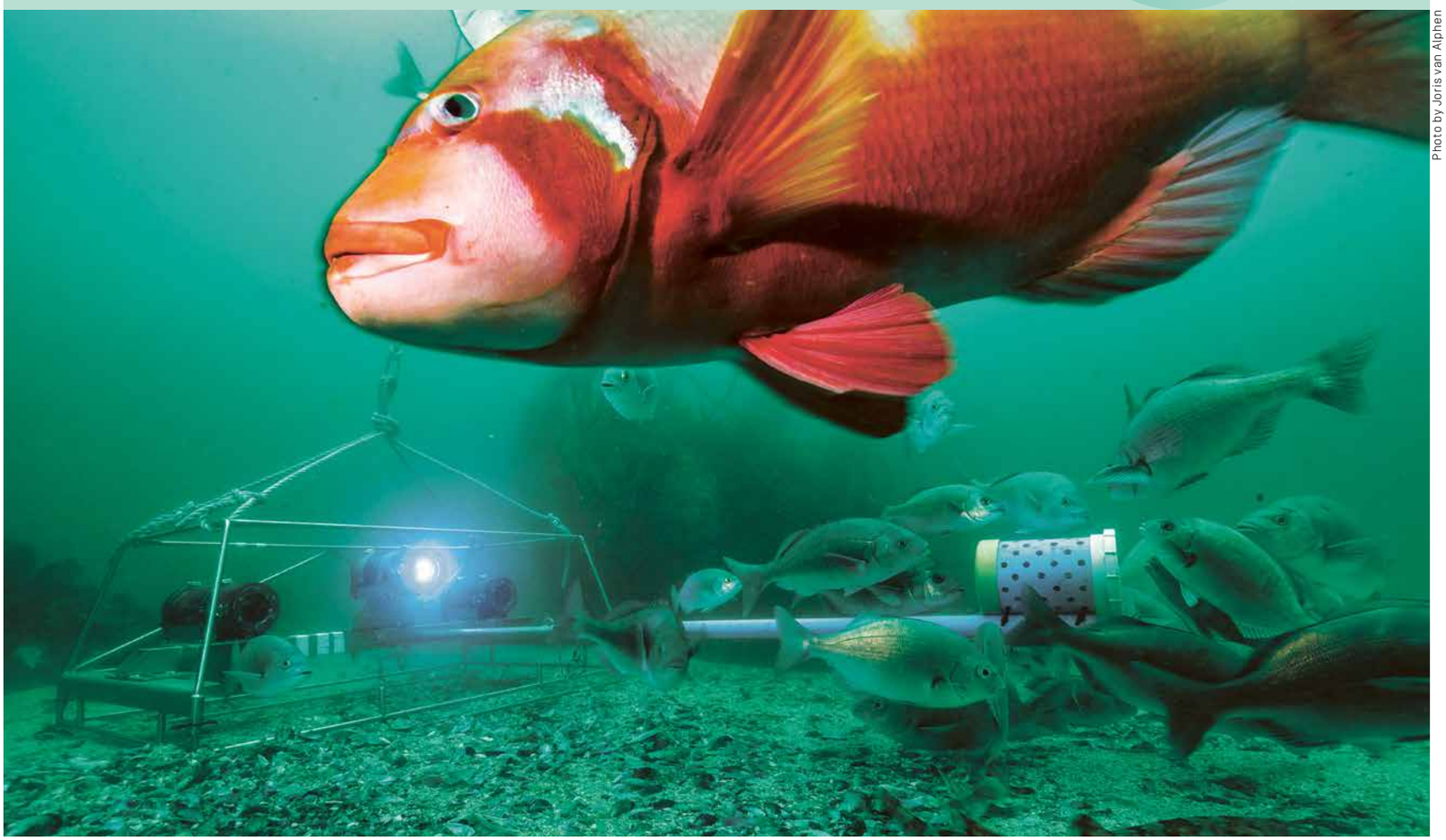
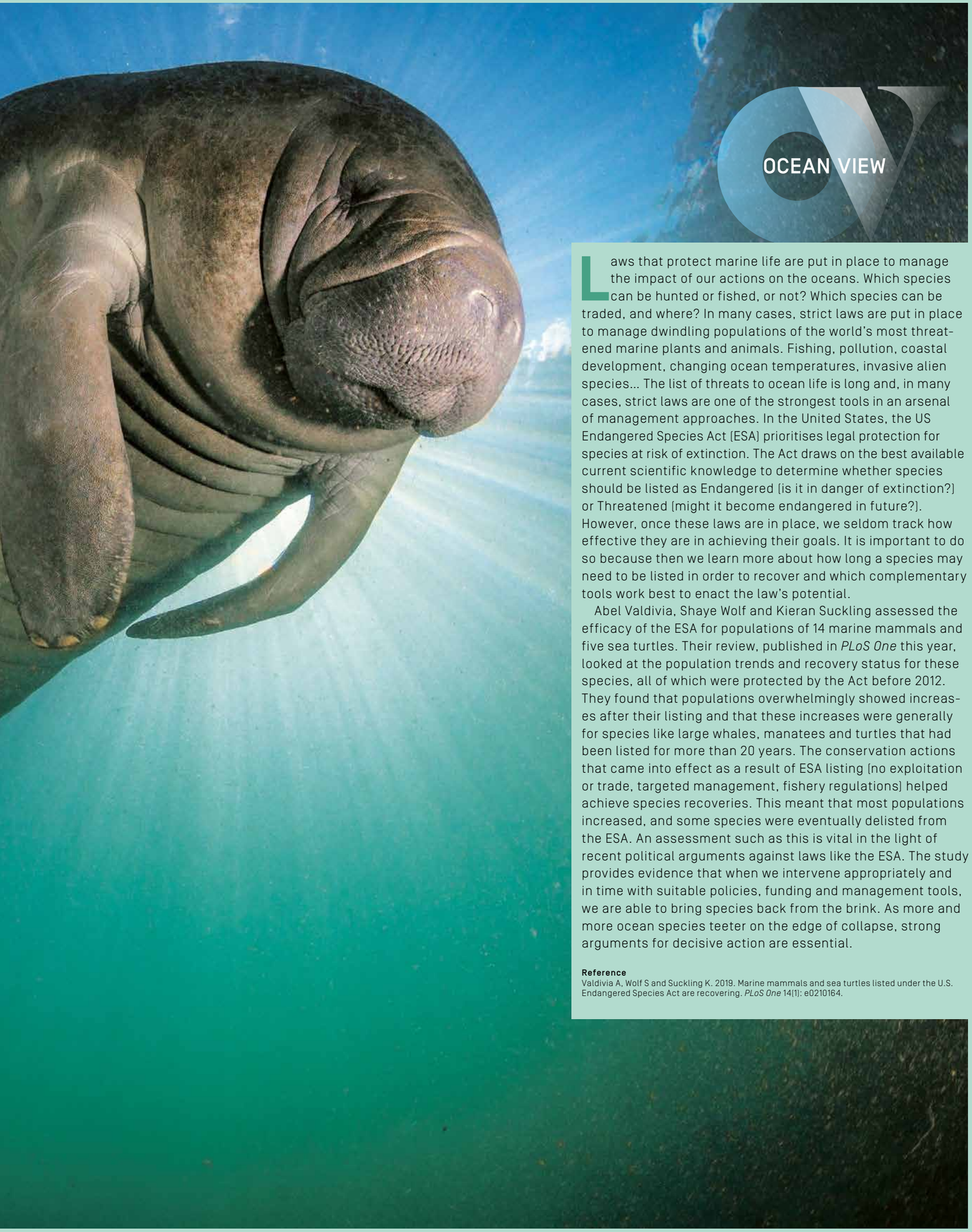


Photo by Joris van Alphen

The ESA: a win for turtles and marine mammals

Photo by Paul Nicklen | National Geographic Image Collection



OCEAN VIEW

Laws that protect marine life are put in place to manage the impact of our actions on the oceans. Which species can be hunted or fished, or not? Which species can be traded, and where? In many cases, strict laws are put in place to manage dwindling populations of the world's most threatened marine plants and animals. Fishing, pollution, coastal development, changing ocean temperatures, invasive alien species... The list of threats to ocean life is long and, in many cases, strict laws are one of the strongest tools in an arsenal of management approaches. In the United States, the US Endangered Species Act (ESA) prioritises legal protection for species at risk of extinction. The Act draws on the best available current scientific knowledge to determine whether species should be listed as Endangered (is it in danger of extinction?) or Threatened (might it become endangered in future?). However, once these laws are in place, we seldom track how effective they are in achieving their goals. It is important to do so because then we learn more about how long a species may need to be listed in order to recover and which complementary tools work best to enact the law's potential.

Abel Valdivia, Shaye Wolf and Kieran Suckling assessed the efficacy of the ESA for populations of 14 marine mammals and five sea turtles. Their review, published in *PLoS One* this year, looked at the population trends and recovery status for these species, all of which were protected by the Act before 2012. They found that populations overwhelmingly showed increases after their listing and that these increases were generally for species like large whales, manatees and turtles that had been listed for more than 20 years. The conservation actions that came into effect as a result of ESA listing (no exploitation or trade, targeted management, fishery regulations) helped achieve species recoveries. This meant that most populations increased, and some species were eventually delisted from the ESA. An assessment such as this is vital in the light of recent political arguments against laws like the ESA. The study provides evidence that when we intervene appropriately and in time with suitable policies, funding and management tools, we are able to bring species back from the brink. As more and more ocean species teeter on the edge of collapse, strong arguments for decisive action are essential.

Reference

Valdivia A, Wolf S and Suckling K. 2019. Marine mammals and sea turtles listed under the U.S. Endangered Species Act are recovering. *PLoS One* 14(1): e0210164.

Sawfishes seemed to be species of the past in the United States, their range restricted to a last stronghold around Florida's Everglades National Park. After 15 years of protection under the US Endangered Species Act, there are signs that the smalltooth sawfish may be increasing in number and spreading back northwards to reclaim its former range. Researcher Tonya Wiley fills us in on her plans for a project to sleuth out signs of this sawfish in Tampa Bay, the next stop on the road to recovery.

What made you decide to start searching for sawfishes in Tampa Bay?

I've been working with sawfishes since 2001, when I first started at Mote Marine Lab. Then in 2010 I went on to found Havenworth Coastal Conservation to conduct my own research. The smalltooth sawfish *Pristis pectinata* is considered Critically Endangered by the IUCN and Endangered under the United States Endangered Species Act (ESA) and its range decreased dramatically to concentrate around south-western Florida, from Charlotte Harbor to the Florida Keys. Historically, the sawfish population was strongest in southern Florida, so when it was decimated the remnants clung on in south-western Florida, a large part of which is the Everglades National Park. Established in the 1940s, the park is probably why this sawfish survived at all: its expanses of natural habitat and the limited fishing pressure in it made it a refuge for the species. As a result, most sawfish research has been centred on south Florida and my work to date has been around the Everglades and the Keys.

The smalltooth sawfish has been listed under the ESA since 2003 and there has been some recent indication of possible signs of recovery. One such sign is that we're starting to see the population spread back northwards. Charlotte Harbor has been the northernmost location from which we regularly received reports of sawfish – and the next stop to the north would be Tampa Bay, where I live. This is where my field project is now concentrated.

You have a major outreach component to your project. Why is public engagement so important?

The outreach part of the project is to firstly let people know that sawfishes exist. Most people have never heard of them, let alone seen one! It's important to let people know that this species is in the region and that it is Endangered, especially since water-users are more likely to encounter a sawfish if the population is indeed recovering and extending northwards. Whether someone is boating or fishing or simply taking a stroll on the shore, we want to equip them with information about how to report a sighting. We want to give fishermen guidelines on how to handle sawfishes and release them safely if they're caught and to tell divers how to view a sawfish safely if they encounter one while diving. This means that I will be giving lots of talks this year at diving and fishing events, setting up a stall at expos and posting information posters at fishing piers and boating harbours. I'm aiming to get the word out in a variety of ways because reports from the public will also help us with our field surveys.

What are your key objectives?

Firstly, I want to know whether sawfish numbers are improving. And secondly, is the distribution of the population expanding? I will be establishing a regular relative abundance survey to monitor the population and see how many individuals we may see up here in Tampa Bay. We've had some reports in this area in the past year, but I'm hoping that combining the reports from a wider public community will give us more information and lead us to more than a mere handful of sightings. The project is two-pronged, really: an outreach component that will hopefully help us refine our ongoing search for sawfish here; and a monitoring aspect to help us get a good handle on the number of sawfishes in the region. We've been putting 10-year acoustic transmitters in the sawfishes in the Everglades and Charlotte Harbor. Last year a few of those were heard moving up the coast in this direction, towards Tampa Bay. Now I plan to place six receivers around the bay, so that we can listen in and detect if these tagged individuals are using Tampa Bay. It feels a bit like searching for a needle in a haystack! I'm positive, though, and hopeful that our combined efforts will lead to results. Once we catch a sawfish, I'll be taking measurements and genetic and blood samples, as well as implanting more 10-year transmitters that will help us track the movements and habitat use of the sawfishes we find.

Photo by Andrea Krotze | NOOA

AN INTERVIEW WITH TONYA WILEY

What might this all mean for sawfish conservation more broadly in the USA?

The big question really is whether sawfish are moving: are their numbers improving to the extent that we see their range expanding? The long-term goal under the ESA is to see sawfish populations re-establish out of Florida. The species was historically found all the way from Texas to North Carolina, and where we used to have two species until the mid-1900s, we now only have the smalltooth sawfish. The largetooth sawfish has, unfortunately, probably disappeared. However, for the smalltooth sawfish to be considered sufficiently recovered under the ESA, it needs to occur outside Florida once more. We'd like to see smalltooth sawfishes in Georgia, Louisiana, Alabama, Mississippi... But for right now, in Tampa Bay at least!

How do you see your research fitting into the future of sawfishes?

Part of what we still have to find out is what habitat sawfishes need, so that we can do some spatial planning that will protect recovering sawfish populations outside Everglades National Park. In many of the regions where sawfishes historically occurred, there has been enormous development that has altered the habitat available for these animals. We don't even know if sawfishes could use many of these areas any more. However, in Florida, where much of the coast is also really modified, we do still see sawfishes. The Caloosahatchee River, for instance, has sea walls on either side of its channel and a dam that regulates its flow. There is fishing pressure and the whole system seems too developed to host sawfishes – but we do find them there regularly. What we don't know is how successful these populations are in terms of growth or survival. That's part of the interesting question about Tampa Bay: one side is relatively undeveloped and one shoreline is totally modified, but we get reports of sawfishes from both sides. So this might help us refine our understanding of exactly what habitat they need. We have a reasonable handle on what habitat is needed for juvenile sawfishes: shallow sandbars where they can stay while the tide comes in and goes out. Once a sawfish is larger than two metres (6.5 feet), it ventures out into deeper estuarine and open-water areas. The insights from this project can feed into a growing understanding of what remaining critical habitat areas should be identified and prioritised for protection, to safeguard some habitat for sawfish populations as they expand northwards.

Communication and collaboration must be key when working on the conservation of species that are of concern, and especially those that might be increasing their range. What has been your experience of this?

There are many of us now focusing on this kind of sawfish research and we aim to keep our methods standardised so that we can compare our data, regardless of where we're working. We meet once a year in person to coordinate procedures for how we conduct our research. The Sawfish Recovery Team was formed in 2003 and wrote a recovery plan for the species, so we use these annual meetings to review our progress and ensure that our technologies and methods are standardised. We talk remotely throughout the year, and all our research is permitted through the National Marine Fisheries Service, which is the agency that put together the recovery team. Our team works together to plan for future research and divide the workload among ourselves. At our meeting last year, we identified the possibility that we might start seeing more sawfishes in Tampa Bay. I'm hopeful that this concerted research effort, combined with a huge push to engage the public, will have us see some more success in the conservation and recovery of the smalltooth sawfish in the USA.

Portfolio by Sirachai Arunrugstichai | Edited by Will White

The story of wedgefishes is one of belated revelations. Almost before any real light has been shone on these species, we have realised that their populations have plummeted and that they face significant threats. Photographer Sirachai Arunrugstichai's images juxtapose the beauty of wedgefishes in their natural environment and the pressures they face from human activities today. Dr Will White helps to narrate this modern conservation story, pointing to the urgent need for evidence-based conservation and fisheries management actions to protect wedgefishes before it's too late.

Wedgefishes are majestic rays that you can guarantee will be a highlight for any divers lucky enough to encounter them. The bottlenose wedgefish *Rhynchobatus australiae* is often found on sand bottoms near reefs. Individuals like this one, seen near Malé in the Maldives at a dive site dubbed 'Fish Tank', frequent an area next to a fish-processing factory, usually at dusk. A local dive operator says these rays are most commonly seen at a depth of about 30 metres (100 feet).

THE RAY THE WORLD FORGOT: WEDGEFISH UNDER THREAT

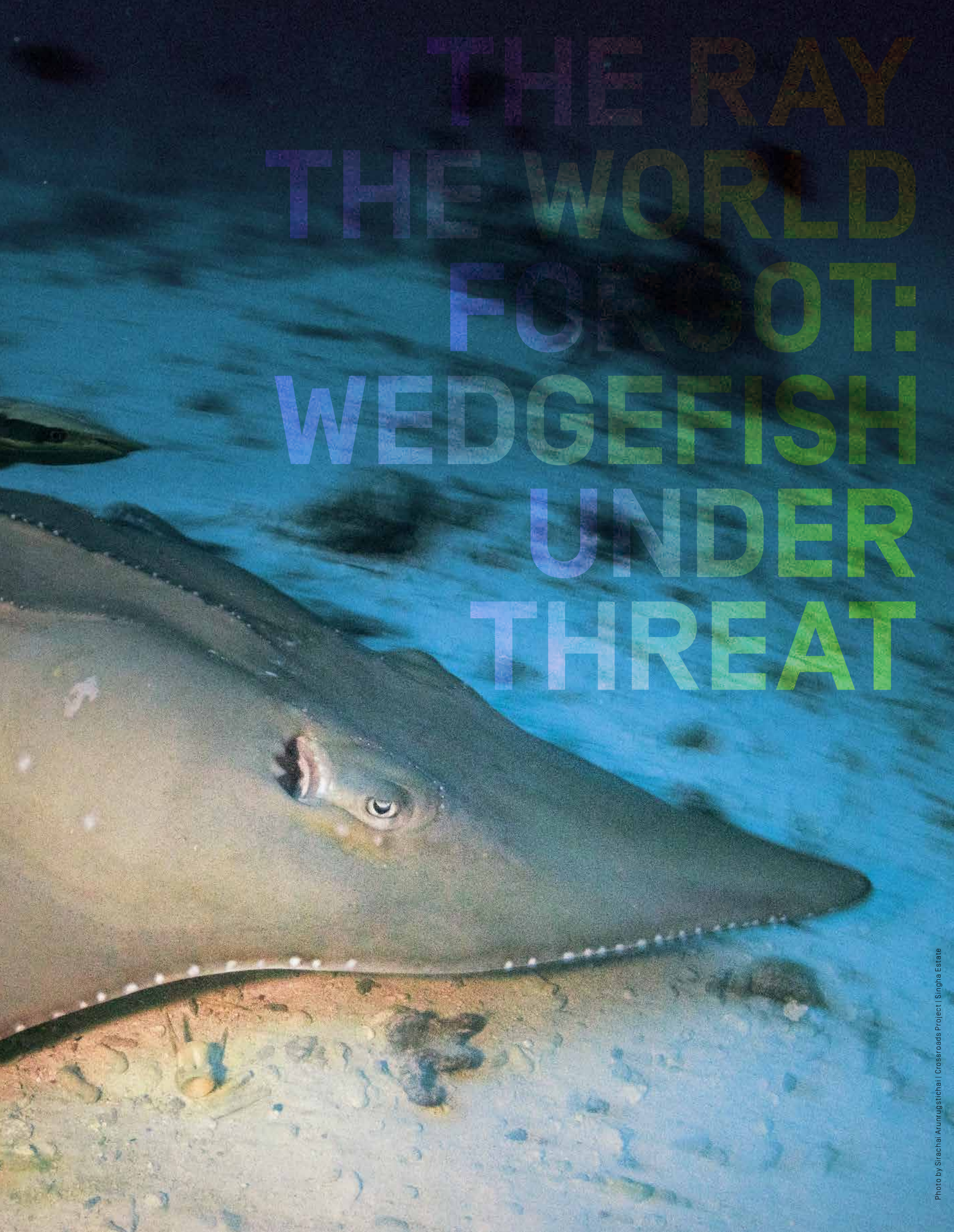
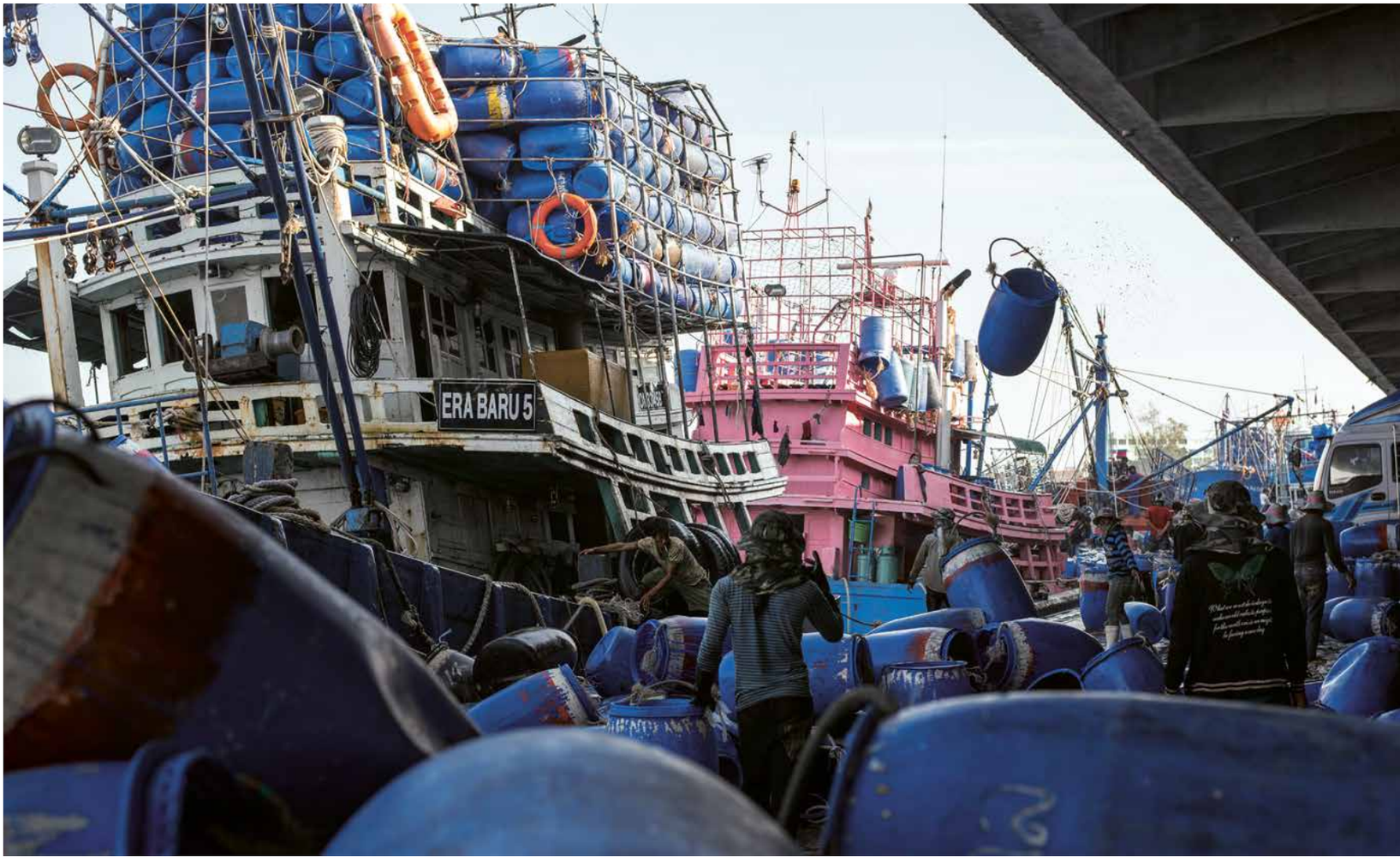
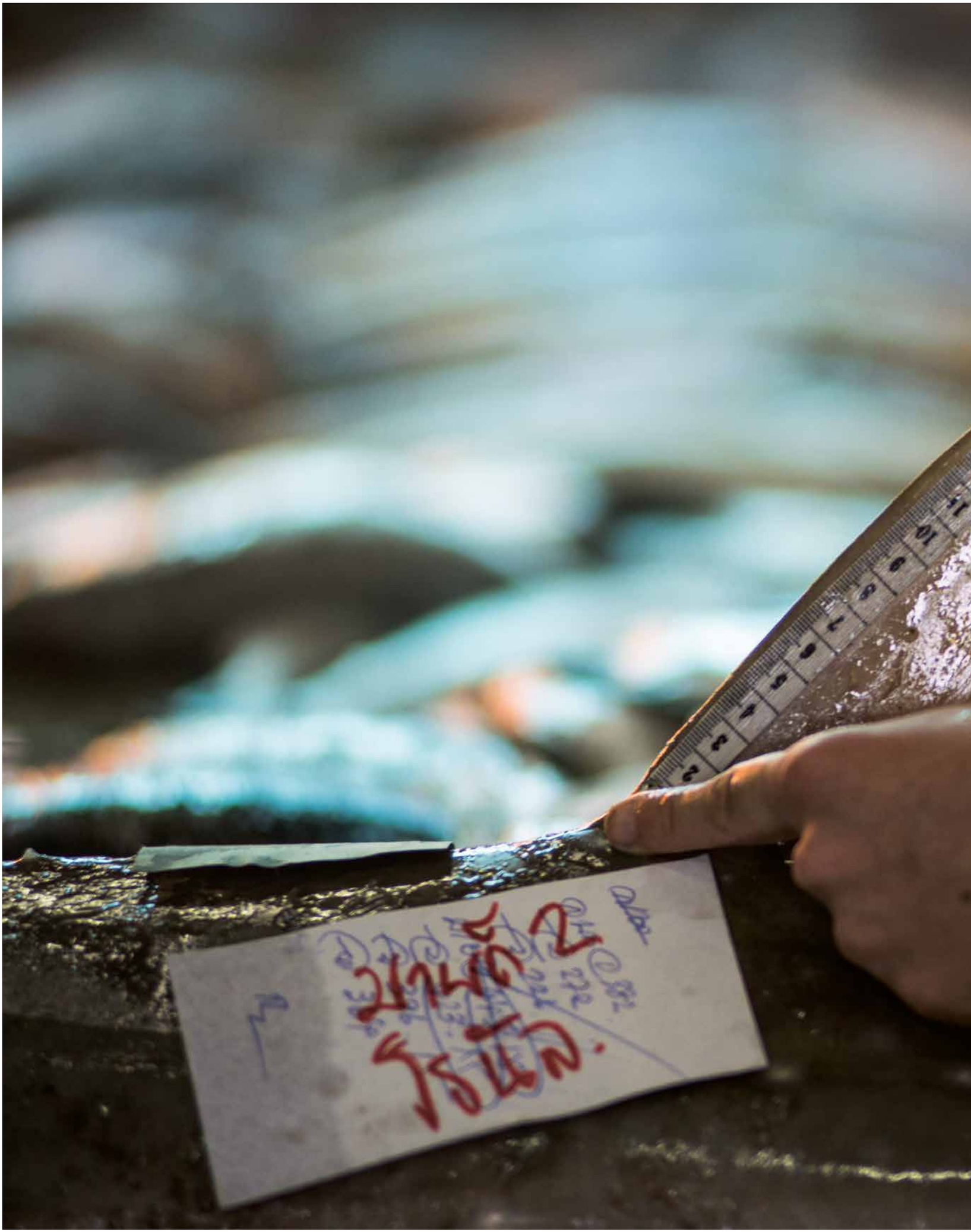


Photo by Sirachai Arunrugstichai | Crossroads Project | Singha Estate

In the tropical Indo-West Pacific there is substantial fishing pressure on marine resources. Trawl fisheries are non-discriminatory in their catches and little of the catch comprises the target species. Large quantities of the by-catch are considered trash fish. Fishing vessels, such as large demersal trawlers, unload their catches at huge fishing ports where the most valuable fish are auctioned.



Wedgefishes are a common sight in the by-catch of a number of demersal fisheries, which use gear such as gill nets, long-lines, trawls, trammel nets and tangle nets. This juvenile bottlenose wedgefish, displayed for auction at a fish landing site in Ranong Province, Thailand, would not yet be mature.



Wedgefishes are highly prized species whose fins are the most sought after in the international shark-fin trade. Mature wedgefishes, at about three metres [10 feet] long, have very large fins that can fetch more than US$700 per dry kilo in the South-East Asian fin market trade. Sadly, localised population depletions have been recorded and in areas like Indonesia, where these species are targeted, fishers have had to move long distances from their home ports to locate them.

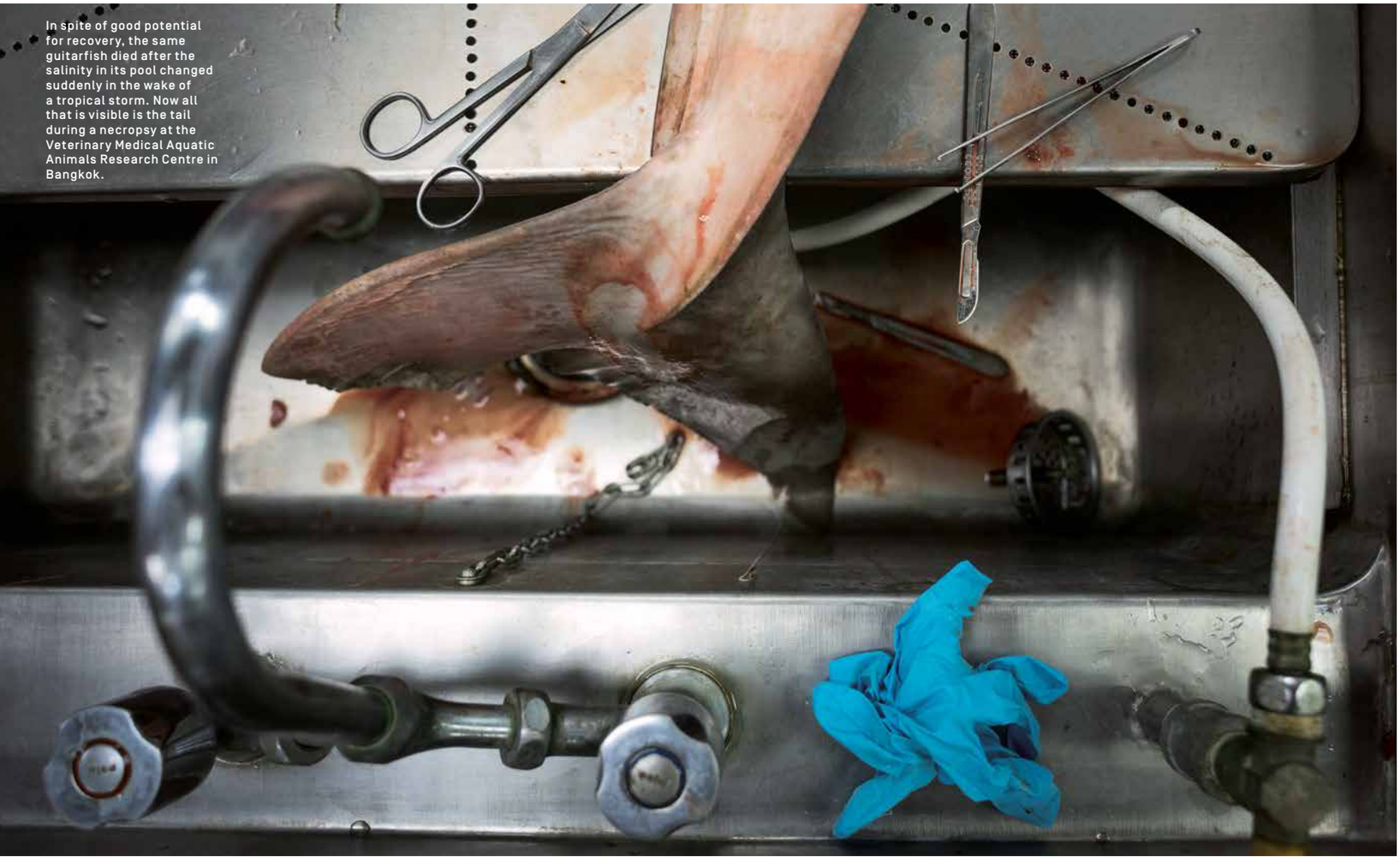
Fins from small sharks and shark-like rays are aired on drying racks at a shark processing factory in Ranong Province. According to a 2015 Food and Agriculture Organization report, Thailand has surpassed China in terms of the export (including re-export) of shark fins and specialises in small, low-quality fins. The fins of wedgefishes are marketed by traders as those of sharks, adding finning to a long list of threats to these rays' survival.

