Navigating Our Way to Solutions in Marine Conservation

Edited by Larry B. Crowder

NAVIGATING OUR WAY TO SOLUTIONS IN MARINE CONSERVATION

Navigating Our Way to Solutions in Marine Conservation

Edited by Larry B. Crowder
Assistant editor: Catherine Lee Hing

OpenBook Publishers

https://www.openbookpublishers.com/

All external links were active at the time of publication unless otherwise stated and have been archived via the Internet Archive Wayback Machine at https://archive.org/web

Digital material and resources associated with this volume are available at https://doi.org/10.11647/OBP.0395#resources

ISBN Paperback: 978-1-80511-254-9
ISBN Hardback: 978-1-80511-255-6
ISBN Digital (PDF): 978-1-80511-256-3
ISBN Digital eBook (EPUB): 978-1-80511-257-0
ISBN HTML: 978-1-80511-259-4

DOI: 10.11647/OBP.0395

Funders: Oak Foundation, Gordon and Betty Moore Foundation, Munson Foundation, Ocean Foundation
Cooperator: Pew Fellows, Global Fellows in Marine Conservation

Cover image by Kelly H Dunn based on a photo of Hōkūle'a — Polynesian Voyaging Society, https://www.hokulea.com/

Cover design: Jeevanjot Kaur Nagpal

Contents

Acknowledgements

Larry B. Crowder

I begin with sincerest thanks to my wife, Judy, who has supported, inspired, and challenged me for over 50 years. She has regularly sacrificed to make my career possible, and she has reflected on my ideas and helped refine them toward my best achievements. Judy is a writer and has always pressed me hard to communicate my science clearly and effectively to a wide variety of people. My children Emily, Sean, and Elias, spent their childhoods in the field, swimming while I built experimental enclosures, and 'saving the fish' by returning them to the experimental salt pond from which we were trying to collect them at the end of an experiment. The whole family spent several Christmas breaks taking care of hundreds of hatchling sea turtles at Duke University Marine Laboratories while students and technicians took a well-deserved break.

Key mentors and colleagues remain in our heads, and in our hearts, decades beyond first contact. Mine include Richard Haas, Bert Tribbey, Bill Cooper, John Magnuson, and Jim Kitchell from my university days. Elliott Norse, Steve Roady, Dan Rubenstein, Andy Read, Pat Halpin, Xavier Basurto, Mike Orbach, Ram Myers, Callum Roberts, Josh Cinner, Kai Lee, Meg Caldwell, and Kristina Gjerde fostered my transition from biologist to interdisciplinary problem solver. I have been a Professor for over 40 years and have interacted with thousands of undergraduate students, hundreds of Masters and PhD students, hundreds of international students including the Global Fellows in Marine Conservation, and dozens of postdoctoral researchers; EXCELLENT all! I can't tell you how much I learned from them! This transition toward interdisciplinary marine conservation aligned with my move to the Duke Nicholas School of the Environment in 1995 and was accelerated by my move to Stanford University in 2011, into what is now the Stanford Doerr School of Sustainability. It was at Duke that I started the first course in Marine Conservation Biology in 1997, the Global Fellows Program in 1998, and the Center for Marine Conservation in 2005. At Stanford, I had the privilege to co-direct the Center for Ocean Solutions for seven years. What audacity? Actually leading a center focused in solutions and not just endless research. The personal story of navigating my way to solutions in marine conservation is available on a podcast from 2019 by Michael Cox: https://www.incommonpodcast.org/podcast/012-ecology-marine-conservation-and-interdisciplinarity-with-larry-crowder/

I have had the extraordinary opportunity to engage in interdisciplinary and international research, teaching, and mentoring; these experiences taught me most of the lessons presented in this book. Since the *Marine Conservation Biology* (2005) book, major funders have included, the Gordon and Betty Moore Foundation, Lenfest Ocean Program, Oak Foundation, Packard Foundation, Rockefeller Foundation, and Sloan Foundation. Government agencies have also provided research support including DOD, EPA, European Commission, NASA, NOAA, NSERC and NSF. University support came from the Duke Provost's Strategic Initiative, the Stanford Woods Institute for the Environment, and the Stanford Center for Ocean Solutions. I have also been supported by the National Center for Ecological Analysis and Synthesis, Conservation International, and National Geographic Society.

I thank all the authors of chapters in this book, who rose up during the global COVID pandemic and provided what I think is an exemplary chorus of voices pointing toward pathways to solutions for wicked problems in marine conservation. I thank my publisher, Open Book Publishers, whose model for publishing open access will make these voices available to scholars, practitioners, and students worldwide. Catherine Lee Hing brilliantly stepped in over the last two years to help me finalize the manuscript, soothe the restless authors, and enhance interactions with the publisher. Many colleagues served as reviewers of the chapter manuscripts including David Ainley, Hannah Blondin, Dana Briscoe, Larry Crowder, Denley Delaney, Asha de Vos, Sibyl Diver, Safari Fang, Elena Finkbeiner, Tim Frawley, Kristen Green, Keiko Kaholoa'a, Catherine Lee Hing, Will Oestreich, Mike Orbach, Catarina Santos, Rebecca Selden, Krista Sherman, Haley Solis, and Taylor Souza. Special thanks to Kelly Dunn, who provided the inspirational cover art for *Navigating Our Way to Solutions in Marine Conservation*.

Over twenty years ago, I wrote (Norse and Crowder 2005):

> Today's students and postdoctoral associates are the first generation of marine conservationists, and it is for them that this book has been written and edited. I hope they enjoy it and find it useful. In a field evolving as rapidly as marine conservation, a textbook is a moving target. Still, I hope the foundational effort of the authors and editors set the stage for continued exciting developments in research, education, and policy in marine conservation.

This new book provides substantially more diverse voices and perspectives on navigating toward ocean solutions. It will also serve a broader audience of scholars, practitioners, and students across the place we call Planet Ocean. Because it is an eBook, it can generate conversations online among the authors and readers. And it doesn't have to get stale; this book can be curated and kept up to date by revisions and new editions (possibly at 3-5 year intervals). I hope it provides the inspiration, networking, and capacity building for a groundswell of interdisciplinary and international effort to promote the sustainability of the global ocean and the people who depend upon it, which quite frankly is all of us!!

Larry B. Crowder
Pacific Grove, California

Foreword

Kai N. Lee

Consider our horizons. Standing in a dinghy in a calm sea, one can look out about 5 kilometers. Slip over the side, and one swims in the photic zone, which extends down as much as 200 meters. Here, 90% of the life in the ocean lives; a free-swimming human can traverse some of this zone. Our horizon is a small disk on the ocean, an ocean that covers more than two-thirds of our planet. Though our wide-ranging species has fished and made observations in many seas and reefs over the centuries, until recently, our knowledge of marine life was limited.

This book is a report from beyond our horizons: a space the French explorer Jacques-Yves Cousteau called *The Silent World*, punctuated by the bubbling of the SCUBA apparatus that he invented in the middle of the 20th century. With exploration comes science, powered increasingly by technologies invented during and after the Second World War. Then, by the turn of this century, an environmental awareness emerged: a realization that mere humans, with our myopic horizons and mighty technologies, were changing marine ecosystems dramatically. The result is a global concern for marine conservation. That is what is described in this volume by an impressive array of today's explorers.

In the pages that follow, the reader finds a diversity of views, mostly anchored in marine science, including, importantly, analytical perspectives from the social sciences. First, a wide span of geographies are discussed, from the Antarctic to the tropics, with a corresponding range of social and ecological circumstances. The authors represent different generations, not only in their ages, but also in how they make their contributions to a rapidly evolving marine conservation – from a focus on charismatic species, to efforts to respond to major pressures on ecosystems including climate change, to wrestling with the challenge of rebuilding sustainable socio-ecological relationships. They also engage with the vexing issues of diversity and equity, which have shadowed the mostly male, mostly white fields of marine science, where the costs of observation have been borne largely by rich countries. In this volume young writers from diverse underrepresented populations are represented to an unusual and commendable degree. Most of the authors have worked with the editor, Larry Crowder, whose research, teaching and mentoring over the past generation have shaped the emergence of marine conservation as a field, both in its intellectual content and the directions in which action has been taken.

Marine conservation has been stimulated by concerns articulated by academic scientists. The burdens of activism and change have been taken up by civil society, some businesses, philanthropies and, haltingly, governments. The concerns reflect the extraordinary fact that humans are measurably interfering with the natural processes of the planet's largest habitat:

- Fishing, an ancient activity, and the largest remaining part of the hunting and gathering economy, routinely reaches or breaches the limits of natural populations. Catches have been level for a generation, and growth in seafood production has been almost entirely in aquaculture.
- Climate change, including changes in chemistry as carbon dioxide increases the acidity of seawater, brings changes in weather, temperature, and the balance of the ocean-atmosphere system. Terrestrials see drought, flood, and storms, but we are less aware of disruptive changes offshore.

- The decline of valuable species, including those prized when caught and those prized when we can visit them at the surface or within diving range, has spurred actions to salvage what is left. Marine protected areas have been declared near every continent, mainly to constrain fishing; these are top-down solutions administered, sometimes indifferently, by governments. Local, bottom-up efforts to declare community rights have taken root – asserting and reasserting governance grounded in traditional knowledge and the realization that place and history matter in the management of resources.
- Still, sweeping changes in the ocean imperil small-scale fisheries, most of them poor, along the coasts. The vast majority of livelihoods dependent on the sea are to be found in these communities. In this way marine conservation intersects with the challenges of development and the improvement of human wellbeing.
- A host of industrial pollutants, including plastics and the residues of oil and gas production and use, have become the focus of what might be called charismatic disasters – oil spills, seabirds strangled by beer-can packaging rings, vast mid-ocean gyres of tiny plastic fragments, and climate change driven by the burning of fossil fuels.
- Underneath all is the reality that the seas are commons, where the interests of actors often do not align with the needs of their communities and ecosystems. In a commons there is no property: what belongs to everyone is no one's responsibility. Garrett Hardin, an ecologist, famously wrote, 'Freedom in a commons brings ruin to all.' That is to say, collective action is essential, in order to channel behavior along constructive paths. A central puzzle of marine conservation is accordingly to strengthen, build, and maintain a range of institutions – from political bodies and administrative agencies to community governance, traditions and values – that can breathe life into rules, enforce them, and sustain responsibility. These institutions are frail or absent in many places, undermining marine conservation and much else.

In the middle of the 19th century, Herman Melville looked northward toward Mount Greylock in Massachusetts, where he could see a looming mass, the outline of a whale. 'The moot point is,' Melville wrote in *Moby-Dick*, 'whether Leviathan can long endure so wide a chase, and so remorseless a havoc; whether he must not at last be exterminated from the waters.' The leviathan that is the oceans has endured much havoc over the generations since. Yet marine conservation is now on a rising trajectory. As one of the authors here writes, 'The tide is turning, but we have a long way to go.' There is navigational advice for the journey ahead in this volume.

Kai N. Lee
Owl of Minerva LLC
Indianapolis

Navigating our way to solutions in marine conservation: An introduction

Larry B. Crowder[1]

It's been nearly 20 years since Elliott Norse and I edited the first book dedicated to Marine Conservation (Norse and Crowder 2005). Elliott envisioned this book and invited most of the authors beginning in the early 2000s, recruiting me to assist in 2003, when I also became a member of the MCBI Board of Directors. At that time, there was increasing concern among scientists and activists about the loss of marine biodiversity. Marine Conservation Biology Institute held the first *Symposium in Marine Conservation Biology* in 1997 (the same year I initiated the Marine Conservation Biology course at Duke) and *The Second Symposium in Marine Conservation Biology* in 2001. As the title of this book suggests, the focus was on science, including a focus on marine populations, and threats to marine biological diversity (with a special emphasis on the impacts of commercial fisheries). The book also emphasized the science behind the emerging place-based approaches to managing marine ecosystems, including marine protected areas and ocean zoning. Human dimension issues, including legal approaches, engaging human communities in local conservation, and addressing governance and integrative management approaches, brought the book to a close.

Looking back at the voices represented in this inaugural book, that celebrates the importance of biological diversity, it appears we failed to represent the diversity of human perspectives. Lead authors were 96% white, 76% male, and 88% academic. All lead authors were North American or European. Science-based chapters accounted for 80% of the offerings. Social science, law, governance, and other human dimensions topics came last in the book, which may appear to the reader to be an afterthought, even though that was not the case. Instead, it appears to be a reflection of the thinking within our community at the time. Refreshingly, we have since progressed and recognize the need for more diversity in thought and inclusivity in contributions. If we consider all the chapter authors, the diversity of people and perspectives is somewhat broader. But critical voices and insights were missing. Furthermore, while the *Marine Conservation Biology* book provided all the ingredients for a 21st century approach to problem solving in conservation, we have now learned better how to stitch these insights together (Crowder 2025, Chapter 24).

I am struck by how much the field of Marine Conservation has changed. The early approach reflected in the 2005 book, was focused on the scientific and primarily biological basis for protection against the loss of marine biological diversity, from individual species to marine ecosystems, and on reducing impacts of human activities such as commercial fishing, which was then considered the number one threat to marine biological diversity. At the ecosystem level, the major innovations were marine protected areas (and often totally protected marine reserves) and ocean zoning. These approaches sought to eliminate (or substantially reduce) the impact of

1 Hopkins Marine Station, Stanford University, https://orcid.org/0000-0003-3131-2579.

 https://doi.org/10.11647/OBP.0395.00

human activities, including fishing, on marine ecosystems. The underlying theme was that human activities cause extreme harm to marine biodiversity, and to protect the structure and function of marine ecosystems and to fix these degraded systems, one must eliminate people (or at least their most harmful effects) from these systems (Soule 2005).

Marine conservation has moved beyond approaches that are purely science-driven. Insights from rigorous scientific research are necessary, but not sufficient, for solving marine conservation challenges in the real world. The emerging approach requires the integration of natural sciences and engineering, with social sciences and governance to design pathways to solutions. Ostrom's (1990) seminal work on governance and rights-based solutions to the tragedy of the commons jumpstarted this integrative thinking regarding social-ecological systems, initially at the local to regional scale. Success also often involves partnerships among researchers, practitioners, and local communities. Designing solutions for marine conservation beyond the local scale requires a deliberate focus on a trans-disciplinary and multi-cultural approach (Crowder 2025, Chapter 24).

Navigating Our Way to Solutions in Marine Conservation was designed to reflect the broader insights and diverse voices that are now revolutionizing marine conservation. I sought chapter authors who were scholars and practitioners, who worked in governance as well as social and natural sciences. I sought authors who reflected a broader global experience and who represented a more diverse perspective than we included in Norse and Crowder (2005). 65% of our lead authors reflect the wide variety of races and cultures (Hispanic, Asian, Black and Indigenous); 35% are white. Male authors account for 46% of the total; academics account for half of the lead authors. Practitioners and people working in NGOs and governments account for 50% of authors. Half of the lead authors are from the US; the other half represent a variety of countries and cultures (Argentina, Barbados, Bahamas, Canada, Chile, China, Cuba, India, Malaysia, Mexico, Portugal, and Sri Lanka). Nearly all the authors fully integrate natural science, social science, and governance in their chapters. Beyond interdisciplinary and international, the emerging focus is trans-disciplinary and multi-cultural. Most of the case studies involve human communities with their biophysical environment in determining pathways to solutions.

University faculty have traditionally pursued basic research focused on advancement of knowledge over applied research aimed at immediate applications. The former is based on acquiring a deep understanding of the mechanisms underlying the dynamics of the system under study. By contrast, applied research is often focused on solving immediate problems or needs, even if the underlying dynamics are not well understood. In academia, the terms basic and applied have begun to fall out of vogue. My colleagues often refer instead to fundamental vs. translational research; the subtext is that fundamental research is preferred, and if that fundamental knowledge has an application, it can be simply translated for designing solutions. Now, researchers have an increasing interest in Pasteur's quadrant (Figure 1, Stokes 1997), characterized by use-inspired research. This research is aimed both at advancing knowledge, and solving problems in the real world. In marine conservation, the knowledge that we base policy and management decisions on must be excellent and unassailable, but it must also be appropriate for the scale and particulars of the problem. Designing pathways to solutions requires our best understanding of the natural science, social science and governance issues at play. There is no one optimal or best solution, but a series of solutions with different constraints and opportunities. Use-inspired research goes beyond just translating findings from basic research to solutions. Use-inspired research that emphasizes rigor and knowledge, as well as the potential for practical applications, may require asking different questions than the basic science researcher might ask.

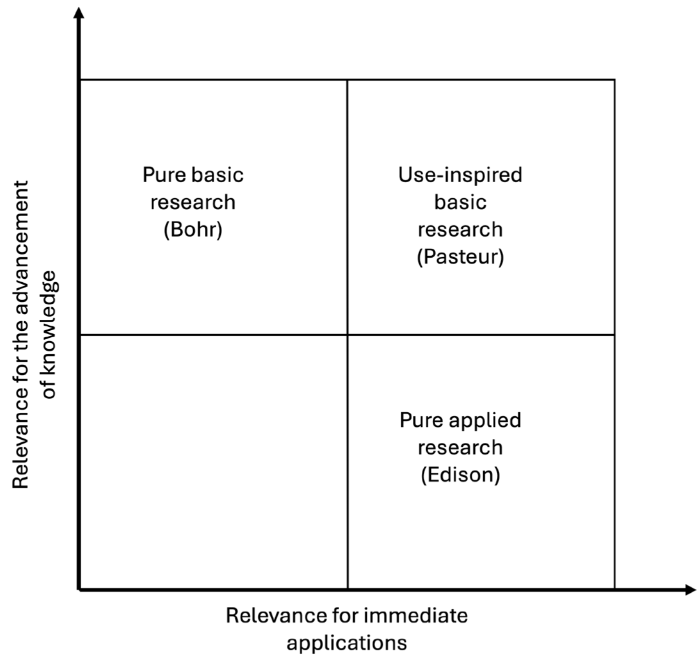


Fig. 0.1 Approaches to research.

Protecting biodiversity is still a laudable goal, of course, but given the myriad of challenges to marine ecosystems, including fisheries, climate change, invasive species, pollution, global markets, and colonialism, many are turning their attention to protecting ecosystem function as a goal. Increasing numbers of programs are being created in universities to address sustainability as the major goal. My university just created the first new school in 70 years, the Stanford Doerr School of Sustainability, and the focus is use-inspired research, as well as interdisciplinary and international engagement, that seeks solutions that work for people and the planet. The question is, where do we look for approaches to sustainability that allow the environment and people to co-exist over long periods of time? Perhaps the Polynesian cultures of the of the world's largest ocean have something to teach us about Navigating Our Way to Solutions (Beamer, Tau and Vitousek 2022).