Two juvenile bowmouth guitarfishes *Rhina ancylostoma* are displayed for auction at a fish landing site in Ranong Province. This species is the sole member of the genus *Rhina* and is distinguished by knobbly 'thorns' on the bony ridges of its head and by its short, wide snout. These rays live in deep waters on the sea floor and are consequently often caught by commercial otter board trawlers.

The bony ridges of a bowmouth guitarfish have been cut off, exposing part of the cartilaginous skull below. Once the thorns on the bony ridges have been removed, the rays are often finned and butchered and the meat is salted in brine before being dried and sold as unidentified 'salted fish'. The internal organs and skeletons are mostly processed into animal feed or fishmeal.

A bowmouth guitarfish that was found stranded is treated at the Eastern Gulf Fisheries Research and Development Centre, Rayong Province. The people of Thailand are growing increasingly aware of the rarity and decline of this species.

The 'thorns' from the bony ridges of bowmouth guitarfishes are sold at a roadside souvenir store in Kawthaung, Tanintharyi Region of the Republic of the Union of Myanmar. These are commonly used for decorating rings and are widely believed to contain magical properties. It is illegal to sell these parts in Thailand, where the species is protected.



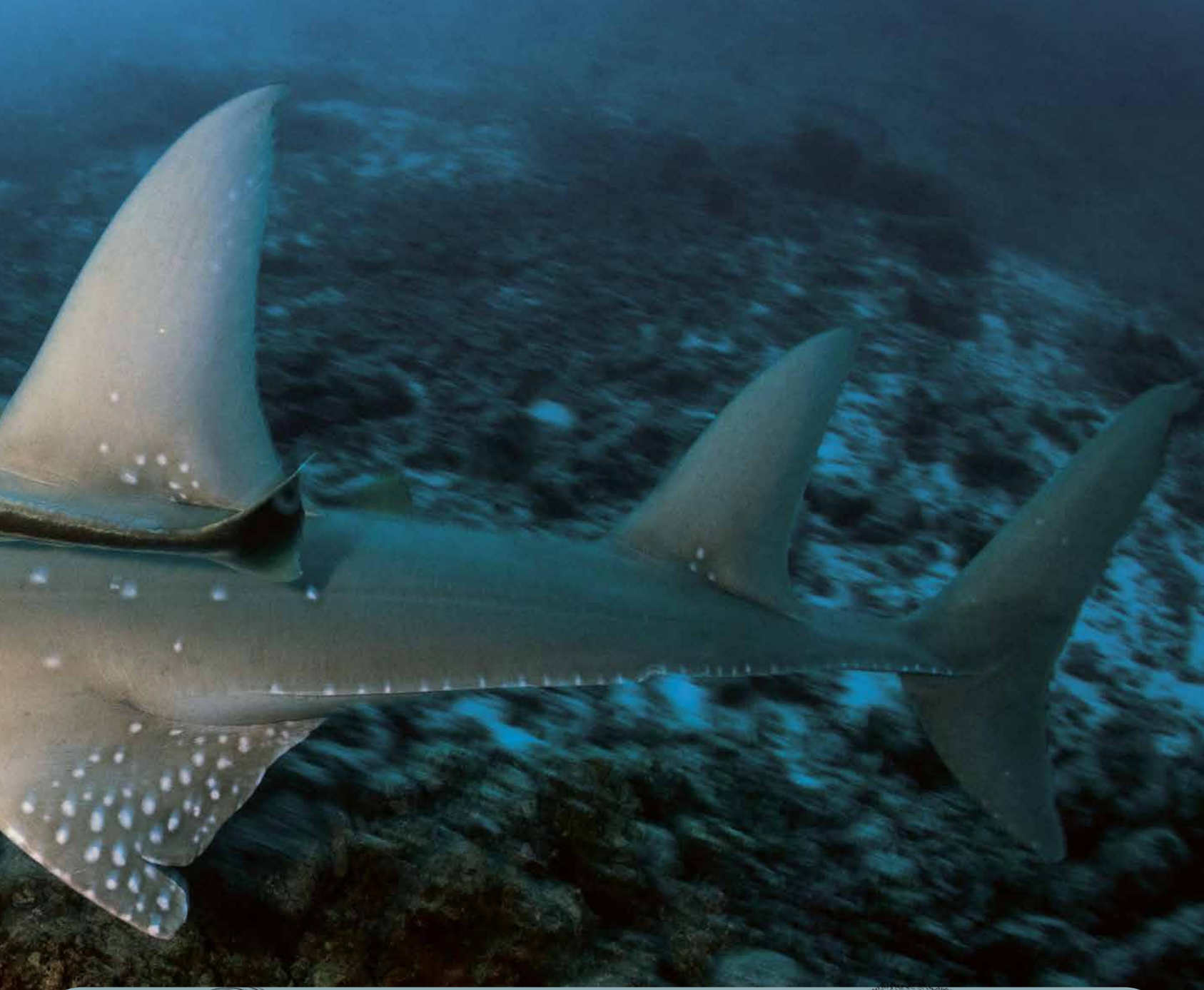
In spite of good potential for recovery, the same guitarfish died after the salinity in its pool changed suddenly in the wake of a tropical storm. Now all that is visible is the tail during a necropsy at the Veterinary Medical Aquatic Animals Research Centre in Bangkok.

A neonate bottlenose wedgefish, its unhealed umbilical scar still visible, is handled by a fisherman in a holding pond after being caught in a crab net in Chonburi Province, Thailand. Wedgefishes are aplacental viviparous: the embryos develop inside eggs that are retained in the mother's body until hatching. The reproductive biology of these rays is for the most part still poorly understood.

Bottlenose wedgefish neonates are tranquillised with dexamethasone by aquatic veterinarians for transportation to a rehabilitation centre in Chonburi Province. These individuals were bought from fishers by a group of scuba divers and veterinarians. Divers usually want to help maintain wedgefish populations in Thai seas, given the limited management strategies to conserve these species in South-East Asia.

A juvenile bottlenose wedgefish is released into the sea by an aquatic veterinarian after being treated for a week. Twenty-eight other juveniles and neonates that were bought by scuba divers from fishers in Ranong Province died during treatment for injuries sustained in gill nets.

A bottlenose wedgefish swoops over a sandy sea floor while a scuba diver observes from a distance. The concern and interest shown by recreational divers in these otherworldly rays is a heartening sign that there is a will to halt their declines. A similar drive from the management and political sector would help to secure a future for them across South-East Asia.



Sirachai Arunrugstichai

A Thai photojournalist specialising in marine conservation, Sirachai 'Shin' Arunrugstichai originally took up photography to document coral reef biodiversity while working as a field biologist, but he changed his career to photojournalism after realising how effectively photography communicates conservation issues. Currently, Shin is a freelance photographer for *National Geographic* Magazine (Thai edition). He has worked with IUCN Asia, the Save Our Seas Foundation, WildAid, Greenpeace Southeast Asia and OXFAM Thailand.

A 2016 recipient of the Save Our Seas Foundation's Marine Conservation Photography grant, he spoke at TEDx Bangkok in 2017. He is an Emerging League Photographer with the International League of Conservation Photographers and was selected as one of six talents from the South-East Asia and Oceania region, representing Thailand for the 6x6 Global Talent Program by the World Press Photo Foundation. Recently, Shin received the explorer award given by National Geographic Thailand for his work in public communications on marine conservation issues in local waters.

Will White

As the senior curator of the CSIRO's Australian National Fish Collection, Will White has been researching the ecology and taxonomy of sharks and rays for more than 20 years. His research includes over 70 new species descriptions, six books and more than 130 journal articles. Will has focused much of his research on fisheries in developing nations, particularly Indonesia and Papua New Guinea.

Photo by Sirachai Arunrugstichai | Crossroads Project | Singha Estate

a sea o

Part one: Finding a voice in the ocean

f sound

Words by Lauren De Vos

Photo by Janie Wray

In the gentle lilt of Janie Wray's voice, a thrill of excitement courses like an electrical undercurrent when she talks about the songs of the sea. The clicks, squeals, whistles and singing that most of us appreciate as beautiful but typically never explore further than some looped recording in a hotel spa or yoga studio hold far more portent for this cetacean scientist. 'I'm pretty sure I was nine years old when I first heard a humpback song,' she says. 'My mother tells me now that I carried a little red tape recorder around with me and refused to let it go. I kept playing that song over and over and over again.' For Janie, the magical voice trapped in her cassette tape spoke to what would become a lifelong passion. 'There was just something about that sound that really had an impact on me as a child, and it obviously stuck…' There was no need for nine-year-old Janie to embellish those voices with kitsch renditions of pop hits on pan pipes like those hotel spa playlists. To her they were a chorus of clues that would help her understand an entirely different world underwater, a song that connected her to the ocean she later learned to love so much.

Sound in the sea means far more to marine scientists than the soothing whale songs we appreciate in recordings; it is an emerging research field that opens up new possibilities for how we interpret and monitor ecosystems. Divers may already be well acquainted with the snapping, popping, crackling and hissing sounds resonating from their favourite reef haunts. I myself have been known to sink to the sea floor, using up what little precious breath I still have to burble alien sounds from my throat to win the attention of a curious roman seabream in the kelp forest of my home dive spot on South Africa's Cape Peninsula. Fishermen on the coastline here know fish for their barking, thrumming and chirping; from the resonant drumming of dusky *Argyrosomus japonicus* and silver *A. inodorus* kob to the jaw-grinding sound of the aptly named spotted grunter *Pomadasys commersonnii*, the ocean expresses itself through its characters and characteristics.

Of all the elements of this dynamic ecosystem that play the sea's symphony, it is the cetaceans – whales, dolphins and porpoises – that are arguably the most famous and whose acoustic communication is extraordinarily sophisticated. The unique and complex voices of whales, and in particular the fin and humpback whales and orcas that cruise the coastal waters of British Columbia, are what keep the scientific curiosity of Janie and her team piqued. 'Some whales spend most of their day underwater. While we can (and do) use a variety of different methods to understand these animals, it makes sense to listen in to what they are mostly doing: moving and communicating underwater, out of sight where we'd typically be tracking them from the surface,' she explains. 'Sound helps us develop a much more complete picture of the life history of whales.'

The North Coast Cetacean Society (NCCS), dubbed BC Whales, is the non-profit organisation tuning in to the conversations of the whales in the remote reaches of the British Columbia coastline. Its newest research camp at Fin Island was established in 2017 and is the site of a novel hydrophone project that employs sound as a means to understand which whales are in the area and what their movement patterns are and to interpret the nature of their different behaviours. In a photograph on the BC Whales website, the Fin Island cabin appears as an ant-sized blip perched on a narrow band of rock surrounded by the dense forest of the Great Bear region and above the gunmetal waters of the Kitimat Fjord System.

The fjord system is located about 500 kilometres (310 miles) north of Vancouver and is made up of a maze of channels and inlets that snake through the coastal waters of northern British Columbia. The traditional territory of coastal First Nations, this remote and complex ecosystem has been shared by humans and whales for hundreds of years and forms part of a core habitat for fin whales *Balaenoptera physalus*, humpback whales *Megaptera novaeangliae* and orca *Orcinus orca*. Squally Channel, a confined waterbody that plunges to a depth of 700 metres (2,300 feet), is where the hydrophones of the Fin Island project have been deployed in a novel configuration. The project is a collaboration between the Gitga'at First Nation and WWF-Canada and includes the work of Eric Keen, a PhD candidate at the University of Victoria. With the pilot phase of its first field season recently completed, the team has been engulfed by a host of new insights and is moving steadily towards its goal of being able to better understand, track and manage whales in the area based on sound alone.

So why exactly sound, and how does it work? 'We're very limited in our ability to understand life underwater when using light or infrared technology, but sound travels well and can extend our reach further, allowing us to probe into the world of whales,' explains Ben Hendricks. A post-doctoral researcher from the University of Victoria working through a Mitacs ELEVATE Postdoctoral Fellowship, Ben is an astrophysicist by qualification. It is his statistical wizardry that is behind the Fin Island hydrophone project's development. 'We can listen in to an ocean soundscape through what is called passive acoustic monitoring, using hydrophones as submarine microphones that can detect and record sound waves as they move through water. We can also transmit sound into the sea through active acoustic probing,' he says.

Whales and dolphins use sound to sense their environment when they are searching for food, navigating a pathway through the ocean and connecting with other individuals. They can passively listen to what is being communicated in the ocean around them and they can actively echolocate, sending out a source signal that bounces off an object and returns. Similarly, humans can both listen to what's being transmitted in the ocean (for scientists, a hydrophone array is the equivalent of an underwater ear) and employ sonar in place of echolocation to explore the ocean.

Using the medium of sound confers several advantages on scientists and whales alike. 'We can use sound all day and all night, throughout the year, in any weather and all ocean conditions,' explains Ben. For scientists keen to understand the lives of animals that don't much care about the vagaries of research equipment, the fickle nature of funding or the real challenges posed by the ocean to humans, these are highly attractive advantages. Whereas boats may run out of fuel during endless hours of surface tracking, divers are limited by depth in their efforts to explore where whales might venture and cameras are obscured by cloudy waters, hydrophones sit passively eavesdropping on the otherwise secret lives of cetaceans. Naturally, no single method works perfectly all the time, but the theory is – for lack of a better pun – sound. Of course, acoustics alone can't answer all ecological questions; it's best used for vocal species, and the signature sounds of different species and behaviours need to be confirmed by observation before scientists can effectively calibrate what all this means. However, it's a powerful way to 'complete the picture', as Janie says.

What makes the Fin Island project different from other passive acoustic monitoring programmes is that the unique placement of four hydrophones in a rectangle allows Janie, Ben and the team to pinpoint the location of a vocalising whale using triangulation. The hydrophones are placed on the sea floor at a depth of about 20 metres (65 feet) and are within 100 metres (330 feet) of the shore. Their recordings are picked up by radio antennas and transmitted to the Fin Island station, where they can be

Photo by Janie Wray

What Jacques Cousteau dubbed ‘Le Monde du Silence’ is anything but a silent world. Sound travels faster, further and more effectively in the ocean, a realm made for acoustic communication and one that is alive with new possibilities for how we perceive the animals that call it home. When it comes to sophisticated singers like humpback whales and complex social creatures like orcas, seeing through sound is the best way to build a more comprehensive understanding of the rich lives they lead underwater. In collaboration with the Gitga’at First Nation and WWF-Canada, Janie Wray of the North Coast Cetacean Society and post-doctoral researcher Ben Hendricks have set up a novel project that tunes into the ocean’s orchestra and will help them gain insights into the life histories of whales on the coast of British Columbia.

streamed and analysed in real time. This differs from other monitoring, where hydrophones are deployed from a boat as researchers move across the water to listen for whales. When a signal has been located on all four hydrophones, the localisation makes it possible to track that whale remotely. This places whales in the context of their environment, the region and in relation to each other, giving a 'map' of which whales are using Squally Channel, how they are using the area and where they move within the region during the year.

After the completion of the first testing phase of the hydrophone project I ask Janie what stood out from listening in on the whales of the area. Her answer speaks to her particular research animal of interest, the humpback whale. The males of the species are known for their haunting songs and in these rich waters their singing has been linked to their presence for feeding; indeed, this is where their 'bubble-net' feeding behaviour has been made famous in footage from documentaries like *Blue Planet*.

'When Ben sent me the vocalisation of a humpback singing and the actual location of that whale, and was able to show that there was another whale that started to sing, and we could see the distance between those two whales, that's when my heart rate went up,' says Janie. 'We don't yet have specific information on where males sing, the distance between individuals when they are singing or whether there are particular features under the water that are attracting whales to sing in a certain location,' she continues, her excitement palpable. 'That's a line of investigation we can follow up in the coming season of field work. It's a huge question that remains to be answered and this method of triangulating whale locations using sound might well enable us to do so.'

The fixed placement of these hydrophones, which are powered by batteries charged by solar panels and transmitting real-time data, moves the project away from the limitations of needing to be on a boat to track whales. Boat-based tracking remains an important part of ground-truthing the information the team are currently gathering, but the long-term goal is to use this soundscape monitoring to passively and non-invasively keep tabs on the life in Squally Channel. 'We can detect this kind of information all the time, without impacting the whales themselves. We are sometimes listening in at midnight in this tiny cabin in the Great Bear Rainforest and occasionally what we hear is in stereo.'

Janie paints a picture of life in this remote corner of the earth, one where the significant challenges to research in the region are rewarded by extraordinary moments of insight into this sonic sea, for those patient enough to work there. In her retelling, it's easy to conjure what emotions the soaring harmonies of whales singing through those long, lonely research hours might elicit. 'We don't just hear them on one hydrophone, we hear them on three or four,' she continues. 'But there is a time delay, so we're hearing it as a whale would be listening to it, as a result of how sound travels from one point to another in the water.'

Photos by Janie Wray

While humpback whales in the waters of British Columbia have been found to be singing in their feeding grounds, building on a song that is transmitted across the population and that changes from year to year, there are other whales vocalising in the area too. 'What I found really interesting with the fin whales that Ben was able to pinpoint through this hydrophone network was how unpredictable they are,' says Janie. 'We knew a little of this from watching them from the surface. By contrast, humpback whales and orca are, to some extent, predictable. If they're heading in a particular direction, we can estimate where they will surface next. We can't do that with fin whales, and these acoustic data confirm that.'

Understanding behavioural idiosyncrasies such as these in the whales of Squally Channel is important because it will ultimately inform how they are managed. Avoiding ship strikes in highly utilised areas, for instance, relies on some idea of how whales move, and where. While their very unpredictability makes it difficult to find an easy solution for fin whales that are active in a shipping area, it is this kind of behavioural pattern that builds a more complete and defensible body of knowledge for the scientists scratching their heads about how best to advise on behalf of the whales in a region they must share with human beings.

This is the type of information that Janie and Ben, together with their collaborators Chris Picard, the acting director for the Gitga'at First Nation, and Hussein Alidina, the lead specialist for Oceans Conservation with WWF-Canada, want to make available. The power of these data is threefold: they can inform the best available scientific advice on how to manage whale populations in the region; they can equip First Nation communities with the information they need to make their own decisions about using the land and ocean in their territory; and they can open an underwater world to a wider community through the power of sound.

The project marks the start of several possible directions for improving our understanding of whales. For Janie, the most important of these is to work in conjunction with other bodies gathering knowledge to build a comprehensive overview of what whales are doing. 'There are a number of hydrophone projects along the coast of British Columbia, listening in to the ecosystem in various ways. We've recently met with several of the other groups working in the region and I believe the next step is to work together with these hydrophone groups so that we are collecting standardised data along the coast using the same methodologies. This makes the data accessible to scientists to understand how whales are using the entire coast. If we really want to know what's happening in the underwater world of whales, we need to look at the larger picture.'

Of the whales that use this region, none capture the collective imagination so effectively as the highly social orca groups. Two distinct ecotypes of orca navigate these waters: the northern residents are chatty salmon hunters that use the territory throughout the year, and the quieter Bigg's or transients prey on mammals and frequent the region on their own terms. 'The other thing that I found interesting from this first season was the track of the

← Getting the logistics right at remote research stations such as the Fin Island cabin takes tenacity, and no small number of tricky moorings as the equipment is loaded onto the vessel for a day at sea.
↑ Tuning in passively to listen to the conversations of whales adds to the boat-based observations that can confirm the identification of different species.

Three different ecotypes of orca are found in Canadian Pacific waters. Janie and her team monitor the northern resident orca and the transient (or Bigg's) orca. These ecotypes differ in their food preferences, style of vocalisation and social structure.

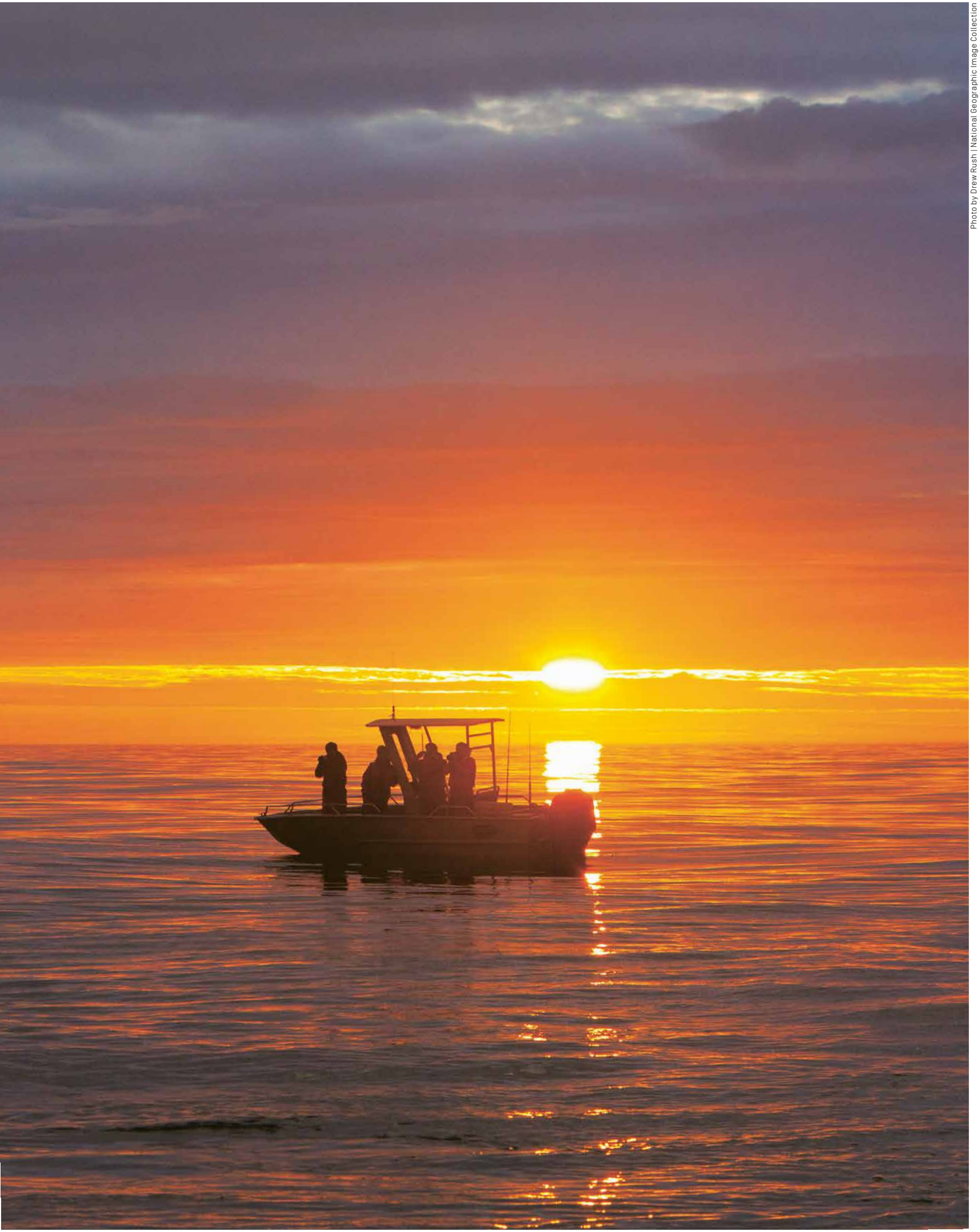


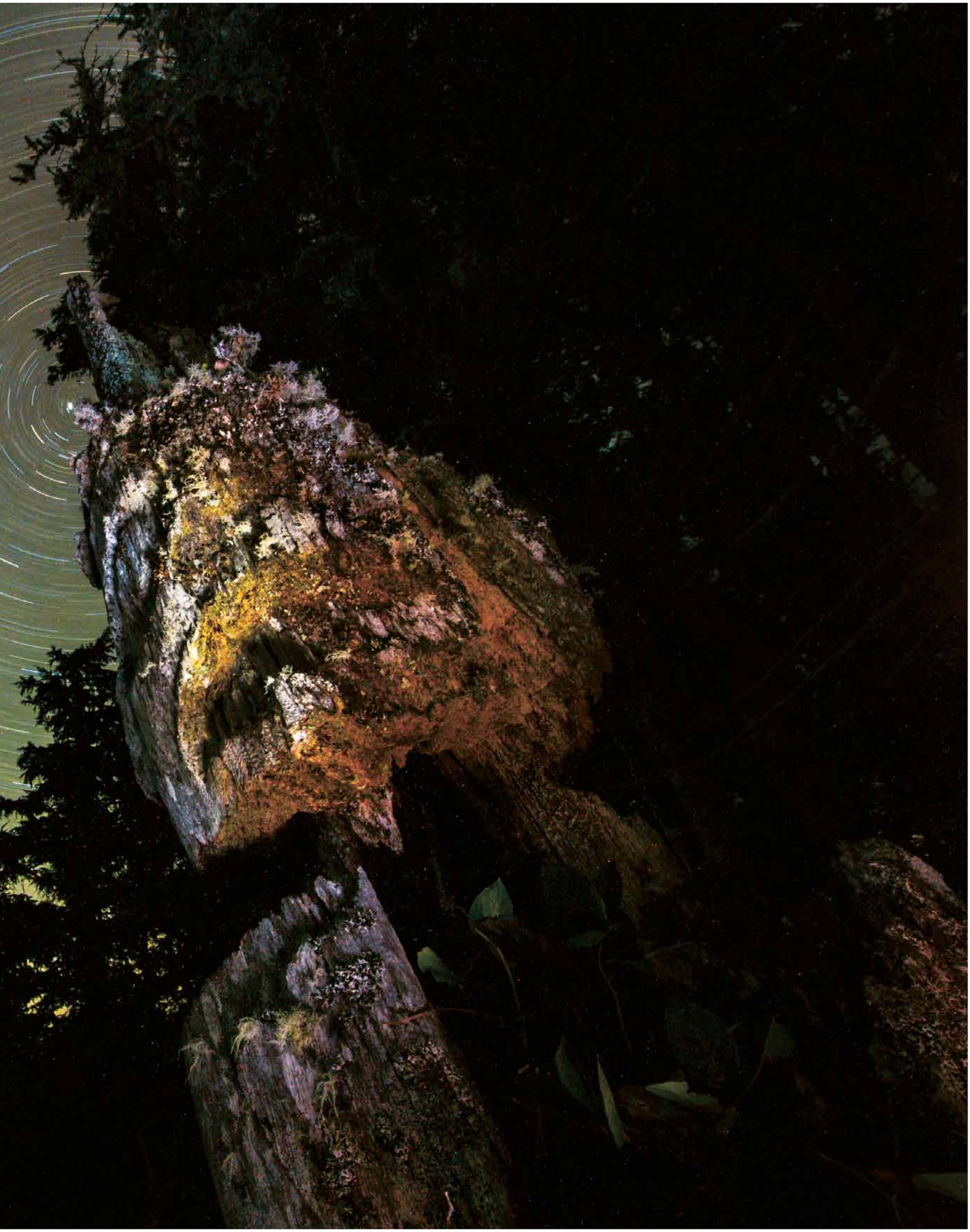
Photo by Drew Rush | National Geographic Image Collection

Transient orca are able to hunt hefty prey such as the Steller sea lions that are pictured here, at the largest haul-out in the north-eastern Pacific. In the north-western Pacific, about 400 transient (or Bigg's) orcas cruise the coastline in search of mammal prey.

Photo by Ian McAllister|
National Geographic Image Collection

Photo by Ian McAllister | National Geographic Image Collection

Empowering First Nations leadership with the data to make decisions about development in British Columbian coastal waters is an important step. This Heiltsuk guardian totem pole still stands sentry at night; many local communities from the Gitga'at and Heiltsuk First Nations have lived in close association with the coast here for generations and maintain strong ties to the ocean.



(northern resident) orca,' adds Janie. 'It was such a direct line and you could really see that they knew where they were going. They were following something that's invisible to us but visible to them.'

What was it that these animals were following? How do they understand, and navigate, their home territory? So much of the ocean remains a mystery to us. The finding of orca moving, unhindered by the presence of humans on a boat, helps piece together some ideas of what makes these particular whales so fascinating. 'I believe that these orca may follow specific pathways. Just as you walk into a forest and observe the tracks of deer, or bears and wolves, I believe that over time we are going to have the same insights into the movement patterns of whales.'

Janie's insights probe the ecology of these whales and remind us of how remote the ocean often feels to us, disconnected as we are from the nuances of the lives of its inhabitants. Whereas Jane Goodall could capture the imagination of the world by observing chimpanzee behaviour and connect us to these creatures by showing us some of the similarities in how they lead their lives, the oceans are often still characterised in terms of what they mean to us in the way of resources. We speak of plummeting fish stocks and strange animals from alien realms, of mitigating the impacts of deep-sea mining and offsetting trawl fishing before we really appreciate what makes the ocean worth protecting beyond our reliance on its provision of services to us. The challenge of sampling at sea has limited our capacity to develop a natural history for many of its truly fascinating ocean inhabitants.

It's often in the details of how all of us – humans and animals alike – lead our lives on the planet that some kind of connection is established. As technology allows us to travel further, deeper and for longer in the ocean, we're set to change all that. For whales, whose voices are perhaps most innately connected to the accurate telling of their story, 'watching' their lives play out through sound helps us do for the ocean what has been done for decades on land. Janie sums up why seemingly simple ecological insights might help us piece together this puzzle and connect us to creatures that live in the sea: 'I think we will be able to predict the pathways of these whales over time, because, like us, they have preferred ways that they travel.'