Island perspectives on sustainability: A parable

People who grow up on islands think differently than people who grow up on continents. All of history's major colonial powers emerged on continents from the Romans, to Spain, Portugal, England, France, and other European powers. The United States, once colonized, is now itself a major colonial power, as are Russia and China. The march of history often begins with a people that, after depleting their own resources, move across continents to take resources from others, by invasion, warfare, and sometimes extermination. Strong forces arising on continents, can move relatively easily into adjoining territories to displace local people and seize their land and resources. Some of these powers leapfrogged to Africa, as well as North and South America, and rolled across those continents displacing major civilizations and native peoples alike. The attraction was often precious metals, jewels, and historically significant places. But captive human resources, in terms of forced labor, were also exploited to build out occupied land on behalf of the invaders. In essence, that mindset is if you need something, go get it, and if it's not there, then go find it.

The whole colonial movement, once celebrated (at least in the colonialist countries), is now subject to critique, and moves to decolonize major regions and nations of the world are emerging as native peoples seek to regain their freedom and autonomy. But colonialist footholds are strong, resisting efforts by indigenous peoples to reclaim their rights and regain their autonomy over their historical lands and resources.

By contrast, island cultures and other remote peoples, have evolved societies that were forced to practice sustainability. The famous 'Ahupua'a' system in Hawaii, focused on a holistic approach to the relationship of people to the land and sea. Local people managed their resources from the top of the mountain to the edge of the reef and beyond. This practice has evolved elsewhere among island cultures and remains central to the thinking of island peoples. Living and non-living components of these watersheds were considered critical parts of the system, as were the people. The islander mentality seems to focus on sharing resources. In fact, the idea of owning land was considered absurd before western contact. This was the first development of the concept of 'ecosystem-based management', thousands of years before western scientists coined the term.

Why did island people focus on sustainability from year to year and across generations? Because their lives and the future of their people depended upon it! Depleting your own resources and simply moving to the next island was not trivial. Indeed, it required highly developed celestial navigational skills to engage in dangerous voyages to other unknown and uncharted islands. It wasn't like fighting across an arbitrary land border. Furthermore, habitable islands were likely already inhabited by people who could see marine invaders at a distance and would fiercely defend their homes.

So, if we want to understand how to *Navigate our Way to Solutions for Sustainability*, who best to teach us? Island cultures or continental cultures?

The Earth is an island, in the sense that it has limited resources. Historically, colonizing civilizations have had a 'move when needed' or 'explore and conquer' mentality, which was not feasible for isolated island civilizations. Colonizing civilizations have also led efforts in sustainability, but maybe we should explore the ideologies behind island and indigenous communities, who have been practicing sustainability for centuries. If the Earth is an island, we need to adopt a sustainable approach to living here 'as if our lives depended upon it'. We can't deplete and despoil the Earth and just move across a border to capture another Earth. Planning to voyage to our new 'earth island' is a challenging and highly risky strategy. We need to seek out the wisdom of island peoples to help us find our way to sustainability for island Earth.

Acknowledgements

Thanks to the hundreds of students from across the globe who broadened my perspectives on *Navigating our Way to Solutions in Marine Conservation*. And thanks to Elliott Norse for sharing the first voyage in writing *Marine Conservation Biology*. Dan Rubenstein and Mike Orbach had profound impacts on my thinking during my 14 years of teaching marine conservation at Duke. I thank Asha de Vos for her comments on the manuscript and Keiko Kaholoa'a, Taylor Souza, and Catherine Lee Hing for their insights on the Island Perspectives part of this essay.

References

Beamer, K., T. M. Tau and P.V. Vitousek. (2022). Islands and Cultures: How Pacific Islands Provide Paths toward Sustainability. New Haven: Yale University Press

Crowder, L. B. (2025). Building a new global vision for marine conservation: Inspiration, networking and capacity sharing, with a box by Asha De Vos, The Duke Global Fellows Programme – a career catalyst. In L. B. Crowder (Ed.), Navigating Our Way to Solutions in Marine Conservation. Open Book Publishers. https://doi.org/10.11647/OBP.0395

Norse, E. A. and L. B. Crowder (eds.). (2005). Marine Conservation Biology: The Science of Maintaining the Sea's Biodiversity. Washington, DC: Island Press

Ostrom, E. (1990). Governing the Commons: The Evolution of Institutions for Collective Action. (Political Economy of Institutions and Decisions)

Soule, M. (2005). Forward, IN: Norse, E.A. and L.B. Crowder (eds.) 2005. Marine Conservation Biology: The Science of Maintaining the Sea's Biodiversity. Island Press, Washington, DC.

Stokes, Donald E. (1997). Pasteur's Quadrant – Basic Science and Technological Innovation. Brookings Institution Press

Diverse approaches to species conservation

Biodiversity and species conservation

It is not unusual in marine conservation for practitioners and researchers to focus on threats to biodiversity at the species level. Although extinction in the sea has been relatively rare compared to that on land and small freshwater systems, we have lost species in recent history, and have species on the brink, largely due to the impacts of people. Human activities including the direct and indirect effects of fishing, ship strikes, development in coastal habitats, invasive species, and climate change have led to massive reductions in species abundance. Concerns about species often reflect the 'charismatic megafauna', but other less visible species are also at risk. In this section, the key authors are researchers/scholars that are actively involved in initiating effective conservation actions.

Pablo Garcia Borboroglu and **Laura M. Reyes** detail their work on Magellanic Penguins in Patagonia. Massive loss and alteration of key nesting rookeries due to coastal ranching led to dramatic declines in the number of nesting penguins. Initial efforts sought to discover and protect these rookeries. But the authors also found critical losses at sea when parents forage to provision their chicks. Solutions to these issues required not only good science, but clever integration with local land owners, fishers and government.

Krista D. Sherman, describes the rapidly emerging and persistent challenges to save the critically endangered Nassau grouper in The Bahamas. This effort has been characterized by short-term gains and setbacks, which requires cutting edge science and high-level engagement with local fishers, coastal communities, and government. Her high level of engagement in the community, as well as the science, seems to be the key to success.

Fabián Pina Amargós, Tamara Figueredo Martín, and **Yunier Olivera Espinosa**, focus on the conservation challenges around the goliath grouper *Epinephelus itajara* in Cuba. Initially the subject of a targeted fishery, this long-lived species became rare and was subjected to several conservation efforts, including marine protected areas, better management of fishing effort and impacts, and a shift toward ecotourism to protect and value this species, all in the context of interesting formal and informal governance in Cuba.

Dana K Briscoe, Bianca S. Santos, Calandra N Turner Tomaszewicz, and **Larry B Crowder**, characterize emerging approaches to conserving endangered sea turtles across the globe. Sea turtles have declined due to direct harvest from eggs to adults, loss of nesting habitat, and bycatch in fisheries. Researchers globally have developed an extensive tool-kit to address the dramatic declines in sea turtles, and have developed focused conservation actions based on detailed understanding of the life histories and spatial dynamics leading to some success in recovering species, such as *Kemp's ridley*. This chapter describes those successes and illuminates remaining challenges.

1. Conserving penguins via land and sea protection

Pablo Garcia Borboroglu[1] *and Laura M. Reyes*

Worldwide, biodiversity is rapidly decreasing (IPBES, 2019). Seabirds are the most threatened bird group, and penguins are one of the most threatened seabird taxa (Croxall et al., 2012; Dias et al., 2019). Anthropogenic sources of mortality, coupled with a rapidly changing climate, have led to significant impacts on several species of penguins. In fact, half of the 18 penguin species are listed as threatened by the International Union for the Conservation of Nature (IUCN, 2020). As important marine predators, penguins play a key role in coastal and marine ecosystem structure and function. This bird group's fragile conservation status foreshadows the urgent need to protect the oceans they depend upon.

Penguins are flightless birds that inhabit the Southern Hemisphere. They breed in colonies, lay one to two eggs per breeding season, and take several months to raise their offspring. Penguins are also long-lived, and depend on marine food sources that are spatially and temporarily unpredictable. As a consequence of their natural history features, they are particularly sensitive to variations in ecosystem structure and processes, caused primarily by climate change, marine pollution, and extensive overfishing (Trathan et al., 2015; Boersma et al., 2020).

We are already feeling the effects of the Earth's changing climate. Regions within the Antarctic are warming much faster than the average rate of the Earth overall. Shifts in ice formation and melting patterns, coupled with increasing rain and snow, have changed the quality and availability of breeding and feeding habitat for many penguin species. Within temperate regions, increases in the frequency and intensity of environmental cycles, such as the El Niño Southern Oscillation (ENSO), have changed the abundance and distribution of penguin species. Within these regions, dramatic population declines, modifications of breeding chronology, and reproductive failures have occurred (Garcia Borboroglu and Boersma 2013; Roupert-Coudert, 2019).

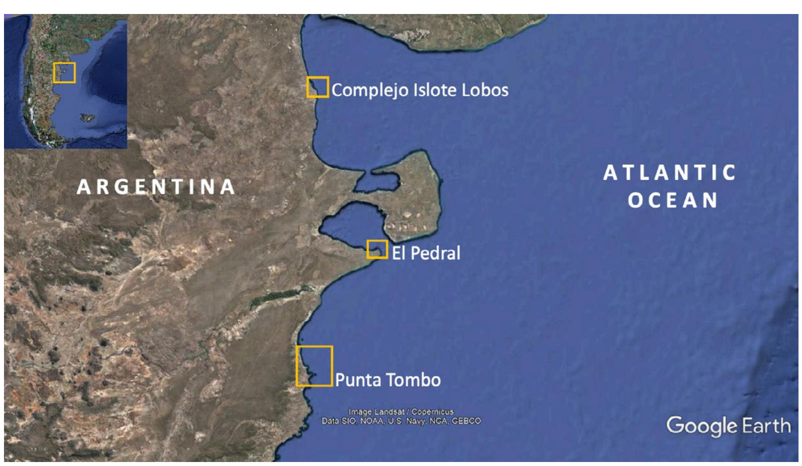


Fig. 1.1 Geographic location of the study cases described: Complejo Islote Lobos (Province of Rio Negro) and El Pedral and Punta Tombo (Province of Chubut). The three locations are found along the Atlantic coast of Patagonia in Argentina.

1 Global Penguin Society, Marcos Zar 2716, Puerto Madryn (9120), Chubut – Patagonia, Argentina, https://orcid.org/0000-0002-9031-5561

 https://doi.org/10.11647/OBP.0395.01

Anthropogenic pollution is a significant source of harm to penguins worldwide. Penguins are particularly vulnerable to petroleum spills, as they surface regularly to breathe while swimming, and do not fly, and so are not able to avoid petroleum in comparison to flying seabirds. The mortality of penguins due to accidental and chronic petroleum discharge is a long-term and large-scale problem. Thousands of penguins in Africa, South America, Australia, and New Zealand, and even Antarctica have been killed as a result (Garcia Borboroglu et al., 2008). More recently, plastic pollution has become a significant global concern. Plastics have invaded even the most remote penguin habitats and are commonly found along shorelines and within nesting sites. Penguins are unable to digest plastics and when ingested, plastic can cause a variety of health issues including neurological and reproductive disorders (Trathan et al., 2014; Wilcox et al., 2015). Furthermore, sharp fragments, known as micro-plastics, can cause internal injuries and blockages in the digestive tract.

Fisheries also threaten penguin populations through competition for food and gear entanglement. Starting in the mid-20th century, large-scale industrial fisheries began to remove large numbers of fish from the Southern Oceans (WWF, 2007). New technology has increased catch capacity and, in some areas like Antarctica, there is high spatial overlap between penguin foraging areas and fisheries operations (Cury et al., 2011).

Currently, some species of penguin face hazards within their colonies related to inadequate regulation of human activities such irresponsible tourism, coastal development, or introduced predators (Garcia Borboroglu and Boersma, 2013; Trathan et al., 2015). In addition, new emerging issues, such as the illegal trade of penguins, are generating concerns within the conservation community. This situation is driven in part by the resurgence of Asian economies, where new markets for wildlife trade have been established (Das, 2014). For example, as the number of aquariums in China increases, the demand for penguins and other marine wildlife has grown. Illegal traffic of wildlife is one of the most lucrative international crimes and is directly linked to species loss in some of the world's most threatened ecosystems (UNODC, 2020).

Overall, the effects of climate change cannot be addressed in the short term. However, we can increase the resilience of penguin populations by improving the management of anthropogenic activities. By reducing human pressures on penguin populations, we can enable them to cope better with the consequences of climate change.

Penguins are excellent indicators of the health of the ocean and the condition of the coasts they inhabit, giving visibility to marine conservation issues. They use a wide range of marine habitats throughout the Southern Oceans, covering thousands of square kilometers during annual foraging and wintering migrations. As ocean samplers, they can serve as cost-effective indicators of the habitats they use, allowing scientists to have better insight into the nature, magnitude, and location of priority marine conservation issues (Agnew, 1997; Boersma, 2008).

Penguins need large-scale conservation protection because they use vast areas of the ocean to forage, but they also require focused local efforts for nesting and breeding habitats. Securing protection for large areas in the ocean presents a challenge, as it can generate strong resistance from political and private sectors that use those areas for fisheries, oil exploration and mining, and maritime traffic. On land, penguins use more restricted areas to build their nests and establish colonies. However, designating protected areas for those habitats can generate resistance in regions where interests exist to develop industrial infrastructure like harbors or energy plants, to promote urbanization, or to allow recreational uses, all of which can cause severe disturbance and impact the habitat quality.

Penguins breed across islands and continents throughout the Southern Hemisphere, so they face different realities depending on the sociocultural, political, and economic scenarios they encounter. Breeding and migration grounds are often under the jurisdiction of developing countries. Specifically, their breeding areas are within main territories of eight countries: New Zealand, Australia, South Africa, Namibia, Argentina, Chile, Perú, and Ecuador. They are also located on islands and overseas territories administered by the United Kingdom, France, and Norway. In some cases, developed countries' administrations have proved to be more effective in addressing conservation problems like oil spills. When oil spills occur within the jurisdiction of these nations, the origin of the spills are able to be identified. These countries often have effective laws and enforcement to prevent spills. In addition, these laws are coupled with effective litigation procedures, and in most cases, the companies that are responsible for spilling petroleum are prosecuted and fined. On the other hand, in Africa and South America, the origin of many petroleum spills, including some of the most harmful ones, remain unknown. Law enforcement is often ineffective, and prosecution procedures are contextualized by judiciary systems that are not always independent from political or economic powers (Spiller and Tommasi, 2007). As a result, many companies that are responsible for oil-spill damage have not been required to compensate for the harm inflicted (Garcia Borboroglu et al., 2008).

Many conservation problems in developing countries are based on little to no protection as a consequence of poor planning and/or ineffective implementation and enforcement. Further, in many developing countries, environmental problems are not prioritized as highly as chronic economic problems and social issues relevant to securing a sustainable economy. The Global Penguin Society (www.globalpenguinsociety.org; GPS) has helped to deliver effective conservation actions to tackle the intrinsic shortcomings linked to developing and developed administrations. Throughout the last thirty years, the GPS has worked to apply science-based conservation to protect both marine and coastal habitats of penguins. These actions have further benefitted thousands of other species penguins coexist with. In this chapter, we describe particular case studies from Argentina, one of the countries where we work and currently live, that reflect the complexities we have faced, and the failures and successes in these endeavors.

Fig. 1.2 Punta Tombo Magellanic penguin colony in Chubut Province, Argentina, is one of the largest colonies of this species on the Planet, with a population of 140,000 pairs (Image: Global Penguin Society).

Case studies

The power of the social fabric: The Punta Tombo management plan case

Punta Tombo, Argentina (see Figure 1.1), is one of the main tourist attractions in Patagonia, and encompassed the largest Magellanic penguin colony in the world until 2017 (Figure 1.2). The colony's population has declined more than 30% since the late 1980s. Current reproductive success is low and feeding trips have lengthened by nearly 45 kilometers every ten years. Starvation, the primary cause of chick mortality, kills nearly 40% of chicks annually (Boersma et al., 2014). Although a 210-hectare provincial reserve protected half of the breeding colony on land, similar protections (e.g., via a marine protected area (MPA)) did not exist to protect their nearby feeding grounds.

The first management plan for the Punta Tombo Protected Area (Garcia Borboroglu et al., 2005) was conceived through a participatory strategic planning process that occurred between 2003 and 2005. This participatory process involved 128 people representing 40 institutions. One major challenge was to sustain the stakeholder participation throughout the two-year process, which included seven intense plenary workshops and hundreds of meetings. Three elements comprised the planning scenario: the provincial government as the main authority, two NGOs as the main sponsors, and the active participation of social stakeholders, including the landowner, scientists, travel agents, tour guides, industrial and coastal fisheries, the coastguard, and authorities of the main towns near the protected area. Along with a social science expert, we formed the planning team that facilitated and coordinated this process. This team was instrumental in achieving consensus among diverse individuals with different priorities, positions, and interests.

Fig. 1.3 Penguin egg hatching and chick asking parent for food. This is the one of the most fragile stages of the breeding cycle since adults have to feed their chicks very frequently, so it is critical to find food available close to their colonies (Image: S. Sainz-Trapaga).

This experience illuminated different strategies that proved successful when managing uncertainty and delivering conservation goals under difficult circumstances. One main accomplishment was the development of a strong social network among stakeholders. Many months of intense, regular, and cooperative work made it possible to integrate common interests into a shared vision. The network ensured the continuity of the planning process, even during very unstable political circumstances, when the official political party that initially drove the process lost the subsequent election. The new authorities did not deem the management plan an important issue. Additionally, throughout the project, five different individuals were named director of conservation within the Protected Areas Bureau. As a result, government support and its *affetio societatis* – the common will of several people or institutions to join and work towards a common goal – were often simply declarative, as they were not really interested in supporting the management plan as a product.

Our team was also able to identify the urgent need to create an MPA around the colony. An MPA protecting the foraging area for adults feeding small chicks (a critical stage of the breeding cycle) would reduce both chick starvation and adult mortality, increasing reproductive success (Figure 1.3). Working synergically, an *ad-hoc* team, composed of fishermen, fishing authorities, the coastguard and scientists developed a proposal for an MPA to be included in the management plan. Surprisingly, the chamber of coastal fisheries supported the creation of this MPA, as this would prevent the large-scale industrial fisheries from operating and competing with the local fisheries within this area.

However, two years after the submission of the completed management plan document, it remained in the governmental offices waiting to be analyzed and officially approved. While the plan had not yet been approved, a recently appointed director of Protected Areas tried to initiate damaging construction activities in a delicate nesting area for penguins. Fortunately, we were able to reconnect the stakeholders' network and request urgent approval of the plan by the governor and immediately stop construction. In 2007, four years after the beginning of the planning process, the management plan for the Punta Tombo Protected Area was officially approved, and the emerging construction was removed from the area. However, the arduous task of the creation of the marine protected area remained pending.