Research. Connect. Protect. The byline on the landing page of the BC Whales website links three important concepts in these succinct words: connection is the bridge that enables people to use the information that research generates to protect the ocean we rely on.

If it seems a little odd that an analytical mind like Ben's turned its attention from the stars in the sky to a world underwater, perhaps his musing on what led him to the Fin Island project helps us better understand the real power of this word 'connection'. Much like Janie's song on a red tape recorder, it was an encoun-

Photo by Janie Wray

The first records of singing male humpback whales in connection with bubble-net feeding behaviour were captured here, in the rich feeding grounds of the Pacific North West and Great Bear ecosystem.

ter with whales that drew Ben to the sea. 'I went kayaking and came across some grey whales…' Ben trails off, lost a little in his reverie before continuing almost wistfully, 'You should come visit here and hear what happens underwater. You'll understand why I've stayed.' These encounters sparked a fascination with what the American writer and naturalist Henry Beston called these 'other nations, caught with ourselves in the net of life and time'. Of course, not all of us might meet a whale and choose to dedicate our lives to understanding and protecting it and its fellows, as Janie and Ben have done. But giving the whales of British Columbia a voice might go beyond ecological interest and scientific innovation to connect us all to an emotional understanding of the sea.

Sound transcends much of what keeps us apart and awakens in us memories, emotions and some intuitive understanding. 'We're hoping that, moving into the next season, we can relay the signal at Fin Island so that we can share our recordings online with the neighbouring community at Hartley Bay and then they too can listen to the underwater world on their doorstep, live,' says Janie. 'We really believe this will be a huge step forward for that particular community and their connection to their natural heritage.'

She slows to reflect on something that may have brought her into this kind of research. 'The next big step would be that the whole world would be able to listen to the underwater world of the Great Bear region. I think it's essential, because I believe that sound has the ability to resonate in our hearts and minds and it has a very different effect on us than reading a formal scientific paper.' A wry chuckle escapes her, then she adds, 'I think this means that you suddenly have the ability to come into the homes of people and bring this world to them. This could have a huge impact when it comes to inspiring people to protect the ocean and to have them truly appreciate how much more is going on under the surface.' We both pause and I think for a moment about that little girl clutching her red tape recorder, a cassette of whale harmonies playing over and over and over again. It was the voice of one whale that captured Janie's imagination as a child and holds her transfixed to this day. What could the effect of choirs of cetaceans be on our collective imagination?

'It's not just the whales that they'd be hearing, you see? It would be the ocean ecosystem; they would hear herring, shrimp, the grunts of fish – a true acoustic work of wonder.' For Janie and Ben, and the research team tuning in to the frequency of these submarine symphonies, the sound of the sea doesn't start and end at the crashing of waves along the shoreline. There is, to borrow a phrase from marine conservation biologist Dr Callum Roberts, 'a natural history of the sea to be told'. And it is history that helps us navigate a shared future on this planet. For the whales of British Columbia, finding a voice and broadcasting that to the world is ultimately what will guide how we better share the ocean with them.

Photo by Fabien Michenet | BiosPhoto

a sea o

Part two: The conductor’s conundrum

f sound

Words by Lauren De Vos

An orca surfaces in parallel with an Alaska Marine Highway ferry in Lynn Canal, Alaska. Our increased reliance on the ocean sees shipping traffic on the rise; its consequences for marine wildlife are now coming to light.

Photo by Design Pics Inc | National Geographic Image Collection

Tuning in to the underwater world has a conservation imperative that goes beyond connecting to a more comprehensive understanding of the life histories of whales; it is critical in an ocean where many voices now compete to be heard. A new study tests a hydrophone array that relays sonic data in real time in Squally Channel in British Columbia and helps us understand how sound data might better protect whale populations where humans and ocean animals share an increasingly busy space. In a conversation with Dr Ben Hendricks, Lauren De Vos delves into what it takes to make sound science work in remote locations. The implications mean a great deal for how we understand sound to protect critical ocean spaces and how we use it to manage busy shipping areas.

I hear them long before I see them: a high-pitched whistle as I sink my head below the water, the trill of an aquatic Mozart's *Zauberflöte* directing my attention to the right. A volley of staccato clicks follows, seconds before a chattering pod of Indo-Pacific bottlenose dolphins swims into view. Off the coastline of Mozambique, this resident group of social dolphins flouts immigration laws as it traverses the invisible border that marks the end of South Africa at Kosi Bay and the start of Mozambique at Ponta do Ouro. I'm swimming in surround-sound, squeaks and whistles filling the water around me. The well-spotted underbelly of an aged male flashes past, his clarinet contribution to the swell of signature voices taking a momentary lead in this overture. The breathy fluting of two mothers follows, their calves piping piccolos close at their sides.

Suddenly, Monostatos' metallic whirr cuts through the calls in this marine performance of *The Magic Flute*. A propeller's percussive clack-clack-clack slicing through the water is the prelude to the low engine hum that drowns the voices of the group. With a start, I realise that it's the boat moving closer to retrieve me from the water. I lose my bearings in relation to the group and although it is still nearby, I can't locate it as easily as when I could hear it. The dolphins quickly outpace me and, even in this clear water, without their sonic cues to guide my gaze, I soon have to concede that I've lost them.

Acoustics guide marine life; it is sound that helps species navigate, hunt, hide from predators, find mates and communicate with each other. The ocean soundscape isn't only made up of calls from different animals, but includes ambient levels of noise from crashing waves and ocean spray, rainfall, and bubbles that form and burst. Somewhere in this oceanic orchestra, the strains of human activities – commercial shipping, seismic exploration, the back-and-forth of recreational vessels – are increasingly heard and, in many cases, overpower the sea's other voices. As the number and size of ships traversing the ocean has increased, explains John Hildebrand from the Scripps Institute for Oceanography in his 2009 paper for the journal *Marine Ecology Progress Series*, ambient ocean noise levels have risen by 12 decibels.

For the humans that are temporary visitors to the ocean's depths, noise pollution is relatively inconsequential. My own survival, for instance, wasn't linked to losing earshot of those dolphins on the day the inflatable boat purred over to collect me off the coast of Ponta Malongane. For many ocean animals, however, noise is the ironically silent pollutant in the oceans today, its insidious impacts less frequently discussed than those of plastic and oil spills.

Hildebrand goes on to explain how ocean construction, oil exploration and seismic surveys have moved gradually into deeper waters, extending their sonic reach far from the coastline and into the abyss. There is less and less ocean that remains 'out of earshot' of human activities. Seismic surveys generate low-frequency noises that travel long distances across entire ocean basins. The lower the frequency, the less it attenuates and the further the sound travels. Reports abound of cetacean strandings or disturbance after offshore seismic surveys, but the causal evidence that links these deaths with noise pollution remains scant. This reflects a need for more comprehensive study and analysis and is not an indication that convincing evidence doesn't exist, say Manuelle Castellote and Carlos Llorens, the authors of the chapter 'Review of the Effects of Offshore Seismic Surveys in Cetaceans: Are Mass Strandings a Possibility?' in a 2016 publication on the effects of noise on marine life.

Sound pollution means different things for different species. Whereas some noises can damage the hearing (and even non-hearing) tissues in the bodies of marine animals, others mask auditory cues in the marine environment that help animals find each other, locate their prey or navigate their way. Some sound pollution can even change hormone levels, resulting in stress and sleeplessness, according to Hansjoerg Kunc, Kirsty McLaughlin and Rouven Schmidt in a 2016 publication on the impact of aquatic noise on marine animals. While the impacts of blasting, oil exploration and seismic surveys are extreme and often deadly for ocean animals, far more pervasive is the noise from shipping and boating, which is ubiquitous and frequent in our oceans. This kind of noise may not directly kill marine life, but it can disrupt animals' ability to navigate, find mates, hunt prey or escape predation. Some of its impacts even affect animals that don't obviously employ sound in their life-history strategies. In a 2014 study, scientists showed how the common cuttlefish *Sepia officinalis* adjusts its complex visual communication display by changing its colour more frequently in response to noises from human sources. This, says lead author Hansjoerg Kunc, is an animal that doesn't rely on sound to communicate at all, but still has its form of communication disrupted by noise pollution.

Some of the species perhaps most affected by noise are those that live in a complex concerto with their environment and other individuals around them: the cetaceans. In the coastal waters of British Columbia, new conflicts play out as the ocean pathways traversed for generations by humpback and fin whales and northern resident and Bigg's (or transient) orcas are increasingly crisscrossed by ships navigating the Kitimat Fjord System. A liquefied natural gas transport and processing facility was approved for the region in 2018, which means that these waters will be busier than ever as tankers move in and out of the channels to deliver the facility's products.

Recording the voices of the whales of this region helps improve our understanding of their lives, contributing to the picture of the natural history of whales that Janie Wray and her team at the North Coast Cetacean Society (NCCS) are piecing together. However, as the instrumentation of the ocean's arias becomes busier, the role of scientists is becoming that of the conductor. Scientists are learning to listen to each and every voice and to manage the delicate balance of sound in the sea.

The hydrophone array in northern British Columbia's Squally Channel, with its four hydrophones placed in their unique rectangular formation on the sea floor, is where Ben Hendricks has been developing the software that will automatically detect, classify, localise and track the vocalisations of ocean animals. On the NCCS website, *BCWhales.org*, the purpose of this software is succinctly summed up for readers: the information from the hydrophone array can be relayed in real time, with the software notifying its users if a whale has vocalised, when that vocalisation happened, which whale species it was and where the vocalisation took place.

To this effect, Ben and the researchers from the NCCS have spent the past few months piloting a project that will direct the procedure for the team to map how whales are using the habitat in the area and to manage the risk of ship strikes. In the long term, the project will help the researchers to understand the impacts of vessel noise and other human activities on the lives of the whales of the region.

I chat to Ben not long after his return from several months of field work and just after he has submitted a publication to the scientific peer-review system. 'The biggest boulder that rolled off my shoulders was when we went out on the boat ourselves to test this concept and transmit our own signals. We had a GPS and therefore knew exactly where we were transmitting from. So we learned nothing about the biology of the whales,' chuckles Ben. 'Importantly, though, we confirmed that we can indeed acoustically determine the position from where we transmitted that signal. That, for my project, was the first big step.'

The cheerful relief in Ben's voice is an understated indication of just how exciting this project is becoming. 'To make this useful to the community – not only for Janie, her team and the NCCS, but for the Gitga'at First Nation that calls this territory home and, eventually, for the management of this region – we needed to show that we can localise everything that whales do. That is, we needed to detect different species, as well as their different behaviours.'

With the success of the first field season and a publication behind them, what exactly does this all mean? 'There are two layers to this project,' explains Ben. 'The first is what this science means for our understanding of the natural history and ecology of whales.' This is what we explored with Janie: the more comprehensive understanding of how the whales of British Columbia live their lives – the possible ocean pathways of orcas, the timing and location of the humpbacks singing their songs.

'But, as you can imagine, as we start localising calls and understanding bubble-net feeding vocalisations, different songs and singing features, we can begin to plot these different calls on a map according to where we're detecting them in the region,' continues Ben. 'Each data point lands on the map, so what you end up with is the distribution of different species in the region and what they are doing in different areas. Where do humpback whales bubble-net feed? Where do the fin whales hang out? What are their pathways and patterns?'

He pauses, then neatly links the natural history element of this project to its conservation imperative: 'Knowing which whales are in the area, what they are doing and where they are exhibiting various behaviours – that kind of map builds a picture of how whales use the Kitimat Fjord System. We already know how ships use the region. We can therefore superimpose two information layers on this ecological map, identifying where the paths of ships may cross those of whales. This helps us to identify critical areas that may need to remain undisturbed by traffic. It's what we call spatial planning and to do this best we need to know the habits and routines of both whales and humans in the area.'

The concept of managing increasingly shrinking habitats where humans and the natural world come into contact is perhaps one we're more familiar with on land, where buildings and roads visibly encroach on the wilderness areas still inhabited by wildlife. Emerging from this need to manage how we balance development with the protection of ecosystems is the field of conservation planning: the art of achieving 'safe operating spaces', according to a review paper in the journal *Encyclopedia of the Anthropocene*.

Conservation planning, for example, contributes to the design of protected areas and involves managing the often conflicting demands of different user-groups. In effect, zones are allocated depending on where animals breed and feed, where they might migrate and what elements of the landscape are critical for their survival. To do this effectively, we need to know how both humans and animals are using the same environment.

This is where piecing together the ecological puzzle of how whales live builds the evidence base that scientists need to advise policy-makers. Where do whales sing, and why? Where do they feed, breed and socialise? How do they move? It is this kind of information that the NCCS and WWF-Canada are working in collaboration with the Gitga'at First Nation to provide. Here, history and context are important: the availability of these data to the Gitga'at First Nation empowers local leaders to make informed decisions about development proposals in their own territory. This kind of transparency and the rapid translation of information is more often than not missing when it comes to projects and policies in regions where traditional communities live in close connection to their environment, but are excluded from voicing their evidence-based decisions about what happens in a region where they have lived for generations.

'What I'm excited about, because this is something novel that hasn't yet been done to my knowledge, is having a real-time tracking system for traffic in the Kitimat Fjord System,' says Ben. 'Imagine an air traffic control system, where the air traffic controllers monitor who flies where, who is taking off when, who is landing … and all this is managed in such a way that no accident takes place. It's a similar idea. With the set-up we now have, we can generate these data points – which whales are calling, and where, and where they are heading – and we can do it live. And now we can add ships to this map because most large vessels nowadays have Automatic Identification Systems (AIS) on board, which enables us to track their positions. So you have a real-time map of both ships and whales, and how they are moving in relation to one another, which means that you can react to situations that are potentially threatening to the whales.'

I press Ben a little further, asking about how translatable this system would be to other ocean areas where cetaceans and humans compete for sonic space. 'Well, now with at least three hydrophones in the water and species that vocalise loudly enough to be detected on the array, you can use the system in all areas. That makes it interesting, but hopefully also puts a bit of pressure on other institutions when it comes to animal welfare. We've proven that it's possible and that it's a viable addition to what will need to be a suite of tools to manage our noisy oceans.'

The reason that we might be more familiar with the idea of managing people and wildlife – and their increasing contact on the same pathways – on land is not only because we live in this realm and are likely to see the visual evidence from day to day. In the ocean, gathering the kind of information that helps inform conservation planning is logistically challenging and takes a huge investment in time, funding and energy.

Making this kind of science work in the British Columbia region is complicated and tough. Remote and rainy, the Fin Island cabin is home to the Squally Channel hydrophone array project, and to the researchers who doggedly tested the hydrophones and transmissions that helped Ben develop the mathematical algorithms that can automate whale localisations. 'We spent a lot of our time climbing trees and fixing radio antennas in the rain so that we could ensure the signals from the hydrophones were clearer when they relayed to the research cabin from their position in the water. A lot of fun, but tricky, and certainly not what any of us are best qualified for. Much of the "behind-the-science" action involved our team getting really good at making a plan, and becoming experts in all kinds of exploits we'd never imagined!'

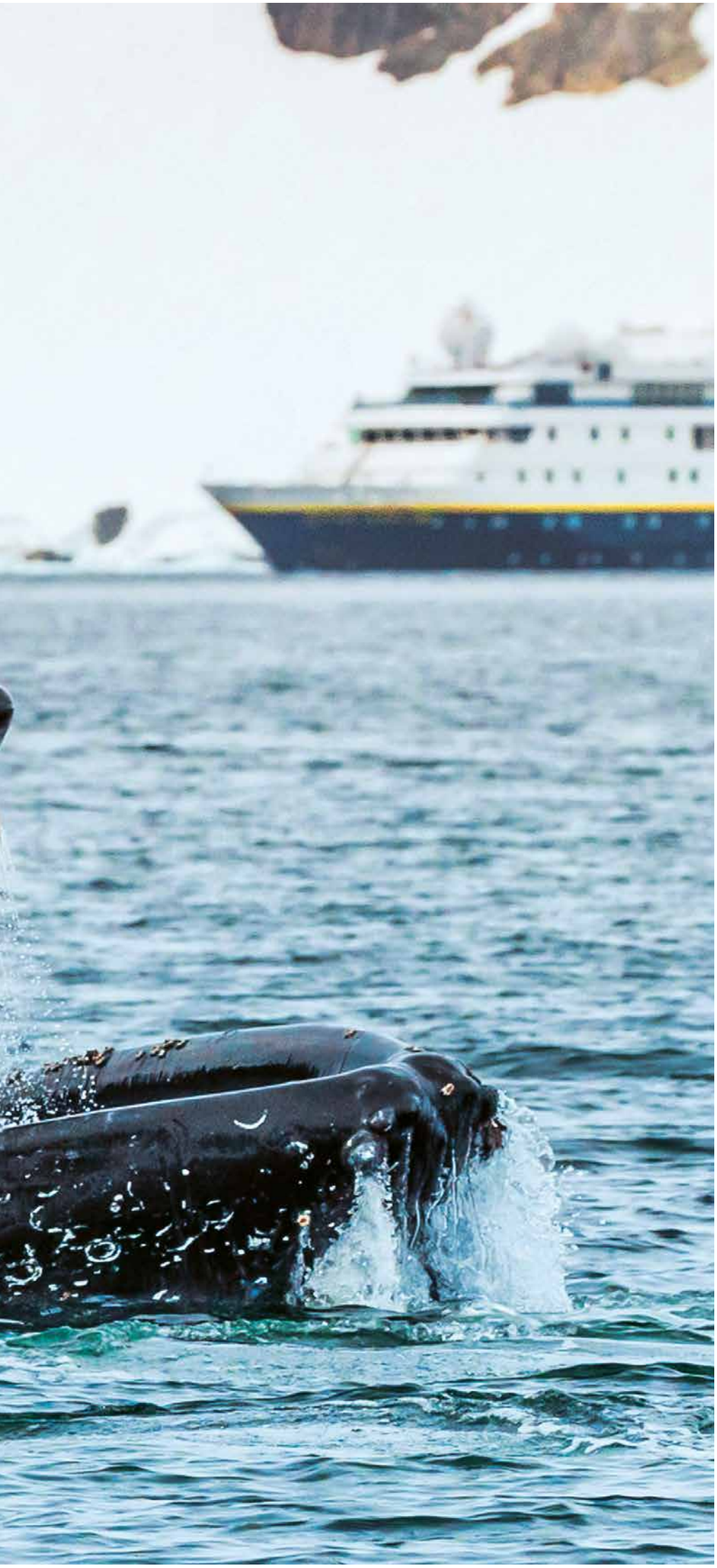
Ben gives a hearty laugh and I recall one of Janie's comments: 'The most heartening thing to come out of this project for me was the phenomenal teamwork and effort from all the people involved.' For Janie, there was deep satisfaction in working with a team so heavily invested in achieving the project's goals. Working together with empathy and good communication made the hardships bearable when shuttling equipment too heavy to convey by plane and kept morale high when (as with all science) most initial tests failed, and failed, and failed again…

Before they head back out into the field, their proof of concept in hand and their algorithms published for the rest of the world to build on so that other researchers and conservation planners – the oceanic conductors, if you will – can integrate this kind of work into their science, I ask Ben what the team has outlined in terms of important development routes for the future of the project. 'I'm not a biologist, so my field of expertise on this project tends to run through my mind in terms of the data analysis and what would be required here in the future. With this in mind, the first step would be to collect data on any environmental parameters that may be related to the activity and behaviour of whales. For instance, rainfall, temperature and the tidal range could all be collected in concert with the acoustic data we're using to track whales in the region. Do these affect how whales behave and where they move, and how? If we start to understand this, we can eventually predict what may happen in areas that share similar environmental conditions.

'Secondly, we'd be interested in ambient noise; that is, if you're an ecologist listening to whales, everything in the ocean that is not a whale. So we'd like to know how whales handle noisy conditions in their environment. What do they do when there's a storm? Of course, if we can measure the natural sounds in a whale's environment, we can also measure the noises related to human activities and begin to understand what impact these have on the whales' behaviour and movement patterns. Measuring ambient noise would be something we'd like to do in the

Photo by Ralph Lee Hopkins | National Geographic Image Collection

Submarine noise and the likelihood of whale strikes increase as ships traverse further, and more frequently, across our seas. This has the capacity to seriously disrupt the ability of many whales to conduct their essential behaviours, like this humpback whale lunge feeding in Paradise Harbor, Antarctica.



future, and it can be done using the data we're already collecting. And of course there is a third, visual aspect to what needs to be done, which is where Janie takes the lead as the expert.' When funding is difficult to cobble together and the elements test the researchers' ingenuity and tenacity, the value of the – dare I say, sound – scientific data that can inform how ships and whales share the British Columbia coast is what drives this project.

Back off the coast of Mozambique, I sink into the water for a last dive the following day. The gunmetal sky is indistinguishable from the ocean where it touches the horizon and the world is hushed with the peace that comes with an overcast day. My ears detect the faint crackling of minute creatures suspended in the sea around me, their tiny presence invisible to my eyes, before the muted conversation of the dolphins murmurs into reception. No piccolo voices today: the calves swim sleepily alongside their mothers, their nap-time dutifully observed.

The impact from the occasional hum of an approaching dive vessel pales in comparison with the sonic consequences of the traffic from a proposed port development just north of the Ponta Partial Marine Reserve where I now fin alongside the resting pod. Much like the waters of Kitimat, where a natural gas processing plant has been approved, the waters traversed by the dolphins and humpback whales that sing their way along these subtropical seas are set to thrum with the constant drone of ships on an oceanic highway. I wonder how the submarine symphony I have front row tickets to will change, and what the voices from those communities that live in connection to the coast here might say if we all worked to share information with the kind of collaborative spirit that Janie so appreciated in British Columbia.

Our seas are set to get busier, but as the Fin Island project shows, there is much we can do to better monitor and manage this trajectory. I think of the words of Benjamin Zander, who was the musical director of the Boston Philharmonic Orchestra: 'The conductor of an orchestra doesn't make a sound. He depends for his power on his ability to make other people powerful.' The work of Janie, Ben and their team is a reminder that there is respect inherent in learning to listen, and that the best conservation science gives voice to the kind of information that helps us better navigate how we share a future on this planet.

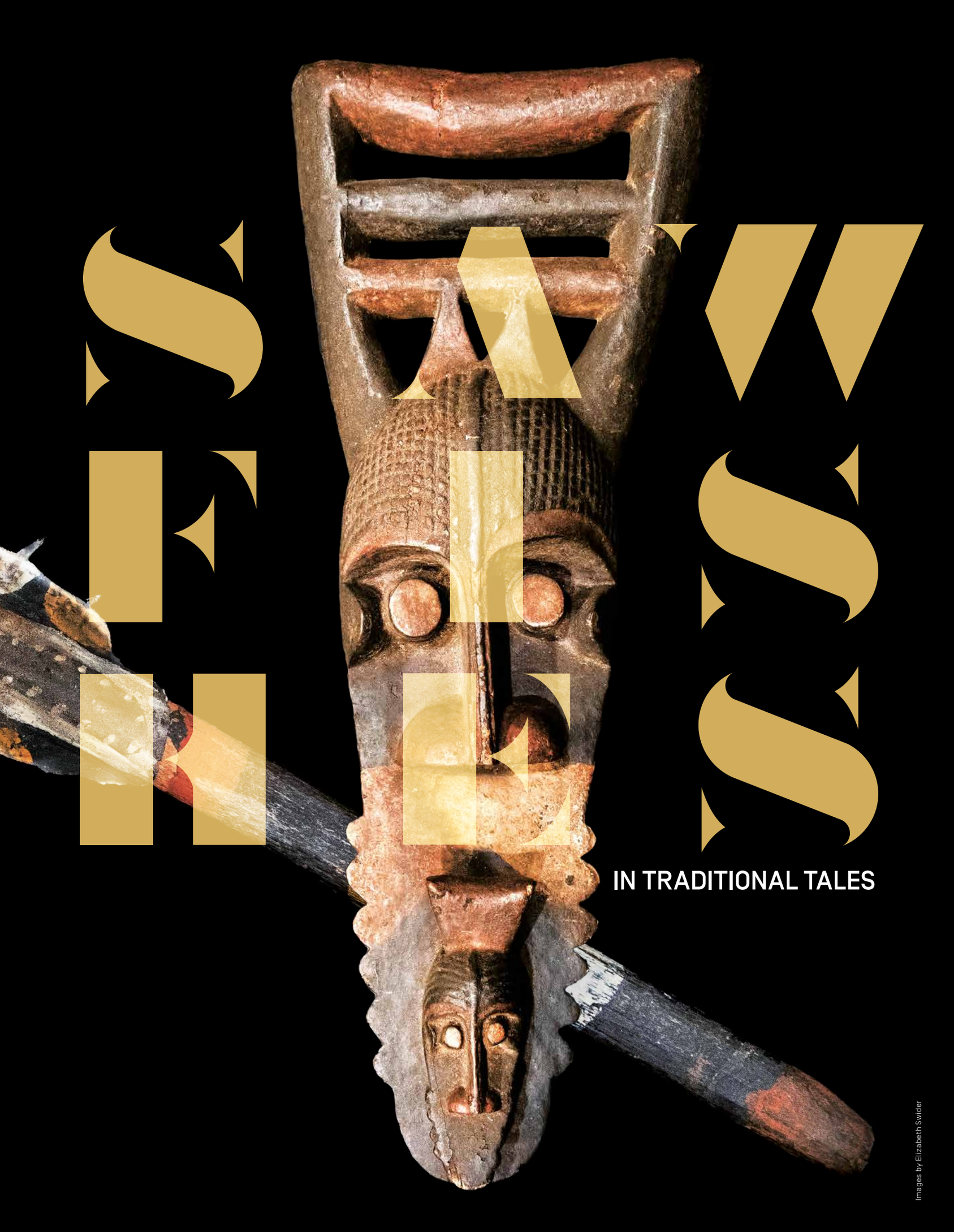
Photo by Sylvain Cordier | BiosPhoto

The songs and sounds of humpback whales form part of complex, and important, social communication, like for this mother and calf near Réunion Island. Recent scientific studies have documented male whales reducing (or outright halting) their songs in response to noise pollution. Author Koki Tsujii from Hokkaido University found that fewer males sang in shipping lanes than elsewhere.

Iatmul sawfish dance wand from the Sepik River, Papua New Guinea, and Ijo sawfish mask from Nigeria, both from Matthew McDavitt's personal collection.

Words by Ruth H. Leeney & Matthew McDavitt

In recent times we have woken up to the fact that sawfishes are now the most endangered fishes in the ocean. In past centuries, though, they were familiar to many societies that lived along coasts and major rivers in the tropics and, moreover, were incorporated into their stories and belief systems. Ruth Leeney and Matthew McDavitt take a brief trip around the world to look at how sawfishes featured in the physical and spiritual worlds of people and what their decline might mean for the survival of traditional cultures and, more broadly, for the connection humans have with the natural world around them.

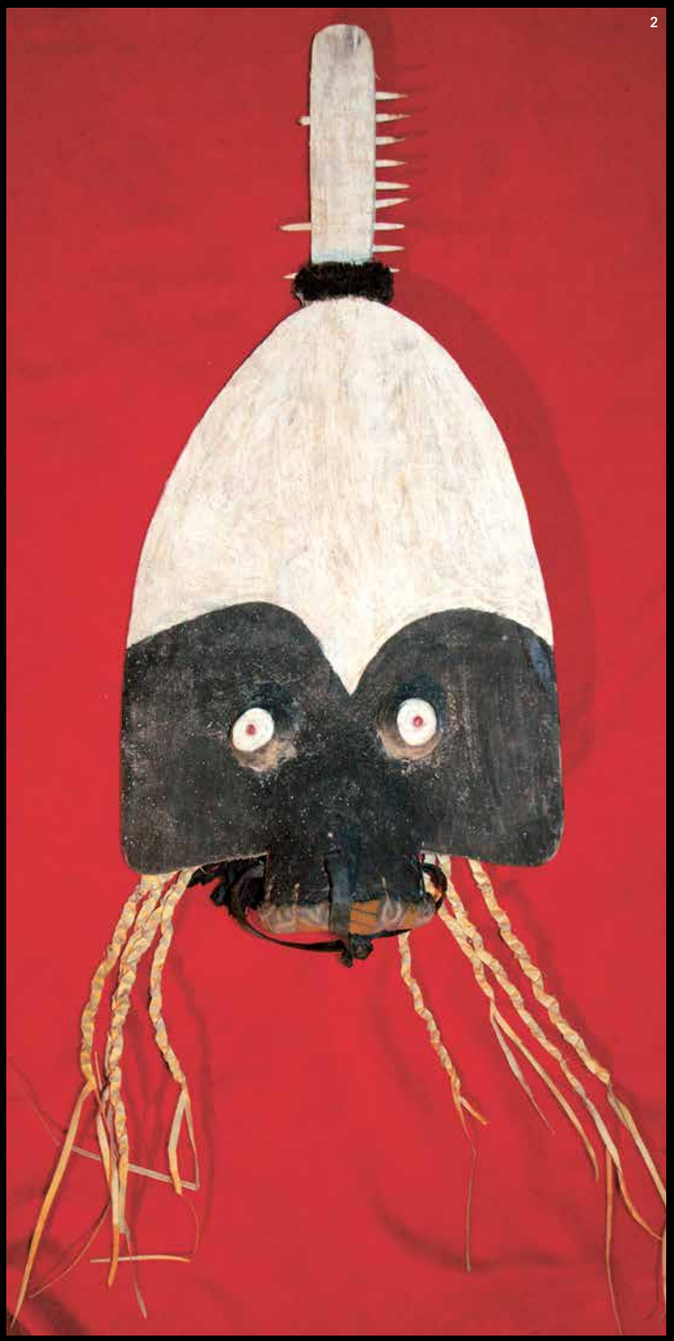


SNAKES

IN TRADITIONAL TALES

Images by Elizabeth Swider

1



2

Sawfishes are among the largest of all sharks and rays (two species reach seven metres, or 23 feet, in length) and have a remarkable and unforgettable appearance. It comes as little surprise, then, that to the communities that lived alongside them – beside shallow coastal waters, estuaries and large rivers – these were mighty creatures with special powers and deserved to be revered in art and daily and ceremonial objects, as well as in legend. In many parts of the tropical world this has been the case...

West Africa

Guinea-Bissau

West Africa's only archipelago, the Bijagos Islands of Guinea-Bissau, harbours a unique culture that has remained relatively intact, thanks to limited transport options from the mainland. On these islands football shirts, miniskirts and flip-flops may now be favoured over grass skirts, but the people still hold their animist beliefs, perform ceremonies and traditional dances and attach special significance to creatures such as the hammerhead shark and the sawfish.

The culture of the Bijogo people includes numerous ceremonies to mark important life stages and events for the islanders. As part of the ceremony for male circumcision, sawfish were caught and brought to the village elders as an offering or sign of respect. In ceremonial dances, men used to wear headdresses topped with the saw of a small sawfish and perform a dance mimicking the sawfish's movements – motions the young initiates reportedly learned while hunting from wooden fishing platforms, below which they could observe sawfishes feeding. Nowadays, sawfish rostra (saws) are so difficult to find that the great triangular headdresses bear carved wooden representations of saws instead of the real thing.

'When a sawfish attacks another fish, the victim never escapes.' Akan proverb | Ghana

Ghana

The Akan people of western Ghana are renowned for making a strong connection between visual and verbal expressions and for how they blend art and philosophy. Proverbs and sayings featured prominently in their culture and had political, economic and social significance. The many beautiful weights they made from 1400 AD onwards were used as counter-weights for measuring out gold dust (their traditional currency until replaced by coins and paper money). These weights, made from brass, often had forms that were linked to specific proverbs.

The sawfish was sacred to the Akan people, symbolising individuals who held power in coastal communities. The proverb associated with the weight depicting a sawfish is 'When a sawfish

3

attacks another fish, the victim never escapes'. This was meant to convey the indisputable authority of the king. More generally, fishes symbolised abundance in West African cultures. The sawfish symbol, which linked prosperity and leadership, was so important for Akan societies that the West African Monetary Union chose it, in the stylised form of the sawfish weight, to adorn all the coins and notes of the West African franc (the currency of Senegal, Guinea-Bissau and Guinea-Conakry).

Around the Volta Estuary in eastern Ghana, the Ewe people revered sawfishes as spiritually powerful entities, classed as *tro*, of a divinity between humans and God. The Ewe had formal sawfish propitiation rites to dispel the danger presented when a sawfish became entangled in a fishing net. The powerful spirit was appeased with offerings of corn meal, alcohol and palm oil. If this ceremony was not performed, fishers who caught sawfishes were believed to have bad luck – illness might strike them or one of their family members, or they might be involved in accidents, for example.

4

Nigeria

In the Niger River Delta of Nigeria, several cultures count the sawfish (called *Oki* in the Ijo language) as the leader of the beneficent water spirits that can bestow good fish catches, wealth and agricultural success and drive out sickness and misfortune from the village. During certain ceremonies, dancers wearing huge, life-size sawfish masks rise from the river or arrive by canoe and enter the village, where they mimic the slashing power of the sawfish to amuse both spectators and the invisible water spirits themselves who, according to local beliefs, originally instructed mankind to make the masks and perform the dances. Mothers present their infants to the sawfish dancers so that their slashing movements will repel childhood illness. These sawfish spirits are seen as good-natured and helpful to humankind and offerings are made to them to encourage good fortune and well-being; the water spirits are said to be wealthy because of all the goods that people accidentally drop in the rivers!

'A sawfish on the beach is already well-known news in the city.' Douala proverb | Cameroon

Cameroon

Another proverb about sawfish was used by the Douala people of coastal Cameroon. 'A sawfish on the beach is already well-known news in the city' highlights that news of spectacular events spreads quickly. It may also be a warning to verify spectacular or outlandish news before believing it – one that still holds good today.

5

1. The form of a sawfish carved into a wooden post outside a government building along the Sepik River, Papua New Guinea. Largetooth sawfishes inhabit the river and feature in the many cultures of East Sepik Province.
Image by Ruth H. Leeney | National Geographic

2. Traditional headdress bearing a carved wooden saw from the Bijagos Archipelago, Guinea-Bissau.
Photo by Simon Wearne

3. Akan weights from Ghana, used for measuring out gold dust.
Photo by Elizabeth Swider

4. Postcard from Loango, Gabon, depicting fishermen and a sawfish – *'poisson-scie'*.

5. A dancer in the Bijagos Archipelago, Guinea-Bissau, wears a headdress topped with a carved representation of a saw. In the past, such a headdress would have borne a real sawfish rostrum.
Photo by Ruth H. Leeney

Papua New Guinea

Among the many tribes that live along the Sepik River and its tributaries, sawfishes were viewed as supernatural creatures that commanded respect. Numerous stories warned of torrential rainstorms and danger to fishers if sawfishes were mistreated. For some of the clans inhabiting villages along the Sepik, certain ancestors originally took the form of sawfishes and these ancestors were thought to have created particular land estates for those clans. For initiation rituals, a ceremonial wand was fashioned from the saw of a sawfish; as initiates pass from childhood to adulthood in the ceremony, the saw was used to scratch their bodies, symbolically killing and devouring them so that they would be reborn in their new role as men.

Sawfish still inhabit the murky waters of the Sepik River, the longest river on the island of New Guinea. Winding its way eastward across Papua New Guinea to the Bismarck Sea, the Sepik passes through districts with numerous distinct languages and cultures. Many of these cultures feature the unique wildlife of the region, including crocodiles, cockatoos and large flightless cassowaries – and sawfishes. Within a village, each clan has 'totem' animals that represent the suite of supernatural creators that founded the clan and images of these totems were, in the past, carved onto shields and the prows of canoes by clan members. Stories featuring totem animals were a part of local culture, a connection between the people, their traditional practices and the natural world around them.

In Angoram, a village along the lower Sepik River, 69-year-old Samsi used to be a school teacher. He shared some of the stories of his Langudubur clan about its totem, the sawfish.

'A local man was fighting off several outsiders along the riverbank. As he approached the river, and having used up all his spears, he called out to the local sawfish spirit, his totem, to help him. A sawfish appeared in the river, swam to the riverbank where the man stood and nodded its head to indicate that he should step onto its back. The sawfish then carried his charge to safety on the other side of the Sepik River.

'If our clan was going to war, the warriors would visit the *haus tambaran* (spirit house) and ask the spirits to send them a sign. Once they set off on the river, if the sawfish spirit "jumped up" in front of them but swam ahead, it meant the warriors should continue on – this boded well for the attack. But if the sawfish rolled and showed its belly this was interpreted as a sign of death, meaning they were going to be ambushed and that they should turn back.'

'The saw of the sawfish has killed the sawfish.'

Australia

Groote Eylandt, Australia's fourth largest island, lies some 45 kilometres (28 miles) from the coast of Arnhem Land in the remote tropical north of the country and is one of the most pristine islands off the Northern Territory coast. The sawfish is a central figure in the creation story of certain clans of the Anindilyakwa people of Groote Eylandt. Indeed, sawfishes are still relatively abundant in this area, and the northern and north-western coasts of Australia are one of the last strongholds for four of the five species of sawfish.

One Anindilyakwa story tells that in creation times, a group of sawfishes (*yukwurrirrindangwa*), eagle rays (*dumarnindangwa*), estuary whiprays (*yimaduwaya*), shovelnose rays (*yilyanga*) and white-spot shovelnose rays (*makabarama*) began their journey from the eastern coast of Arnhem Land in search of a suitable place where they could rest forever. On their way across the bay to Groote Eylandt they stopped at Bickerton Island, transforming themselves from human beings to sea creatures. Finding that island unsuitable, the rays continued eastward. On reaching Groote Eylandt they found their way blocked by the rocky coast, so they launched inland, carving out the Angurugu River with their toothy snouts. As the tide rushed into the newly formed riverbed, the other rays followed this watery pathway. Their journey was eventually impeded by a rocky barrier at the centre of the island. Exhausted and injured, the sawfishes turned around near Makbulamanja (Pelican's Nest) and left the river to rest and dry themselves at the sawfish-shaped rocky outcrop named Wurajanbujanbumanja. They then travelled west to Mungkadinamanja, where they made a waterhole, went back to the coast and travelled across to the mainland.

This epic story of the migration of ancestral rays has many important functions in Anindilyakwa society. It establishes the social links between the clan groups that share these totemic fishes as ancestral creators and it explains why certain clan groups possess particular land estates along the rays' path. In addition, the journey of the rays and sawfishes echoes the historical migration of Aboriginal people when they first travelled from the mainland to Groote Eylandt.

↖ **The creation of the Angurrgwa (Angurugu) River by Stingray, Ray Shark and Sawfish.** Artwork by Nandabida Maminyamanja | Museum and Art Gallery of the Northern Territory (MAGNT) | Reference ABART-1649 | Reproduced with the permission of the artist's family.

← **Cave art from Groote Eylandt, Australia, depicting a sawfish.** Photograph provided by the Anindilyakwa Land Council | Reproduced with permission of senior Maminyamanja Clan site custodians, Groote Eylandt.

Indonesia

In Indonesia, the teacher who brought Islam to the Hindu kingdom of Borneo arrived atop a huge sawfish, one of several miracles he performed to prove the power and righteousness of the new faith. This pioneering teacher is therefore now known by the nickname 'Tuan Tunggang Parangan', which translates as 'Mr Sawfish Rider'. Sawfish imagery appears in Islamic art throughout the Indonesian archipelago.

Some reverse-glass paintings made on Java feature the story of how the mighty King Solomon achieved humility before his creator. The story goes that when King Solomon took over from his father David, the angel Gabriel appeared and granted Solomon a divine ring from Paradise that gave him dominion over humans, the animal kingdom and the supernatural *jinn* spirits. Solomon employed his *jinn* to build a miraculous flying palace and to equip his kingdom with innumerable goods and treasures. In time, he became emboldened by his vast dominion over the earth, its inhabitants and even the winds. To prove his might, he asked God if he might feed all the animals of the world for a day, a task God usually undertook. God warned Solomon that he lacked such power, so Solomon agreed to attempt his wish for just an hour. He used his magic to gather a mountain of grain – enough to feed his entire army for a month – commanding divine winds to transport the sustenance to the seashore. Solomon then called for all sea creatures to assemble to be fed. The first ocean denizen to open its massive maw for food was a whale, which at once engulfed the king's entire stockpile of food. Aghast, Solomon asked the ravenous whale, 'Are there other creatures as enormous as you?', to which the whale replied, 'O prophet of God, in the sea there are fish so large that if they ate me, I would be as a seed in the desert!' Solomon then realised that, even wielding the vast powers bestowed upon him by God, he was nothing compared to the greatness of the Creator. So he departed, content with his place in the cosmos.

The Ancient Near East

In Iran, images of sawfish have been uncovered in ancient ruins dating to 6,000 years ago. A text from medieval Baghdad details that sawfish were numerous along the Persian shore, where they were caught and sold for food in the markets, and that sawfish entered the Shatt-al-Arab River as far as Basra, Iraq. Sawfishes were depicted in ancient Persia as an animal swordsman, a symbol of warriors. Modern Persian artist Fereydoun Ave drew upon such symbolism when, in creating his sculpture *Divas 2*, he combined classical architectural elements, human faces and a glittering sawfish saw, painted with gold leaf, to create a chimeric form evoking the ancient gods who instilled both fear and stability.

Panama

The indigenous Guna of Panama occupy the San Blas archipelago and the adjacent mainland along the Caribbean coast. For this people, the sawfish held a special position as an important and beneficial species that, according to their folklore, had been placed in the world to safeguard the coasts and the humans who inhabited them from dangerous sea creatures, including sharks and crocodiles. In this way, the Guna attitude towards sawfishes was similar to the attitude towards dolphins found in much of the modern Western world: sawfishes were protectors and friends of humankind.

Remarkably, the protective role of sawfishes also extended into the supernatural realm. When Guna shamans (a healer or someone with access to the spirit world) entered the watery spirit realm to battle the evil spirits that caused sickness and death, they called upon golden sawfish spirits. Those spirits would appear and repel the titanic crocodiles that the sickness spirits rode, thereby assisting the shaman healers. *Molas* – the colourful, elaborate panels embroidered by Guna women – often depict scenes and characters from the natural landscape and Guna folklore, including sawfish, crocodiles and sharks. *Molas* were originally incorporated into blouses and shirts worn by the Guna and are now also sold to tourists as decorative pieces.

A colourful *mola* depicting three sawfishes. *Molas* are hand-made appliqué textiles produced mostly by the Guna women of the San Blas Archipelago, Panama, and often incorporate designs relating to their natural and mythological landscapes.
Photo by Matthew McDavitt

Warrior, ancestor, protector, bringer of good fortune. It is hardly surprising that creatures as fantastic as sawfishes, which shared their coastal habitats with so many human communities throughout the tropics, became key characters in the folklore and cultures of those communities. And it is notable that in most cases, sawfishes were seen as a benevolent force rather than a threat to humans. Despite this, humans have brought about their demise. Modern fishing gear and fisheries targeting sharks and sawfishes for their fins, as well the destruction of the mangrove and estuarine habitats so important for sawfishes, have had catastrophic effects on many populations.

The traditions and cultures in which sawfishes featured may also be disappearing. Perhaps this is a result of far fewer encounters between people and sawfishes now than in the past, so the stories and beliefs associated with them are slipping from people's memories. Or it may be that as our world grows smaller and more connected, cultures become homogenised and traditions are cast aside by younger generations, who see them as dated, tedious and irrelevant to their lives. Probably it is a combination of both. Many of these cultural narratives have been passed down orally from generation to generation and may be lost forever as the elders who still recall them reach the end of their lives.

As humanity exerts ever more pressure on our planet, wild places and creatures are becoming increasingly rare and we understand far less what it means to be one species among many – part of an ecosystem. Many of the stories, beliefs and art forms documented here may have been rooted in attempts to make sense of the natural world and our relationship with it, or may simply have been amusing diversions. Either way, they provide us with a window to

Indonesian glass painting depicting Nabu Sulaiman trying to feed all the creatures of the sea.
Photo by Matthew McDavitt.

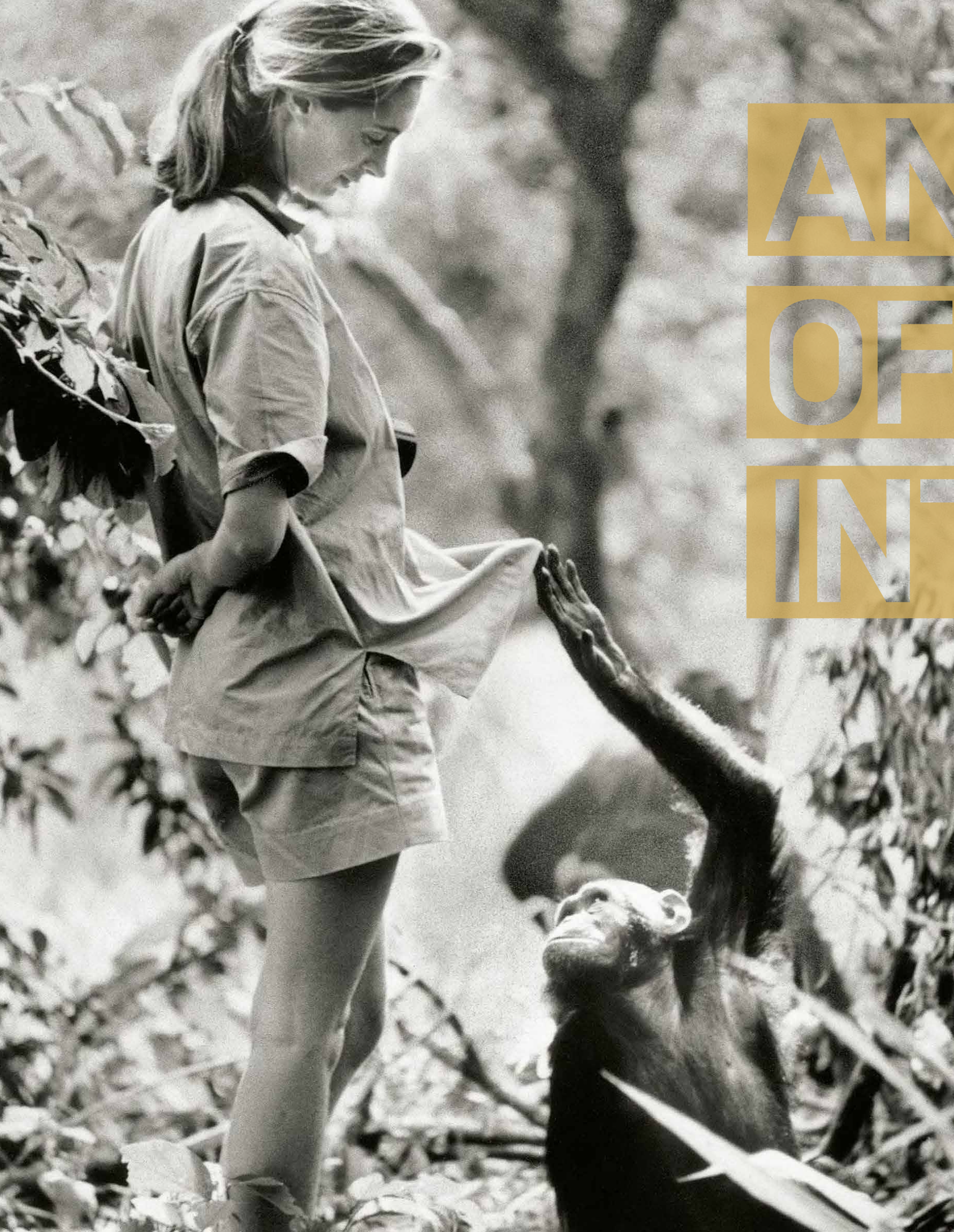
a time when humans understood that they were reliant upon the well-being of the world around them for their survival. A proverb from the Duala people of Cameroon, 'The saw of the sawfish has killed the sawfish', teaches that the power a sawfish wields in its saw could, if mis-used, lead to its downfall. While this speaks in literal terms to the vulnerability of sawfishes to fishing nets, it could also be interpreted as a warning to humans. Our brains and technologies have led us to greatly alter the world in which we live, so much so that our own survival is now at risk.

Acknowledgements
Sincere thanks go to the senior clan members of Groote Eylandt for giving permission to reproduce their story about the creation of Groote Eylandt, as well as the cave art depicting a sawfish rostrum in this article. Thanks also go to the family of Nandabida Maminyamanja.

We are also indebted to Hugh Bland, Leslie Pyne and Ross MacDonald of the Anindilyakwa Land Council, Elaine Labuschagne of MAGNT, Ingeborg Eggink of the Wereldculturen Museum and Elizabeth Swider.

***Maro* (bark cloth) painting from Lake Sentani, West Papua, depicting two sawfishes.**
Collection Nationaal Museum van Wereldculturen. Coll.no. RV-3600-749.

***Maro* painting from Lake Sentani depicting sawfishes and numerous other aquatic animals.**
Collection Nationaal Museum van Wereldculturen. Coll.no. RV-5875.


AN
OF
IN

OCEAN

TELLIGENCE

Words by Haley R. Pope

In the 1960s, Jane Goodall helped change the way we viewed intelligence and sentience in chimpanzees. Her research triggered a core question: if chimpanzees have complex inner lives, what about other animals? Haley Pope explores pioneering research that shows marine organisms also possess and exhibit facets of consciousness, including sentience, self-awareness and intelligence.

Photo by Bettmann Archive | Getty Images

Photo by Hugo van Lawick | National Geographic Image Collection

Jane Goodall changed the way humans viewed animal intelligence with her groundbreaking work with the chimpanzees of Gombe, Tanzania. The ensuing decades have widened recognition that intelligence is not limited to our primate cousins, who share 98% similarity with our DNA, and that our definition of, and research into, this field has been limited elsewhere.

The young, blonde Brit had come all the way to Tanzania, notebook and pen in hand, with no concept that she would change the way we understood and studied animal behaviour and cognition; specifically, how we viewed intelligence and sentience in the chimpanzee, our closest living relative. Jane Goodall's first ground-breaking discovery came in 1960, the same year she arrived in Tanzania to begin her research. While out in the forest one day, she saw a chimpanzee whom she called David Greybeard poking pieces of grass into a termite mound to fish out the insects and eat them. This was the first documented example of genuine tool use in a species other than *Homo sapiens*. Until then, tool use had been considered a defining characteristic of humankind.

Jane's findings were published three years later by the National Geographic Society in an article titled 'My life among wild chimpanzees', which was accompanied by romantic photos of her in the forest surrounded by chimpanzees. For many of us, the connection Jane shared with them was plain to see. A famous photograph shows her stooping down and extending her right arm to a chimpanzee baby that is mirroring her posture, its fingertips stretched out to touch her hand (see previous spread).

Her research exposed a 'human' side of another animal species, one that begged us to reconsider our understanding of animal sentience and intelligence. The scientific community, though, found her discoveries difficult to swallow. Everyone, especially anthropologists, struggled to understand what this knowledge would mean for our species' identity. When Louis Leakey, Jane's mentor, received her telegram describing her landmark observation he stated, 'Now we must redefine "tool", redefine "man", or accept chimpanzees as humans.' Among the many questions triggered by her research, one stood out: if chimpanzees have more complex internal and social lives than previously thought, what about other animals? The floodgate was open.

A decade later, an enthusiastic marine biologist began his scientific career studying bottlenose dolphins off the coast of Hawaii. Louis Herman endeavoured to gain insight into the dolphins' mental faculties by studying how they communicate. So complex did this field prove to be that he dedicated the next 46 years of his career, and life, to it. What he discovered would also change the course of behavioural and cognitive science.

Louis and his colleagues documented dolphins' abilities to learn and respond to human language transmitted through auditory and visual signals. Not only did they teach two dozen words of an artificial language to a pair of dolphins, but they also realised that the dolphins could understand what individual words meant and how their arrangement affected the meaning of a sentence.

Unlike many animals, which take time to learn what human gestures mean, dolphins were immediately able to understand a signal such as pointing. This hadn't been observed in other species and it showed, crucially, that dolphins are able to understand a species other than their own. Also unknown until Louis' research was that dolphins use echolocation to image their environment and detect the distance, shape and size of objects. His pioneering work and discoveries proved that dolphins have complex communication and comprehension skills, which is why they are now considered the cognitive cousins of chimpanzees.

Jane Goodall and Louis Herman helped shape the animal cognition field and ignite scientific interest in the subject. It became clear that, at least for mammals, animal sentience and intelligence are complex and mysterious. Future scientists would branch out to explore the inner lives of countless other animals: elephants, dogs, pigs, ravens, whales, fishes, octopuses and sharks and rays, among others. Yet historically the marine world has received less attention than its terrestrial counterpart. For that reason, it's not widely known that the ocean also harbours intelligent beings.

Only in the past few decades have scientists begun to peel back the layers of ocean intelligence. The discoveries have been both surprising and enlightening. What has this research

Photo by Ian Nichols | National Geographic Image Collection

Tool use was the benchmark used to mark the dawn of much of human intelligence; that is, until Jane Goodall observed chimpanzees fishing for termites using twig 'tools'. Since then, animals from crows to octopuses have been known to use tools and forced us to wrangle with how we define intelligence across species lines.

told us about the intelligence of marine organisms? And how does it affect the ways in which we view our own intelligence?

Consciousness abounds

When scientists conduct research on animals to explore their inner lives, what exactly are they studying? In the broadest sense, consciousness equates to 'I think, therefore I am'. To unpack this abstract idea, experiments explore the facets of consciousness, namely sentience, self-awareness, cognition and intelligence. Sentience is the ability to feel sensations, while self-awareness refers to the understanding that one is an individual separate from others and the rest of the world. Cognition is simply information processing: the ability to perceive and acquire knowledge. Intelligence goes a step further, requiring the organism to consider something that's been perceived and successfully apply that knowledge to solve problems. Intelligence is influenced by the survival requirements an animal faces in its own environment; it is inferred by scientists by assessing behavioural flexibility. Have these concepts been found in marine organisms? Undeniably, but it's taken a while to get here.

For centuries, science adopted the views of the 17th-century French philosopher René Descartes. He claimed that non-human animals were not conscious and therefore could not reason or learn, didn't feel pain or have language; although they were living creatures, they were like mechanical robots. *Homo sapiens*, on the other hand, was the pinnacle of creation at the end of a long yet discontinuous progression of increasing complexity that leaped from the animal kingdom to humans. Under this anthropocentric view, anthropomorphism (attributing human characteristics to other animals) was not just taboo but completely wrong, and we were prompted to categorically deny consciousness in other animals.

In *Beyond Words*, Carl Safina sums up our centuries-long mistake by saying, 'Not assuming that other animals have thoughts and feelings was a good start for a new science. Insisting they did not was bad science.' Anthropomorphism is certainly not the best model for understanding the minds of other animals since it still uses humankind as the benchmark for comparison. However, it does allow for a degree of understanding with regard to a possible evolutionary connection between animal behaviours and our own.

Thankfully, today Descartes' claims are considered unfounded due to a greater understanding of brain structure and function and of evolution. For instance, in 2015 Herzing and Johnson showed that dolphins have a complex and well-developed paralimbic region similar to that in humans for processing emotions, setting goals, motivation and self-control. Similarly, bony fishes and elasmobranchs (sharks, rays and skates) have a region called the pallium, which is present in all vertebrate brains and equivalent in function to a human brain's hippocampus, amygdala and neocortex. The pallium functions in learning, memory, individual recognition, play, tool use and cooperation. In 2016, scientists Byrnes and Brown showed that Port Jackson sharks display individuality and personality traits, which may influence their prey choice, habitat use and activity levels.

Evolution tells a meandering yet clear story that links us as *Homo sapiens* to all life forms on earth. Sure, humans are more closely related to some species than others, yet many cognitive commonalities, like biological commonalities, are due to shared ancestry. Humans are animals with inherited sensations and inherited nervous systems. We share enough similarities in brain structure and function to believe that the underlying traits of consciousness and sentience evolved long before our own species. After all, Mother Nature is conservative. In 2012, the Cambridge Declaration on Consciousness finally concluded that non-human animals, including all mammals and birds, and many other creatures, such as octopuses, possess consciousness.

Recognising intelligence

Suspend your biases for a moment and consider that every living animal is intelligent in some way. Not in the same way, but in a way that makes their own existence possible. Would we treat animals differently? Marine animals are not granted the same amount of moral consideration as are many terrestrial mammals, in part because of the gap between our perception of their sentience and its reality. However, marine animals are without a doubt sentient and intelligent beings, as shown by their self-awareness, tool use, memory and cooperation.

Personal reflections

When was the last time you looked in a mirror? Did you recognise you were seeing a reflection? Did you recognise yourself? If you did, congratulations: you're self-aware! Or so the mirror self-recognition (MSR) test would conclude. Since its design in 1970 by Gordon Gallup, the MSR test has been used in countless experiments to assess self-awareness in non-human animals, including primates, elephants, dolphins, manta rays and fishes.

In 2001, after the great apes passed the MSR test, Diana Reiss and Lori Marino conducted it with dolphins. In the experiment, a mirror was placed in the aquarium tank and the dolphins were marked in locations that could not be seen without a mirror. Sure enough, the dolphins spent more time gazing at themselves in the mirror when they were marked than when unmarked. One dolphin with a mark on its tongue even opened and closed its mouth to see it! No dolphin showed any social behaviour towards the mirror, indicating that they recognised the reflections as themselves rather than another individual. And just like that, evidence showed that self-awareness was not isolated to primates (elephants were also added to the list).

Then, in 2016, self-recognition was recognised in a cartilaginous fish. Csilla Ari and Dominic D'Agostino gave the MSR test to two giant manta rays in The Bahamas. The rays displayed specific repetitive behaviours, like bubble blowing, frequent cephalic fin movement and exposing their ventral side to the mirror only when in front of it. These behaviours enabled the rays to see whether the image moved when they did and also see parts of their bodies they cannot usually see. As in the dolphin study, no social behaviour was observed. The researchers concluded that the rays perceived their reflection to be themselves and therefore have some concept of self-awareness.

Although bony fish species have been given the MSR test, to date none has passed. However, scientists like Cullum Brown blame flaws in the test for the absence of evidence. Fish rely more heavily on chemical cues for navigating their world than they do on vision. Since visual self-recognition in their environment would be relatively useless, they are not likely to have developed it. Thus, fish are more likely to display olfactory self-recognition. Experiments exploring this have yet to be carried out.

Other scientists, like Carl Safina, have criticised the test for its over-simplicity. They assert that the MSR test does not actually test for self-awareness, but rather whether an animal understands reflection and what it represents. Because some species like fighting fish attack their reflection, it was believed they lacked self-awareness. However, an animal that does not recognise its reflection only shows that it doesn't understand reflection, not that it lacks self-awareness. In fact, because it attacks its reflection it clearly doesn't view the reflection as itself – an important distinction that is also a component of self-awareness. When an animal does recognise its reflection, it is demonstrating that it understands symbolism: the reflection is not actually me, it symbolises me. If that's the case, dolphins and manta rays, among others, may be capable of abstract thought in addition to self-recognition!

The coconut octopus, found in Lembeh Strait, Sulawesi, secretes itself inside a shell for shelter and as camouflage from predators.

Photo by Stocktrek Images | National Geographic Image Collection

Skilful masters & planners

Before Jane Goodall discovered that chimpanzees use tools, tool use was a defining characteristic of our own species. Since then we've discovered that many animals use tools. Tool use – defined as an action that involves an agent to achieve a goal – is an interesting way to assess intelligence, as it hints at the ability to plan for the future and anticipate outcomes. While only a few interesting cases are highlighted here, in 2013 Janet Mann and Eric Patterson completed a review of 30 known tool uses in marine animals. For marine species, tools were employed for three main identified reasons: protection, parental care and foraging.

It's not difficult to imagine a chimpanzee using a tool, but a mollusc? For nine years, Julian Finn and his colleagues witnessed veined octopuses in Bali, Indonesia, carrying coconut shell halves and hiding in them. Equipped with six arms and two legs, they would slide over the top of the shells and while some arms would grasp the husk, the other arms and legs would scuttle across the ocean floor to a lair. The soft-bodied cephalopods would then hide beneath or inside the shells, using them as a protective shelter. Seemingly, the octopuses were planning for the future and weighing the costs and benefits: while travelling with the coconut shells they would be vulnerable to predators, yet once inside or underneath their shells they would be safe. Even species like crabs can be seen carrying or wearing objects for protection and concealment.

Humans use a variety of tools to look after their babies, including bottles, strollers and baby monitors. Surprisingly, fish do too. One in four fish species devotes time to caregiving and the use of parental care tools has been noted in bony fishes like gouramis, whitetail majors, catfish and cichlids. One striking example, depicted in the book *What a Fish Knows* by Jonathan Balcombe, involves whitetail major damselfish and sandblasting. Before the mating pair lay the fertilised eggs, they remove debris from their chosen site by scooping up sand in their mouths and spitting it onto the rock surface. By fanning the site with water or plucking each grain in their mouths, they remove any remaining sand. Once the eggs have been laid, they may fan them with water to help them stay oxygenated, as do many fish: two instances of tool use in one example!

Water itself can be used as a foraging tool. Just as archerfish squirt jets of water through the air to shoot down insects, stingrays use water to flush out prey. In a 2009 study by Michael Kuba and colleagues, frozen shrimp or pieces of squid were placed inside a plastic tube. One end, painted black, was covered with mesh that prevented the largespot river rays from getting the food, whereas the white end was open, allowing food to be extracted. The rays not only learned they could retrieve food only from the white end of the tube (evidence they respond to visual cues), but they also employed various methods to obtain it: they used their bodies like suction caps, undulated their fins to create waves and blew jets of water into the tube. Each stingray learned to use water as a tool in order to get its meal. One of them never made an incorrect choice, always going to the white end of the tube that it knew would be open. This experiment mimicked foraging situations in which prey might be hiding or unreachable in the wild. For instance, the cownose ray and eagle ray have demonstrated that they use water jetting from their mouths to uncover prey hidden in the sand.