When opportunity knocks at your door: A marine protected area for Punta Tombo and the magic of Mickey Mouse

Creating the marine protected area that the management plan proposed was a difficult task to achieve due to governmental proceedings. The provincial parliament was required to analyze, vote, and approve the proposal, despite pressure from the fisheries against its designation.

In the years following the approval of the plan, our team continued to follow up with authorities on the status of the MPA. Through the GPS, we contacted and informed the governor and several congressmen about the urgent need to create the MPA to help increase the availability of food in critical stages of the breeding season, and reduce the high mortality of chicks by starvation. Unfortunately, our multiple attempts were always unsuccessful, despite the strong scientific evidence behind the proposal.

Eight years after the completion of the management plan, an unexpected opportunity appeared when we received a visit from representatives of the Walt Disney Company. The corporation had been financing several educational and conservation projects for the GPS and wanted to learn more about the progress of the activities and the individuals who made it possible. During their stay, we informed them about the need to increase protections in the oceans for penguins. The governor learned about the visit and immediately required a meeting with the Disney team and the NGO. During the meeting, we immediately saw a window of opportunity.

And the request from the Disney directive did not wait:

—Mr. Governor, everything is beautiful and magnificent, but the penguins need a Marine Protected Area for Punta Tombo.

After several years of inaction, this simple and overwhelmingly clear sentence catalyzed political interest in the MPA. Over the next several weeks, the GPS team worked with the government of Chubut Province to design the new area, using the best available science, while Disney Fund for Nature supported the effort.

Fig. 1.4 Magellanic penguin adult group socialising at the beach. During the planning stages of a penguin colony, it is fundamental to zone the area considering the different habitats relevant for the species, because not only the nesting area should be protected but also the beach areas that are intensively used (Image: Global Penguin Society).

The MPA is now located on the central Patagonian coast of Argentina. It includes 60 kilometers of coastline and will influence the management of 100,000 hectares extending 12 nautical miles offshore. Its main goal is to protect the feeding area of 500,000 Magellanic penguins that breed in nearby colonies (Figure 1.4). The MPA also aims to protect the ecotourism industry and improve the management of fishing activity in the area. Nature-based tourism is one of the main sources of income and jobs for this region. The MPA is now one of the core areas of the Blue Patagonia UNESCO Biosphere Reserve, another layer of protection that we helped to designate in 2015.

Seven days before the change of governors, legislators, and the President in Argentina, the Legislative Body of Chubut Province approved the MPA (Law 103/15). Science was important, but political and economic interests behind the scenes were crucial aspects of negotiation. When industrial fisheries began to pressure politicians to stop the MPA process so that the law could be discussed at the congressional plenary session, scientific evidence was not significantly considered. At this point, we implemented a coordinated strategy, including interaction with the media, current and future government officials, and travel agents that operate in Punta Tombo, to help balance the discussion. Again, the official political party lost the election and had no power to foster the approval of the law, so we were left to negotiate with the political parties directly to obtain their votes before the official session. This was, by far, the most challenging and critical moment of the process, as most politicians could not initially understand the significance of this MPA. An influential member of one party did not read or write, therefore, we translated the available science into friendly and accessible language so he could better understand the project. After tackling several obstacles and making agreements through negotiations, the modified proposed area and draft law were successful in protecting foraging areas for penguins (Figure 1.5) and a rich assemblage of other marine species using these waters. Unfortunately, the marine protected area is still waiting for its effective implementation. We hope that the next opportunity will not be delayed for another ten years.

Fig. 1.5 Aerial image of a group of penguins going into the ocean. Penguins can take hours to go back walking to their nests but they can swim hundreds of kilometers per day when they are in the ocean (Image: S. Sainz-Trapaga).

El Pedral: The power of the few

In 2008, we discovered a recently established penguin colony in an area of Patagonia called El Pedral (see Figure 1.1). Over the years, the GPS has helped transform El Pedral into a healthy coastal habitat. When penguins first arrived, El Pedral was littered with trash and the fledgling colony was plagued by severe human disturbance. People hunted wildlife, burned and destroyed penguins' nests, and brought dogs to the area that often harmed the penguins. Moreover, people with vehicles and motorbikes drove across the area without paying attention to the nests. The fate and persistence of this colony depended on our ability to improve their habitat and implement adequate protections from human activities.

When a new colony is established, the area is surveyed by the founder group of penguins that decide breeding site suitability. The site chosen will be utilized for the duration of their lives, as they have a strong bond with the place they breed. We realized that we needed to implement actions urgently to secure a safe place for the first few breeding pairs. If we were successful, penguins would continue recruiting within this colony. Unfortunately, after speaking to the government, we learned that protection tools could not be applied immediately. Therefore, in agreement with the landowners, we closed the access gate to protect the emerging colony, and to provide time to explore other options. Several pressures, threats, acts of vandalism, and even intimidating phone calls resulted from the decision to close the gate. Despite all these shortcomings, we maintained our position. After two years, we were able to advance measures by working with the local government and landowners to designate El Pedral as a protected wildlife refuge (Figure 1.6). Although it was a challenge to foster agreements among landowners, convince decision-makers of the relevance of this area, and negotiate with groups of recreational fishermen who used the area, we were able to design and implement the management plan for this area.

Fig. 1.6 A Magellanic penguin stretching its flippers on the beach at El Pedral colony, Patagonia, Argentina (Image: S. Sainz-Trapaga).

We helped landowners develop a responsible and sustainable small-scale ecotourism operation. This allowed not only oversight into the area and implementation of the management guidelines, but also generated jobs and significant income for the local economy. In addition, we developed educational activities to engage children and the local community in various conservation actions. For example, we bring adolescents from local schools to collect garbage and debris from the beach and nesting areas before the penguins arrive from their annual winter migration. We have also established a program for thousands of children to visit the refuge and learn about the value of penguins to help connect them to nature.

Fig. 1.7 During very warm days, Magellanic penguin concentrate along the beach of their colonies to refresh and wait for the sea breeze to arrive (Image: Global Penguin Society).

These conservation efforts, along with their education and community engagement programs, have helped El Pedral to become a beautiful and safe coastline and have allowed the colony to grow from six pairs in 2008 to 3,200 pairs of penguins in 2020 (Figure 1.7). A thriving ecotourism operation now brings income to the area while protecting the colony. The conservation effort has benefitted this fragile coastal zone and several other species, including elephant seals, sea lions, guanacos, and Patagonian hares. This case study serves as a model to combat the challenges of a changing ocean and foster the movements of species to areas where they did not previously occur and protect species from threats they did not previously encounter.

Complejo Islote Lobos National Park: Redefining identity and the sense of ownership in an industrial mining town

Sierra Grande and Playas Doradas are two coastal towns in northern Patagonia whose economies, growth and identities have long been based on an iron mining industry. Located only 30 kilometers from these towns, the Complejo Islote Lobos provincial protected area (Figure 1.1), designated in 1977, is home to seabird and sea lion colonies. However, this designation was largely ineffective as the protected area did not have a strategic plan, and local wardens maintained a very limited oversight of it.

Local people were not aware of this natural area and its valuable resources. Even during the summer when tourists came to enjoy the beach, the natural area was not advertised as a regular attraction. In 2002, a new Magellanic penguin colony was established in this natural area, adding potential value to the site. However, the area remained without effective protection and outside of the community's awareness.

In 2018, the GPS coordinated the development of the first management plan (Reyes and Garcia Borboroglu, 2019) through a participatory process where 47 stakeholders from 21 private and public institutions joined organized workshops. In addition, 12 researchers contributed their expertise to enrich the document. This process was critical to increase the value and visibility of the natural area for the community. Local people learned about the 464 terrestrial and marine species that inhabit the area, including the northernmost Magellanic penguin colony in the Atlantic Ocean. Moreover, the workshops heightened awareness of the valuable cultural resources of the area, particularly graves of indigenous people that occupied the area 2,700 years prior. The rich biodiversity, attributes of the coastal marine landscape, unique archaeological features, and relative proximity to major cities in Patagonia, highlighted the value as a potential tourist destination.

Both the community and the government were positively impacted by the planning process. The management plan developed through this process reached the desks of important decision makers, and was instrumental in catalyzing the designation of this area as a new National Marine Park for Argentina. The plan became the core of the document that justified its creation and even allowed the transfer of jurisdiction from the province to the country. Scientific literature was previously available in English via international peer-reviewed journals, but it was not available in Spanish or in a format accessible to the local citizens or decision makers. The participatory process made this information available. The process provides an example of how to make science accessible so that it can be used for solutions that enrich communities socially and economically, while securing conservation outcomes. Overall, this case demonstrates why science was critical to help redefine the identity and sense of ownership of a mining industry community that will now foster conservation as a source of income and jobs.

Conclusions and lessons learned

Science is a critical component, but is not sufficient alone, to deliver solutions in conservation planning. Within each case study described, sound and compelling scientific evidence to reasonably justify the designation of each protected area had been previously available for many years. However, the evidence alone was not enough to ensure action. Oftentimes, scientific information is only available within jargon-heavy English papers or publications, leaving it inaccessible for Spanish-speaking decision makers and stakeholders. In these scenarios, science-based conservationists must make information available in clear and understandable language, to generate the interest of communities and catalyze political support.

Conservation problems are multidimensional, and therefore efforts to address these issues require contributions from several disciplines (Clark et al., 2002). While natural sciences provide sound information related to wildlife and the environment, social sciences are necessary to provide insight and understanding of the human dimensions that govern decision making. In many cases, scientists provide information to managers but do not effectively engage in conservation processes and policy development. Additionally, many countries lack the intermediate institutions needed to facilitate the process between when a conservation issue is discovered, and the development of a solution. Researchers have a critical role in helping to foster a solution, but must also be aware of the social components of the problem-solving process, which are often based on politics and human values, rather than only scientific evidence. When conservational biologists contribute to management, they can find themselves in a role of political advocacy, which has garnered criticism in the past for straying from the value-neutral domain expected of most scientific disciplines (Soule, 1985). Today, the growing urgency of conservation issues has fostered the resurgence of a new generation of researchers willing to both generate science, and work to integrate their research into applied solutions. Some scientists still question advocacy, especially for a particular solution or outcome; however, scientists can always advocate that solid science be used to inform decision making.

Within uncertain scenarios, the key is to build a network of committed stakeholders. Developing countries can be very unstable, politically, socially, and economically, and often see high turnover of decision makers. One solution is to build a social network within the members of the community that will persist throughout these instabilities. The involvement and investment of these stakeholders will increase the likelihood that a conservation outcome will be successful in its implementation and long-term impact. This was a key component within the case of the Punta Tombo management plan, where the network of stakeholders fostered the continuity of the planning process and the final approval of the management plan.

As conservationists, we must be ready to act when an opportunity arises. Within the Punta Tombo MPA case, ample scientific evidence was available to justify the MPA designation, yet that was not sufficient to generate the necessary political support. Windows of opportunity can open and close very quickly within the political domain, so being ready to act, and moving quickly, is crucial. Sometimes, it is not possible to accomplish everything you aim to do. Lack of time to conduct a comprehensive participatory process, data gaps, and political circumstances, such as changes in authority, can alter original plans and require adaptations. If a political opportunity opens, it is advantageous to implement conservation measures that may not be perfect, but can be improved upon in the future.

Allies can emerge unexpectedly in conservation. In some cases, the private sector can be a great ally for conservation measures. The El Pedral conservation success story demonstrates how partnerships with landowners helped to address an urgent situation that could not wait for political action. This partnership allowed for the initial protection of the penguin colony, and helped to generate economic benefits from tourist operations for the local people. Within the Punta Tombo example, the coastal fisheries unexpectedly agreed to support the creation of the MPA, as it would prevent competition with the large-scale industrial fisheries.

Causes of biodiversity loss are primarily grounded in economics, however effective solutions are also grounded in economics (Fisher et al., 2015). Economics is the study of how individuals make choices under conditions of scarcity, and of the results of those choices for society (Frank and Bernanke, 2003). A major challenge in conservation is determining how to protect resources, while also benefiting communities and incentivizing people to make sustainable choices. The key to garnering the support of a community or government is to highlight the economic and social benefits that can result from conservation measures. In the case studies presented here, we were able to sustain livelihoods within each community through the development of ecotourism operations, which became a powerful tool in the negotiations with decision-makers.

You may ask, what was the key to accomplish conservation goals against the many challenges that are intrinsic to developing countries? If we had to summarize the answer in a few words, we would say: Tenacity, patience, adaptability, passion, optimism and most importantly… hope.

References

Agnew, D. J. (1997). The CCAMLR ecosystem monitoring programme. Antarctic Science 9: 235–242. https://doi.org/10.1017/S095410209700031X

Boersma, P. D. (2008). Penguins as marine sentinels. BioScience 58: 597–607. https://doi.org/10.1641/B580707

Boersma, P. D., G. A. Rebstock, and P. García-Borboroglu. (2015). Marine protection is needed for Magellanic penguins in Argentina based on long-term data. Biological Conservation 182: 197–204. https://doi.org/10.1016/j.biocon.2014.12.005

Boersma, P. D., P. G. Borboroglu, N. J. Gownaris, C. A. Bost, A. Chiaradia, S. Ellis, T. Schneider, P. J. Seddon, A. Simeone, P. N. Trathan, L. J. Waller and B. Wienecke. (2020). Applying science to pressing conservation needs for penguins. Conservation Biology 34(1): 103–112. https://doi.org/10.1111/cobi.13378

Croxall, J. P., S. H. M. Butchart, B. Lascelles, A. J. Stattersfield, B. Sullivan, A. Symes and P. Taylor. (2012). Seabird conservation status, threats and priority actions: A global assessment. Bird Conservation International 22: 1–34. https://doi.org/10.1017/S0959270912000020

Cury, P. M., I. L. Boyd, S. Bonhommeau, T. Anker-Nilssen, R. J. M. Crawford, R. W. Furness, J. A. Mills, E. J. Murphy, H. Österblom, M. Paleczny, J. F. Piatt, J. P. Roux, L. Shannon and W. J. Sydeman. (2011). Global seabird response to forage fish depletion—one-third for the birds. Science 334: 1703–1706. https://doi.org/10.1126/science.1212928

Das, D. K. (2014). The Role of China in Asia's Evolution to Global Economic Prominence. Asia & the Pacific Policy Studies 1(1): 216–229. https://doi.org/10.1002/app5.10

Dias, M. P., R. Martin, E. J. Pearmain, I. J. Burfield, C. Small, R. A. Phillips, O. Yates, B. Lascelles, P. Garcia Borboroglu, and J. P. Croxall. (2019). Threats to seabirds: A global assessment. Biological Conservation 237: 525–537. https://doi.org/10.1016/j.biocon.2019.06.033

Fisher, B., R. Naidoo, and T. H. Ricketts. (2015). A Field Guide to Economics for Conservationists. Greenwood Village, Colorado: Roberts and Company

Garcia Borboroglu, P., L. M. Reyes and A. Tagliorette. (2005). Plan de Manejo del Area Natural Protegida Punta Tombo, Chubut, Argentina

García-Borboroglu, P., P. D. Boersma, L. M. Reyes and E. Skewgar. (2008). Petroleum Pollution and Penguins: Marine Conservation Tools to Reduce the Problem. In T. N. Hofer (ed.), Marine Pollution: New Research (pp. 339-356). New York: Nova Science Publishers Inc.

IPBES. (2019). Summary for policymakers of the global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. In S. Díaz, J. Settele, E. S. Brondízio, H. T. Ngo, M. Guèze, J. Agard, A. Arneth, P. Balvanera, K. A. Brauman, S. H. M. Butchart, K. M. A. Chan, L. A. Garibaldi, K. Ichii, J. Liu, S. M. Subramanian, G. F. Midgley, P. Miloslavich, Z. Molnár, D. Obura, A. Pfaff, S. Polasky, A. Purvis, J. Razzaque, B. Reyers, R. Roy Chowdhury, Y. J. Shin, I. J. Visseren-Hamakers, K. J. Willis and C. N. Zayas (eds.). IPBES secretariat.

García-Borboroglu, P. and Boersma, P. D. (eds.). (2013). Penguins: Natural history and conservation. Seattle: University of Washington Press.

International Union for Conservation of Nature (IUCN). (2018). IUCN Red List of threatened species, Version 2018.2. IUCN.

Frank, R. H. and Bernanke, B. (2003). Principles of Macroeconomics. McGraw-Hill Ryerson.

Reyes, L. M. and Garcia Borboroglu, P. (2019). Plan de Manejo del Area Natural Protegida Complejo Islote Lobos, Rio Negro, Argentina.

Ropert-Coudert, Y., et al. (2019). Happy Feet in a Hostile World? The Future of Penguins Depends on Proactive Management of Current and Expected Threats. Frontiers in Marine Science 6. https://doi.org/10.3389/fmars.2019.00248

Soulé, M. E. (1985). What Is Conservation Biology? BioScience 35(11): 727–734.

Trathan, P., P. Garcia Borboroglu, D. Boersma, C. Bost, R. Crawford, G. Crossin, R. Cuthbert, L. S. Davis, S. De la Puente, U. Ellenberg, T. Mattern, K. Putz, P. Seddon, W. Trivelpiece, B. Wienecke and P. Dann. (2014). Pollution, habitat loss, fishing and climate change as critical threats to penguins. Conservation Biology 29(1): 31-41. https://doi.org/10.1111/cobi.12349.UNODC. (2020). World Wildlife Crime Report 2020: Trafficking in Protected Species. United Nations Publications.

Wilcox, C., E. Van Sebille and B. D. Hardesty. (2015). Threat of plastic pollution to seabirds is global, pervasive, and increasing. Proceedings of the National Academy of Sciences 112(38): 11899-11904. https://www.pnas.org/doi/abs/10.1073/pnas.1502108112

WWF. (2020). Penguins in peril as climate warms. WWF Report. Retrieved from https://wwfint.awsassets.panda.org/downloads/folleto_penguins.pdf

2. Conservation as a marathon vs. a sprint: The race to save critically endangered Nassau grouper in the Bahamas

Krista D. Sherman[1]

Humans are intrinsically linked to the environment and have the potential to hinder or support management policies aimed at protecting ecosystems and the species that reside within them (Turner et al., 2014; Wise, 2014; Hayes et al., 2015). As such, species conservation is a complex and nuanced process, requiring robust scientific data to help inform and evaluate management strategies that encompass both biological and socioeconomic factors. Significant and sustained investments in time and financial resources are required to facilitate this process and work toward achieving desired conservation outcomes.