Three-second memory no more

If you kept a goldfish when you were young, you probably believed it suffered from short-term memory loss. Remember the anecdote about fish having a three-second memory? Or forgetful Dory from *Finding Nemo*? Happily, this couldn't be further from the truth. The ability for animals to remember certain events, locations, skills or other stimuli over long time periods is advantageous to their survival, just as it's advantageous for

Photo by Stocktrek Images | National Geographic Image Collection

us to remember where we live and who are our family members.

It is currently not known how and where sharks process and store memory. However, research has shown that grey bamboo sharks have similar cognitive abilities to birds, monkeys and humans when it comes to memory and understanding optical illusions. In an experiment conducted by Fuss and Schluessel in 2015, sharks were taught to recognise and remember a specific shape (either a triangle or a square). Then the researchers tested their ability to transfer that knowledge and identify the same shape created by Kanizsa figures, which are illusory diagrams that trick the brain into seeing shapes that are not actually there. The sharks responded just as humans do: they saw and selected the shape they were trained to identify. They were also taught to select a hollow square on a background of diagonal lines over a similar rhomboid and to recognise Müller-Lyer deceptions (differences between line lengths). One year later, the sharks were retested… Surprise! The researchers found evidence that sharks have long-term memory. The sharks remembered their training and selected the same shapes and line lengths they had been trained to pick in the past.

Bony fishes are also able to retain long-term memories. As Cullum Brown describes, many fishes are social learners, in that an individual learns a task or piece of information from other individuals. When that knowledge passes through several generations it becomes a cultural tradition. The migration routes of fishes exemplify social learning and how memories can be passed down through generations for navigation and survival. Negative experiences, like being exposed to painful stimuli, also help solidify a memory. Over a century ago, Jacob Reighard showed that when sardines were dyed red, modified with stinging tentacles and fed to snapper fish, the snappers learned to avoid them and continued to avoid them 20 days later. Similarly, previously hooked fish, like pike and carp, showed hook-shyness for over a year after the event.

Unlike sharks or bony fishes, cephalopods are not vertebrates. They are so far removed from our own species in evolutionary terms that our last common ancestor was about a billion years ago. Yet it turns out that cuttlefish have episodic-like memories, or the ability to recall particular events. This has provided credence to the parallel evolution of memory.

In 2013, Jozet-Alves and colleagues provided cuttlefish with a choice of food (shrimp or crab) and placed each in a different location in an aquarium and with a different visual cue. Shrimp, the preferred food choice, was replenished only three hours after the cuttlefish had eaten it, whereas crab was replenished every hour. The cuttlefish learned that if they had eaten the shrimp less than three hours before their release into the aquarium, there was no point in checking the shrimp location, as shrimp would not be there. Instead, they would swim over to the crab location for their meal. If it had been longer than three hours, however, the cuttlefish would check the shrimp location first!

Unexpectedly, the cuttlefish kept track not only of what they had eaten, but also when and where they had eaten it. By doing so, they were able to maximise their foraging time – a beneficial behaviour in the context of the open ocean. Memory is so important to animal cognition that it did not evolve just once in our own evolutionary line; it expanded throughout several lines simultaneously – an example of convergent evolution.

Plurality of partnerships

Cooperation between individuals requires a high degree of social intelligence and is most commonly found in species living in complex social groups. It's a complicated agreement, in which all individuals within the group must have a shared understanding of not only what one individual needs from its neighbour, but also what that neighbour needs from the individual – and how they can reach their common goal together. Therefore, cooperation is a wonderful measure of another facet

Photo by Brian J. Skerry | National Geographic Image Collection

Dolphins have learnt to churn mud from the sea floor in Florida Bay, encircling a panicked shoal of mullet that leap into the mouths of other cooperating dolphins in the group.

The social intelligence of many of the ocean's mammals, like these spinner dolphins *Stenella longirostris* off Oahu, Hawaii, has fascinated humans for decades. How we recognise and respect this level of cognition, however, lags behind in practice what keeps us enthralled in theory.

of intelligence. Cooperation is well known in humans and other primates, but what about marine organisms? Do they cooperate and if so, with whom?

Cooperation within a species is quite common. Consider lions or wolves, which hunt together in a coordinated effort to bring down prey. After all, you're familiar with your own species and what other individuals need. Cooperative breeding is an example that is found not only in birds, but also in fish. An individual fish will give up breeding in order to help rear the offspring of another individual and provide additional parental care and protection. Cooperation for food is another example. In 2008, Visser and colleagues observed for the first time how several killer whales worked together to isolate a fur seal on an ice floe and flush it off by creating waves with their bodies and tails. The coordination and complexity of their actions showed they were communicating about their individual roles and how they could accomplish the feat. This has also been seen as evidence for killer whale tool use, since the killer whales used waves proactively with a goal in mind.

Many marine animals cooperate with members of other species, as shown in a study by Bshary and Noe in 2003. Cleaner wrasses remove dead skin and parasites from 'client' fish that signal to the wrasse they would like to be cleaned. A fair trade: a meal for a cleaning. Wrasses were able to differentiate between transient and local clients as well as predator and non-predator, which helped them decide whom to service first (transient before local), if at all (predators).

Some cooperation starts with direct communication. Researchers Bshary in 2006 and Vail in 2013 with their colleagues found that when hunting, groupers will elicit the help of another individual to snag a meal. A deliberate gesture from the grouper, like a head shake, will draw the attention of a partner, say a moray eel or Napoleon wrasse, to encourage it to assist in the hunt and point out the location of prey. The two swim off together and when they find the prey, each attempts to flush it out using complementary hunting tactics. Although only one of the hunters will be rewarded with the meal, each has the chance to eat. Working together therefore increases their hunting success rate.

Fish are not the only marine species that cooperate to get a meal. Whitehead and Rendell reported in 2015 that bottlenose dolphins cooperated with an unlikely partner. Along the Brazilian coast, a generational cooperation exists between dolphins and fishermen. When the fishermen head out with their nets and wade into thigh-high water, they slap the surface to let the dolphins know they are there. The dolphins then herd the fish towards the coast and with distinctive dives signal to the fishermen where to cast their nets. Fish that are caught in the nets are the fishermen's, while those that escape are gobbled up by the hungry dolphins.

In the early 1900s, when whaling was legal, there was similar cooperation between killer whales and whalers in Australia. Upon noticing a humpback whale in the area, the killer whales would drive the humpback towards the whaler vessels. Others would alert the whalers by breaching and lobtailing. When the whalers had successfully harpooned the humpback, they would anchor it to the ocean floor in a gesture of thanks so that the killer whales could eat their favourite bits: the tongue and lips. Then the humpback would be pulled to the surface and brought in for processing – a win-win for all but the humpback!

Photo by Brian J. Skerry | National Geographic Image Collection

Righting a prejudice

After decades of exploring animal cognition, we're finally starting to understand we are not the only intelligent life on earth. In fact, our planet is filled with intelligent life above the waves and below. We've learnt that many marine animals share similar brain structures and functions with us; that dolphins and giant manta rays have a concept of self-awareness; and that octopuses use coconut shells as tools for future protection, fish use sand to clean their egg-laying site, and stingrays use water as a tool for extracting or uncovering food. We've discovered that sharks are capable of retaining long-term memories; that fish can pass down knowledge as cultural traditions and remember negative experiences; and that cuttlefish remember what they have eaten, when and where. And we've found out that wrasses and their clients trade a cleaning for a meal; groupers and eels work together when hunting prey; and dolphins and killer whales cooperate with each other and humans to obtain food.

Yes, the earth harbours an ocean of intelligence. To detect it scientists must be creative and resourceful in their approach. In the past, a major limiting factor was study design. Operating from an anthropocentric foundation, we assumed tests that would be appropriate for humans would also be appropriate for other animals. But this assumption was wrong. During a study, researchers discover only what their methods allow them to see. If their assumptions are incorrect, they may be using inappropriate methods to understand an animal's cognition and intelligence. In other words, the knowledge acquired depends on the methods used.

Every species is uniquely adapted to its own ecology and has a long evolutionary (and cognitive) story of its own. As scientists, we need to design studies that account for this so that we can determine what assumptions and methods are appropriate. Assessing the intelligence of a species based on the ecology of another is like testing whether an octopus can open a jar after seeing a crayfish locked inside. The researchers failed to realise that octopuses depend more on tactile and chemical inputs than on vision for catching prey. When the design was changed and the exterior of the jar was smeared with crayfish scent, the octopuses quickly and easily opened the jar. This example illustrates the importance of a tenet of scientific research: absence of evidence is not evidence of absence.

The more we learn about animal cognition, the more we realise that we are not unique in our mental capacities, but share many cognitive traits with our distant evolutionary cousins. We have had to redefine what it means to be human multiple times in light of research that shows us how ordinary we are. While this can be difficult to accept, we should not be blinded by the lies of anthropocentrism. We should strive to understand our true place in the animal kingdom in relation to animals both great and small.

A final question to ponder: if we admit we were wrong in assuming other animals are not conscious, sentient beings and we're now armed with knowledge about their complex internal lives, how should our thoughts and actions change when it comes to interacting and managing marine animals? Might they be entitled to greater moral consideration and treatment?

Photo by Brian J. Skerry | National Geographic Image Collection

Individual Atlantic spotted *Stenella frontalis* and bottlenose *Tursiops truncatus* dolphins are documented by a researcher in the waters of Bimini, The Bahamas.

Photo by Guy Stevens | Manta Trust

As tourism based on encounters with manta rays booms, years of research have enabled the Manta Trust to issue best-practice guidelines to responsible interaction with these charismatic creatures of the sea.

TURNING THE TIDE

for manta and devil rays

Photo Tom Burd

Words by Isabel Ender

Having begun with a vision – to see experts in a range of fields working around the world to protect manta and devil rays – the Manta Trust eight years on has a long and laudable list of achievements. The charity's head of conservation strategy, Isabel Ender, looks back over what it has accomplished.

In 2010, after two depressing weeks of counting and photographing dead manta and devil rays at fish markets in Sri Lanka, two good friends returned to their lodgings to try and wash away the smell of dead fish. At dinner that night, with the scent and memories of the day's work still lingering, the discussion turned to the alarming threats facing these rays globally. There was talk about the use of the rays' gill plates as an Asian health tonic, a practice that was driving international trade and targeted fisheries, and about the impacts of by-catch, climate change and the development of tourism. After dinner an idea emerged that a global network of experts could be created and they would work together specifically to conserve manta rays and their relatives. The network would cover a range of expertise (scientists, media specialists, fundraisers, policy experts) to effectively protect these species from the increasing threats they face globally. That night, the friends reached out to a handful of colleagues – and in doing so laid the foundations for the Manta Trust charity.

Fast forward eight years and the Manta Trust has become the world's leading organisation dedicated to the conservation of manta rays, their relatives and their habitat. Our network spans 23 countries via affiliated projects, collaborations and partnerships with scientific institutes, NGOs and some of the most passionate conservationists and media experts imaginable. We are supported by great funders, including the Save Our Seas Foundation and Shark Conservation Fund, and can look back at a track record of incredible achievements.

'As a founding associate director of the Manta Trust, I have been truly inspired by the selfless dedication and commitment of the Manta Trust team, who use innovative science and effective advocacy to help drive the global conservation of manta and devil rays. The calibre and diversity of skills and the experience of the team are unrivalled in this space.'

Shawn Heinrichs,
Blue Sphere Foundation

Regulation of international trade in manta and devil rays

Thanks to a concerted effort by the Manta Trust and by our partners and collaborators, we achieved the regulation of the international trade in manta and devil rays through the listing of these species on Appendix II of the Convention on International Trade in Endangered Species (CITES) in 2013 and 2016 respectively. This means that the export and import of manta and devil ray (mobulid) products is permitted only if strict measures apply and if the take is not detrimental to the population. Targeted fisheries are the primary threat to these species, driven by the international trade in gill plates. This protective legislation therefore represents a crucial milestone.

Through its global network, the Manta Trust was in an ideal position to gather the scientific evidence required to support these CITES listings – and we set about this work in earnest. With the aid of various collaborators, we compiled the latest data, from both published and grey literature, which provided insights into the biology, ecology, threats, decline and conservation status of these poorly understood rays. As the scientific experts, we defended the *Mobula* proposal at a panel meeting of the Food and Agriculture Organization (FAO) and developed resource materials, such as the *Devils in Distress* brochure and fact sheets, to communicate the need for conservation action to stakeholders and the general public.

To elicit support for the 2016 proposal to list devil rays on CITES Appendix II, we spearheaded a conservation media campaign, #LOVEminiMantas. The campaign revolved primarily around a 360 virtual reality (VR) film that was made in the Azores and proved to be a huge success. More than 350 delegates from 56 of the 152 nations in attendance at that CITES Conference of the Parties (CoP) came to view the film. Titled *The Mini Mantas of Maria*, it ultimately played a small but significant role in ensuring that the votes were stacked comfortably in the green zone for the *Mobula* proposal as it went into the final voting stage. A coordinated CITES outreach and media strategy approach for sharks and rays by NGOs and Inter-Governmental Organisations (IGOs) also contributed to the successful listing. The Manta Trust worked closely with its partners and collaborators before and during the CITES CoP in 2016 to align their media activities – and ultimately celebrate when all species of devil rays joined their larger cousins on the CITES Appendix II.

Improved national and regional protection

We were also a key player in the successful listing of mobulid rays on Appendices I and II of the Convention on the Conservation of Migratory Species of Wild Animals (CMS) in 2014. Countries that are Range State Parties to a species listed on the CMS Appendix I commit to strictly protecting that species by 'prohibiting the taking of such species'. They should also endeavour to 'conserve, and where appropriate restore, the species' habitats; preventing, removing or mitigating obstacles to their migration and controlling other factors that might endanger them'. This can be a challenge, particularly in locations where communities depend on fishing for these species for their livelihood.

Therefore, together with the Wildlife Conservation Society, the Manta Trust developed a Concerted Action proposal for mobulid rays, which was adopted at the CMS CoP in 2017. The document outlines clear objectives and actions that will help parties to implement their obligations under the CMS. It also serves as an opportunity for parties to collaborate and share and propagate conservation knowledge, monitor the progress of work and generate coordinated actions. At the 2nd CMS Memorandum of Sharks convention, the Manta Trust became an official collaborating partner to the CMS, joining other international NGOs such as the Shark Trust, Project AWARE and the International Fund for Animal Welfare.

'By coordinating the work of field researchers and scientists around the world with conservation policy advocacy and community outreach, the Manta Trust brings together all the elements needed to achieve win-win solutions that benefit manta and devil rays and local communities.'

Mary O'Malley
WildAid

Data put out by the Manta Trust and its collaborators, in combination with concerted efforts to liaise with decision-makers, led several governments to declare national protection of manta rays (and in some cases also devil rays) over the past decade: Indonesia, the United Arab Emirates and the Maldives in 2014, Peru in 2016 and Thailand in 2018. Indonesia's decision to protect manta rays was a major breakthrough, as the nation is one of the largest exporters of mobulid products. Peru's protective measure is crucial for the region because oceanic manta rays *Mobula birostris* migrate between Peruvian and Ecuadorian waters and evidence points to this being the largest-known population of this species in the world. Thailand officially declared measures to protect 12 marine species by adding them to its national protected list in 2018, including all six species of manta and devil rays seen in Thai waters. This means it is now illegal to kill, trade or possess any of these species. In terms of oceanic manta tourism, Thailand is the second most popular place in Asia to dive with these gentle giants and manta tourism generates millions of dollars for the country each year.

The Manta Trust has also been fundamental in driving protection at a local scale, such as through the establishment of marine protected areas (MPAs). Our most successful example was the creation of the Hanifaru Bay MPA as part of the Baa Atoll UNESCO Biosphere Reserve in the Maldives.

Implementing legislation by building capacity

In 2014, the Manta Trust launched its Global Mobulid Conservation Programme (GMCP) to coordinate and carry out a

strategic, long-term conservation plan for manta and devil rays. Through the GMCP, the trust supports the effective implementation of legislation through capacity building, particularly in key mobulid fishing countries such as Sri Lanka, Indonesia, the Philippines, Peru and India. It is critical to build the capacity of governments to ensure that policy changes are effectively implemented and enforced. This includes being able to identify products being traded and knowing the legal requirements for export. We conducted more than two dozen training workshops, often as part of collaborative CITES implementation efforts, so that customs and fisheries officials acquire the skills and knowledge to monitor trade in mobulid products.

We also provided the tools and materials for countries to monitor mobulid fisheries and support enforcement, for instance through developing a mobulid identification guide, and we were thrilled to see them increasingly clamping down on the illegal trade in gill plates. In addition, we organised interdisciplinary National Elasmobranch Working Group (NEWG) meetings in two key mobulid fishing countries, Sri Lanka and Indonesia. In Sri Lanka, the first meeting brought together scientists, government representatives and NGOs to review national management and regulations on mobulid rays, learn about the research being conducted and pave the way forward for improved domestic regulations.

Better species-specific knowledge

Research by the Manta Trust's projects and network has improved knowledge about individual manta and devil ray species. Relatively little research was conducted on these species for most of the 20th century, but in recent years public awareness and scientific interest in them have increased greatly. Through our network, we have published more than a dozen scientific papers and provided data for the IUCN's Red List reassessments of manta rays and three species of devil rays.

In 2018, we assembled 30 leaders and emerging experts in the fields of mobulid biology, ecology and conservation and, in order to facilitate improved science-based management of mobulids, produced a scientific publication that identifies pressing knowledge gaps. The Manta Trust's chief executive, Guy Stevens, published his PhD findings from a 14-year study that shed light on the entire courtship and mating behaviour of manta rays using behavioural observations, video and photographic records. And our genetics project leader, Jane Hosegood, submitted her manuscript 'Phylogenomics and species delimitation of mobulid rays reveals cryptic diversity and a new species of manta ray'. This paper shows robust evidence for an undescribed species of manta ray in the Gulf of Mexico and for the resurrection of a recently synonymised species, *M. eregoodootenkee*, and generates a taxonomic framework to support effective management and law enforcement strategies.

'The Manta Trust is one of those rare conservation organisations that places a great premium on scientific excellence. Not only do they base their conservation efforts on solid evidence, they have been responsible for research that has generated major leaps in our understanding of these magnificent and threatened creatures.'

Professor Callum Roberts,
University of York

As part of the GMCP, we conducted research into the catching of mobulid rays in key fishing countries to inform policy and management decisions. By collecting detailed data that shed light on the shark and ray fishery in a fishing hotspot in Java, Indonesia, we compiled the most comprehensive dataset on the fishery in this location, while interviews with fishers provided socio-economic information to support the dataset. Through our local partner, we monitored fisheries in Sri Lanka and documented over 10,000 elasmobranch specimens (all sharks and rays) over more than 500 survey days across eight main survey sites. And again through a local collaboration, we collected 18 months of data on the elasmobranch fishery in Guinea, West Africa.

Thanks to an agreement with Australia's James Cook University, these data are in the process of being published and have already been presented to relevant governments. This work ties in with our charity objective of building capacity for community members. We were particularly proud to hear that one of the two Indonesian interns employed and trained in monitoring the elasmobranch fishery received a job offer as a fisheries researcher from the Indonesian government. This is the true aim of building capacity: to provide the tools and expertise for talented local people to continue this important work even when Manta Trust projects and their funding come to an end.

Publications

In addition to key scientific papers, the Manta Trust has produced a range of publications for the general public. In collaboration with the Save Our Seas Foundation and the award-winning photographer Thomas P. Peschak, it created and launched the first natural history book on manta rays. This beautiful coffee-table book provides a comprehensive overview of the latest understanding of the biology and ecology of mantas, the threats they face and their conservation status. Illustrated by unique images, it gives a glimpse into the secret life of manta rays from populations around the world.

'Guy and Thomas have brought together their knowledge and expertise to create a book that perfectly captures the essence of manta rays. It stirred within me a desire to do more to help conserve our oceans, and I hope that it does the same for you.'

Sir Richard Branson,
Virgin Group

In addition, we published and launched *Guide to the Manta and Devil Rays of the World* by Stevens, Fernando, Dando and Notarbartolo di Sciara. This comprehensive 144-page field guide provides detailed information about the identification, characteristics, threats and distribution for each of the species within this family of rays. Illustrated with more than 200 beautiful colour photos, drawings and plates, it also contains an expansive introduction packed full of useful information about the general taxonomy, biology and behaviour of these iconic animals. Being lightweight, easy to use and attractive, the guide is an invaluable field companion for any scientist, diver or marine enthusiast who has an interest in mobulids. It is also an essential resource to promote fisheries management and international trade enforcement, as well as for anyone wanting to become involved in the ongoing efforts to research and conserve this threatened family of rays.

Global road map

The Manta Trust has developed a global plan for mobulid conservation that incorporates the directions set forth by the IUCN's Shark Specialist Group and the CMS Concerted Actions. Over a year in the making and funded by the Shark Conservation Fund and the Save Our Seas Foundation, the Global Strategy & Action Plan outlines what actions need to be taken to ensure the long-term survival of mobulid rays. We started out by defining our overall vision: to see all manta ray species and their relatives protected or effectively managed for sustainable or non-consumptive use by the people closest to them and in a way that promotes wider ocean conservation. Then, by asking what is preventing this from happening right now, we identified the key threats that still exist: targeted fishery, by-catch, unregulated tourism and the indirect threat from environmental degradation, which includes climate change and pollution.

Through a theory of change approach, we defined the individual factors that influence the threats and what actions need to occur to eliminate or reduce each one. We then defined the priority, cost, scale, time and responsible party (NGOs, governments, industry) needed to tackle individual actions, and developed graphic illustrations of our thinking. While global in scope, the strategy highlights how the Manta Trust fits into it all, as

A researcher swims down to attach a Crittercam to a reef manta in the Raa Atoll, Maldives. The insights delivered by these cameras into how mantas lead their lives help to guide better policy and protection measures for these animals.

Photo by Guy Stevens | Manta Trust

Photo by Guy Stevens | Manta Trust

A host of new technologies, from satellite tags to underwater cameras, help researchers better fill in the gaps in the natural history of manta rays. These data form the foundation of what the Manta Trust can go on to advocate as informed management of their populations.

Photo by Joao Rodrigues

Regional insights into the conservation status of and challenges facing mobula rays help build a better global picture of how these species are faring. Local projects like the Mobula Project Indonesia can find relevant solutions for specific problems.

well as the areas where we believe we can be most effective as part of the wider conservation effort. The Global Strategy & Action Plan was officially launched at the 3rd CMS Sharks MoU meeting in 2018, held at the breathtaking Oceanographic Museum in Monaco. It is now publicly available to download from our website (*mantatrust.org*).

Sustainable management of mobulid tourism

By developing a scientifically supported Code of Conduct for manta tourism and a best-practice guide for shark and ray tourism, the Manta Trust has advanced the sustainable management of mobulid tourism. In collaboration with Project AWARE and the WWF, it completed and launched the best-practice guide, which was developed with a team of scientific experts and industry professionals. The guide, *Responsible Shark and Ray Tourism – A Guide to Best Practice*, provides a suite of free, practical, downloadable tools that can be used by operators, NGOs, local communities and resource managers.

Shark and ray tourism is becoming increasingly popular worldwide, but there is limited guidance on aspects of best practice. Guidelines are needed to ensure that sites are established and operated in a manner that benefits sharks, rays and local communities, while also inspiring in tourists awe, respect and a greater appreciation of the need to conserve these animals. Shark and ray tourism, when properly designed and managed, can provide alternative direct and indirect benefits to local communities and economies.

We launched *swimwithmantas.org*, an online resource hub for tourists and manta tour operators around the world. On this micro-site, members of the public can freely watch the film aimed at tourists, *How to Swim with Manta Rays*. Additionally, they can learn about the importance of global manta tourism, browse a Wall of Fame dedicated to tourism operators who have committed to sustainable practices, and become acquainted with the new 10-step guide to swimming with mantas. The guide is a revised version of the Manta Trust's Tourism Code of Conduct, with illustrations and simple captions that explain how to interact responsibly with a manta during an encounter. There is also a scientific publication in press on creating an evidence-based code of conduct for manta ray tourism interactions.

'With the exponential growth in marine ecotourism, coupled with increased threats from overfishing and habitat loss, developing a set of responsible operator guidelines is something that conscientious travellers have been requesting for a number of years. In 2017, Project AWARE partnered with the Manta Trust and WWF to develop a comprehensive set of recommendations that would assist tourism operators not only to minimise any impacts they would have on sharks and rays, but also to actively contribute to conservation and management. With manta rays a significant attraction for tourists, having the Manta Trust's input was invaluable to ensuring that the guidelines incorporated the latest scientific understanding of these majestic creatures.'

Ian Campbell,
World Wide Fund For Nature

New research methods

Pioneering and testing new research methods is an important part of the Manta Trust's work and in 2015 it joined forces with the National Geographic's Crittercam team and the Scripps Institution of Oceanography at the University of California, San Diego, to attach Crittercams to wild mantas for the first time. There are so many unanswered questions about manta rays' behaviour. Why, for example, do they dive so deep? What do they eat in each season? Why do they congregate in certain areas? These are interesting from an ecological perspective, but also for conservation: if we can work out what mantas are eating at certain times of year, based on those food sources, it becomes easier to predict where they will be. A big threat to manta rays is accidental fishing, or by-catch, so by identifying their feeding grounds we get a better idea of where the rays are most vulnerable to being caught.

The team set off for the Revillagigedo Islands off central Mexico's Pacific coast and for the first time ever cameras were successfully attached to the animals. A year later, we undertook another expedition with the same team to Raa Atoll in the Maldives. The Crittercams filmed more than 24 hours of onboard footage of reef manta rays *Mobula alfredi*, capturing some extremely exciting and revealing behaviour. For the first time, we were able to observe what these rays do when they leave the atoll's reefs and venture into deeper water away from humans. We also used advances in technology to carry out ultrasounds on wild manta rays underwater and investigate the reproductive biology and behaviour of these species in the Maldives.

Mobulid experts around the world

We have established a global network of mobulid experts that comprises affiliate projects, partners, collaborators, research institutions and media experts, all of whom are working together to advance the knowledge and protection of mobulid rays. Who could have guessed eight years ago that not only would we meet our vision of creating this incredible platform that forms the foundation of global mobulid conservation efforts, but exceed it? With affiliate projects in 23 countries across Latin America, South-East Asia and the Pacific and Indian oceans – all led by passionate project leaders and research teams – we are fortunate to work with one of the most inspiring global teams I have ever met. Our projects and their research and conservation work are as diverse as the nationalities that form our organisation.

In the South Pacific, we established a collaboration with Conservation International, forming the New Caledonia Manta Initiative to investigate the spatial ecology and movement of the manta population, led by local PhD candidate Hugo Lassauce. Our associate director Shawn Heinrichs produced a short movie named *New Caledonia, Mother of the Coral Sea*, which features the incredible diversity of the Coral Sea in New Caledonia and how it provides for the people of the archipelago, where nature and people are inextricably linked. The film includes Hugo's work and can be viewed at *conservation.org/coralsea*. Building on the in-country work, we also formed a collaboration with the University of Queensland to investigate the connectivity of manta populations across the Coral Sea, working together with our projects in Indonesia, Papua New Guinea, New Caledonia, Fiji and French Polynesia.

'The Manta Trust has been an incredibly strategic and valued partner for our marine conservation work in Indonesia, Papua New Guinea (PNG) and New Caledonia. Starting with some early joint expeditions in Raja Ampat that opened our eyes to both the value and the vulnerability of the manta populations there, our partnership rapidly grew from conservation science roots to regional and national policy engagement, culminating in the Raja Ampat Shark and Ray Sanctuary and later Indonesia's landmark decision to grant full protected species status to both manta species throughout its territorial waters. Other partnership initiatives with the Manta Trust in Milne Bay (PNG) and New Caledonia have enjoyed similar success in building photo ID databases while dramatically increasing public and policy-maker exposure to and appreciation of mantas. Our partnership in Indonesia has now expanded to also focus on mobula rays. I really can't say enough good things about the organisation – it brings enormous enthusiasm, passion and expertise to its work and has been a natural partner to our marine conservation efforts in the Pacific.'

Mark Erdmann,
Conservation International

Across the Pacific, we supported the creation of the Mexico Caribbean Manta Ray Project, which incorporates a research as well as an educational outreach component. We launched a plastic pollution study in collaboration with the

Photo by Joao Rodrigues

Betty Laglbauer and Didik Rudianto take measurements of the remains of a mobulid ray for the Mobula Project Indonesia.

Photo by Tane Sinclair-Taylor

A 360 degree virtual reality film created in the Azores, where this school of mobula rays was photographed, formed part of the campaign to get the listing of devil rays on CITES Appendix II approved in 2016.

Mexican government, collaborated with the Eye on the Reef programme to look at marine debris in the Mexican Caribbean, and delivered recommendations and a Guide for Good Practices with Mobulid Interaction to the Mexican Caribbean Biosphere Reserve, the Whale Shark Biosphere Reserve and the Isla Contoy National Park. In Peru, we achieved national protection for manta rays following groundwork done by our local collaborators. We conducted socio-economic research to inform the effective implementation and enforcement of this legislation and helped communities to address challenges such as by-catch.

The Maldivian Manta Ray Project (MMRP), the founding project of the Manta Trust, has developed into an active and integrated research and education programme that spans the entire Maldives archipelago. It employs a dozen full-time members of staff and operates in partnership with half a dozen resorts and dive centres. Now in its 15th year, the MMRP hosts six volunteers and several MSc students as part of its research internship programme every year. A successful crowd-funding campaign, 'Eyes on the Reef', was launched to uncover the hidden habits of reef manta rays by using remote underwater camera rigs installed at cleaning stations and, in collaboration with Manta Expeditions, the Manta Trust conducted its first Citizen Science Expeditions in the Maldives half a decade ago.

The MMRP takes part in numerous educational festivals in the Maldives every year. In 2016 it launched the Maldives Education Programme (MEP), which focuses on enhancing the development of local community members, students, staff and schoolchildren, particularly with regard to marine biology and conservation. As part of this programme, a PADI Manta Ray Speciality course for snorkellers and divers was developed and implemented at several resorts across the Maldives and has now been extended to schools and local communities in Baa Atoll, Laamu Atoll and Lhaviyani Atoll. The programme includes a component that focuses particularly on empowering young women to engage in marine conservation and research. In October 2018 the MMRP organised the first Manta Festival, which was held at the island of Dharavandhoo in Baa Atoll.

Social media and marketing

Our vision as a charity is to conserve mobulids through research, education and collaboration and we are proud to have extensively raised awareness and inspired action through the media. The primary way that we publicise the research and conservation initiatives we are part of is through social media, which we use to convey the latest news and discoveries relating to mantas and their habitats. Our social media platform is the most powerful tool we have to connect directly with our followers and rally them behind specific causes on an international scale. While the exact strategy and goals vary depending on which medium we use, the overarching purpose of the charity's social media output remains unified: to raise awareness about manta conservation and, to a lesser degree, provide education about our marine ecosystems. Simply put, social media are arguably the most effective means for us to raise awareness consistently and to an ever-growing audience. Our social media work has grown from a single Facebook page with 900 followers in 2012 to an audience numbering tens of thousands across three platforms – and it continues to grow at an ever-increasing rate.