Nassau grouper (*Epinephelus striatus*) is a predatory marine fish that occupies nearshore habitats throughout the Tropical Western Atlantic, the Caribbean Sea, and parts of the Gulf of Mexico. This species is ecologically, economically, and culturally highly valued in The Bahamas and the Caribbean (Sadovy de Mitcheson and Colin, 2012; Sherman et al., 2016). In The Bahamas, Nassau grouper have generated over $32.5 million USD in revenue within the last two decades through commercial landings alone, and remain highly sought after across commercial, subsistence, and recreational fisheries (Sherman et al., 2016, 2018c). Unfortunately, due to their life history characteristics, overexploitation, and unsustainable fishing practices (e.g., fishing on fish spawning aggregations (FSAs)) along with other biotic and abiotic threats, Nassau groupers are currently listed as critically endangered on the IUCN Red List (Sadovy et al., 2018) and the long-term viability of the fishery is at risk. Within The Bahamas, commercial harvest peaked at 514 tons in 1997, but has declined by 86% over the past 20 years (Sherman et al., 2016). Moreover, several historically active FSAs no longer form and those that persist have reduced spawning biomass, and as such capacity to replenish the fishery (Sherman et al., 2016; Stump et al., 2017).

Selected countries (e.g., the Cayman Islands and St. Thomas) have documented conservation success for Nassau grouper, driven by proactive and properly enforced management measures (e.g., bans on fishing at spawning sites) in conjunction with well-funded long-term research, and community education and outreach programs (Sadovy de Mitcheson and Colin, 2012; Waterhouse et al., 2020). In contrast, The Bahamas has had fewer resources to support consistent enforcement, research and monitoring, and community engagement, despite covering a much broader geographic area than any of these countries. Indeed, information on the status of many Nassau grouper FSAs is lacking, yet identifying active sites, where they still aggregate to spawn is critical to protect this species. FSAs are crucial because they account for almost all the reproductive output for Nassau groupers. Reducing knowledge gaps with regards to the status of Nassau grouper spawning stocks, characterization of FSAs, genetic connectivity, and spatiotemporal patterns of fish reproductive behavior

1 Perry Institute for Marine Science, https://orcid.org/0000-0001-9859-8781

 https://doi.org/10.11647/OBP.0395.02

throughout the country have been identified as national priorities and research is ongoing to address these needs (Sherman et al., 2016, 2018a, 2018b; Nassau grouper PSA).

Nassau grouper PSA[2]

Various management strategies have been implemented to conserve Nassau grouper within The Bahamas. These include the establishment of the country's first no-take marine protected area, the Exuma Cays Land and Sea Park, a 3 lb (≥1.36 kg) minimum size limit, partial site-specific FSA closures, varied (1–3 month) national closed seasons, and ultimately a fixed national three month closed season (1 December–28 February) each year to protect fish from capture during part of the spawning season (Sherman et al., 2016). Despite these regulations, however, groupers are still being harvested illegally and sold during the closed season (Nassau grouper PSA). In part, this can be attributed to the continued practice of cultural and historic traditions associated with fishing Nassau grouper and eating them in classic Bahamian dishes that coincide with the spawning season and Christmas holidays. However, illegal fishing or poaching by Bahamians and foreigners is also problematic especially in the southern parts of the archipelago. Accordingly, decades of conservation efforts have had limited success in improving the status of Bahamian Nassau grouper populations (Sherman et al., 2016, 2017, 2018b, c; Stump et al., 2017).

As such, in addition to addressing ecological gaps for the country (Sherman et al., 2016, 2018b), understanding the motivations and perspectives of local stakeholders is critical (e.g., Wise et al., 2014), but has been lacking, necessitating the integration of social science into the fisheries management process. Utilizing this information to develop and strategically implement communication and outreach materials can help to build consensus and promote behavior change among key stakeholders (e.g., Ghazali et al., 2019).

Preliminary research has been conducted to investigate and assess stakeholder knowledge and perspectives regarding the status and management of Nassau grouper and the commercial fishery (Sherman et al., 2018a, 2018b). This initial study along with a national survey administered by the Department of Marine Resources (2019-2020) has provided useful insights into barriers that constrain progress for effectively managing Nassau grouper populations within The Bahamas (Sherman et al. in prep). Some of the major challenges facing Nassau grouper conservation, potential solutions for tackling these issues, and desired outcomes are presented in Table 2.1.

Table 2.1 Barriers, potential solutions, and desired outcomes for Nassau grouper conservation in The Bahamas.

Challenges/Barriers	**Potential Solutions**	**Desired outcomes**
Cultural norms/ traditions	Integrate/incorporate key findings from social science & economic studies into messaging for different stakeholders. Develop and implement communication strategy and campaign to effectively engage all stakeholders - fishers, marine resource managers, policymakers, consumers, etc. Explore use of incentives to encourage sustainable fishing practices	Increased local stakeholder knowledge and awareness about the status of Nassau grouper and reason/need for fishery regulations. Increased stakeholder compliance with fishery regulations and support for marine conservation.

2 Bahamas National Trust, 'Nassau Grouper PSA', YouTube, 25 March 2015, https://www.youtube.com/watch?v=KISSamuyztY&t=5s; Perry Institute for Marine Science, 'Saving the Nassau Grouper – A Call to Action', YouTube, 28 February 2023, https://youtu.be/3CWsxCMkm3M?si=mDOpTLBmRTGIjKXM; Perry Institute for Marine Science, 'Save Our Grouper Featuring Miss Universe The Bahamas', YouTube, https://youtube.com/shorts/RokOhDqbnVM?si=sQewurkxTWjC558R

Lack of funding	Explore non-traditional funding streams. Increase private-public partnerships (nationally, regionally, and internationally). Solicit annual financial commitments from the government to support Nassau grouper research and conservation.	Adequate funding exists to support research and monitoring, enforcement, stakeholder engagement and communication. Annual funding made available by the government to subsidize and support research and conservation.
Capacity constraints	Strengthen existing collaborations/ partnerships and develop new partnerships at national, regional, and international scales to leverage better support (resources, staffing + technical capacity) for enforcement, research and monitoring and governance.	Expanded capacity (skills + resources) for enforcement, research and monitoring, communication, and outreach.
Politics	Improve intra- and inter-agency communication and cooperation using sound legislation, policies, cross-sectoral agreements, standardized data collection and reporting etc. Conduct economic valuation studies to highlight the benefits/value of Nassau grouper and provide additional justifications for its sustainable management. Link and/or make stronger connections between the impacts of coastal development and national projects on marine ecosystems, fisheries productivity, and coastal protection.	Increased collaboration, cooperation, and strategic coordination within and among government agencies and NGOs tasked with fisheries and marine resource management. Increased collaboration with regional fisheries management authorities to strengthen and support governance frameworks. Politicians support and encourage sustainable development projects that do not undermine conservation efforts.
Inadequate fishery regulations	Inclusion of scientific data into national regulations and policies via amendments to existing fishery regulations or the creation of new regulations. Use of precautionary management approaches and regional or international best practices to inform decisions where data deficiencies exist.	Established process/system to facilitate timely adoption and implementation of science-based policies to support sustainable fisheries management.

Although Nassau grouper populations are in a precarious position (Sherman et al., 2017, 2020; Stump et al., 2017), there is still hope. The Bahamas has more reported Nassau grouper spawning aggregation sites than any other country, relatively healthy fish biomass, and has made progress in addressing national research priorities and advocating for science-based policy reform (Sherman et al., 2018b and references therein). The significance of Nassau grouper to the Bahamian culture, economy, and environment warrants a well-defined management approach to mitigate threats and improve conservation efforts to cultivate a sustainable fishery (Sherman et al., 2016). With a true commitment from all stakeholders and sustained support, we can collaboratively continue the race to conserve this species.

References

Ghazali, E. M., B. Nguyen, D. S. Mutum and S. F. Yap. (2019). Pro-Environmental behaviours and value-belief-norm theory: Assessing unobserved heterogeneity of two ethnic groups. Sustainability 11: 3237. https://doi.org/10.3390/su11123237

Hayes, M. C., M. N. Peterson, J. L. Heinen-Kay and R. B. Langerhans. (2015). Tourism-related drivers of support for protections of fisheries resources on Andros Island, The Bahamas. Ocean & Costal Management 106. https://doi.org/10.1016/j.ocecoaman.2015.01.007

Ray, G. C. (2000). Investigations of Nassau grouper breeding aggregations at High Cay, Andros: Implications for a conservation strategy. Final Report, Department of Fisheries, Nassau.

Sadovy, Y., A. Aguilar-Perera and E. Sosa-Cordero. (2018). Epinephelus striatus. The IUCN Red List of Threatened Species 2018: e.T7862A46909843. https://dx.doi.org/10.2305/IUCN.UK.2018-2.RLTS.T7862A46909843.en

Sadovy de Mitcheson, Y. and P. L. Colin. (eds.). (2012). Reef fish spawning aggregations: Biology, research and management (Vol. 35). Fish and Fisheries Series. New York, NY: Springer.

Sherman, K. D., C. P. Dahlgren, J. R Stevens and C. R. Tyler. (2016). Integrating population biology into conservation management for endangered Nassau grouper Epinephelus striatus. Marine Ecology Progress Series 554: 263−280.

Sherman, K. D., R. A. King, C. P. Dahlgren, S. D. Simpson, J. R. Steven and C. R. Tyler. (2017). Historic and contemporary anthropogenic activities influence genetic population dynamics of Nassau grouper (Epinephelus striatus) within The Bahamas. Frontiers in Marine Science 4: 393. https://doi.org/10.3389/fmars.2017.00393

Sherman, K. D. (2018a). Integrative Approaches for Conservation Management of Critically Endangered Nassau grouper (Epinephelus striatus) in The Bahamas (PhD Thesis). University of Exeter. https://ore.exeter.ac.uk/repository/handle/10871/33061

Sherman, K. D., C. P. Dahlgren, L. R. Knowles. (2018b). Nassau Grouper (Epinephelus striatus) Conservation Management Plan for The Commonwealth of The Bahamas. Prepared for the Department of Marine Resources, Nassau, Bahamas.

Sherman, K. D., A. D. Shultz, C. P. Dahlgren, C. Thomas, E. Brooks, A. Brooks, D. R. Brumbaugh, L. Gittens and K. Murchie. (2018c). Contemporary and emerging fisheries in The Bahamas – conservation and management challenges, achievements and future directions. Fisheries Management and Ecology 25: 319−331.

Sherman, K. D. and C. Tyler. (in prep). Stakeholder perspectives on the status and conservation management of Nassau grouper in The Bahamas. Forthcoming.

Stump, K., C. P. Dahlgren, K. D. Sherman and C. R. Knapp. (2017). Nassau grouper migrations during full moon suggest collapsed historic fish spawning aggregation and evidence of undocumented aggregation. Bulletin of Marine Science 93: 375–389.

Turner, R. A., N. V. C. Polunin and S. M. Stead. (2014). Social networks and fishers' behaviour: Exploring the links between information flow and fishing success in the Northumberland lobster fishery. Ecology and Society 19(38). https://doi.org/10.5751/ES-06456-190238

Waterhouse, L., S. A. Heppell, C. V. Pattengill-Semmens, C. McCoy, P. Bush, B. C. Johnson and B. X. Semmens. (2020). Recovery of critically endangered Nassau grouper (Epinephelus striatus) in the Cayman Islands following targeted conservation actions. Proceedings of the National Academy of Sciences 117: 1587−1595.

Wise, S. P. (2014). Learning through experience: Non-implementation and the challenges of protected area conservation in The Bahamas. Marine Policy 46: 111−118.

3. Goliath grouper *Epinephelus itajara* conservation in Cuba: A protected area, ecotourism and fisheries effort

Fabián Pina Amargós,[1] *Tamara Figueredo Martín, and Yunier Olivera Espinosa*

The goliath grouper *Epinephelus itajara* is the largest grouper in the western hemisphere and one of the two largest groupers in the world, growing to 250cm in total length (TL) (Heemstra and Randall, 1993) with a maximum weight of 320 kg (Smith, 1971). The goliath grouper is a long-lived species (at least 37 years) and reaches maturity at 6-7 years (120 to 135cm TL) for females and 4–6 years (110 to 115cm TL) for males (Bullock et al., 1992). The species makes ontogenetic, seasonal, and spawning migrations (Coleman et al., 2000) and forms relatively small (10 to 100 individuals) spatially and temporally predictable spawning aggregations (Sadovy and Eklund, 1999). Adult and juvenile goliath grouper show high site fidelity (Eklund and Schull, 2001). These combined features make goliath grouper particularly susceptible to overexploitation. Once relatively abundant throughout its range, goliath grouper populations began to decline in the 1960s, undoubtedly a consequence of both intensive fishing on spawning aggregations and spearfishing on unwary adults (Sadovy and Eklund, 1999). As a result, the goliath grouper is now overexploited and rarely observed (Sadovy and Eklund, 1999). In the USA, population declines led to a fishery closure and catch moratorium in 1990 in all territorial waters (SAFMC, 1990) until recently when a limited catch had been authorised through a harvest permit and tag system due to the recovery of the species (FFWCC, 2024). Internationally, the goliath grouper was listed as Critically Endangered but now is considered Vulnerable (Bertoncini et al., 2018).

In Cuba, the goliath grouper has been poorly studied and, until recently, inadequately protected. A single management approach through fisheries regulation was for many years the common practice, missing the diverse management approaches, based on the goliath grouper conservation success presented in the previous paragraph. For many years, the protection was an arbitrary 40-cm minimum size regulation which permitted landing almost all goliath groupers caught in Cuban waters (Resolution 561/96 Ministry of Fisheries, Resolution 126/09 Ministry of Food (formerly Ministry of Fisheries)). There is only one peer-reviewed manuscript published specifically about goliath grouper, which focused on the species movement patterns in southeastern Cuba (Pina-Amargós and Gonzalez-Sansón, 2009). Claro and Lindeman (2003) reported 21 spawning aggregation sites for snappers and groupers on the Cuban shelf but none of these are reported spawning aggregation sites for goliath grouper. Previous research has investigated the relationship between predator-prey sizes (Claro et al., 2001). Pina-Amargós and Gonzalez- Sansón (2009) used conventional external tagging within and adjacent to the Jardines de la Reina Marine Reserve (JRMR) to understand goliath grouper movement patterns. This information was applied to improve management for this endangered species. Tagging for this study took

1 Center for Marine Research of the University of Havana, https://orcid.org/0000-0003-3837-3673

 https://doi.org/10.11647/OBP.0395.03

place in Jardines de la Reina (JR) in 2001, taking advantage of traditional knowledge of abundant populations of goliath grouper and logistic support from the tourism company. Five individuals were tagged in 2001 and tracked until 2003, with 541 underwater resightings through summer 2002 at the tagging sites. None of the tagged goliath groupers were again sighted after July 2002 at JR diving sites. In February 2002, one individual was caught 36km northeast of the tagging site. In August 2002, a second tagged specimen was caught 77km southeast of the tagging site. In August 2003, two individuals were captured 168km southeast of the tagging site, at a possible spawning aggregation site. All recaptures took place outside JRMR boundaries. The authors highlighted that despite the protection afforded to juveniles and adults by the JRMR, individuals obviously remain susceptible to capture during migrations.

Pina-Amargós and Gonzalez-Sansón (2009) recommended that management approaches to conserve the species included combining fisheries regulations and protected areas. The first approach would entail protecting the spawning aggregation sites, if they occur, by means of catch moratoria and gear restrictions; the second would require the creation of small or medium-sized marine protected areas (MPAs) that contain the spawning aggregation sites and migratory corridors in conjunction with other already established MPAs protecting non-spawning grouper habitat. As such, more research is needed to verify and characterize the status of potential goliath grouper spawning aggregations at Punta Macao and Cabo Cruz and provide recommendations for the spatial planning and designation of MPAs.

Pina-Amargós and Gonzalez-Sansón (2009) implicitly recognized the importance of promoting non-consumptive use of the goliath grouper as an ecotourism attraction for SCUBA divers and snorkelers, as has been happening in JR since the 1990s, but it was Figueredo-Martín et al. (2010a) who quantitatively assessed the importance of large fish species for JR ecotourism. Several of these facts were also included in a peer-reviewed paper about MPAs in Cuba (Perera-Valderrama et al., 2018).

Extensive interviews have been conducted throughout the entire country to gather traditional knowledge (ecology and fisheries) of goliath grouper (authors FPA and TFM, unpublished data). Traditional knowledge has proved to be an invaluable source for the gathering of information, and the protection and management of species of which little scientific information is available, such as goliath grouper in Cuba. Traditional knowledge about goliath grouper has been used to assess changes to abundance and distribution (Bravo-Calderon et al., 2021); understand reproduction, feeding, and behavior (Gerhardinger et al., 2006); generate information on spawning aggregation sites (Gerhardinger et al., 2009); consider the impacts of some fishing gears (Giglio et al., 2017); and discuss the effectiveness of certain conservation strategies (Zapelini et al., 2017).

Recently, a comparison of the monetary benefits contributed by large groupers (including the goliath grouper) between fisheries and ecotourism was published (Figueredo-Martín and Pina-Amargós, 2023). Fisheries of large groupers in the fishing zone surrounding Jardines de la Reina National Park (JRNP) represented US$121,707 per year, while ecotourism with these species inside JRNP reach US$417,328 annually. This result showed that the enjoyment of large grouper by SCUBA divers and snorkelers provides 3.4 times more monetary benefits than their consumption as food.

Here we summarize the scientific knowledge of the species in Cuba, including unpublished results on movements outside the spawning aggregation site, dynamics at the spawning aggregation site and fisheries information, and how a combination of tools (protected areas, ecotourism, and fisheries) and stakeholder involvement, has strengthened the protection of goliath grouper in the largest archipelago of the Caribbean. In this chapter we aim to show that diverse sources of information, stakeholders' involvement and the combination of management tools yield the best results for conserving endangered species such as goliath grouper.

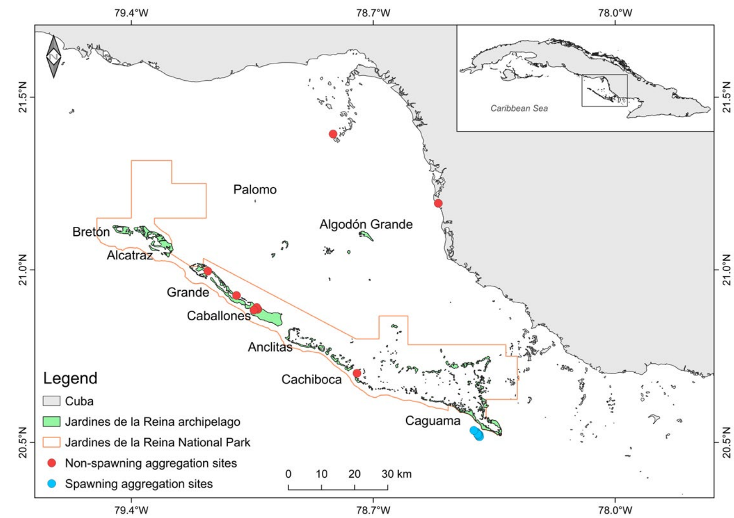


Fig. 3.1 Map of the study sites. Details showing goliath groupers tagged and released outside the spawning aggregation site (red circles) and goliath groupers tagged and released and sighted at the spawning aggregation site (blue circles).

Information about goliath grouper: quantitative and qualitative

This research took place nationwide, but with an underwater fieldwork focus in southeastern parts of Cuba, on Sancti Spíritus, Ciego de Ávila, and Camagüey provinces, mainly in Cayos de Ana María, islands of the Golfo de Ana María and JR (Figure 3.1), spatially expanding upon the previous study (Pina-Amargós and Gonzalez-Sansón, 2009). In 1996, approximately 950km^2 of JR was declared as a Marine Reserve (JRMR) where only lobster fishing and limited catch and release recreational fishing was allowed as part of a tourism operation that included SCUBA diving (Figueredo-Martín et al., 2010a, b) (Resolution 562/1996, former Ministry of Fisheries). In 2010, around 2,170km^2 were declared as a National Park (JRNP) (Agreement 6803/2010, Council of the State). JRNP regulations are based on fisheries regulations of the JRMR but more detailed zoning was included and regulations were expanded to all uses allowed in the area such as tourism, navigation, anchoring, scientific research.

Ten expeditions were carried out to study the goliath grouper (2013 (March, April–May, July, August, September); 2014 (April–May, July, August, September); 2015 (February)). Fishing effort of set-lines on mangrove shorelines and mangrove channels (0.5–4m deep) was 21,750 hooks.hours during 91 days at 74 sites (Box 3.1, Figure 3.2A). Fishing effort of hand-lines on coral reef slopes and spur and groove (25–45m deep) spawning aggregation sites was 417 hooks.hours during 32 days at one site (Figure 3.2B). Visual census effort on spawning aggregation sites consisted of 52.7 dives.hours during 22 days at 6 sites (Figure 3.2C and 3.3). Logistical constraints prevented surveys during all moon phases, so we decided to focus on before and during the Last Quarter, which corresponds to peak spawning according to the fishers we interviewed. We collected measurements and biological data from goliath groupers caught by fishers at the spawning aggregation site to assess their size, sex structure, and reproductive status. We classified gonad stages according to García-Cagide et al., (2001).

Fig. 3.2 Research methods used to study goliath grouper. Legend: A: set-line, B: hand-line, C: visual census, D: interviews.

We interviewed 36 fishers at sea and within their communities to obtain local ecological knowledge about the species ecology and history of goliath grouper fisheries (Figure 3.2D). We used a semi-structured questionnaire for the interviews (see Supplemental Bibliography). We also reviewed fisheries data from Cuba from 2000 to 2013 to assess temporal changes of commercial landings of goliath grouper.

Movements outside the spawning aggregation site

We caught (tagged and released) a total of 15 specimens and sighted a total of five specimens outside spawning aggregations (mean size 92.37 $\pm$ 2.83cm) (Table 3.1, Figure 3.1, Figure 3.3). One specimen (69.2 cm) was caught on a patch reef 3m deep outside JRNP. One specimen (89.7 cm) was caught on a wreck in a seagrass channel 3m deep inside the JRNP. Thirteen (81–120.5 cm) were caught in mangrove channels 2.5–3.5m deep inside JRNP. The five sighted goliath groupers were seen in mangrove channels (sizes around 1m and 1–3m deep), inside JRNP. Regardless of the high fishing effort of the project, abundance was very low even in the well protected JRNP. This is not surprising due to the large size of the species and its spatial and feeding requirements (Sadovy and Eklund, 1999) and also owing to the high artisanal and commercial fishing pressure outside the protected area at the time of the study. The smallest specimen was observed in shallow water close to the mainland of Cuba. Medium sized fish (around 1 m) were located around shallow waters far from the mainland. The largest individuals (>1.5 m) were found on deep coral reefs along the shelf edge. This finding is consistent with ontogenetic habitat shifts and differences between juveniles and adults (Coleman et al., 2000).

Table 3.1 Tagging information of goliath grouper on southeastern Cuba. PR: patch reef, MC: mangrove channel, W: wreck.

Tagged				Recapture			Growth (cm.y-1)
Date	Tagged location	Habitat	Size (cm)	Time at liberty (days)	Recapture location	Size (cm)	
03/10/2013	Punta Arena	PR	69.2				
05/07/2013	Auras	MC	120.5				
05/14/2013	Cachiboca	MC	103.2	449	Same	110.0	5.53
06/03/2013	Estero Guasa	MC	100.0				
08/06/2013	Auras	MC	92.0	5	Same	92.0	0
08/07/2013	Auras	MC	92.5	267	Same	101.5	12.3
08/11/2013	Auras	MC	92.0	264	Same	97.0	6.91
05/01/2014	Auras	MC	93.5	90	Same	97.0	14.19
05/01/2014	Nicola	MC	93.0				
05/02/2014	Auras	MC	93.0	89	Same	97.0	16.4
05/04/2014	Juan Grin	W	89.7				
05/19/2014	Tronconera	MC	81.0	87	Same	83.0	8.39
05/20/2014	Tronconera	MC	88.0	87	Same	90.0	8.39
08/15/2014	Tronconera	MC	88.0				
08/15/2014	Tronconera	MC	90.0				

It is premature to discuss movement patterns and site fidelity since we have only recaptured eight goliath groupers, all of which were juveniles or early adults (90 -110 cm). All specimens were recaptured no more than 100m from their release point in mangrove channels, after 87 - 267 days (Figure 3.5A). This result is consistent with movement patterns detected for juveniles and early adults elsewhere (Eklund and Schull, 2001). As more movement data come in, we are expecting longer distance movements of adults, as found in Florida, U.S. (Eklund and Schull, 2001) and Jardines de la Reina, Cuba (Pina-Amargós and Gonzalez- Sansón, 2009). Growth was estimated at 10.30 $\pm$ 1.53cm per year, similar to those reported elsewhere for the size range of our study (Sadovy and Eklund, 1999; Artero et al., 2015a).

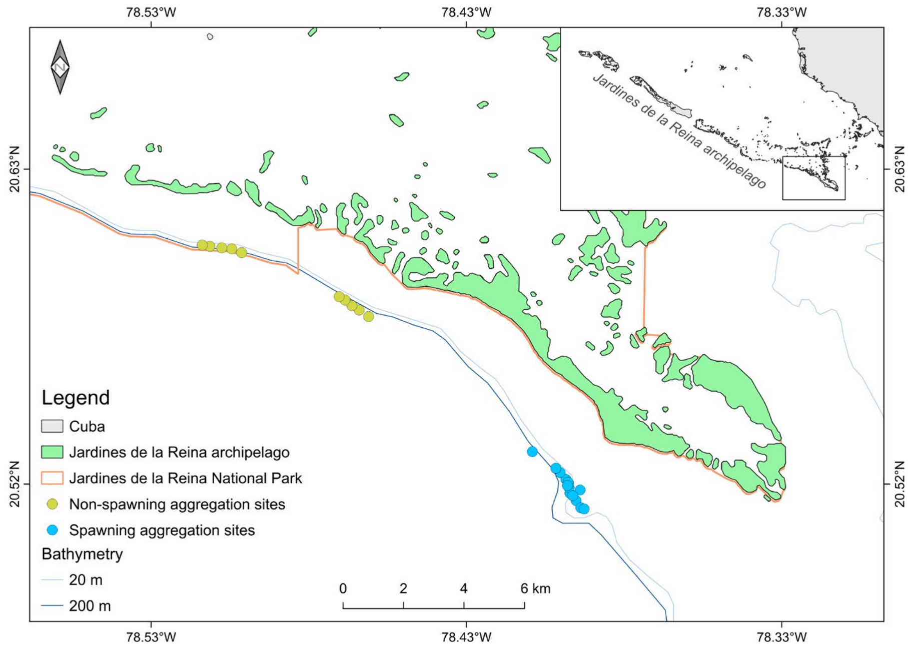


Fig. 3.3 Location of underwater visual census at a goliath grouper spawning aggregation site off Jardines de la Reina, Cuba.

Dynamics at the spawning aggregation site

Goliath groupers were mostly observed during the morning and afternoon during the two moon phases we surveyed (Full Moon and Last Quarter). In a 200m segment of the easternmost site, we counted 21 specimens (average of 5.3 specimens per dive) and caught (tagged and released alive) 11 specimens (Table 3.2, Figure 3.3 and 3.4). Mean size of caught specimens was 160.78 $\pm$ 8.57 cm. Our estimate of abundance is among the lowest reported for goliath grouper spawning aggregation sites (GMFMC, 1990; Sadovy and Eklund, 1999) and is presumably an indicator of overfishing. Out at the easternmost site no goliath groupers were sighted.

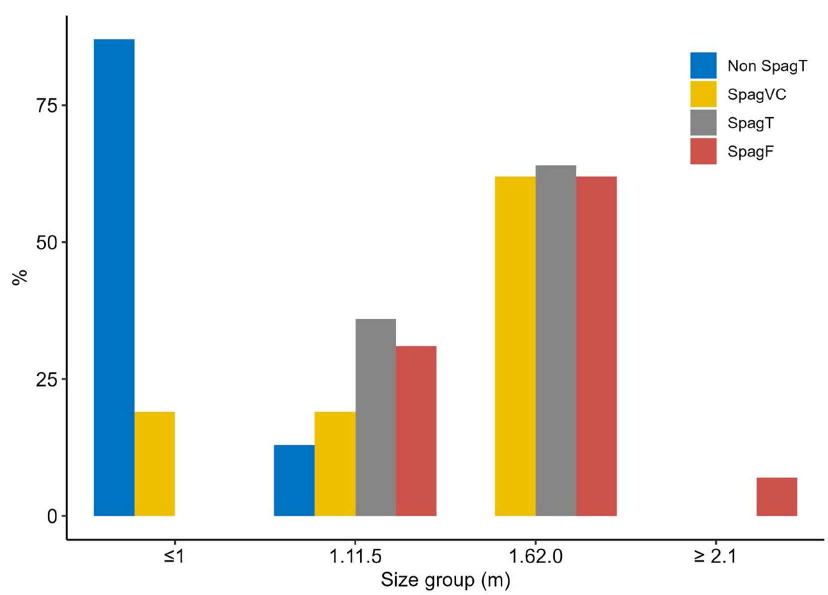


Fig. 3.4 Size composition of goliath grouper in south eastern Cuba. Legend: Non SpagT: specimens tagged outside the spawning aggregation site, SpagVC: specimens sighted by visual censuses on the spawning aggregation site, SpagT: specimens tagged at the spawning aggregation site, SpagF: specimens caught by fishing boat at the spawning aggregation site.

Table 3.2 Goliath grouper caught at the spawning aggregation in Jardines de la Reina. NI: not identified, M: male, F: female, Gonad stage according to García-Cagide et al. (2001): V: Ovulation and sperm release, VI: spent.

Method	**Date**	**Size (cm)**	**Sex**	**Gonad stage**
Tagging	09/02/2013	107.4	NI	NI
Fishing	09/02/2013	123.5	M	V
Fishing	09/02/2013	157.4	F	V
Tagging	09/05/2013	178.5	NI	NI
Fishing	09/05/2013	183.7	F	V
Fishing	09/05/2013	142.5	M	V
Tagging	07/19/2014	124.5	NI	NI
Fishing	07/19/2014	171.4	F	VI
Tagging	07/23/2014	168.5	NI	NI
Fishing	07/23/2014	190.0	F	V
Tagging	08/17/2014	136.0	NI	NI
Tagging	08/18/2014	175.5	NI	NI
Tagging	08/19/2014	186.5	NI	NI
Fishing	08/19/2014	201.6	F	VI
Fishing	08/19/2014	134.7	M	V
Fishing	08/19/2014	158.5	F	VI
Tagging	08/21/2014	192.7	NI	NI
Fishing	08/21/2014	180.0	F	V
Fishing	08/21/2014	145.3	M	V
Fishing	08/21/2014	169.5	F	VI
Tagging	09/16/2014	145.5	NI	NI
Fishing	09/16/2014	182.5	F	V
Fishing	09/16/2014	185.7	M	V
Tagging	09/17/2014	164.5	NI	NI
Fishing	09/17/2014	147.5	M	VI
Fishing	09/17/2014	163.2	F	VI
Tagging	09/18/2014	189.0	NI	NI

We used a generalized additive mixed model (GAMM) (the model) to analyse the data gathered (see details in Supplement section). The model showed an increase in the abundance of goliath groupers in the spawning aggregation site as the Last Quarter moon phase advanced (Table 3.3). Furthermore, the abundance of goliath grouper decreased during the morning and increased toward sunset (Table 3.3, Figure 3.6A).

Table 3.3 Results of the GAMM model applied to goliath grouper abundance and presence/absence by size (TL in meters) at one spawning aggregation site. Significant variables are in bold. St. error: standard error, edf: effective degrees of freedom, sq. Chi: squared Chi.

Negative binomial GAMM model (abundance)

	Estimated	St. error	Z	P
Intersect	-0.065	0.226	-0.288	0.773
Day	**0.059**	**0.028**	**2.116**	**0.036**
	edf		sq. Chi	P
Hour	**4.784**		**9.531**	**<0.001**

Logistic GAM model (size < 1 m)

	Estimated	St. error	Z	P
Intersect	-0.300	0.431	-0.695	0.487
day_2	-27.330	78310.0	0.000	1.000
day_7	-0.472	0.589	-0.801	0.423
day_8	-0.446	0.607	-0.735	0.463
day_10	-0.533	0.595	-0.897	0.370
day_11	**1.102**	**0.555**	**1.987**	**0.047**
day_12	0.064	1.136	0.056	0.955
	edf		sq. Chi	P
Hour	**4.223**		**26.140**	**<0.001**

Logistic GAM model (size 1-1.5 m)

	Estimated	St. error	Z	P
Intersect	**-1.801**	**0.451**	**-3.994**	**0.000**
July.2014	**0.950**	**0.424**	**2.240**	**0.025**
August.2014	**1.412**	**0.438**	**3.227**	**0.001**
Septiembre.2014	**1.043**	**0.393**	**2.656**	**0.008**
day_2	-31.630	790700.0	0.000	1.000
day_7	0.513	0.434	1.182	0.237
day_8	0.640	0.441	1.453	0.146
day_10	-0.311	0.461	-0.675	0.500
day_11	0.016	0.442	0.036	0.971
day_12	-1.856	1.063	-1.746	0.081
	Edf		sq. Chi	p
Hour	**4.710**		**30.820**	**<0.001**

Logistic GAM model (size >1.5 m)

	Estimated	St. error	Z	p
Intersect	**-4.258**	**1.707**	**-2.494**	**0.013**
July.2014	**1.386**	**0.582**	**2.383**	**0.017**
August.2014	**1.294**	**0.591**	**2.190**	**0.029**
September.2014	0.395	0.515	0.767	0.443
day_2	-28.500	73500.0	0.000	1.000
day_7	-0.016	0.793	-0.021	0.983
day_8	0.322	0.851	0.379	0.705
day_10	-1.018	0.826	-1.233	0.218
day_11	**2.058**	**0.799**	**2.577**	**0.010**
day_12	**-2.950**	**1.286**	**-2.294**	**0.022**
Depth	**0.136**	**0.052**	**2.585**	**0.010**
	edf		sq. Chi	p
Hour	**3.501**		**28.430**	**<0.001**

Fig. 3.5 Field work on goliath grouper in southeastern Cuba. Legend: A: goliath grouper recaptured at mangrove channel, B: goliath grouper caught at the spawning aggregation site landed, C: Testis of goliath grouper full of milt, D: hand line gear.

The model showed significant differences in the days of the lunar phase, with smaller goliath grouper occurring in larger numbers towards the end of the surveys (Table 3.3). Diel patterns were the same as observed when we modelled total abundance, where the presence of small goliath groupers decreased during the morning and increased toward sunset (Table 3.3, Figure 3.6B).

According to the model, medium-sized goliath groupers (1–1.5m TL) sighting frequency showed significant differences between September 2013 and the three months surveyed in 2014, but there were no differences among 2014 months nor among the days of the moon phase (Table 3.3). Diel patterns were consistent with the previous two analyses (Table 3.3, Figure 3.6C).

According to the model, large-sized goliath groupers (>1.5m TL) sighting frequency showed significant differences among September 2013 and July and August 2014 (Table 3.3), with more presence of those large individuals in 2014, but there were no differences among spawning months in 2014. The model showed significant differences in the days of the lunar phase, with large goliath grouper occurring more towards the end of the Last Quarter moon phase (Table 3.3). In the case of depth, large goliath groupers were more abundant in deeper waters. Diel patterns followed the same as the previous three analyses (Table 3.3, Figure 3.6D).

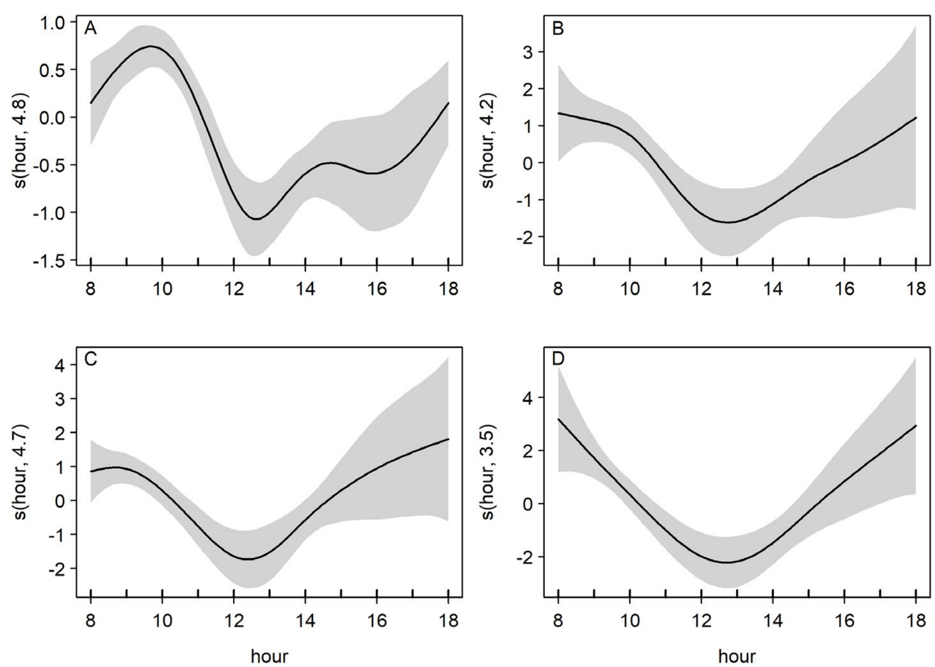


Fig. 3.6 Curves of the GAMM models applied to goliath grouper abundance (A) and to presence/absence by size (TL in meters) (B-D) from a spawning aggregation site at Jardines de la Reina, Cuba. (A) abundance, (B) <1 m, (C) 1-1.5 m, (D) >1.5 m. The shaded area represents the 95 % confidence interval.