In 2018 we launched The Cyclone, a membership and fundraising platform where supporters can contribute directly to the conservation of the oceans and manta rays, their relatives and habitats. By joining The Cyclone, anyone can get a front-row seat to our global conservation efforts. We created an exclusive area on our website available only to The Cyclone members, where we introduce our manta family and show the research we are doing and why it is so important. We share our successes and discoveries as they happen, as well as the challenges we face along the way, giving The Cyclone supporters a unique view behind the scenes via videos, stories and regular updates from the field. Members donate whatever they can each month, united by the same desire to create a lasting future for these animals and the oceans they call home.

In other initiatives, the Manta Trust developed a 360VR film of feeding reef manta rays in the Maldives to be used as part of the Dubai Aquarium's VR Zoo exhibit, which gives people of any age and physical ability the opportunity to experience an underwater encounter with mantas. We secured a corporate partnership with Carl F Bucherer for a limited-edition Manta Trust watch (*watchmymanta.com*), with donations from the sale of the watch funding the research of our core project, the MMRP. We also supported Roger Munns, a BBC cameraman and Manta Trust patron, with his manta ray filming project for *Blue Planet II*.

Finally, we have established a solid core operations team to ensure that the Manta Trust continues its important work for many more years. This includes a director of operations, a head of fundraising and communications, a head of conservation strategy and a media and communications manager. Together with our chief executive, they coordinate and plan our global activities. We have developed a fundraising, communications and media strategy and secured core funding from several corporate partners, philanthropists and foundations. It has been such an honour to see the Manta Trust charity grow over the years and to be part of driving its achievements near and far. We are now the largest and most diverse global network of mobulid ray experts and I cannot wait to see what else lies ahead. Thank you to all our amazing projects, collaborators, funders and friends for sharing this journey with us.

WILL YOU STAY OR WILL YOU GO?

Photo by Michael Scholl

Words by Lauren De Vos

The great hammerhead shark plays a key role in maintaining healthy ocean systems in the tropics, but overfishing has sent its populations into free fall. Understanding how these sharks move between The Bahamas and the USA could be essential for their conservation. Lauren De Vos discusses a publication by Tristan Guttridge that provides the first evidence that great hammerheads travel huge distances but repeatedly return to specific sites and may stay there for months at a time.

Nomads are nothing new to the islands of Bimini. For adventurous souls with a taste for the outdoors, the islands in this archipelago have been a favourite escape into a quiet corner of The Bahamas that keeps its 'authentic Caribbean flavour'. Novelists with a restless spirit, bohemian musicians and the philosophically inclined have all crossed the powerful Gulf Stream that separates the mainland coast of the USA from the westernmost islands of The Bahamas. The manifold charms of Bimini prove an irresistible lure to such visitors, some of whom return time and time again. From Ernest Hemingway, who famously penned *The Old Man and the Sea* here, to Martin Luther King Jr, who retreated to ruminate on his Nobel Prize acceptance speech, and guitar-toting Jimmy Buffett, who wrote *Tales from Margaritaville* on South Bimini in the 1980s, some of the region's most famous guests might only have visited once, but those who were hooked loved to return.

As the hurricane season fades and the trade winds keep temperatures balmy, a shark called Gaia makes her way into these familiar waters. Secretive in her ocean home, she travels long distances over a vast sea. Although she is one of the islands' repeat visitors, she has proved far harder to track than her terrestrial counterparts.

Bimini's magnetic allure may persuade some iconic land-dwellers to keep returning to these mangrove-edged islands, but it is the whereabouts of its ocean inhabitants that have scientists really scratching their heads. The comings and goings of the region's marine creatures are the subject not of novels but of scientific studies that are probing their lives and behaviours and unveiling their mysteries. Perhaps akin to the spirit of Hemingway's storytelling, biologists are now writing the biographies of the wilder citizens of Bimini's waters. Unlike the margarita-sipping, marlin-fishing brigade, Gaia returns annually in winter. Finding out what lures her back each year and exactly where she goes when she leaves will enable scientists to better manage her species' dwindling populations.

The movement patterns of Gaia and great hammerhead sharks *Sphyrna mokarran* like her is the subject of a publication by Tristan Guttridge and his co-authors in *Frontiers in Marine Science*. Tristan was the lab director and senior scientist at the Bimini Biological Field Station at the time that this research was conducted, and if you know anything about his passion for sharks, you'll understand why he asks the kind of research questions that can uncover important findings to better inform the conservation of these elasmobranchs.

Tristan is equal parts zeal and concern as he explains the need for this kind of research. 'We've never really known much about these sharks,' he says. 'There is still so much to learn. We're just scratching the surface with these first insights.' For him and his colleagues, the overarching question is 'how do we best manage and protect great hammerhead sharks?' Answering it takes time, patience and continual probing into where, when and why these sharks travel. Tristan's article asks two questions. Firstly, do great hammerheads stay for prolonged periods in, or reliably return to, the coastal regions of The Bahamas and the USA? In other words, do they show site fidelity to these locations? And secondly, how much do they move between The Bahamas and the USA and how far do they travel?

Swinging its head from side to side to detect the minute electrical pulses emitted by stingrays as they hunt above the ocean's sandy floor, the great hammerhead shark is an iconic creature. Named for the cephalofoil that forms the distinctive 'hammer' of its head, it ranges widely throughout tropical waters. 'This species inhabits deep waters, shallow lagoons and coral reefs,' writes Tristan, adding that it is 'considered an upper trophic-level consumer'. Being a predator that moves long distances and possibly links different ecosystems would make the great hammerhead key to maintaining the stable functioning of the different regions it visits.

Its distinctive appearance notwithstanding, very little is known about the great hammerhead. Understanding more about how this shark lives is crucial if we are to confirm its effect on the ecosystem. What little we do know suggests that it is vulnerable to the effects of overfishing. It has what scientists call a 'conservative life history', tending to grow slowly, live long and have few offspring. This means that its populations are slow to recover after suffering a rapid decline.

It's difficult to imagine a powerful predator with such a wide range being classified as Endangered on the IUCN Red List, but great hammerheads are caught as target species and by-catch wherever they are found. The result is that their populations are in decline in many places. Concerns about the species have been raised at international level and it is listed on both the Convention on International Trade in Endangered Species (CITES) Appendix II and the Convention on the Conservation of Migratory Species of Wild Animals (CMS) Appendix II. The listings raise the profile of the great hammerhead, making it easier to regulate legal trade in its products and to manage the fishing effort for it. They also emphasise that the discussion of this species' conservation must be global. Great hammerheads pay no heed to the arbitrary political boundaries that humans have sketched onto maps to divide the ocean into territories. Managing their populations as they roam freely across the boundaries we've invented will need, as Tristan writes, 'cooperation between jurisdictions to ensure great hammerheads receive necessary protection throughout their migrations'.

The great hammerheads of the western North Atlantic range from the balmy Florida Keys northwards to the oyster shores of coastal Virginia and eastwards to The Bahamas. The Bimini Biological Field Station (popularly known as the 'Shark Lab') on South Bimini is a hub of marine research in these waters and scientists have been recording great hammerheads here since the early 1990s. In fact, two particularly fascinating events have been reported: one great hammerhead was observed preying on a southern stingray *Dasyatis americana* and another on an eagle ray *Aetobatus narinari*. These sightings aside, visits from great hammerhead sharks were historically sporadic and unpredictable. Over the past 10 years, however, the Shark Lab team has been seeing great hammerheads more frequently.

Sharks might be resident in an area, staying there for prolonged periods of time. They might perform return migrations, moving away from a region that they've occupied for a period and then returning to it. They might occupy different places in different seasons or travel vast distances. Understanding the hows, whens and whys of shark movements can help scientists to choose the strategy best suited to addressing specific conservation challenges. Is prohibiting fishing in certain areas useful for protecting a highly mobile creature like a shark? If scientists know that sharks spend significant time in an area for a certain period, protecting that area makes a lot more sense. This goes a step further when one understands why an animal moves to a particular location. Is there food there? Is it breeding there? Is there a nursery? It is easy

Photo by Michael Scholl

to understand how vital shark movement patterns are when it can be seen how this information underpins smart conservation strategies. Why then is there a distinct lack of these data for the great hammerhead and many species like it?

Tracking great hammerhead sharks is tricky. Tristan writes that they 'move long distances, live in concealing environments, are logistically difficult to capture and, as upper-trophic predators, are naturally low in abundance'. And because they occur in low numbers, they are hard to find. However, ever-evolving technology provides scientists with new tools and the Shark Lab team took up the challenge with gusto. Tristan and his colleagues used a combination of methods to answer his questions over a period from 2012 to 2016. They were interested in two study sites: Bimini, and Jupiter in Florida. Great hammerheads at both sites were caught and fitted with either acoustic or satellite tags. In Bimini, divers also took underwater photographs of great hammerheads for photo identification. (Any permanent wounds or marks on a shark, as well as unique fin shape, can be used to distinguish an individual in a photograph and ultimately build a visual archive of identified sharks.)

Acoustic tags emit sounds that are detected by receivers deployed underwater in a range of habitats along the coast. As a shark passes a receiver, its unique code is logged and it is identified as having moved into the region. Researchers can then decipher which habitats the shark spends most time in and how long it stays in an area. With the aid of renowned free-diver William Winram of The Watermen Project, sharks were tagged underwater in Bimini. The sharks tagged in Jupiter were given acoustic tags with a 10-year lifespan so that scientists can track cross-border movements. To investigate where these sharks move in summer and the extent of their migrations, satellite tags donated by Microwave Telemetry Inc. were inserted into five sharks. Satellite tags transmit GPS coordinates and depth, temperature and light-level information every 15 minutes to a satellite constellation that relays the data to the scientists. The tags are scheduled to pop off the shark after 30 days and they float on the ocean surface to be retrieved or are washed ashore.

Mapping the results of all these acoustic and satellite tags revealed the answer to the first question posed in Tristan's article. Great hammerhead sharks of both sexes do indeed show site fidelity: many returned annually to either Bimini or Jupiter. Males and females tagged at both these sites returned reliably, 'with some individuals recorded on up to four consecutive winter seasons', notes Tristan. Not only did these sharks prove faithful to their favoured overwintering sites, but many individuals were actually resident during the season. These sharks followed Hemingway's habits and hunkered down for up to five months at a time, a tendency scientists call 'seasonal residency'. And what of Gaia? She's been sighted at Bimini for five consecutive years. However, results from her external acoustic tag show that she is not simply a lady of leisure languishing in the comfort of Bimini's waters. Gaia completed two consecutive voyages northward to South Carolina – a round trip of 1,600 kilometres (994 miles).

In answer to the scientists' second question, Tristan writes that 'great hammerheads were found to make regular movements across state boundaries, as well as between the US and Bahamas EEZs'. The Exclusive Economic Zone (EEZ) is a country's designated coastal waters for economic activities. That sharks move between The Bahamas and the USA was evident in the journeys of some individuals between Jupiter and Key Largo in Florida and the Andros, Bimini and Grand Bahama islands in The Bahamas, usually towards the end of winter. The extent of their movements was far-ranging. The team found that great hammerheads travel epic distances – up to 3,030 kilometres (1,883 miles) – in what they dub 'large-scale return migrations'. Some of these sharks returned from as far afield as Virginia, a return trip of about 3,000 kilometres (1,864 miles). These findings prompt the question why? This would be the next step to investigate.

As far as the sharks' seasonal residency is concerned, Tristan has a preliminary hunch. 'At our study sites, there was an absence of fresh mating wounds on female great hammerheads, or swollen claspers in males, which suggests that the main purpose of site fidelity in great hammerheads is not mating, pupping or use of natal sites.' So they're not there to mate, perhaps, but to feed? The mangroves of Bimini are nurseries for many other species of sharks and rays that are great hammerhead prey and the Gulf Stream brings warm, nutrient-rich water to the region that is rich in marine life. 'Both our study sites are productive systems, prompting the hypothesis that great hammerheads return for feeding opportunities,' writes Tristan. This makes sense if one recalls the earlier Shark Lab sightings of great hammerheads hunting a southern stingray and an eagle ray. What about when they're moving between The Bahamas and the USA, or travelling long distances while making return migrations? Changing water temperatures and the resultant presence of prey like blacktip reef sharks have been suggested as a possible explanation. Some pregnant females observed on these routes offer the possibility that they may be travelling to give birth.

What does all this mean for great hammerhead sharks? Tristan notes that 'the predictable, seasonal, return-use of specific locations, areas or migratory routes enhances vulnerability to spatially focused fishing'. That great hammerheads are resident in or return to overwintering sites in the USA and The Bahamas is vital information that can help define what scientists call 'essential fish habitat' or, as the National Oceanographic and Atmospheric Administration (NOAA) records: 'those waters and substrate necessary to fish for spawning, breeding, feeding or growth to maturity'.

Armed with this knowledge, it is possible to look at where and when the majority of fishing activity happens and match it to where great hammerheads are moving. This could inform time-area fishing closures to improve fisheries management or help designate protected waters. If females are indeed pregnant and moving to pupping sites, protecting them as well as the breeding and nursery sites could be important. Knowing whether they are returning to their birthplace to pup would provide vital information about gene flow across the Atlantic. Finally, the evidence that these sharks move across state boundaries underscores the need for geopolitical coordination and cooperation.

In grainy, black and white photographs of famous travellers to The Bahamas, Ernest Hemingway grins roguishly as he poses next to unfathomably large marlin, tuna and mako shark trophies. It's a strange irony to think that Gaia and the great hammerheads of the region have been ocean voyagers for far longer than Hemingway and his kind. They have roamed these same waters so beloved and pilfered by adventurers, fishers and storytellers without any fanfare or popular records of their travels. It's perhaps a strange irony then, that the story scientists are beginning to tell about Bimini's ocean travellers will now be with the aim of saving their populations from overfishing.

Reference
Guttridge TL, Van Zinnicq Bergman MPM, Bolte C, Howey LA, Finger JS, Kessel ST, Brooks JL, Winram W, Bond ME, Jordan LKB, Cashman RC, Tolentino ER, Grubbs RD, Gruber SH. 2017. Philopatry and regional connectivity of the Great Hammerhead Shark, *Sphyrna mokarran* in the U.S. and Bahamas. *Frontiers in Marine Science* 4:3

Photo by Brian J. Skerry | National Geographic Image Collection

Dr Amy Apprill from the Coral Chorus project deploys single channel hydrophones, submarine listening stations that can detect sound on the reefs Amy and her colleagues research.

Crackling, popping, barking and singing; life in the sea is anything but silent. A chorus of sound guides ocean life on the reef, helping an array of animals to find their home, new mates and food and to defend their territory. How this happens, and what it all means, is the focus of a ground-breaking project in the Caribbean. Coral Chorus is bringing new insights to light and at a time when the effects of human activities in the sea threaten to overrun the delicate orchestra at play underwater. Post-doctoral researcher Paul Caiger from Woods Hole Oceanographic Institution leads us on a sonic tour of one of the Virgin Islands, where the science of sound might just help us save reefs in the future.

Can sound science help reefs?

Words by Paul Caiger

Dr Sylvia Earle was part of the pioneering team that created Tektite, the underwater habitat built in the 1960s at one of the same locations the Coral Chorus project now focuses on.

Submerged 40 feet (12 metres) below the surface in warm, clear waters, one could be forgiven for expecting the only sound disturbing the tranquil setting to be the intermittent gurgling of scuba bubbles. After all, Jacques Cousteau introduced millions to the marine realm with his ground-breaking documentary *The Silent World*. However, the reality is anything but silent. A cacophony of sounds emanating from the diverse animals that call the ocean home, as well as from the watery environment that surrounds them, competes for acoustic space on any given reef. Marine mammals are perhaps best known for their songs, but many more animals also contribute. Fishes grunt and chatter, sea urchins graze the rocks, their bodies resonating loudly as a result, and snapping shrimps pop away pervasively with a broadband crackle. All this noise is used in communication, foraging, predator avoidance, orientation and more. Understanding the importance of sound to animals and the reef has changed the way we view – and listen to – the underwater realm, opening up a rapidly expanding field of science called bio-acoustics.

Scientists from Woods Hole Oceanographic Institution (WHOI) have set out to understand how both the reef community structure and the ocean life that it harbours are influenced by the soundscapes. They also want to know how the biophysical soundscape – that is, the sounds from the non-living elements of the ocean environment – influences the make-up of the reef. In addition, and perhaps more importantly, the goal is to discover whether a healthy reef can be distinguished from a struggling one based on its acoustic properties alone. This involves characterising the soundscapes across a gradient of reefs and then comparing the result to other factors that can help assess reef quality. These range from the diversity and abundance of corals, fishes and microbiome life that are found on each reef to the water quality, the nature of the habitat and the patterns in how different species settle on the reef. Detailed observational and monitoring techniques have also been built on by some experimental and modelling work, such as sound playback experiments and passive drifting recorders, to narrow in on specific research questions and address some of the mechanisms behind these reef and settlement patterns.

To achieve all this, a diverse group of biologists have teamed up to form the Coral Chorus project, led by Aran Mooney, Amy Apprill and Joel Llopiz. Together, they bring their respective areas of expertise: Aran a bio-acoustician and sensory ecologist, Amy a coral microbiologist, and Joel a larval fish ecologist. To keep all the moving parts of this four-year National Science Foundation (NSF) project on the go, a throng of postdoctoral researchers, students and volunteers have helped in the field and back at the lab sorting samples and analysing data, simultaneously moving the project along while gaining invaluable scientific training and experience. This interdisciplinary attitude to environmental research is undeniably valuable, a comprehensive, creative and open-minded approach that will, for the sum of its parts, produce a more complete and holistic view of what shapes these reefscapes and helps them to function.

The setting for this project is the southern coast of St. John in the Virgin Islands National Park. St. John, one of the US Virgin Islands tucked in among the coral reefs of the Caribbean, is an ideal location for this ecological endeavour. A marine park is in place, where it is not permitted to anchor from anything larger than a small dinghy, and there is very limited infrastructure or human habitation on the southern shore of the island. This means higher levels of protection and less input into the ocean from human activities on land, where lush forest stands guard over the bays. The marine environment here is much quieter than at most other Caribbean destinations and it supports a rich scientific history, providing some very useful background data to build on. In fact, one of Coral Chorus's research sites, Tektite, was the location of the underwater habitat of the same name where, in the late 1960s, divers and researchers lived underwater for days to weeks at a time, observing marine life and studying human physiology. Sylvia Earle was one of these intrepid aquanauts.

Vocalisations are known to many of us who dive on both temperate and coral reefs. It is often quite obvious that the fish are barking at us, letting us know to keep our distance. It is also apparent that their barking serves as communication between members of the same species or other animals sharing habitats. It is even known to be a form of contact calling, used to maintain some level of shoaling (for instance, at night with sweepers). What is really exciting, however, is when species gather en masse to spawn and engage in dense vocalising bouts, males advertising their wares to females and competing vigorously with other males. One such site has been identified on a ledge south-west of St. John, where thousands of red hinds *Epinephelus guttatus*, a small grouper, gather in these noisy spawning aggregations. Many other groupers are known for this acoustic behaviour and even the famed Atlantic cod *Gadus morhua* from the North Atlantic is such an example. Further identifying these types of important spawning sites shaped by sound, and subsequently where and when to offer protection, is imperative to the replenishment of reefs. Of course, all these vocalisations are also adding to the soundscape of each reef.

One of the principal discoveries that has driven an increased focus on underwater sound in reef environments, and a central theme in this project, is the role that sound plays in orientation cues. As the vast majority of reef animals have a planktonic life stage where they move freely through the ocean, distinctive reef sounds have recently been shown to provide orientation cues to these larvae that are ready to settle, acoustically inviting them to a suitable home. For example, characteristic reef sounds such as sea urchins and snapping shrimps are very different from the sounds produced in sandy bays and therefore give the larvae an idea of where a reef lies, based on the specific animals living within its structure.

The discovery that sound, combined with their other sensory abilities such as vision, chemosense and swimming capabilities, might guide larvae to their eventual home has changed

Photo by Bates Littlehales | National Geographic Image Collection

Bigeye snappers *Priacanthus* spp. are among several noisy fish species that can be monitored using sound science on reefs.

The indigo hamlet *Hypoplectrus indigo*, here nestling among soft corals on the reef, is another vocalising species of fish. It is occasionally found in the aquarium trade.

the misconception that the larvae of fishes and invertebrates – and even corals – were passive, ending up where they did completely by chance. Thus, in order for new recruitment of animals onto a reef, it has to be healthy to begin with – a tightly connected loop – and this is something that can quickly spiral downwards. However, there is little understanding of what soundscape information is available to larvae or how differences in sound can influence their settlement on a particular reef. The crux of this project therefore lies in understanding the highly variable and complex soundscapes of the many different reefs around St. John. Documenting larval settlement on the different reefs via daily light trapping efforts and then comparing those data to the sound characteristics is also an integral part of the research. By understanding how sound may drive recruitment ultimately sheds light on local species diversity and abundance, and equally, what impedes such recruitment.

An impending issue in underwater sound is the addition of noise from our human activities to the ocean environment. The knowledge that sound is ubiquitous underwater, and that it plays an integral role in reef life, brings with it the knowledge that these same ocean sounds can be overrun by more powerful and prevalent noises. The very properties that make sound a useful sense underwater – sound travels much, much faster and further underwater than in air – also means these activities reach almost every pocket of the ocean. Expanding human populations and ever-developing technologies mean that more humans are making more noise in the oceans. Global shipping, seismic and sonar activities on a loud and broad scale and, on a smaller scale, recreational boats, ports and coastal living all add noise to the underwater world. The effects of extremely loud inputs, seismic for example, are more obvious, triggering animals to flee and even causing irreparable damage. However, the effects of low-level chronic exposure are far less clear; we don't know the consequences of most instances, or are only just beginning to work them out. Certainly, noise from human activities has the potential to mask and disrupt important ocean life activities, so studies like this one are imperative if we are to understand and preserve reefs.

As this four-year NSF project begins to wrap up in St. John, it will hopefully provide increased knowledge and awareness of underwater sound, as well as a mechanistic understanding of how young larvae use natural sounds to orient towards, locate and settle in preferred reef habitats. Furthermore, the aim is to carry on recording, creating an unbroken acoustic time series that will be the longest of its kind. Consequently, by continuing to monitor the acoustic environment over time, we can begin to really understand change and determine how the condition of the marine environment is altered by human activities and climate change. Scientific presence in St. John during the devastating hurricanes of 2017 is just one prime example of this. By having data from before, during and after such large events as these, we can better understand their impacts and, more importantly, the recovery of the reefs.

Ultimately, soundscape monitoring provides a relatively cheap and non-invasive technique for monitoring aspects of reef health. With the shifting baselines of most marine environments today (we tend to forget what things used to look like and to measure what we see today against a 'new normal', an ecosystem that is already disrupted), it is imperative to have a clear idea of the direction and rate of change. Coral reef ecosystems are the hub for some of the greatest biodiversity on earth – and are of huge importance to humans as a source of protein, for shoreline protection and, more recently, to generate tourism income. So moving forward, if we can gather reliable information about the health of a reef without having to do extensive and costly surveys each time (now the comparative groundwork will have been done, at least in this region), then it is more likely to be an implemented tool. Novel techniques to study vulnerable coastal ocean systems are needed now more than ever. Knowledge of the role of sound in the delicate balance of coral reefs has great potential to inspire much future research, increase public awareness and potentially drive policy change. Here in this little corner of the Caribbean, sound science is doing just that.

These mating Caribbean reef squid *Sepioteuthis sepiodea* aren't vocal themselves, but are sensitive to low-frequency sound and may be impacted by noise pollution.

A shark by any other name

Words by Lauren De Vos

Making sense of nature – ordering its different forms and naming its various characters – is a scientific practice that dates back centuries. Since Aristotle's day, the field of taxonomy and systematics has been developed by scientists and natural historians to classify our planet's inhabitants. In today's conservation climate, this oft-ignored sector is increasingly important as subspecies are translocated across regions and new species are discovered with little time to spare before they disappear entirely. Dr Dave Ebert tells Lauren De Vos what it takes to attract students into what has been called a dying field and how shark taxonomy can be made exciting and relevant to a new generation and a wider audience.

Photo by George Steinmetz | National Geographic Image Collection

Careful attention to the details, morphologically (how species look) and genetically speaking, helps taxonomists decipher individual species and understand their relationships to other species groups.

'Lost Shark Guy'. That's Dave Ebert's nickname in the shark world and it gives a clue to the purpose, and passion, he's found in his scientific career: to search the oceans for undiscovered shark species. For a field that is often poorly understood outside the scientific world, Dave's zeal has done much to make his discovery of more than 40 new shark species familiar to a wider audience. If ever you've channel-surfed different natural history documentaries, chances are you've encountered his work on *Alien Sharks* for Discovery Channel's Shark Week or for the BBC series *Shark*. For scientists, his work is familiar as we page through seminal tomes like *Sharks of the World* to identify the various species we work with and try to understand. Dave's background lies, in fact, in the field of ecology. For his MSc he worked on the life history of sixgill *Hexanchus griseus* and sevengill *Notorynchus cepedianus* sharks that cruise the California coast in the eastern North Pacific Ocean. It was his association with the shark taxonomist Leonard Compagno that took him to South Africa and from there on to a lifetime of searching for sharks to name and describe.

'Just as Leonard was leaving San Francisco, I jokingly suggested that if he needed anybody to carry his bags, he should let me know!' Dave chuckles, as he frequently does during our conversation and in a tone that betrays the enthusiasm that helps propel his work across the world and over scientific boundaries to a wider public audience. Compagno had accepted a job in South Africa at what was then the JLB Smith Institute (now the South African Institute for Aquatic Biodiversity) in Grahamstown (now Makhanda). It was there that Dave would eventually find himself settling in for a PhD and where he'd go on to describe many of the region's shark species. That's how he detects my South African accent via our Skype call, its flattened vowels seldom correctly identified by any other international ear. 'South Africa is like my second country after my home country,' he jokes, but it seems fitting that someone who has built a career on paying attention to detail would hone in on the most accurate description of my particular origin.

While it was Aristotle who first devised the key concepts of taxonomy, grouping animals with similar features in his *Historia Animalium* published in 350 BCE, it was the Swedish botanist Carl Linnaeus who prescribed the system of binomial classification that underpins how we order and describe life on earth today. Over the centuries, physicians and scientists had devised many varied and fairly inconsistent ways of naming and describing species by the time Linnaeus published his *Systema Naturae* in 1735. This system explained kingdoms, classes, orders, genera and species and, although it has been modified over time, it still forms the basis of how we classify the natural world.

Undeniably old, the field of taxonomy and systematics is perceived in some quarters to be a dying art form, a sector that struggles to attract young graduates into its detailed, attentive fold. 'Oh, that's absolutely true,' agrees Dave. 'In general, across all taxa, it's something of a waning sector. When it comes to shark taxonomy, most of the mentors and experts that I knew have now retired and nowadays only a handful of us are still active in the field.'

Part of the reason for this, he explains, lies in the difficulty of finding positions, support and funding. 'Most of what I do is a labour of love; there's very little support for it.' Dave's approach is pragmatic, bearing in mind the real-world conundrum that faces his students after he's instilled a passion for discovering and naming sharks and equipped them with the requisite skills to describe species before they move into the job sector. 'I train students here, but once they go out into the world, they need to get a job – as we all do – and there are no real positions for them in the field of taxonomy.' So how does Dave manage to maintain his own enthusiasm for this field? 'I've just been muddling along, I guess, managing to weave my taxonomic work in with other ecological projects so that I can merge funding opportunities and make all of it happen.' His seemingly casual answer belies the more than 28 books he's published and over 500 scientific articles he's written. Clearly, the need for expertise in shark systematics has not declined over the centuries, even if the support and external enthusiasm for it have waned.

In theory, the prospect of finding new species and making sense of the world of sharks would seem highly attractive, both in terms of drawing new researchers into the field and in attracting funding. Who wouldn't want to find something called a ninja lanternshark? *Etmopterus benchleyi*, described with Victoria Vásquez and Dr Douglas Long, was named in part to commemorate the 40th anniversary of the movie *Jaws* and in collaboration with schoolchildren (which gives some insight into why the common name is so instantly appealing). Why is it, then, that the exodus of experts isn't being filled by a flood of new scientists clamouring to find their feet in this sector? 'In many cases, a lot of attention is focused on several charismatic species that are undeniably spectacular. People tend to aim for what they like and much of that involves a few big, toothy characters.' So what is it about Dave's work that keeps a steady stream of students knocking on his lab door?

'Most students come to my lab after their undergraduate degrees, admittedly interested in the charismatic species but keen to hone their skills and learn whatever they can about sharks. Often, it's a side project that I've asked them to do that can teach them how to write, research, present and publish – but its subject tends to be a little-known or new species that offers them the opportunity to do something a bit differently and follow a new path into shark science. Suddenly there's the option to have a type specimen placed in a museum or a new species described and published.'

Dave touches on something that many scientists probably feel, but aren't always consciously communicating: the concept of effecting some kind of lasting change or leaving some legacy that is a bit bigger than themselves. 'I have to say, the idea of naming a species that your great-grandchildren will know you found is an appealing thought to many. Publications in taxonomy seldom gain traction in journals with a high impact factor. That isn't necessarily attractive to all academics, but it's the kind of science that will ultimately persist for generations. It's not a bad thought, to make some lasting impression on the field of shark science.'

It seems at times that the idea of scientific discovery has gone a little out of mode in our current climate. Certainly, Charles Darwin, Alfred Wallace and Alexander von Humboldt generated interest in their work and commanded conversations quite outside the scientific circle of their day. How did things go so out of fashion? 'I grew up absolutely fascinated by the natural world and have remained so throughout my life. I think a lot of young kids start off with that same curiosity and enthusiasm, and the scientific community could do a lot to harness that natural attraction. From my own work, I'm aware of just how much excitement this field can generate, but it requires finding out ways to connect with an audience outside of the one we grow accustomed to speaking to once we're inside the scientific community.'

Dave fends off the idea that he's become particularly good at this challenge, but he does admit, 'I try at least to be conscious of how I communicate. If I throw around some exclusive ecological jargon, people may well say "Wow! Dave's really excited about his work, but I have no idea what he's talking about." So you lose your audience very quickly. I prefer to try to be fun about things, bearing in mind that most people don't want to be preached to.'

Since more than 1,200 elasmobranchs have been described to date and since the habit of naming species goes back to Ancient Greece, it hardly seems feasible that there could be much more

'Type specimens', like these shark skins from the 18th and 19th centuries in Berlin, Germany, are often samples stored in natural history museums. They form the basis on which taxonomists describe and name species.

Photo by Gerd Ludwig | National Geographic Image Collection

to learn about our oceans and their sharks. However, more than 240 shark species have been described in the past 15 years alone. It's likely that most of us would be able to name only a handful, and that only because they are the ones that have captured our collective imagination on account of misconceptions about them or their misadventures on the silver screen.