Most of our findings related to spawning months are consistent with previous research. Summer spawning has also been confirmed in the south-eastern U.S.A. (Bullock et al., 1992; Eklund and Schull, 2001; Koenig et al., 2011). Previous studies have shown that the New Moon is the peak of the spawning in several places (e.g., Koenig et al., 2011 for U.S.A; and Bueno et al., 2016 for Brazil). In the present study, goliath grouper abundance and catch rates were highest during the Last Quarter moon. As we did not see actual spawning at daylight, we assume spawning of goliath grouper occurs at night as reported by fishers and scientific publications (e.g., Mann et al., 2009). To the best of our knowledge, the two findings of diel abundance changes and large-size specimens being more abundant on deeper reefs have not previously been reported. In all cases, the number of goliath grouper at the spawning aggregation site decreased through the morning, with a minimum at noon, and increased again toward the end of the afternoon. Whether that is a result of a daily movement pattern to deeper/shallower habitats, and what the causes of it are, deserves further research.

The other novel finding is that larger goliath groupers (presumably females according to our data, see below) were consistently observed in deeper waters while medium and small size fish seem to use the whole range of depth surveyed. Sex segregation by depth on spawning aggregations (and out of spawning season as well) has been observed on gag grouper (*Mycteroperca microlepis*) (Coleman et al., 1996; Koenig et al., 1996; McGovern et al., 1998; Sedberry et al., 2006). Females of this species form pre-spawning aggregations in relatively shallow water (20 m) before moving to shelf-edge reefs (50-100 m) for spawning. Outside of the spawning season, males remain on spawning sites while females move into shallower water. Whether goliath grouper show similar behaviors requires further research. Although statistically significant, diel fluctuations of abundance/presence/absence and size related depth findings were based on small sample sizes, thus these findings should be taken cautiously. An alternative explanation would be that larger specimens are scarcer in shallower water due to fishing. This is supported by anecdotal information showed in the following section but, to the best of our knowledge, this hypothesis has not been tested for this or other species in the Caribbean or elsewhere.

Fisheries information at the spawning aggregation site

We were able to survey one commercial fishing boat fishing at the goliath grouper spawning aggregation site for eight nights in September 2013, and July, August, and September 2014. A total of 16 goliath groupers were caught (123.5–201.6 cm; 32–155 kg gutted; sex ratio 1.66:1 (10 females, 6 males)) (Table 3.2; Figure 3.3, 3.4, 3.5B). This sex ratio is similar to that previously reported (Bullock et al., 1992). The gonads were in spawning condition (stage V, 62%) or spent (stage VI, 38%), as found in previous studies on spawning season (Bueno et al., 2016; Koenig et al., 2016) (Figure 3.5C). The stomachs of all specimens were empty. Previous studies show around half of the stomachs empty (Artero et al., 2015b), likely, due to its larger sample size when compared to our study.

The abundance/presence/absence of goliath grouper detected through underwater visual censuses on the easternmost site, temporal patterns of those variables (day, moon phase and months), the confirmation of the commercial fishing of goliath groupers taking place in the site as well as the active reproductive condition of gonads sampled suggests the existence of a spawning aggregation site, the first detected by science in Cuba.

According to fisheries data and fisher interviews, the goliath grouper is not a highly valued fishery resource in Cuba, despite being considered a high-quality species. Commercial fisheries data from southern Cuba between 1981-2013 show that goliath grouper landings represented an average of 0.02% (average of 8.6 tons, minimum of 0.9 tons and maximum of 23.7 tons) of the total national landings (Figure 3.7). Commercial landings from southern Cuba have decreased steadily since 1981, reflecting overfishing: average landings between 2003 and 2013 (3.2 tons) represented 17% of that between 1981-1991 (18.6 tons). Southern Cuba was the most important goliath grouper fishing ground: average landings represented 76% of the entire country between 1981-2013 (8.6 tons of 11.6 tons) (Figure 3.7). However, this data does not reflect the total fishing mortality since, according to our interviews, goliath grouper is heavily targeted by spear fishers nationwide, which species' landings likely surpassed those of the commercial fisheries as reported in the Atlantic and Gulf of Mexico coasts of U.S.A. (Sadovy and Eklund, 1999).

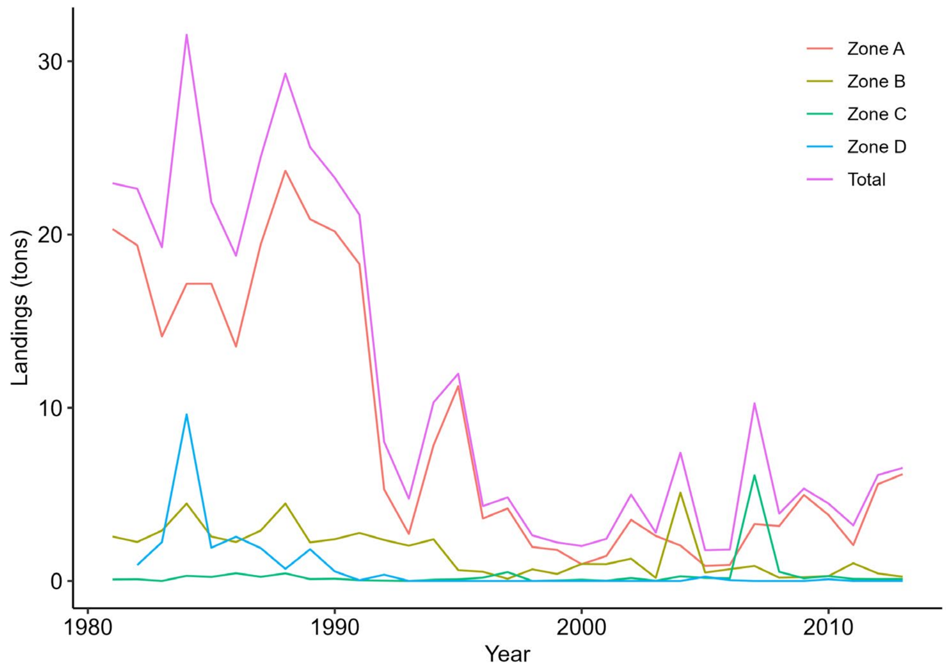


Fig. 3.7 Landings of goliath grouper between 1981 and 2013 from the four Cuban fishing zones.

Despite its low commercial fisheries importance, goliath grouper caught are consumed by fishers and their families or marketed informally. Thus, commercial fisheries data do not accurately reflect true catch. The fishery of goliath grouper in Cuba is divided into artisanal and commercial. The artisanal fishery uses spearguns throughout the year, and handlines during the spawning season. Speargun fishers targeted the species at fish aggregating devices, wrecks, piers, deep mangrove channels, patch reefs, and deep coral reef slopes, and spur and groove habitats. During the spawning aggregation season (July to September) artisanal fishers used hand-lines (Figure 3.5D). The gear is made of 2–3mm monofilament and/or 8–10mm rope armed with large hooks baited with large pieces of fish such as barracuda chunks, whole lobsters, or medium-sized live reef fish. 20 or more years ago, hand line fishing for goliath grouper took place around 30m depth, but in 2013-2014, fishers began fishing deeper (e.g., > 50 m). This was likely due to the depletion of spawning populations in shallower waters, though, we saw spawning size specimens around at 30 to 40m deep. Commercial boats fished for goliath grouper as a secondary source of income. All boats had another primary target species, typically deeper water snappers and groupers, but at the end of the fishing day they anchored in a selected spot (known in Cuba as "*potala*") and fished for goliath grouper throughout the night until daylight.

Fishers indicated that goliath grouper bite more during the Last Quarter moon between the months of July–September and less in other moon phases during the spawning season. Fishers also reported that during the Last Quarter goliath grouper are caught in larger numbers in shallow waters, but this differs from other phases of the moon where fish are caught in deeper water. Based on our limited catch surveys, and fisher interviews, we estimated that an average of 154 goliath grouper were caught every year from the population at only one site (surveys: 16 specimens caught over 8 nights, commercial fishing effort on the spawning aggregation site averages 77 nights per year). The average weight of those goliath groupers was estimated to be 35.7 kg (154 specimens divided by 5.5 tons (average landing per year of the fishing boat surveyed)). The largest goliath grouper ever caught by the fishing boat surveyed was a 173 kg gutted specimen.

History of goliath grouper conservation in Cuba

There are several tools available for protecting goliath grouper. Fisheries regulation was the only one used in Cuba for long time, with spatial protection and non-consumptive uses such as ecotourism, as the ones Cuba has been implementing for this iconic species in the last few years. Spatial protection of the marine environment is relatively new in Cuba. In the early 1990s, there were no marine protected areas (MPAs) declared under environmental or fisheries legislations, but in 2001, 18 MPAs were designated under environmental legislation (Perera-Valderrama et al., 2018) and 40 marine reserves were declared under fisheries legislation (Kritzer et al., 2014). In 2012, numbers increased to 56 MPAs (Perera-Valderrama et al., 2018) and as of 2021 Cuba legally has approved 64 MPAs (Perera-Valderrama et al., 2021). More than half of these MPAs do not allow fishing inside their boundaries. Even though none of these MPAs have been created specifically to protect goliath grouper, their coverage of Cuban shelf habitats should contribute to its conservation. Currently, a fifth of the entire Cuban shelf, more than a third of Cuban coral reefs, more than a quarter of seagrasses, and more than a third of mangroves are located inside MPAs (Perera-Valderrama et al., 2018). Scientific evidence in Cuba and elsewhere suggest that goliath grouper have a relatively small home range that theoretically should allow even small, protected areas to support its conservation. However, with periodic migrations outside the boundaries of protected areas, they remain highly vulnerable to fishing. In addition to this, enforcement of regulations within many MPAs is still weak and illegal fishing is common practice (Perera-Valderrama et al., 2018).

Among Cuban marine protected areas, JRNP is one of the best examples of strong enforcement. This is mainly due to the ecotourism that takes place there, a successful example of mixing spatial protection and alternative use of the species. SCUBA divers and snorkelers are willing to pay to enjoy large fishes, such as goliath grouper, during their underwater activities (Figueredo-Martín et al., 2010a; Figueredo-Martín and Pina-Amargós, 2023). A portion of the financial benefits are used to support the enforcement of fisheries and environmental regulations within the protected area, to effectively deter illegal fishing and repel poachers. Tourism also supports research by providing the logistical support for long-term continuous monitoring in JRNP. These activities help protect the natural resources upon which tourism depends, and staff conservation ethos is concomitantly high. The high abundance and biomass of large and commercially important fish such as sharks, groupers, and snappers in JRNP, result from proper enforcement and incentives favouring conservation, while allowing humans to make a living from it.

Unfortunately, JRNP is only a small portion of the Cuban shelf, and more is needed to protect goliath grouper nationwide, beyond spatial protection and the promotion of non-consumptive use. Next, we discuss fisheries regulations that promote conservation of goliath grouper in Cuba, their pros and cons, and how a step-wise approach was applied to stakeholder involvement. All of the above, based on the best science available and traditional knowledge, led to success in protecting this endangered and important species.

For many years, the only fishing regulation for goliath grouper in Cuba was a minimum size limit, which was 960 grams (around 25cm TL) (Resolution 561/96 Ministry of Fisheries). That was increased to 40cm more than ten years later (Resolution 126/09 Ministry of Food (former Ministry of Fisheries)). Those regulations allowed almost 100% of goliath groupers caught in Cuban waters to be landed, and obviously contributed nothing to the species' protection. Increasing the minimum size to 110cm TL, was one of the alternatives we proposed to enhance goliath grouper protection in Cuba. This would allow most goliath groupers to spawn at least once before being caught. It is also a rule relatively easy to enforce among Cuban spear-fishers, since they are capable of selecting specimens by estimating their size. However, it is not very effective for handlines that target spawning aggregations, since hooks, and abrupt pressure change, usually damage internal organs (due to expansion of the swim bladder), causing high mortality rates of released undersized fishes. On the other hand, large minimum sizes such as the one proposed for goliath grouper are hard to enforce, as a consequence of the apparent contradiction that many undersized goliath groupers would be larger than almost all legal-sized fishes of the other species. Furthermore, Cuban fishers are culturally more willing to release small fishes than large ones.

Another fisheries regulation that we assessed to promote conservation of goliath grouper in Cuba, was to prohibit spearfishing of goliath grouper nationwide. Spearfishing is considered the most effective fishing gear for goliath grouper (Sadovy and Eklund, 1999) and is widespread in Cuba. Therefore, implementing this rule would undoubtedly benefit the species. However, there were two main reasons this regulation would be hard to implement. First, it would be considered discriminatory of the spear fishers, with concomitant implication on compliance. Second, its compliance would be even lower because spear fishers target large specimens, and they would not naturally agree to leave goliath groupers alive when spotted.

The fisheries regulation likely to be the most effective for goliath grouper conservation and most accepted by fishers, would be prohibiting fishing around the reported spawning aggregation site of Punta Macao in July, August and September, a combination of spatial and temporal closure, supported by scientific and traditional knowledge. Although fishers usually oppose any regulation limiting their livelihood, the small spatial and temporal scale of the limitation imposed by this regulation, would be expected to produce high compliance, and would protect locally the species on its more vulnerable life cycle phase.

Taking into consideration the pros and cons of the above regulations, we accepted the challenge. At the beginning of 2018, a group of scientists from Avalon Fishing and Diving Center (authors FPA and TFM), and the Center for Coastal Ecosystems Research (author YOE) submitted a petition, supported by the Center for Fisheries Research, to the Consultative Fisheries Commission to advance goliath grouper conservation in Cuba. The petition compiled the state of the knowledge of the species in its natural range, including possible actions to protect the species. It also included the scarce, but important information obtained in Cuba, coming mainly from JRMR: evidence of declining populations nationwide; movement patterns that do not offer full protection even inside a large MPA; higher economic value for ecotourism versus fisheries; the unsustainable nature of the current minimum legal size; the fishing on spawning aggregations; and the existence of a spawning aggregation site without spatial protection. Taking into account the null precedent on bans of fisheries resources in Cuba, the proposal made three recommendations: prohibiting fishing around the reported spawning aggregation site of Punta Macao in July, August and September; establishing a minimum legal size at 110cm of TL; and last, prohibiting spearfishing of goliath grouper nationwide. The proposal was so compelling, that the Consultative Fisheries Commission agreed to propose a complete ban of fishing goliath grouper in Cuba and carry out a nationwide consultation among fishers and other stakeholders.

For several months there were meetings at fishing communities, and the proposal was shared among other stakeholders. Fishers first opposed the proposed regulations for reasons discussed previously, but scientific facts provided them with enough information to support the proposal later. As important as the scientific facts, were the ways we interacted with the fishers, and how we presented the scientific information. There were several formal meetings, but most of the interactions with fishers were informal (taking advantage of our personal relationships with many of them, built during many years of knowing each other), meetings at their homes, harbours and gathering places. We showed them pictures and videos of spawning aggregations of goliath grouper with many specimens, and others where they no longer aggregate, and with divers enjoying the underwater experience with goliath groupers in order to show them the success and failure stories of human interaction with this species. After the involvement with fishers and other stakeholders, consensus was achieved and the Resolution 178/2018 was passed, to fully protect goliath grouper in Cuban waters.

Closing remarks

In this chapter, we aimed to show that diverse sources of information, stakeholders' involvement, and the combination of management tools, yield the best results for conserving endangered species. The case of goliath grouper conservation in Cuba is an example of the hard, but possible task of protecting traditional fisheries resources. Science, traditional knowledge, political will, stakeholders' involvement, delivering messages in several ways and venues, international collaboration and multiple management tools acting together, helped to advance conservation for this endangered species. This is a good example how diverse approaches have more profound positive impacts on species conservation, than a single approach. This diverse approach is worthy of application for endangered fish species not only in Cuba, but also in the Caribbean and elsewhere.

Acknowledgements

The authors thank Avalon Fishing and Diving Center for its incredible and long-lasting support for scientific research on Jardines de la Reina, especially G. Omegna (Pepe) and Noel López; and the Pew Fellowship for Marine Conservation and Environmental Defense Fund for contributing to the conservation of goliath grouper in Cuba, through the FPA Fellowship. We are also grateful to the personnel of several institutions who support research and conservation of goliath grouper in Cuba: Center for Coastal Ecosystems Research (Cuba), Center for Environmental Research of Camagüey (Cuba), fishers from Júcaro, Santa Cruz del and Cabo Cruz, Ministry of Food (Cuba), Center for Fisheries Research (Cuba), Center for Marine Research of Havana University (Cuba) and World Wildlife Fund (WWF) Canada.

Supplementary section

Box 3.1 Explanation of hooks.hours and dives.hours.

Hooks.hours and dives.hours are not averages but totals. The fishing effort using set line hooks and the survey effort using dive time are not always the same. Therefore, these methods are the best ways to demonstrate and standardize those efforts. For clarification, please see the following two examples below:

1. If we place 32 set line hooks in a mangrove channel for 5 hours, we would have 160 hooks.hours (32 hooks x 5 hours = 160 hooks.hours). Similarly, if we place 50 set line hooks in the same channel for 4.5 hours, we would have 225 hooks.hours. This allows us to calculate the catch per unit of effort by dividing the number of fish caught by either 160 or 225, or the sum of both (385).

2. If at a coral reef spawning aggregation site, you have 5 divers and each one stays underwater for 30 minutes (0.5 hour), you would have 2.5 dives.hours (5 dives x 0.5 hours = 2.5 dives.hours). Similarly, if you have 4 divers at the same site and each one stays underwater for 45 minutes (0.75 hour), you would have 3 dives.hours. This allows you to calculate the abundance per unit of effort by dividing the number of fish sighted by either 2.5 or 3, or the sum of both (5.5).

Quantitative data analysis

We used a generalized additive mixed model (GAMM) to characterize the total abundance of goliath grouper at the spawning aggregation site as a function of hour of the day, day of the moon phase, month, and depth, using the mgcv package in R (Wood 2017; R Core Team 2018). The optimum GAMM model incorporated the hour of the day adjusted (*cyclic cubic regression splines*) and the days of the moon phase. The GAMM model included a spherical correlation structure that adjusted a self-correlation of the days of the moon phase and months. The optimum GAMM model for presence/absence of small size goliath groupers (< 1m TL) incorporated the hour of the day adjusted (*cyclic cubic regression splines*) and the days of the moon phase. The optimum GAMM model for presence/absence of medium size goliath groupers (1–1.5m TL) incorporated the hour of the day, days of the moon phase, and months. The optimum GAMM model for presence/absence of large size goliath groupers (>1.5m TL) incorporated the hour of the day, days of the moon phase, months, and the depth.

References

Artero, C., D. J. Murie, C. C. Koenig, R. Berzins, C. Bouchon and L. Lampert. (2015a). Age, growth, and mortality of the Atlantic goliath grouper Epinephelus itajara in French Guiana. Endangered Species Research 28: 275-287. https://doi.org/10.3354/esr00691

Artero, C., C. C. Koenig, R. Berzins, C. Bouchon and L. Lampert. (2015b). Ontogenetic dietary and habitat shift in goliath grouper Epinephelus itajara from French Guiana. Endangered Species Research 27: 155-168. https://doi.org/10.3354/esr00661

Bertoncini A. A., A. Aguilar-Perera, J. Barreiros, M. T. Craig, B. P. Ferreira, C. C. Koenig. (2018). *Epinephelus itajara* (errata version published in 2019). The IUCN Red List of Threatened Species 2018:e.T195409A145206345. https://dx.doi.org/10.2305/IUCN.UK.20182.RLTS.T195409A145206345.en

Bravo-Calderon A., A. Saens-Arroyo, S. Fulton, A. Espinoza-Tenorio, E. Sosa-Cordero. (2021). Goliath grouper Epinephelus itajara oral history, use, and conservation status in the Mexican Caribbean and Campache Bank. Endangered Species Research 45: 283-300. https://doi.org/10.3354/esr01135.

Bueno, L. S., A. A. Bertoncini, C. C. Koenig, F. C. Coleman, M. O. Freitas, J. R. Leite, T. F. De Souza and M. Hostim-Silva. (2016). Evidence for spawning aggregations of the endangered Atlantic goliath grouper Epinephelus itajara in southern Brazil. Journal of Fish Biology 89(4): 2378-2391. https://doi.org/10.1111/jfb.13028

Bullock, L. H., D. Murphy, M. F. Godcharles and M. E. Mitchell. (1992). Age, growth, and reproduction of jewfish Epinephelus itajara in the eastern Gulf of Mexico. Fishery Bulletin 90(1): 243-249.

Claro, R. and K. C. Lindeman. (2003). Spawning aggregation sites of snapper and grouper species (Lutjanidae and Serranidae) on the insular shelf of Cuba. Gulf and Caribbean Research 14(2): 91-106.

Claro, R., K. C. Lindeman and L. Parenti. (eds.). (2001). Ecology of the Marine Fishes of Cuba. Washington, DC: Smithsonian Institution Press.

Coleman, F. C., C. C. Koenig and L. A. Collins. (1996). Reproductive styles of shallow-water groupers (Pisces: Serranidae) in the eastern Gulf of Mexico and the consequences of fishing spawning aggregations. Environmental Biology of Fishes 47(2): 129-141.

Coleman, F. C., et al. (2000). Long-lived reef fishes: The grouper-snapper complex. Fisheries 25(3): 14-21.

Eklund, A. M. and J. Schull. (2001). A stepwise approach to investigating the movement patterns and habitat utilization of goliath grouper, Epinephelus itajara, using conventional tagging, acoustic telemetry, and satellite tracking. In J. R. Sibert and J. L. Nielsen (eds.), Electronic tagging and tracking in marine fisheries (pp. 189-216). Philadelphia, USA: Kluwer Academic Publishers.

Figueredo-Martín, T., and F. Pina-Amargós. (2023). Fish Can Be more Valuable Alive than Dead. In Zlatarski, V. N. et al (eds.), Coral Reefs of Cuba (pp. 429-438). Switzerland: https://doi.org/10.1007/978-3-031-36719-9.

Figueredo-Martín, T., F. Pina-Amargós, J. A. Angulo-Valdés and R. Gómez-Fernández. (2010a). Buceo contemplativo en Jardines de la Reina: caracterización y percepción sobre el estado de conservación en el área. Revista de Investigaciones Marinas 31(1): 23-32.

Figueredo-Martín, T., F. Pina-Amargós, J. A. Angulo-Valdés and R. Gómez-Fernández. (2010b). Pesca recreativa en Jardines de la Reina: caracterización y percepción sobre el estado de conservación en el área. Revista de Investigaciones Marinas 31(2): 141-148.

FFWCC (Florida Fish and Wildlife Conservation Commission). (2024). https://myfwc.com/license/recreational/saltwater-fishing/goliath-grouper-harvest-permit/

García-Cagide, A., R. Claro and B. V. Koshelev. (2001). Reproductive patterns of fishes of the Cuban Shelf. In R. Claro, K. C. Lindeman and L. Parenti (eds.), Ecology of the Marine Fishes of Cuba (pp. 73-114). Washington, DC: Smithsonian Institution Press.

GMFMC (Gulf of Mexico Fishery Management Council). (1990). Amendment Number 2 to the Fishery Management Plan for the Reef Fish Fishery of the Gulf of Mexico. GMFMC.

Gerhardinger, L. C., R. C. Marenzi, Á. A. Bertoncini, R. P. Medeiros and M. Hostim-Silva. (2006). Local ecological knowledge on the goliath grouper *Epinephelus itajara* (Teleostei:Serranidae) in southern Brazil. Neotrop Ichthyol 4: 441-450.

Gerhardinger, L. C., M. Hostim-Silva, R. P. Medeiros, J. Matarezi, Á. A. Bertoncini, M. O. Freitas and B. P. Ferreira. (2009). Fishers' resource mapping and goliath grouper *Epinephelus itajara* (Serranidae) conservation in Brazil. Neotrop Ichthyol 7: 93-102.

Giglio, V. J., M. G. Bender, C. Zapelini and C. E. L. Ferreira. (2017). The end of the line? Rapid depletion of a large-sized grouper through spearfishing in a subtropical marginal reef. Perspect Ecol Conserv 15: 115-118.

Heemstra, P. C. and J. E. Randall. (1993). FAO species catalogue. Vol 16. Groupers of the world (Family Serranidae, Subfamily Epinephelinae). An annotated and illustrated catalogue of the grouper, rockcod, hind, coral grouper, and lyretail species known to date. FAO Fisheries Synopsis no. 125, FAO.

Koenig, C. C., F. C. Coleman, L. A. Collins, Y. Sadovy and P. L. Colin. (1996). Reproduction of gag (Mycteroperca microlepis) (Pisces: Serranidae) in the eastern Gulf of Mexico and the consequences of fishing spawning aggregations. In ICLARM Conference 48. ICLARM Conference Proceeding (pp. 307-323). Manila, Philippines.

Koenig, C. C., F. C. Coleman and K. Kingon. (2011). Pattern of recovery of the goliath grouper (Epinephelus itajara) population in the southeastern US. Bulletin of Marine Science 87(4): 891-911. http://dx.doi.org/10.5343/bms.2010.1056

Koenig, C. C., L. S. Bueno, F. C. Coleman, J. A. Cusick, R. D. Ellis, K. Kingon, J. V. Locascio, C. Malinowski, D. J. Murie and C. D. Stallings. (2016). Diel, lunar, and seasonal spawning patterns of the Atlantic goliath grouper, Epinephelus itajara, off Florida, United States. Bulletin of Marine Science 92(1): 1-16. http://dx.doi.org/10.5343/bms.2016.1013

Kritzer, J. P., C. C. Hicks, B. D. Mapstone, F. Pina-Amargós and P. F. Sale. (2014). Ecosystem-based management of coral reefs and interconnected nearshore tropical habitats. In M. J. Fogarty and J. J. McCarthy (eds.), Marine Ecosystem-Based Management (pp. 369-428). Harvard University Press.

Mann, D. A., J. V. Locascio, F. C. Coleman and C. C. Koenig. (2009). Goliath grouper (Epinephelus itajara) sound production and movement patterns on aggregation sites. Endangered Species Research 7: 229-236.

McGovern, J. C., G. R. Sedberry and P. J. Harris. (1998). Status of stocks of reef fishes in the South Atlantic Bight, 1983-1996. Proceedings of the Gulf and Caribbean Fisheries Institute 50: 871-895.

Perera-Valderrama, S., A. Hernández, J. González, O. Moreno, D. Cobián-Rojas, H. Ferro-Azcona, E. Milián, H. Caballero, P. Alcolado, F. Pina-Amargós, Z. Hernández, L. Espinosa, L. F. Rodríguez. (2018). Marine protected areas in Cuba. Bulletin of Marine Science 94(2): 423-442.

Perera-Valderrama, S., J. González-Méndez, A. Hernández-Ávila, R. Estrada-Estrada, D. Cobián-Rojas, A. Ramón-Puebla, E. de la Guardia-Llansó, H. Ferro-Azcona, J. Hernández-Albernas, Z. Hernández-González, L. Espinosa-Pantoja, A. Lara, F. Pina-Amargós, P. González-Díaz, P. P. Chevalier-Monteagudo, N. Rey-Villiers, J. Antonio Tamayo-Fonseca and H. Caballero-Aragón. (2021). Coral reefs in Cuban marine protected areas. In Z. N. Vassil and B. J. Greenstein (eds.), Coral Reefs of Cuba (Series of Coral Reefs of the World). Springer. In review.

Pina-Amargós, F. and G. González-Sansón. (2009). Movement patterns of goliath grouper Epinephelus itajara around southeast Cuba: implications for conservation. Endangered Species Research 7: 243-247.

Sadovy, Y. and A. Eklund. (1999). Synopsis of biological data on Nassau grouper, Epinephelus striatus (Bloch 1792), and the jewfish, E. itajara (Lichtenstein 1822). NOAA Tech Rep NMFS 146. US Dept Commerce.

safR Core Team. (2018). R: A language and environment for statistical computing. R Foundation for Statistical Computing. Retrieved from https://www.R-project.org/

SAFMC (South Atlantic Fishery Management Council). (1990). Amendment number 2, regulatory impact review, regulatory flexibility analysis and environmental assessment for fishery management plan for the snapper grouper fishery of the South Atlantic region. SAFMC.

Sedberry, G. R., O. Pashuk, D. M. Wyanski, J. A. Stephen and P. Weinbach. (2006). Spawning locations for Atlantic reef fishes off the southeastern US. Proceedings of the Gulf and Caribbean Fisheries Institute 57: 463-514.

Smith, C. L. (1971). A revision of the American groupers: Epinephelus and allied genera. Bulletin of the American Museum of Natural History 146: 69-241.

Wood, S. N. (2017). Generalized Additive Models: An Introduction with R (2nd edition). Boca Ratón: Chapman and Hall/CRC Press. https://doi.org/10.1201/9781315370279

Zapelini C., V. J. Giglio, R. C. Carvalho, M. G. Bender, L. C. Gerhardinger. (2017). Assessing fishing experts' knowledge to improve conservation strategies for an endangered grouper in the southwestern Atlantic. J Ethnobiol 37: 478-493.

4. New approaches to conserving endangered sea turtles

Dana K. Briscoe,[1] *Bianca S. Santos, Calandra N. Turner Tomaszewicz, and Larry B. Crowder*

In 1996, marine biologist Wallace J. Nichols and colleagues released a female loggerhead sea turtle (*Caretta caretta*) named Adelita off the Pacific coast of Baja California, Mexico (Resendiz et al., 1998; Nichols et al., 2000). After spending most of her adult life in captivity it was hoped that Adelita, outfitted with a satellite tracking device, would provide insight into the at-sea portion of a sea turtle's life history for which little was known (Carr, 1980). For decades, aggregations of juvenile loggerheads were known to feed along the coast of Baja California Sur, but scientists were unable to locate their nesting beaches anywhere in the region. The vastness and sheer complexity of the ocean made it difficult to monitor sea turtle movements beyond the coastal zone, causing much of their life history between the time they disappeared into the ocean upon hatching to re-emerging as adults, to remain one of the greatest mysteries in sea turtle conservation biology. For Adelita, where she might go and how far she might swim was unknown, but it was hoped that this relatively new satellite tagging technology might provide a peek into her oceanic world. However, no one expected Adelita's journey to completely change the course of sea turtle ecology.

After traveling over 11,500km (7,145 miles) in 368 days, Adelita reached the coast of Japan and became the first ever animal to be tracked swimming across an entire ocean basin (Nichols et al., 2000; Seminoff et al., 2018). Her remarkable journey captivated international audiences and provided scientists with an understanding of basin-wide population connectivity that up until then seemed unimaginable (see Adelita's tracks on seaturtle.org and learn about her story here).[2] Since then, the combination of satellite tracking and genetic analyses have confirmed the North Pacific loggerhead sea turtle as one distinct population, with all individuals originating from Japan and dispersing across the entire North Pacific Ocean as juveniles, only to return home upon maturity—a level of population connectivity that would be impossible to understand without the mighty Adelita guiding the way.

Today, sea turtles are some of the most well-tracked species in our world's ocean, and the ability to study their life at sea has greatly complemented the rich history of scientific research and conservation efforts that, until the last 25 years, have primarily focused on land (i.e., adult nesting females, embryos, and hatchlings). Together, these efforts have fundamentally advanced our understanding of sea turtle biology and conservation, but for an elusive animal that spends more than 99% of their lifespan in the ocean, a more complete picture has been necessary to fill the critical gaps across their understudied oceanic life history stages. This is especially true given concerns over the global rates of decline for many populations and the challenging suite of pressures individuals must navigate during their time at sea (e.g., fisheries interactions, pollution, and climate change).

1 Woods Institute for the Environment at Stanford University, https://orcid.org/0000-0002-8891-9294
2 https://vimeo.com/3115729

 https://doi.org/10.11647/OBP.0395.04

Traditional methods of studying sea turtle movement ecology relied on information gathered from nesting beaches, survey data, and fisheries catch and observation data. For this reason, we have long known their geographic distributions, but as a highly migratory species, our ability to understand where they go upon leaving their natal beaches and how they get there has remained one of the most arduous challenges in marine science. With emerging and innovative technologies, researchers have been able to peer into the oceanic phase like never before, extracting new insights across these knowledge gaps in sea turtle biology and conservation (reviewed in Dutton et al., 2019; Maxwell et al., 2019). Given the at-sea stage represents the longest part of their life history and the most sensitive to population growth and recovery (Crouse et al., 1987), it is important to review what we have learned about this historically under-studied phase. Specifically, we asked: What technologies and applications are we now using to expand our knowledge and how have these tools advanced our approach to successful sea turtle conservation and research during their time at sea?

Here we review several new directions and research advancements that have been transformative to our understanding of the at-sea phase for sea turtles. First, we highlight some of the emerging innovations in technology and monitoring capabilities employed to study this cryptic phase. We then discuss the application of these tools in the development of diverse conservation and mitigation approaches, across a range of in-water threats. Finally, we address some of the challenges and limitations that persist, and the future directions to ensure the successful protection and management of these vulnerable species.

Innovations: Advancements in technology and monitoring capabilities

Tagging technology and biologging capabilities

The advent of satellite telemetry in the 1980s was a breakthrough in the study of animal movement, and sea turtles were some of the first ocean migrants to be tracked. Such technologies were pivotal in taking marine turtle research from land to sea, addressing key ecological questions, and breaking down some of the greatest barriers to understanding the oceanic phase, including long-distance migration, behavior, and population connectivity (e.g., Luschi et al., 1998, 2007; Hays et al., 2004; McClellan and Read, 2007; Dodge et al., 2014; and see references within Supplemental Bibliography).

In the past few decades, the number and scope of sea turtle tracking studies have increased exponentially (*see* Godley et al., 2008; Hart and Hyrenbach, 2009; Hays and Hawkes, 2018). Tagging technologies have now been deployed on every species and stage of sea turtle, with state-of-the-art developments that reduce some of the inherent biases and limitations that persisted with early tagging studies (e.g., skewed representations by geography and age-stage, and limited battery longevity). While challenges still exist in animal telemetry (including tag cost and data capture, reviewed in Hazen et al. (2012) and Harcourt et al. (2019)), the sheer volume, and application to sea turtle research, is now more robust and reliable than ever before (Hays and Hawkes, 2018). Sophisticated designs in electronic tags now allow for multi-year (e.g., Shillinger et al., 2008; Briscoe et al., 2016a), multi-population (Bailey et al., 2012; Fossette et al., 2014), and multispecies tracking studies (Shimada et al., 2016; Lamont and Iverson 2018; and see Supplemental Bibliography). Time-depth recorders, acoustic transmitters, and animal-borne videos can reveal fine-scale movements and behaviors in relation to foraging ecology and diving behavior (Seminoff et al., 2006; Chevis et al., 2017; Tyson et al., 2017; Hardin and Fuentes, 2021). Equally fascinating, satellite biologgers outfitted with autonomous sensors have transformed animals into physical oceanographers, collecting a suite of environmental variables, especially from regions otherwise difficult to sample (Doi et al., 2019; Harcourt et al., 2019; Bousquet et al., 2020). Most recently, the miniaturization of tagging devices has allowed researchers to follow the earliest portion of the at-sea period, with studies deploying tiny acoustic (Thums et al., 2013; Scott et al. 2014a; Hoover et al., 2017) and solar-powered (Mansfield et al., 2014, 2021) trackers attached to the shells of neonate sea turtles as small as 11cm carapace length during the 'lost years' (Hays and Hawkes, 2018). Once thought impossible, these technologies have provided empirical evidence into every stage in a turtle's life history, fundamentally shifting the paradigm of sea turtle research from land to sea.

Coupling environmental data, ocean physics, and computer simulations to simulate sea turtle movements and strandings

In recent years, the coupling of environmental datasets with sea turtle tracks has played a significant role in understanding oceanic distribution and habitat preferences in relation to a suite of biotic and abiotic processes (e.g., Coles and Musick, 2000; Polovina et al., 2000; Gaspar et al., 2006; Hawkes et al., 2007; and see Supplemental Bibliography). For example, species distribution models (SDMs) are now common tools used to explore mechanistic and correlative linkages between an animal and its environment across a geographic space (Guisan and Zimmermann, 2000; Elith and Leathwick, 2009; Melo-Merino et al., 2020). State-space models allow researchers to estimate biologically relevant parameters with satellite telemetry (Jonsen et al., 2007). Such applications employ a wide range of statistical and machine learning techniques to understand, predict, and manage a species in a changing environment, and there is now a wealth of detailed literature in this field (e.g., Guisan and Thuiller, 2005; Aarts et al., 2008; Robinson et al., 2017). For sea turtles, some examples of habitat characterization include identification of high use areas under contemporary conditions and prey landscapes (e.g., Witt et al., 2007; Fossette et al., 2010; Mencacci et al., 2010), exploration of distributional shifts under changing oceanic and atmospheric conditions (e.g., Saba et al., 2008; Willis-Norton et al., 2015; Patel et al., 2021), and most importantly, serving as mitigation tools for effective conservation and management (Maxwell et al., 2011; Scott et al., 2012; Roe et al., 2014; Howell et al., 2015; Smith et al., 2021).