'I've used my "Lost Sharks" concept to garner public attention,' says Dave. 'It gets people excited about the idea and opens doors to talk about expeditions to discover all kinds of sharks.' His work is a bid to bring to light those species that not only are unknown to the public at large, but remain little known to the scientific and conservation communities that are ultimately tasked with managing their populations. 'The fun part is going out and looking for something new,' he adds. 'The second part of what I do is a bit more *CSI*, you know? That involves figuring out whether what you've found is really something new and different, and it's a scientific process in and of itself. It's definitely still a cool part of the job, particularly if you're keen on discovery and understanding what's really new.'

So what is the current state of shark taxonomy and where might the field be heading in the future? 'I think the development of molecular tools has helped taxonomy, but there is a concern that the skills for the morphological description of a new species aren't keeping pace with the interest in genetics. You need to marry the two to be more certain; you need to be able to identify *why* something is different.' This, Dave believes, will ultimately mean that a combination of digital images will be used as a more lasting record over time: a description from what is called a type specimen that is housed in a museum and some degree of confirmation by means of genetic markers.

Regionally, he still thinks that most countries need to work on determining the status of their shark diversity. 'You have to have a sense of what's out there, but sharks aren't often high enough on the list of commercial fishery priorities for many nations. There's much that remains to be done, particularly in the Western Indian Ocean, where I've focused much of my career. So many species haven't been confirmed in decades, but it's difficult to even devise a plan to go look for them because there's no support. How do you persuade someone to fund an expedition to go look for a species of shark you haven't seen for years and years?'

Books keep Dave busy these days, with the second edition of *Sharks of the World* and *Field Guide to Sharks, Rays and Chimaeras of Europe and the Mediterranean* published just this year. A guide to ghostsharks is in production. 'I enjoy taking the knowledge and experience I've accumulated and putting them in a format that allows others to go out and explore, and really get to know these sharks too,' he comments. He hints with a wry laugh at redoing the field guide to southern African sharks. In the moment's pause that follows we both reflect on the lifetime of work – several lifetimes, it feels – that exists if we are to get to grips with the lost sharks of all our oceans.

Taxonomy, it seems, is a sector of seasons; but wherever winter feels longest, spring will surely follow. It's hard to imagine the search for sharks grinding to a halt after hearing Dave's indefatigable enthusiasm. 'People always ask me for my favourite find. What's the coolest shark I've ever discovered? I have to say – and it's the honest truth – that it's the one I haven't found yet.' He chuckles again. 'This is what always gives me a sort of Christmas Day feel' – a nod to the sense of anticipation and excitement that hasn't waned since he first crossed the Atlantic in search of sevengill sharks on the South African coastline. It's this sense of discovery that has kept the field of taxonomy alive over centuries; its conservation imperative today surely marks a new season for rejuvenation, if only the passion of Dave and other scientists like him can help it find favour once more.

Photo by Sophie Hart | Bimini Biological Field Station Foundation

INSIDE STORIES

The Save Our Seas Foundation (SOSF) is proud to support research and conservation in different ways. While it funds many individual projects that start and finish over the years, several key relationships with partner organisations have been fostered to continue into the future.

Research and education are the focus of the three centres that the SOSF manages directly. Cutting-edge science and long-term scientific observation are the mainstays of the Shark Research Center in the USA and the D'Arros Research Centre in the Seychelles. Nurturing the marine conservationists of the future falls to the Shark Education Centre in South Africa. The success of these centres underpins the SOSF's work on the ground, extending its conservation footprint and cultivating a wider community of ocean stewards.

The SOSF also partners with a collection of five independent NGOs that share a common goal: tackling head-on the challenges of global ocean conservation. The Bimini Biological Field Station (also known as the Shark Lab), Cetacea Lab (North Coast Cetacean Society), the Manta Trust and the Shark Spotters NGOs, as well as the Acoustic Tracking Array Platform (ATAP), each bring unique insights that weave together different realms of expertise. All are carrying out long-term research and conservation work. In terms of funding and communication, the SOSF partners closely with this community. Read on to explore and be inspired by the phenomenal work carried out by these centres and partners.

The plight and flight of stingrays from southern Africa

Acoustic Tracking Array Platform

The ATAP, a network of acoustic receivers around the southern African coastline, is providing invaluable information about the movements of little-known stingrays.

Words by Paul Cowley

The seas around the southern tip of the African continent are well known for their biological diversity. This hotspot is home to approximately 185 species of cartilaginous fishes, or elasmobranchs, of which about 50 (27%) are endemic to the region and, in terms of their conservation status, more than 25% are regarded as threatened according to the IUCN's Red List of Threatened Species. Sadly, a general lack of research attention has resulted in a dearth of knowledge about these species' life history, which is typically characterised by slow growth, late maturity and low fecundity. These are traits that make sharks and rays vulnerable to overexploitation and other anthropogenic impacts.

The populations of many elasmobranchs in the region have declined as a result of targeted fishing and being taken as by-catch, raising concerns about their conservation status. In South Africa, the management of elasmobranch populations is further complicated by the fact that two different government departments are responsible: one is mandated to ensure the sustainability of shark fisheries, while the other regulates non-consumptive activities, such as shark cage diving, and the conservation of threatened and protected species.

Stingrays are probably the least studied of all southern Africa's elasmobranch fauna, making conservation efforts very difficult. Approximately 25 species are known from the

Photo by Dennis King | Artwork by Marc Dando

region, but good biological data have been collected for only one species, the blue stingray *Dasyatis chrysonota*. Although stingrays make a negligible contribution to commercial fishery landings in South Africa, they are subjected to several other threats, including being caught in bather protection nets along the KwaZulu-Natal coastline and being taken as by-catch by inshore trawlers and demersal long-line fisheries. Moreover, many of the coastal stingray species are targeted by recreational beach anglers, especially during fishing competitions. Although these competitions adopt a catch-and-release approach, inappropriate handling could result in post-release mortality. In some cases, stingrays are targeted during a vulnerable time in their reproductive cycle and caught pregnant females are often observed aborting their young.

While the known threats to local stingray populations may appear to be negligible, virtually nothing is known about their coastal movements and migrations. Knowledge of movement patterns, and thus population distribution, is increasingly recognised as being vital to achieving conservation objectives. For example, there is considerable risk for several of the more tropical stingray species that might undertake migrations into the coastal waters of neighbouring Mozambique, where artisanal fisheries actively target and harvest stingrays for consumption.

Unfortunately, stingrays are poor candidates for dart-tagging projects such as South Africa's Oceanographic Research Institute's Cooperative Fish Tagging Project (ORI-CFTP). Although several thousand individuals of the common stingray species have been tagged in the ORI-CFTP, recapture rates are extremely low (less than 1%) due to the tags being shed. Stingrays are, however, good candidates for acoustic telemetry studies, whereby transmitters are surgically implanted into the body cavity and animals can be tracked for periods of up to 10 years.

South Africa hosts the Acoustic Tracking Array Platform (ATAP), comprising a network of deployed acoustic receivers spanning more than 2,200 kilometres (1,367 miles) of coastline from False Bay (Cape Town) to southern Mozambique. This marine science platform, funded by the Save Our Seas Foundation, provides an unprecedented opportunity to study the movements and migrations of data-deficient animals such as stingrays.

The insights gained from this research project have already shed new light on aspects of the movements and patterns of habitat use of southern African stingrays, which will assist with conservation planning initiatives. The research team plans to tag more individuals and more species, with more emphasis on some tropical species that might undertake trans-boundary movements into Mozambique.

Researchers at the South African Institute for Aquatic Biodiversity (SAIAB) are currently making use of the ATAP and to date more than 60 individuals from four stingray species have been internally tagged with acoustic transmitters. This study has already yielded fascinating information about the habits of these animals.

The maximum movement distance recorded by the ORI-CFTP for a duckbill ray is 123 kilometres (76 miles). However, one of the duckbill rays equipped with an acoustic transmitter has already been recorded 850 kilometres (528 miles) from its initial tagging site – seven times more than previously recorded! These large-bodied rays appear to be making regular longshore movements, travelling up to 42 kilometres (26 miles) per day. The roaming behaviour is interspersed with periods of residency (up to 164 days) in sheltered coastal embayments.

The diamond (butterfly) ray *Gymnura natalensis* also appears to undertake longshore movements, possibly even seasonal migrations. Interestingly, these rays are not detected by the ATAP as frequently as the other species tagged, suggesting that they might spend more time in deeper waters outside the reception range of the coastal receiver network.

In contrast to the previous two examples, the smaller-bodied blue stingray appears to display more restricted movements and possibly long-term residency in coastal emdayments.

There's a new education coordinator at the Shark Education Centre: Wisaal Osman, who has a Master's degree in applied marine science from the University of Cape Town. Five months in, she explains to Eleanor Yeld Hutchings what brought her to this position and how she's enjoying it.

Have you settled into your new role?
I keep joking with friends and family that I'm in a Venn diagram: marine science and education are overlapping and I'm smack in the middle – the perfect place to be!

What sparked your passion for the environment?
Actually, it was a person who sparked my passion. At a career day in primary school, we had a visit from a marine scientist. To this day, I can't remember her name, but in my mind's eye I can still see her explaining fish biology to the class. That was the turning point for me. She opened my eyes to a world I hadn't been aware of. I was hooked! I just had to see and experience this world.

My family encouraged me to follow my dreams, even if they were a bit different from the usual career paths... And off I went, pursuing tertiary degrees in zoology, ecology and marine biology. The field trips are some of my best memories and included many first experiences for me: Dassen Island's penguins, the rocky shore at Dalebrook, Langebaan Lagoon and its diverse invertebrates. For my Honours research, I spent six weeks living in a caravan on the beach at Paternoster. Is there anything better than the sounds and smells of the sea?

What were your plans after your studies?
During my tertiary career I honed my scientific skills: research, data collection, analytical thinking. I realised that science is not just about the sexy field trips; there's behind-the-scenes work too and it involves hours in the lab, doing analyses and interpreting findings. My aim was to use my skills to contribute to the world around me.

Once I'd completed my studies, I worked at WWF South Africa in its consumer outreach programme SASSI (Southern African Sustainable Seafood Initiative) and then at the Council for Scientific and Industrial Research (CSIR). Both organisations had work cultures that resonated with me: using scientific findings to improve the world for the generations to follow.

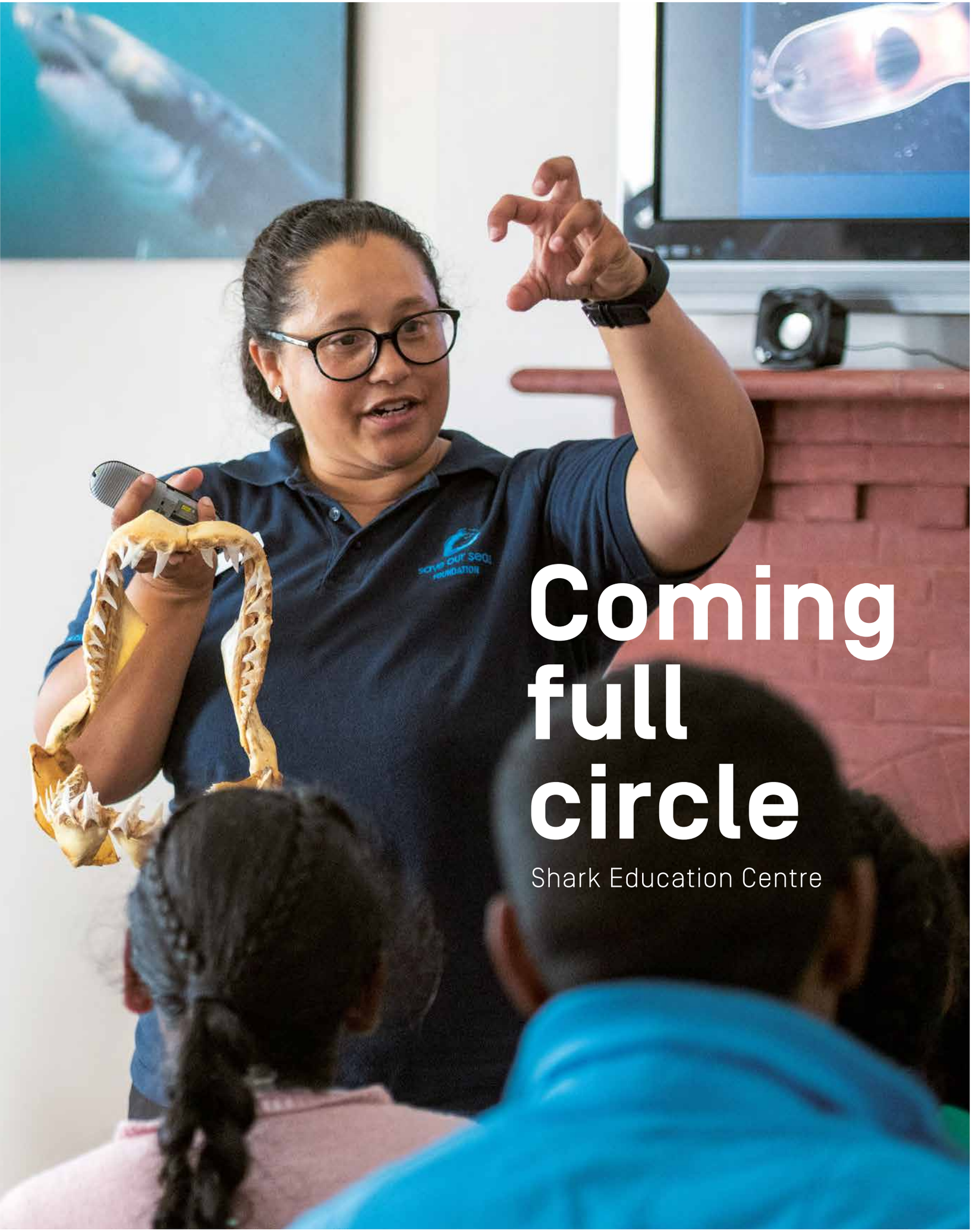
You also taught for a while...
I had occasionally tutored students over the years. In 2016 I had an epiphany: teaching is where I felt I was needed. I taught maths and science at an under-resourced high school. It was a steep learning curve with many challenges and rewards!

My aim was to help students to grasp new learning concepts. I also wanted to contribute to their holistic development as they navigated their life path. I had to make learning fun and relevant, using whatever tools were available. So the kids and I sang songs, used props... I may even have occasionally baked cupcakes to inspire my learners! We also went on hikes to improve the class culture for learning.

And now I've come full circle – back to Dalebrook to help children discover the fascinating world under the sea. The environment is magic, inspiring people and nurturing ambassadors for life. I see now how important that first spark was to me: to have someone nudge me and open my eyes to the world around me... That's why I am here: to help unlock the vast potential in all the kids who visit the Shark Education Centre.

INSIDE STORIES

Photo by Francis Moult



Coming full circle

Shark Education Centre

Photo by Martijn Schouten

Shark Spotters

Running scared: when predators become prey

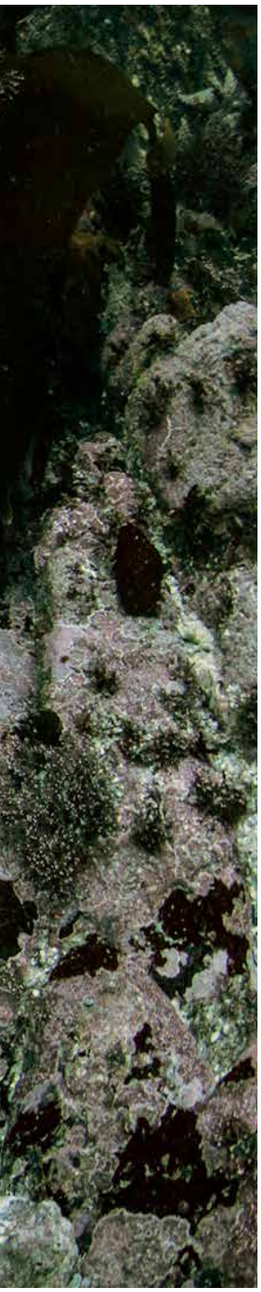
Words by Tamlyn Engelbrecht

Along the south-western coast of South Africa, the terms Port and Starboard have gained a new meaning. No longer just shipboard directions, they refer to a pair of black-and-white predators that are changing the marine landscape of False Bay and its environs.

It seems that False Bay is one of those places that will never cease to surprise, particularly with regard to the dynamics among its top predators. The area hosts not one, but two of the largest known aggregations of sharks globally. Of course, the presence of white sharks *Carcharodon carcharias* is one of False Bay's most prominent claims to fame and the sharks' aerial antics at Seal Island keep tourists coming annually from all over the world. However, along the western border of the bay there is another, lesser-known aggregation. Nestled in a sheltered cove where kelp forests and sandy channels are interspersed, Miller's Point is home to a unique aggregation of broadnose sevengill sharks *Notorynchus cepedianus*. Although these docile kelp-dwellers clock in at half the maximum size of white sharks and more closely resemble animated oven mitts than lethal predators, studies have shown that they feed on many of the same prey species as white sharks and hence have an equally important role in the coastal ecosystems they inhabit.

When I began my PhD in 2015, one of my primary aims was to improve our current understanding of the role that sevengills play as a predator in False Bay. Miller's Point provided a fascinating and unique study site as well as a scuba diving hotspot, where it is possible to get up close and personal with as many as 70 broadnose sevengill sharks in a single hour's dive. The primary reason for sevengills aggregating at this particular spot is thought to be as a refuge; however high up the food chain these sharks technically are, they would rather avoid direct confrontation with a species double their size. White sharks are known to shun dense kelp forests, so the sevengills had found the perfect spot to cool their heels during the day before venturing out to hunt at night, when the chance of running into a white shark was greatly reduced. And so the dynamic between these two predators was maintained, with each playing its respective role at the top end of the food chain.

However, a spanner was unexpectedly thrown into the works when a new predator arrived in the waters of False Bay: the killer whale *Orcinus orca*. This super predator has historically been incredibly rare in this area, with only



The remains of a sevengill shark lie waiting to be scavenged on the rocky sea floor in a kelp forest in False Bay, South Africa.

a handful of sightings over the past century. However, since 2009 there has been a steady increase in its presence in False Bay. Initially, there appeared to be little impact on the shark species in the bay and the killer whales were only ever observed feeding on marine mammals such as dolphins and seals. A fascinating characteristic of the species is its incredible dietary specialisation and prey selectivity. Although globally it is known to prey on more than 120 species, different pods have been shown to specialise on a key prey type or species, adapting specialist hunting tactics tailored to capturing their chosen prey. This specialisation has led to divergence among pods, even those that have sympatric ranges, resulting in differences in social structure, behaviour, communication and even morphology. Therefore, despite the current classification of killer whales as a single species, there are a number of different subgroups or 'ecotypes' that exist globally. In False Bay, it appeared that the pods that had been observed were a 'mammal specialist' ecotype, so their sporadic presence had little effect on either white sharks or sevengills.

However, this pattern changed abruptly in the late spring of 2015. On 9 November a group of divers at the ever-popular Miller's Point aggregation site descended to find that the area had been completely abandoned overnight. The number of sevengills at the site peaks in late spring and summer and finding the area suddenly abandoned in mid-November was unheard of. And it was to get worse: a search of the aggregation site resulted in the discovery of multiple sevengill carcasses, each fully intact except for a gaping ventral wound stretching between their pectoral fins. Both divers and researchers were baffled, although foul play by fishermen was at the forefront of everyone's minds. Unfortunately, no carcasses were recovered and the event remained a mystery. After a month of complete absence at the aggregation site, the sevengills slowly trickled back and resumed their usual behaviour. All seemed to be back to normal.

Until 12 April 2016. Again, the sevengills disappeared overnight and a number of carcasses were found littered over the seabed at the aggregation site. This time divers managed to recover these remains and our research team could inspect the wounds and carry out detailed necropsies. As we'd seen in the photographs from November, each shark bore a gaping wound across the pectoral girdle, but the key evidence that revealed the culprit in each case was found on the pectoral fins of each shark. Round, evenly spaced bruises were present on both the left and right pectoral fin, a pattern that lined up perfectly on the dorsal and ventral side of each fin. The bruises were clearly bite marks and when we consulted the literature and mammal specialists, it was confirmed that the bite pattern was that of a killer whale. As we progressed with the internal inspection of each carcass, it was immediately clear that the large liver (which can make up as much as a third of the shark's bodyweight) was missing from each individual. However, the heart, stomach and reproductive organs had all been left intact. What we had discovered was a unique and unprecedented occurrence. Not only was this the first time killer whales had been recorded preying on sevengill sharks in South Africa, but this method of accessing the liver by applying force to the pectoral fins and hence rupturing the pectoral girdle was a world first.

But why would killer whales suddenly target sharks after years of apparent co-existence? Due to the prey selectivity of killer whales, switching from marine mammals to a risky species like sharks was highly unlikely. In addition, the specialised technique of selectively removing the liver indicated that these killer whales were familiar with sharks as a prey item. Studies from other areas globally have shown that killer whales that habitually feed on sharks display severe tooth wear, thought to arise from frequent contact with the abrasive dermal denticles that make up shark skin. Therefore, this method of selectively removing the nutrient-rich liver while minimising contact with the skin of the shark appears to be a specialist adaptation by killer whales to reduce contact with the damaging denticles. We thus speculated that a new 'ecotype' of killer whale had arrived in the bay – one that habitually fed on sharks.

This theory was corroborated by sighting records, which showed the arrival of two new individual killer whales in the bay in January 2015. By now 'Port' and 'Starboard' have become well known, but back then this was the first introduction of these flop-finned sea pandas to False Bay. These two were never too far behind an incident at Miller's Point and were spotted in the area around the time of both events in November 2015 and April 2016. Furthermore, when white sharks began washing up liverless in Struisbaai and Gansbaai in 2017, guess who not-so-coincidentally happened to be sighted in the area at the time? Following these events, the white sharks in Gansbaai had a similar reaction to the sevengills in False Bay, swiftly disappearing for extended periods.

Port and Starboard appear to be roving bandits and over the past few years they have been sighted as far afield as Walvis Bay in Namibia and Algoa Bay in the Eastern Cape of South Africa. They have been in and out of False Bay sporadically over the past two years, with the last recorded sighting of them near Miller's Point in November 2018. Again, this was followed by the discovery of a lone sevengill carcass in the area bearing the signature wounds that perfectly matched the modus operandi of these two shark hunters. Today, the sevengill aggregation site is all but abandoned, as the previous refuge for these sharks is now clearly on the map of favourite spots for these two liver-loving killer whales. The number of white sharks in False Bay and Gansbaai has also seen a drastic decline in the past few seasons, although we cannot yet pin this entirely on the increased presence of these killer whales, as there may be other factors at play. One thing is certain though: Port and Starboard are bad news for sevengills and white sharks alike and their increased presence in coastal areas could have dire consequences not just for these shark species, but for the ecosystems of which they are a fundamental component.

Dive tourism dynamics

Bimini Biological Field Station Foundation
Words by Vital Heim

Photo by Matthew J. Smukall

Wildlife viewing has become a popular form of ecotourism and is considered beneficial to conservation. It does, after all, contribute to local economies and increase support for conservation initiatives. But how does it affect the wildlife being viewed? Having begun to look into the effects of providing food for great hammerhead sharks in Bimini to bring them within reach of ecotourists, Vital Heim has found a whole lot of new questions.

Large-bodied animals often occupy high positions in the food web and, if they are apex predators, they can shape ecosystems. Yet the populations of many such animals are in severe decline because their habitat is being destroyed by human activities or they are being harvested. In the marine realm, large sharks are especially vulnerable because their growth rate is slow, they mature late and their reproductive rate is low. As a result, many shark populations around the world are shrinking significantly. There is increasing evidence that the loss of an apex predator – the function of some shark species as the predator right at the very top of the food chain – can have a far-reaching impact on an ecosystem.

Diving with sharks is gaining in popularity in many parts of the world and nowhere more so than in The Bahamas, which is bucking the trend of global declines in shark populations. Thanks to conservation measures such as a ban on commercial long-line fishing in 1993 and the declaration of The Bahamas as a shark sanctuary in 2011, the populations of various shark species here are healthy – and contributing to the island nation's popularity as a diving destination. Of the more than US$100-million generated by the Bahamian dive industry each year, a large proportion comes from shark diving.

Many sharks are by nature both rare and elusive, so food is used to attract these marine predators to locations where ecotourists can experience close encounters with them. As yet, however, little is known about the potential effects of provisioning on both the targeted sharks and other species in the vicinity.

The great hammerhead *Sphyrna mokarran* is a large shark that inhabits coastal waters and open seas in tropical regions around the globe. Typically solitary, it is rarely seen in the wild, yet every winter numbers of this charismatic apex predator congregate in Bimini, a group of small, mangrove-fringed islands at the western edge of the Great Bahama Bank. Divers from all parts of the world are drawn to this seasonally resident population of great hammerheads – and pour into the local economy more than half of the annual revenue generated by shark diving in Bimini.

Its apparently healthy population around Bimini notwithstanding, the great hammerhead is classified as Endangered on the IUCN Red List of Threatened Species. Previous research conducted by the Bimini Biological Field Station Foundation (BBFSF) found evidence that several individuals return to Bimini each season. Visual identification played an important part in this research and an ID database currently comprising 35 great hammerheads has been set up. This could be done because individuals have certain characteristics that remain consistent over many seasons: distinctive fin shapes, notch patterns on the first dorsal fin and spot patterns on the belly, for example. Newly identified sharks added to the database each year improve our knowledge of the population's size and structure.

It is important to understand what could impact the behaviour or movements of the great hammerhead, but no work had been done to investigate the effects of feeding and dive tourism on this species. Other studies on the provisioning of sharks indicated that the impacts were site-specific and species-specific, and even that they may have varied from one individual to another. Our research aimed to describe the behaviour of the great hammerheads at the feeding site in Bimini and determine whether the provisioning and the daily dive tourism activities had an impact on how they used the local space. Thanks to our collaboration with local dive operator Neal Watson's Bimini

Scuba Center, we were able to collect data on every commercial dive led by the company.

Because they were not able to distinguish between individual sharks, previous provisioning studies could record neither the amount of bait consumed by each shark, nor how often it returned to feed during each session. Our ability to identify individuals gave us an edge, enabling us to record the number of bait pieces – and hence the weight – taken by each animal. We documented how much bait each shark consumed, how long it spent at a provisioning event, how long before it took the first food reward after arriving at the site, and its reaction to both biotic and abiotic factors.

Additionally, we used passive acoustic telemetry to find out how individual great hammerheads moved around Bimini. Of the nine sharks monitored by means of internal acoustic tags, two have been detected within the BBFSF acoustic receiver array but have not been observed at the dive site. Since our study, like other provisioning research, lacks baseline data on the ecology of the species before tourism activities began – in our case in 2012 – these two sharks provided us with a reasonable control group.

To assess to what extent the sharks responded to the provisioning activities, we established two indices. A provisioning index was calculated as the number of times a shark attended a provisioning event divided by the total number of events it could have attended. The feeding index was the product of an individual's provisioning index multiplied by the average amount of bait it consumed at each event.

During 104 provisioning events held over a period of 94 days we tallied 483 observations of great hammerhead sharks involving 28 individuals. There was remarkable variation in the number of dives the sharks attended. Four females that had been known in Bimini for up to four years before our study were present at more than 50% of the provisioning events. In contrast, recently identified hammerheads attended the events less frequently.

Differences were found in the amount of bait the sharks took each day. Predictably, the length of the provisioning event was a factor, as was the amount of time the sharks were present. It was also determined that individuals were capable of eating a substantial percentage of their body weight. Nemesis, a female well known to us, was reported to have consumed 101 pieces of bait weighing 16 kilograms (35 pounds) during a diving event that lasted nearly four hours. We estimated that she weighed about 200 kilograms (440 pounds), so on this occasion she ate 8% of her body weight.

By looking at the movement patterns of the great hammerheads within the local area, we learnt that they could be affected by the amount of time the sharks spent at provisioning events. The movements of sharks that ate more and spent more time at the provisioning site tended to be more restricted around the site, whereas the core areas of sharks with a lower feeding index were more widely distributed within the environs of Bimini. Our findings suggest that providing food to attract sharks impacts the local movements of individual sharks to a varying degree.

Given what we have learnt about the feeding behaviour and movement patterns of provisioned sharks, our future focus will be on the ecological impacts of provisioning. The effects of predators on the demography of their prey and on interactions within the food web, as described by previous studies, mean that changes in the natural movements of large sharks may have repercussions for animals at lower trophic levels. We will look at the extent to which wildlife tourism activities affect how an ecosystem functions by altering the role of apex predators.

Does the provisioning enable Bimini's great hammerheads to meet their daily energy demands or do they still hunt local prey species? Are we creating a hotspot for great hammerheads where they would normally not spend much time? Does that affect prey species through changes in normal predator–prey relationships? Will the sharks begin to arrive earlier and leave later in future seasons as a response to the provisioning? Could provisioning affect the total amount of time they spend in Bimini and subsequently their annual regional migrations? These are all questions we will try to answer.

INSIDE STORIES

Listen and learn

Words by Janie Wray

INSIDE STORIES

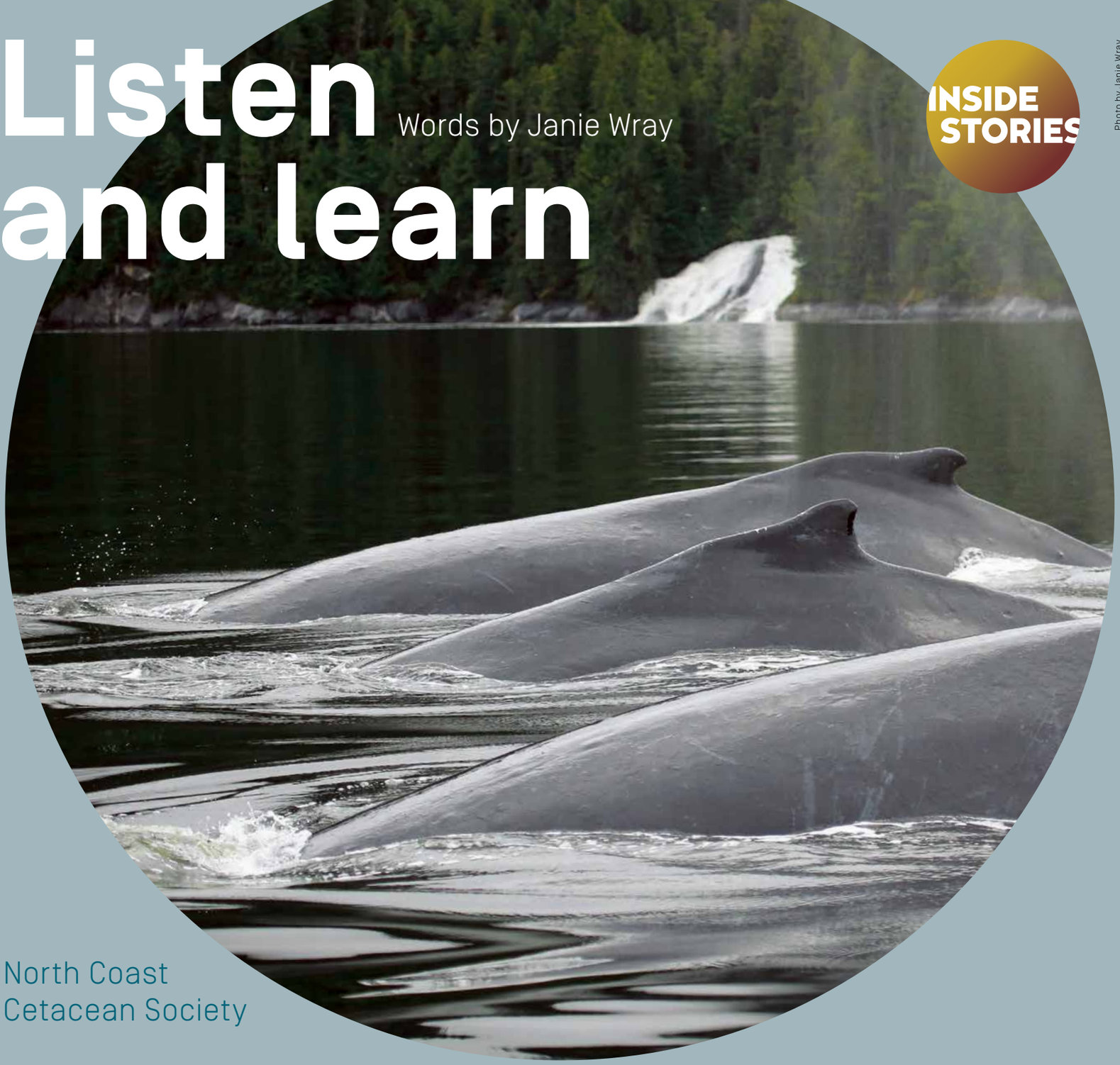


Photo by Janie Wray

North Coast Cetacean Society

Along the coast of British Columbia, sound rather than sight is what researchers rely on to locate and identify the whales they are studying – and what the whales themselves rely on to communicate and find food. But what would happen if tankers carrying liquid natural gas were to ply the same routes as the whales, overlaying with their own noise the sounds that are so important to whales?

It is cold and wet, and at the moment there is no source of heat in this tiny whale research cabin located on Fin Island. The station is still under construction, power comes from a few solar panels and batteries, the outhouse is a bit of walk from the shelter and the walls are still bare. We catch rain water for drinking and washing and at night the sleeping arrangements are very tight.

But the moment you step outside onto the deck, you feel the magic of this place. You're struck by the openness of space, an ocean just metres from your feet, mountain ranges in the background and a sunset that casts over it all a fiery blaze, with oranges and pinks from the depths of your imagination that change constantly and reflect back from the ocean's surface. When the whales make their way into the picture everything comes into focus and we remember why we are here. This station is built for one purpose: to listen to and observe the behaviour of whales so that we can learn how best to protect these precious creatures. A route has been proposed along which tankers carrying liquid natural gas will travel these pristine waterways – and it could destroy this safe haven for

whales. Our team this year is here to start a unique project that will enable us to better understand the underwater world of whales and hopefully encourage others to follow our lead and protect these coastal fjords.

Back in the cabin, we are trying to organise the small space to somehow accommodate three more people, who will be arriving tomorrow to help us install four hydrophone stations. I can only hope they are rugged enough in spirit to deal with this and the fact that the Great Bear Rainforest of British Columbia is living up to its reputation as one of the wettest places on earth. By the end of the day, with the help of Rob and Rosie, two very keen assistants from Australia, we feel that we've done the best we can to make the next 14 days as comfortable as possible.

The next morning, I canoe to our boat and make my way to Hartley Bay to pick up the crew. Tom Dakin is a scientist who works for Ocean Networks Canada and is an expert on how hydrophones function. A hydrophone is the instrument that connects us to the underwater world of whales. Our goal is to set up each hydrophone in at least 80 feet (25 metres) of water close to shore. For this we will need a diver, and an old friend from the south has volunteered to come and help us out. His name is Mike and he is definitely one of those coastal characters who will be talked about for generations; a little grumpy at times, but it's all part of his old-timer charm. Then there is Chenoah, my research assistant for the season, who is truly a gem and can read my mind and knows what needs to be done before I can even speak the words. I pick them up at the ferry and after lots of hugs and hellos, we grab our boxes of food, jump back into the boat and are off to Fin Island.

Our first day as a team involves going to each of the four hydrophone locations by boat to determine line of sight from each one back to Fin Island. Once we've done this, we need to calibrate each hydrophone to ensure we are measuring ocean noise and the source level of whales as effectively as possible. Installing hydrophones is no easy task, especially in such a remote area. You need to find a location suitable for the hydrophone, which is connected to an 80-pound (36-kilogram) cement block, to be secured 60 feet (18 metres) underwater. This needs to be close enough to land to enable us to link the hydrophone to the shore by means of a cable that will follow the intertidal zone and connect to a land-based transmitter that is powered by solar panels and a battery bank.

Setting up the first two hydrophones goes smoothly and we take this as good karma for the rest. We probably shouldn't be so optimistic, as every project has its nadir. Ours comes as we try to install the third hydrophone at Gil Island. In hindsight, we should have attempted this one first as we knew it would be the most difficult. The location is a steep underwater cliff and Mike has to find a small pinnacle on which he can place the cement block with the hydrophone. He finds one, but the block falls off the little shelf. He dives to 100 feet (30 metres) and from there can see the cable as it stretches down into the abyss. Returning to the boat, he explains the situation. We all know the cable will never hold that kind of weight for long. Mike has already done one too many dives for the day, so we tie a float to the line attached to the cable and hydrophone and, with heads hanging low, we go back to the cabin. We can do nothing more until tomorrow, but we know that chances are the hydrophone will be gone by then.

The next day, with renewed energy and a plan, we return to the site. To our astonishment, the float and cable are still there. We set in motion the plan we discussed the night before. With all six of us aboard, my job is to manoeuvre the boat, praying like mad, while the others, very slowly and completely in sync, pull on the 300-foot (90-metre) cable. As the cable comes up, inch by inch, we are expecting it to break at any moment. When Mike suddenly screams, 'I can see the hydrophone,' the energy on the boat switches from fear to absolute shock. None of us really thought this plan would work. Once the block of cement and hydrophone, completely undamaged, are back in the boat, I realise I'm holding back tears. Not just because we've rescued the hydrophone, but because of the deep appreciation I feel for every person on the boat – and they're all grinning madly!

Learning from our mistakes, we work out a new plan and this time the deployment of the hydrophone goes smoothly. Now that everything is set up, it's time to return to Fin Island and turn the system on. Via the computer, we connect each hydrophone to a transmitting radio using a software program called Lucy. When a small box turns green, we know the hydrophone has been detected by the radio and is transmitting to our station. The first green light comes on: it's Fin Island, then Gil island, next Otter Pass. When the last light, for Campania, turns green we sit in silence and listen as the sounds beneath the sea fill every molecule of space within the station.

Now we're ready to collect data and start answering important questions about how to protect this habitat for whales. The daily routine starts at 6 am, when the first shift goes on deck and begins scanning with a pair of Big Eyes, massive binoculars placed on a tripod. We scan this vast ocean every hour on the hour until 10 pm. All whale and marine vessel sightings are entered into an app on our tablet to be analysed in a statistics program called R. In conjunction with this, we listen to the hydrophones and make a note every time a whale vocalises.

Having been listening to the calls of whales for over 20 years, I have developed the ability to identify orca pods by family, as each has its own language and dialect; and humpback whales by their bubble-net feeding calls and their long, beautiful songs that echo through the fjords all night. We will combine these acoustic results from beneath the sea with the behaviour we see of whales when they come to the surface. The hydrophones will also supply a whole new dimension to our work as they have been placed in such a way as to pinpoint the exact location of a whale. As whales continue to vocalise and travel, their calls are producing underwater acoustic trails for us to follow. We will layer these acoustic trails from three whale species – orca, humpback and fin – and compare them to boat traffic already known, as well to the proposed route for the tankers.

From the deck of the Fin Island whale research station our data suggest that if these tankers go through, it will not be a matter of whether a whale will be hit, but how many. We have seen up to 34 humpbacks and 11 fin whales within just one 20-minute scan, spread out as far as the eye can see as they forage. There is an urgency to understand how these whales will react to an increase in ambient noise and how it will affect not only how they locate food, but also how they communicate with one another. Listening is essential for both activities and at the moment this area is one of the quietest underwater sections along the entire coast of British Columbia – which is possibly why they return in such high numbers. As I stand and look to the south, I see blows in all directions and hear the calls of whales echoing through the shelter – and I understand that this vast area of green forests and vivid intertidal zones, surrounded by an ocean that is the home of orca, humpback and fin whales, is no place for tankers. Now we have to prove it.

A white shark skirts the edge of a shoal of fish off the coast of Massachusetts.

What's in a

Shark Research Center
Words by Mahmood Shivji

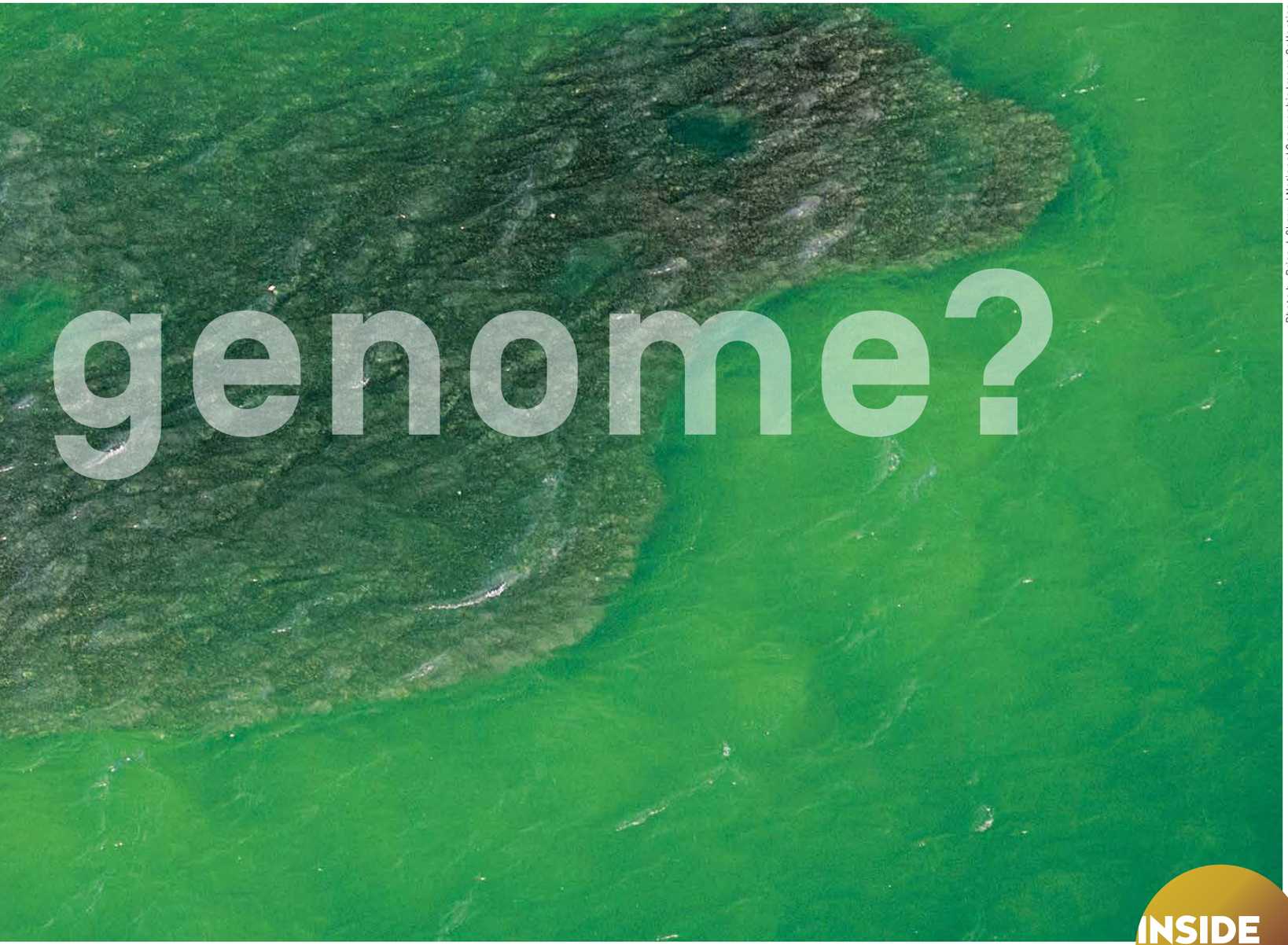
It's been a busy year for the Shark Research Center, with the publication of several key papers that point to the complex and highly tuned functioning of sharks. Among these is a study indicating that the fully sequenced white shark genome is much larger than our human genome. It also shows some interesting results of potential biomedical value.

As part of the Shark Research Center's ongoing work in the field of comparative genomics of sharks, the complete set of white shark *Carcharodon carcharias* genes – known as the genome – have been sequenced and the findings were published in the journal *Proceedings of the National Academy of Sciences*. The research paper, titled 'White shark genome reveals ancient elasmobranch adaptations associated with wound healing and the maintenance of genome stability', gives new insights into why sharks are so well adapted to their environment, why they are able to heal quickly from wounds and why they seem to suffer less than humans do from age-related diseases and cancers. The paper's lead author, Nicholas Marra, worked with a host of co-authors to look at how the white shark has been adapted right from the molecular level of its DNA to its ocean environment. This work forms part of a much bigger body of research that we are still conducting – and a busy year it appears lined up to be!

Our current focus lies in three areas. Firstly, we're interested in the conservation genetics of sharks, which involves identifying genetically unique elasmobranch populations and understanding their dynamics, deciphering elasmobranch breeding behaviour and developing genetic tools to investigate the trade in shark body parts. All this research contributes to how we better manage dwindling or threatened shark populations, using a host of genetic tools as a way to add to the current arsenal of scientific methods.

Secondly, we are investigating comparative genomics, which involves studying how elasmobranchs function at their most fundamental biological level; that is, their whole genomes, especially with regard to the genetic basis of their ability to heal from wounds efficiently and their apparent higher resistance to cancers. The white shark study formed part of this line of investigation. Lastly, we're looking into the movement ecology of sharks, which is the study of shark migration patterns and their interaction with commercial fishing.

Follow-up genomics research for this year includes digging deeper into the genome sequences of the white shark to gain more insight into its population trends, as well as advancing our work



genome?

Photo by Brian J. Skerry | National Geographic Image Collection

INSIDE STORIES

on assembling and characterising the genome of the endangered great hammerhead shark. This research is an extension of the previous work we did on sequencing a subset of white and great hammerhead shark genomes; that is, the transcriptomes, which represent only the sequences of the shark genes that are expressed.

The publication of the white shark's entire collection of genes is interesting to us at the SOSF Shark Research Center for several notable features in white shark biology that are particularly illuminating and were revealed by sequencing the species' entire genome. Given the word limits for scientific journals, when it came to writing our paper we focused on reporting three unexpected, but major findings.

Firstly, the white shark genome is large – 1.5 times the size of the human genome, in fact! We believe this is, in part, the result of a high proportion of a particular type of DNA sequence motif known as LINEs. These LINEs (also known as 'jumping genes') are prone to making copies of themselves and then inserting the copies in various places around the genome, which requires first breaking the DNA at the insertion site. Although such breaks are fixed, mistakes do occur in the fixing process, resulting in the genome becoming unstable. This genome instability is well known to cause diseases (such as cancers) in vertebrates (including humans), which have been well studied at the genome level. The finding of such a high proportion of LINEs in the white shark raises the question, did their genomes have a higher susceptibility to becoming unstable?

Our second major finding is related to this genome instability issue and is also unexpected but quite interesting. The white shark has a large number of genes involved in the maintenance of genome stability that have undergone a type of natural selection known as 'positive selection'. This selection can be thought of as changes in the gene sequence that confer biological advantages. Notably, many of these positively selected genes are involved in repairing sequence mistakes in the DNA and suppressing tumour formation. This finding suggests that the white shark has evolved superior genetic abilities to keep its genomes stable, despite the fact that it has such a large proportion of LINEs.

Finally, the third novel finding we focused on was that several genes known to play key roles in vertebrate wound healing pathways have also undergone positive selection. This finding fits in nicely with the well-known observation that sharks can heal from wounds quite quickly. The positive selection in wound-healing genes could explain the genetic basis underlying the efficient wound healing observed in sharks.

Sharks in general represent an ancient vertebrate lineage. Their evolutionary success probably stems from having acquired key adaptations to their environment, including the ones we found by decoding the white shark genome and analysing the whale shark genome. We have just scratched the surface when it comes to discovering how finely tuned sharks are to their complex, three-dimensional environments. I'm sure we will discover many more novel adaptations as we dig further into the genome and specific genes and their functions. These findings highlight what evolutionary marvels sharks are and provide yet another compelling and urgent reason to conserve these animals before we lose them to overfishing.

North Coast Cetacean Society
Words by Janie Wray

Where are all the whales?

As summer draws to a close along the British Columbia coast, Janie Wray sets off on probably her final humpback survey of the season. Wondering whether she'll see any of the whales at all, she discovers that the best has been kept for last.

The days were getting shorter and colder and I knew that winter would soon be closing in. The next day could well be the last whale survey of the season and I would need to make every moment count. I spent the evening organising my camera equipment, the proper gear for the long boat ride, my notebooks and enough food and coffee to last the full day. The next morning I was up and ready to leave before the sun had risen over the mountains to the east. Today my research companion would be Cohen, the best whale-detecting dog ever! This was the first time in more than two weeks that my feet had left the island and the feeling of freedom was intense as I put the boat in gear and was on my way.

After three stops and a travel time of two hours, I hadn't seen a single blow and was beginning to get worried. I turned from Whale Channel into McKay Reach, hoping my luck would change. Slowly I continued, maintaining the same technique of stopping, scanning and listening for whales. By the time I reached Bishop Bay my level of concern had risen dramatically. Where had all the whales gone? I travelled deep into the end of the bay and turned off the engine. Even with no whales, this place is the true inspiration for 'sound of silence – my old friend'. Giant old-growth trees, reflected on the still, emerald sea and with moss dripping from their thick branches, took the breath from my body. When I heard the blow of a humpback, then another, I wondered if I had fallen asleep and was now dreaming. It was all just too perfect to absorb. I hesitated to start the engine, believing that the sound would break this moment. So I sat and waited.

My patience that day was rewarded: a mother, her calf and two adult humpbacks formed a line and glided towards the boat, so relaxed as they passed us it was as if we weren't even there. Then to my delight the little calf turned back towards the boat and did a complete roll just a few feet away, stopping halfway and making serious eye contact. My heart and jaw hung over the side of the boat, as did Cohen's, which is what may have aroused the calf's curiosity. The water at this time of the year is so clear I could easily make out specific markings on this unusual creature's face. Then just as quickly, and with a swift flick of its tail, it was back at its mother's side.

The sound of a huge inhalation caught my attention. This signalled that at least one whale in this group was about to take a long dive, which increased my chances of getting an identification photo of the fluke. I really wanted to know who this mother was! One after the other, each whale arched its majestic back and then gracefully raised its tail high into the air, just long enough for me to take a photograph. Finally, it was the mother's turn. Effortlessly she too arched her back and then the moment of truth was revealed, as her black fluke slid through the water and they were gone. Her tail was completely black, not a speck of white. Who could this be? I immediately checked our photo database and can honestly say that tears followed shortly afterwards when I realised that this was Velvet. The outline of her fluke has a small dimple and her tail is the colour of midnight black. We have been watching this whale for years, wondering whether it was male or female. Now, with a calf by her side, we knew for sure. I sat alone in the boat and sighed, feeling so proud for a whale that did not even know my name.

It was then that I noticed there was a fifth whale, fast sleep, floating on the calm surface. Had it not taken a breath, I would have never have been aware of its presence. I dared not motor over and

Photo by Janie Wray

disturb this sleeping wonder, so instead I followed the four whales as they playfully travelled back towards the entrance to Ursula Channel. They slowed down considerably and, much to the small calf's dismay, went to sleep. The mother was completely relaxed, but her calf danced around at her side, obviously not at all ready for a nap. The other two whales were also next to one another, but a good 300 metres (1,000 feet) away from the mother. I decided to go back and see if by chance the lone sleepy whale had woken up. I didn't have to travel far. To my surprise, not only was this whale awake, it had followed my boat and, more probably, the group of whales out of the bay. It suddenly fluked and I was grateful my camera was already in position. In less than a second I had a perfect photograph.

By now it was mid-afternoon and time for me to continue the survey, as in only three hours' time I would have to race home before night fell. My departure would have to be slow amid all these sleeping giants. There was a bit of wind picking up, but nothing too serious. The sun was still shining and it was actually warmer than I had anticipated. I turned into Verney Passage and hoped I would see another blow soon. Once again I followed the stop, look, listen procedure. After 45 minutes I feared there would be no more whales.

Then, directly in the sun's glare, the most beautiful sight ever for a cetacean nut like me: blows! Big, beautiful, explosive blows. It was a feeding group for sure, but they weren't bubble-net feeding. Though they all dived together and surfaced together, there were no calls and no bubbles. I assumed they were feeding at depth on krill. I tried to collect samples when they surfaced, but there was nothing in the water to indicate their prey type. Instead I focused on identification pictures and soon realised there were four groups of at least 30 humpback whales in total. There was the constant sound of blows as one group would dive to feed and the other group would surface to breathe.

What I found most interesting was that two whales, both female, would switch from one group to another. I wondered why, and if perhaps this behaviour was a more complex interaction than just feeding. Then something I had never witnessed before occurred. All the groups surfaced at the same time and, moving slowly towards one another, one by one they positioned themselves beside the next whale to form one giant resting line. There they stayed, breathing as one, floating on the surface. I felt as though I were watching an ancient feast and dance of a culture lost long ago. The peace was broken as one whale let out a tonal blow that echoed throughout the channel. This ended the trance and the whales once again broke off into their tight social groups and went back to feeding.

I knew it was time to depart as I was over an hour away from the lab and it would soon be dark. Deep in my heart I sensed that this would be the last survey of the season. Just as I was about to start the engine, a group of four whales surfaced 100 metres (330 feet) from the boat and then, as one, they turned and headed straight towards me. Is it possible that they also knew this may well be the last time we would encounter each other until the next season? I will never know, but in that moment it did not matter. I experienced a deep inhalation as these colossal bodies of pure intelligence disappeared one after the other beside me while I stood motionless, arms at my side, in complete gratitude for this day.

Young Vezo girls fish in the shallows of Morondava, Madagascar. Blue Ventures has worked extensively on this island for years, where local communities remain closely linked to coastal livelihoods.

In conversation with Alasdair Harris

The real moment that draws us to conservation, says Alasdair Harris, is one of empathy and recognition that this is as much a story about people's survival, identity and future as it is about the conservation of the natural world and biodiversity. Lauren De Vos chatted to the founder of the award-winning social enterprise Blue Ventures about what we're still getting wrong when it comes to empowering communities in conservation – and what might be worth thinking about to get things right.

There is much talk about community-based natural resource management, with many different definitions. What is your particular take on the idea?

At its core, community conservation means conservation by and for communities – protecting nature in ways that benefit local people in a meaningful way. This could be through enhanced livelihoods or improved community governance. And if the goal of community conservation is for nature to be managed by communities, ultimately the involvement of external actors and organisations should be decreasing over time. Our goal should be a journey towards community empowerment in which local leadership is paramount. And herein lies the paradox: as conservationists supporting community conservation, our ultimate objective should be to work ourselves out of a job. In the end, if we're not handing over to community leaders so that they can continue the work we've supported, we haven't succeeded.

Leading on from that question, what has been your approach to the concept of community-based conservation?

Across our programmes we're increasingly seeing the value of empowering communities with the training, services and human rights they need to take action to safeguard natural resources. But that's easier said than done and in many contexts this is a journey that realistically will take decades rather than years, with substantial ongoing costs. So we must be wary not to oversell community-based conservation as a solution that will work for people or nature in the short term. While that's of course our goal, and there is rightly encouraging enthusiasm and momentum around the movement today, evidence of the biodiversity benefits is often harder to come by, and we mustn't underestimate the costs. It's imperative therefore that we share what we're discovering about the benefits and pitfalls as we learn, and the conservation connection. For example, while there's growing evidence that local marine management can improve fisheries' productivity and incomes, evidence of actual conservation impact remains scarce. And while alternative livelihoods are often hardwired into project design, the arrival of new incomes – although undoubtedly beneficial to families and communities – might not necessarily bring about any actual change in fishing, or deforestation. But it is clear that by addressing local needs and rights first, this approach is transformative in communities at the centre of environmental protection, which is ultimately a fundamental prerequisite to any lasting conservation outcome.

Photo by Cristina Mittermeier - Minden Pictures - © National Geographic Image Collection

How do you find an entry point where you approach communities as an organisation to gain initial traction, remaining respectful of local knowledge and without foisting foreign ideas and ideals onto a situation?

Blue Ventures started out as an ecotourism social enterprise and that underlying business remains central to our work in several countries. We take people on long-term educational diving expeditions. Whether in Belize or Timor-Leste, these trips provide local employment, and by introducing dive tourism they can demonstrate a new economic value in an ecosystem that may previously have been undervalued. Crucially, our business also gives us the opportunity to get to know a community because we're there for the long haul, living and working within and alongside a village. Working this way conveys a degree of access and legitimacy that can be instrumental in starting conversations about what matters to that community, whether it's meeting unmet demands for essential services like healthcare or education or whether it's getting a better understanding of the nuances of a particular fishery, or of the trade-offs that the community might face when we start talking about conservation. The relationships that we've developed with communities take many years to build, but are based on a concerted emphasis on listening and understanding rather than proposing predesigned 'solutions' from the outside. These relationships would not have been possible had it not been for the presence and permanence afforded us by our social enterprise. Being present and invested as well as staying the course are critical for any organisation thinking of supporting 'community conservation'.

Focusing on this requirement for proximity and permanence with communities has been central to the design of our own strategy for scale. We're working to scale up our impact without growing our own organisation – recognising that with growth we inevitably become less proximate to the communities we need to serve, and ultimately less effective. So we're focusing our resources on sharing our experiences and supporting local organisations whose values are aligned with our own. Today we're providing support to dozens of community-based organisations that have that strong community presence and trust. Our role is purely supportive and facilitating, and increasingly we find that we're learning from them, following their leadership when it comes to community engagement and collaboration.

What, in your experience, drives the pre-determined approach to community-based conservation that is problematic? How is it that few projects employ this commitment to presence and permanence?

Sadly, many prevalent funding models, particularly those for institutional donors and development agencies, present barriers to effective conservation and often act as an impediment to good practice. There are several key issues with how funding is structured and disbursed that perpetuate a highly dysfunctional funding system. Funds often need to be spent quickly and accounted for in a very onerous way, following strict budgeting rules that rarely allow for adaptive management. Arcane and bureaucratic demands are piled on grantees, many of which are only really realistic for large, heavily resourced contractors who invest in administrative teams strong enough to handle the paperwork, but who are – by their very design – likely to be largely absent from the communities they purportedly serve. Administrative requirements for proficiency in English or international accountancy qualifications inevitably preclude many local groups from accessing the resources needed to deliver conservation work on the ground. The irony is that it is those very groups – communities, community-based organisations, local NGOs – who are best placed to get the work done well, to understand the complexities and nuances of sites, to empower communities and to deliver value for money. And a requirement to spend ludicrous sums of money quickly, and often inappropriately, on projects that have been poorly designed by ill-informed outsiders can erode the goodwill and trust of the communities on whose buy-in effective conservation work depends. While the donor's initial vision might have been laudable, the manner in which funding is allocated and delivered often ultimately causes far more harm than good to the intended goal of biodiversity conservation, sowing discord rather than community engagement. This is a lamentable feature of our sector that we rarely discuss, but it's one that we must overcome.

What would be the best way forward, given your concerns?

Ultimately, community conservation requires small amounts of money disbursed in perpetuity and in ways that respond to community needs. Rather than spending huge levels of funding in short bursts, which remains the current trend, a similar amount of money could be invested and the interest generated could be used to support local efforts on the ground in perpetuity. I'm often baffled that I've never met a funder interested in investing in a trust fund, yet that's the one thing I would do if it were my money.

There is an increasing understanding that much of conservation and science lacks true representation and inclusivity. Has this been your experience? And if so, why do you believe this is the case?

As long as the barriers to working in the conservation sector are financial and technical, it will always be a challenge to democratise conservation and make it more inclusive. When a ticket to a conference costs several months' salary and requires months of preparation of paperwork for visas, flights and accommodation, will a graduate from Papua New Guinea ever make it to Cambridge to have their voice heard? It's harder still for a community member working on the ground who might not speak English or French, or the rarefied language of science that can be so intimidating to self-expression.

We need to massively increase the resources we're allocating to training conservationists and practitioners from low-income countries. This would provide some of the technical support and qualifications for a more representative pool of conservationists to access these forums and have their perspectives heard, while also providing role models for a new generation of conservationists from the global south.

As we continue to accelerate into this mass extinction nightmare, each and every one of us needs to challenge ourselves every day – is what I am doing having an impact on this planetary emergency?

This may mean that we need to reclaim conservation from the ivory tower of academia. Of course conservation requires science to measure, inform and improve its impact and effectiveness, and ours must always remain an evidence-based movement. But more resources are urgently needed to get the scientific information off the page and into the hands of practitioners. Decolonising science and conservation means ensuring the process of disseminating knowledge focuses on making it available to those to whom it is most valuable – typically communities and local practitioners. This means investing in translations and accessible resources. Toolkits and guides will often have more beneficial impact than a paper in *Nature*. This might not appeal to the purveyors of peer-reviewed science, but ultimately it's more likely to deliver meaningful impact on the ground. And science is not where conservation practice ends. We must prioritise support for practical community actions at a local level and in the long term.

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*

Editor-in-chief
Michael Scholl

Ocean View
Lauren De Vos

Sub-editor &
proofreader
Leni Martin

Additional writing
Lauren De Vos

Additional editing
and proofreading
Nadia Bruyndonckx

Design & art direction
Peter Scholl
scholldesign.com

Published by the
Save Our Seas Foundation
Rue Philippe-Plantamour 20
CH-1201 Geneva | Switzerland
saveourseas.com

Reproduction and
Printing by Polygravia
Arts Graphiques SA
Route de Pra de Plan 18
1618 Châtel-St-Denis
Switzerland | *polygravia.ch*

ISSN (Print) 2296-8199
ISSN (Online) 2296-8202

ISSN (Print) 978-2-9701221-9-7
ISSN (Online) 978-2-9701223-9-5

MIX
Paper from
responsible sources
FSC® C011249
www.fsc.org

myclimate
neutral
Printed Matter | 01-19-936916
myclimate.org

save our seas
foundation

save our seas
foundation

WWW.SAVEOURSEAS.COM | WWW.SAVEOURSEASMAGAZINE.COM