In addition to using satellite-derived and *in situ* environmental measurements, more sophisticated particle tracking, and numerical models, are now used to simulate the transport and spatial distribution of hatchlings, and subsequently juveniles, in relation to ocean currents. Demographic, behavioral, and observational turtle data can be combined with ocean circulation models to provide transport predictions (forecasts and hindcasts), simulating such scenarios oceanic-stage survival (e.g., Shillinger et al., 2012a; Putman et al., 2013; Chambault et al., 2021), dispersal pathways (Gaspar et al., 2012; Briscoe et al., 2016b; Lalire and Gaspar, 2019; DuBois et al., 2021), and neonate drift experiences that may ultimately drive population dynamics and shape the ontogeny of migratory routes as adults (Hays et al., 2010; Scott et al., 2014b; Ascani et al., 2016; and see Supplemental Bibliography).

Sea turtle stranding events can provide unique opportunities to study drivers of at-sea turtle mortality. Sea turtles that are found injured or ill on beaches, or floating at-sea, are considered 'stranded' and often recorded and necropsied by regional standing networks. Stranding data can provide critical information around potential causes of sea turtle mortality and their spatio-temporal trends (Chaloupka et al., 2008; Casale et al., 2010; Koch et al., 2013; Monteiro et al., 2016). Importantly, new efforts to combine stranding records with oceanographic models can further help illuminate drivers of mortality through a deeper understanding of the oceanic transport of dead sea turtle carcasses (Hart et al., 2006; Santos et al., 2018a; Liu et al., 2019). These approaches simulate the movements of carcasses using methods such as ocean circulation models and virtual particle tracking tools to determine where sea turtles might have been after death, and prior to washing ashore.

In addition to using virtual particle tracking tools, various studies have also used drifter experiments in the field to better parameterize surface movements of floating sea turtle carcasses. Surface drifter experiments, aimed at improving our understanding of carcass drift, have been deployed with different objects such as individually marked oranges (Mancini et al., 2012; Koch et al., 2013), drift bottles (Hart et al., 2006), bucket drifters (Santos et al., 2018b), standard surface drifters (Liu et al., 2019), wooden sea turtle models (Santos et al., 2018b; Cook et al., 2021), and even actual sea turtle carcasses (Santos et al., 2018b; Cook et al., 2021). Studies that have used actual sea turtle carcasses have used both reconstructed sea turtle drifters made from cadavers and insulating foam to ensure positive buoyancy (Santos et al., 2018b), and also intact bloated sea turtle carcasses to allow for the incorporation of natural decomposition and scavenging (Reneker et al., 2018; Cook et al., 2021). Such field research can improve our ability to use oceanographic models to simulate sea turtle carcass drift prior to beached stranding events. Importantly, the ability to backtrack the drift movements of stranded carcasses can allow us to better pinpoint where mortality may have occurred, which can help scientists determine what might have caused this mortality in the first place.

Advanced data collection and computation

Innovations in animal-based telemetry and animal-borne imaging techniques have rapidly advanced our understanding of animal movement and behavior (see Dutton et al. (2019) for examples), but their expense and requisite physical contact can be limiting factors in the data collection process (Hanna et al., 2021). The integration of uncrewed instrumentation, novel computational approaches, and citizen science participation, now offers new ways to collect information, providing alternative, cost-effective, and contactless monitoring and threat assessment, both above and below the water's surface. For example, high-tech advancements in unmanned aerial vehicles (UAVs, commonly known as drones) now provide efficient, cost-effective ways of obtaining population estimates using aerial imagery and photogrammetry (3D models) to collect a suite of information from hard to monitor, free ranging individuals (Varela et al., 2019; Varela and Rees, 2020). In addition to UAVs, the use of submersible cameras and autonomous underwater vehicles have become increasingly common tools to monitor wildlife in the past decade, due to their ability to provide high resolution information and offer an alternative to common in-water and aerial surveys (e.g., boat-based, manned aircraft, or SCUBA and snorkeling surveys) (Rees et al., 2018). Sightings and information provided by citizen-scientists have also enabled researchers to collect constant streams of data in the form of descriptions, web maps, and smartphone 'apps' (Baumbach et al., 2019; Hanna et al., 2021). Together, such forms of data collection have helped to bridge the gap for researchers, especially for hard-to-reach habitats or when individuals are hard to find (Rees et al., 2018). Given their low cost and practicality of use, especially under limited funding, such advanced monitoring platforms have provided new opportunities for remote observation and surveillance. For sea turtles, some applications of these approaches include in-water density and abundance estimates (e.g., Sykora-Bodie et al., 2017; Mello-Fonseca et al., 2021), foraging behavior (Letessier et al., 2014; Patel et al., 2016), courtship and mating interactions (Bevan et al., 2016; Papafitsoros et al., 2022), and uncovering more unique behaviors, such as the use of fish cleaning stations during breeding periods (Schofield et al., 2017).

Another rapidly developing field combines the use of drones with artificial intelligence, for near real-time detection of animals (Varela and Rees, 2020). Computer vision and image recognition techniques such as Convolutional Neural Networks (CNNs), a prominent type of deep learning classifier, have been used to detect and classify sea turtles on land and in water (Badawy and Direkoglu, 2019). Maki et al. (2020) combined drones with CNNs, as a form of tagless tracking of individuals with multibeam sonar imagery, and Gray et al. (2019) used neural networks and drone images to gain population-level insights, detecting and enumerating olive ridley sea turtles (*Lepidochelys olivacea*) in the coastal waters of Ostional, Costa Rica during a mass-nesting event.

Such advanced detection techniques have not only transformed our monitoring and detection capabilities of sea turtles in their marine environment, but they have also enabled the exploration of a wide range of research questions in relation to critical habitat use, behavior, and population-level estimates that have been inherently too difficult to access. Importantly, when paired with other datasets, these approaches can provide a new level of understanding of threats, such as fishing activity. Drones and object-based detection algorithms have been used to reveal sea turtle behavior in relation to fishing gear (Reavis et al., 2021), and to detect fishing vessel interactions (Varela and Rees, 2020) and illegal fishing practices (Zendejas, 2013) for effective enforcement bycatch regulations.

Understanding neonate survival from land to sea

While much of the focus has been on the juvenile and later stages at-sea, methodological advances have also allowed for new and innovative ways to better understand sea turtle behavior during the critical 24 hours after emerging from nests. Known as the frenzy period, newly hatched sea turtles will scramble across the beach and then start their long and dangerous swim to offshore habitats. Hatchlings face several threats throughout these early days, including predation risks on land that depend on how quickly they can run along the exposed beach and safely disappear into the darkness of the oceans. These animals can be disrupted by artificial lighting in urban areas, disorienting them and making their path towards the open sea more challenging. As coastal areas become increasingly urbanized and developed, assessing energy usage during this time of potential disorientation has been important for understanding its impact on animal survival. Survival during the high energy frenzy period can depend on swimming performance. Mortality rate from predation is high during these hours, and one of the factors that hatchlings rely on to evade predators is their speed. Importantly, the additional energy used from crawling unnecessary distances from lighting disorientation can negatively impact their offshore swim and decrease their overall survival rate.

To study energy use, as hatchlings made their way from land to sea, researchers sought to measure oxygen consumption during crawling and swimming phases. In the first study of its kind, Pankaew and Milton (2018) constructed tiny treadmills from modified belt sanders and placed them within airtight respiratory chambers. Hatchlings were placed on the treadmills and monitored throughout their movement and rest periods. These frenzy crawl trials were coupled with swim trials, and energy consumption was calculated during both crawl and swim periods to mimic frenzy period conditions. Videos of these trials can be seen on National Geographic's Youtube[3] channel and Florida Atlantic's Youtube[4] channel. Although the researchers ultimately found that the longer distances during disorientation crawling did not appear to affect swim performance, they note that disorientation can still negatively impact hatchlings by more rapidly depleting the limited energy stores that the animals rely on in the upcoming days. While constructed treadmills have been used in other animal studies (e.g., Rubin and Mickle, 1982), this is the first study of its kind to apply these methods to sea turtles. Coupled with the aforementioned neonate tagging technologies (Mansfield et al., 2021), these studies provide some of the earliest insights into movement and survival at the very outset of their 'lost years' journey.

Development of novel genetic and molecular techniques

At the molecular level, rapid advances in laboratory technology, combined with decreasing per-unit-costs for sample analysis, are opening new avenues for sea turtle research. Samples collected from wild animals (i.e., skin, blood, and bone from recovered caracasses), and even older, historical samples stored in archives, are being used in new, and more widespread ways, to inform conservationists and population managers about stock structure, foraging and nesting habitat connectedness, habitat movement patterns, responses to stressors including fishing, pollution and climate change, and more. The ever-expanding field of genomics - guided by the recently published whole genomes of several sea turtle species - is beginning to illuminate many aspects of sea turtle biology and ecology (e.g., Komoroske et al., 2017; Mayne et al., 2022; Bentley et al., 2023). Further, genetic 'tagging' and chemical 'tracing' techniques are illuminating sea turtle populations and habitat connectedness. For example, genetic and chemical analyses of sea turtle tissues can serve as forensic tracking methodologies to explore foraging dichotomies associated with differential habitat use (McClellan et al., 2010; Zbinden et al., 2011; Ceriani et al., 2012), geographic origin of foragers at the population level (Vander Zanden et al., 2015), ontogenetic recruitment (Turner Tomaszewicz et al., 2016; Ramirez et al., 2019), and habitat use patterns and

3 https://www.youtube.com/watch?v=XtjF5dIedhI
4 https://www.youtube.com/watch?v=itkAuPubbxI&t=19s

residency duration, useful for informing bycatch reduction and prioritizing habitats for conservation (Turner Tomaszewicz et al., 2015; and see Supplemental Bibliography).

Genomic applications for at-sea life stages

Genetic tagging has become a valuable tool for conservation of sea turtles for several reasons, ranging from understanding habitat connectivity between foraging and nesting areas, to establishing phylogeography and stock structure (see full review in Komoroske et al., 2017). Emerging genomic techniques, and the studies that follow, will continue to elucidate the 'how' and 'why' of sea turtles' population ecology (e.g., Shirtika et al., 2022; Bently et al., 2023). Specifically important for turtles in the high seas, genetic analysis informs managers of the origins of sea turtles captured as bycatch during fishing activities. The relatively simple process of collecting skin (or other tissues) from bycaught turtles can reveal which populations and stocks are being most affected by specific fishery types in specific ocean regions, allowing for a more targeted approach for conservation efforts. This is done by first having individual nesting subpopulations characterized by unique haplotypes (mitochondrial DNA, mtDNA) and defining management units (Wallace et al., 2010; Dutton et al., 2014; Komoroske et al., 2017). For example, Stewart et al. (2016) identified source populations for leatherback sea turtles bycaught during pelagic longline fishing throughout the Western North Atlantic. This study used many-to-many mixed-stock analysis to reveal an unexpectedly disproportionate number of leatherbacks from Costa Rica being caught in longline fisheries in the Gulf of Mexico. Ongoing observer and at-sea monitoring in cooperation with fisheries allow for the collection of these samples for genetic analysis, which ultimately helps guide policy for bycatch reduction. A similar approach was also used by Stewart et al. (2019) to conduct mtDNA and mixed stock analysis on samples collected from 850 loggerhead turtles bycaught across the Western North Atlantic over a 14 year period. The study identified which distinct management units of loggerheads were most affected by different fishing efforts and revealed size-structured differences in bycatch rates in distinct spatial regions. Most recently, such applications have been used to address and reduce illegal poaching and trade of products made from protected species, including sea turtles (e.g., hawksbill carapace shell, LaCasella et al., 2021).

Using chemical tracers

As with the explosion in genomic studies, the past decade has seen a great increase in studies utilizing various chemical and biogeochemical tools for ecological, conservation, and management research of sea turtles. Methods include: stable isotope analysis, trace element analysis, contaminant concentrations, and even hormone levels. Stable isotope analysis – both bulk and compound specific amino acids – have been applied on all sea turtle species, to address several biological and conservational questions (Haywood et al., 2019). Analysis of stable nitrogen ($\delta^{15}N$) and carbon ($\delta^{13}C$) of a variety of sea turtle tissues have been widely applied to study turtle foraging behavior and trophic position (Jones and Seminoff, 2013), connectedness among different habitats (Avens et al., 2021) and populations (Figgener et al., 2019), timing of ontogenetic shifts (Reich et al., 2007) and even inform survivorship as determined by residency time (Turner Tomaszewicz et al., 2017), with many opportunities for future studies (Pearson et al., 2017).

As studies strive to collect and process samples with consistent methods, comparisons among studies are beginning to illuminate not just ocean-basin differences in baseline stable isotope (SI) ratios (Wallace et al., 2006) and sea turtles as region-specific consumers (Seminoff et al., 2012), but also subtle differences in foraging and habitat use of juveniles vs. adults, and foraging behavior, such as specialized foragers in groups that were assumed to be generalists (Vander Zanden et al., 2010). As more studies utilize stable isotope analysis as a powerful tool, the abundant SI data generated makes the creation of large-scale isotope mapping, or 'isoscapes' possible (Graham et al., 2010; McMahon et al., 2013) when care is taken to specify distinct regions being mapped or specific sea turtle populations and tissues being used (Ceriani et al., 2014; Turner Tomaszewicz et al., 2017; Haywood et al., 2020). For example Hatase et al. (2013) identified that North Pacific loggerheads from the same nesting sites had two different foraging behaviors, with smaller turtles foraging in oceanic habitats, and larger turtles feeding in neritic habitats, and that these differences likely affect the fitness and spatial risk of the different groups - an important factor in tracking population abundance trends. Using both bulk and compound specific amino acid analysis of stable nitrogen isotopes, together with satellite telemetry, Seminoff et al. (2012) revealed that the endangered Pacific leatherbacks nesting in Indonesia have split migratory strategies - some remaining in the Western Pacific to forage, while others traversed the entire ocean basin to forage in the Eastern Pacific. The application of biogeochemical analysis to address questions about the ecology and behavior of sea turtles when they are in remote oceanic locations – indeed, where they spend the most of their time – has been especially valuable. Continued studies that build upon lessons learned, and combine different techniques, will be extraordinary in how they further our understanding of the oceanic phases of sea turtles.

A recent example of a study that combined molecular lab techniques (skeletochronology with stable isotope analysis (Turner Tomaszewicz et al., 2017), land-based headstarting and in-water satellite tagging with remotely sensed satellite data (Briscoe et al., 2016a), sample recovery from beach surveys (Peckham et al., 2008), and aerial surveys (Seminoff et al., 2014; Eguchi et al., 2018)), was Briscoe et al. (2021). This hugely collaborative effort pooled together results about North Pacific loggerhead turtles, to propose that the mechanism behind movements between the Central North Pacific and the Eastern Pacific (including bycatch regions near southern California, US, and Baja California, Mexico) may be facilitated by a dynamic thermal corridor between the two ocean regions, the frequency of which may vary with ocean climate (El Nino-La Nina) and anomalous oceanographic conditions (such as the 'blob' and other marine heatwaves), becoming more common (Oliver et al., 2021; Samhouri et al., 2021).

Evolving molecular techniques

The continued expansion of molecular tools like genetic tagging and chemical tracing, will open the door for new combinations of multi-pronged approaches to study sea turtles at sea (and on land). As these tools become more widely applied and novel laboratory techniques advance, continued monitoring and sampling effort will facilitate further understanding of the life history and ecology of sea turtles (and other marine megavertebrates). One example is the utility of combining SI and chemical analysis with hormone analysis to better assess health, nutrition, stress and reproduction (Fleming et al., 2018); estimate population sex-ratios using blood hormones (Jensen et al., 2018); assess stress-related responses to fishery bycatch and cold-stun events (e.g., Hoopes et al., 2000; Hunt et al., 2016); and analyze pollution in distinct habitats using fatty acids, contaminant concentrations, and trace elements (Ramirez et al., 2019; Avens et al., 2021; Shaw et al., 2021).

Another rapidly evolving method that can be used to monitor species is environmental DNA (eDNA), which can be used to detect the presence of animals through the cellular material they deposit (Thomsen and Willerslev, 2015). Species expel DNA into the environment from various sources, such as through the shedding of skin cells, urine, and saliva, which can be sampled and detected using molecular techniques. Emerging eDNA capabilities allow for the non-invasive detection of aquatic organisms through DNA identification in water samples. Eliminating the need to manually capture, collect, or otherwise physically observe live animals to document their presence, eDNA has great potential for use in biodiversity monitoring (Thomsen and Willerslev, 2015). Animal detection and assessments of species distribution is often a critical first step for conservation efforts, and eDNA can be particularly useful for collecting data on endangered species where physical detection can be difficult. The popularity of eDNA as an emerging tool has increased since it was successfully used in 2008 to detect the presence of the invasive American Bullfrog in French wetlands (Ficetola et al., 2008). eDNA techniques have since been used in marine environments, successfully detecting harbor porpoises (Foote et al., 2012), orcas (Baker et al., 2018), and sharks (Boussarie et al., 2018).

A limited number of studies have applied eDNA to aquatic reptiles (Roussel et al., 2015), and only in recent years have eDNA methods been studied in sea turtles. Kelly et al. (2014a) used eDNA to detect the presence of green sea turtles (*Chelonia mydas*) within a mesocosm community, although the study site was a non-natural tank environment. Harper et al. (2020) used the technique to successfully track greens in a Californian estuary, demonstrating the potential to use these methods to assess sea turtle presence in the wild, without animal capture. The ability to use eDNA to detect organisms directly from the environment can fundamentally transform ecological monitoring and management. eDNA can replace labor intensive and time-consuming conventional methods, to assess species richness and abundance more rapidly, as well as on a much wider and more comprehensive scale (Deiner et al., 2017). In the case of endangered species, such as sea turtles, the ability to conduct cost-efficient and non-invasive biodiversity assessments through eDNA can allow for improved estimates of species distribution and facilitate targeted policy and management efforts (Kelly et al., 2014b; Thomsen and Willerslev, 2015).

Understanding at-sea threats and applications for conservation

Plastic ingestion threats

From viral videos of a sea turtle with a straw wedged up its nose (Robinson et al., 2015) to provocative images of decomposing carcasses with stomachs full of trash, attention on the impacts of pollution on the marine environment, and its effects on sea turtles (Santos and Crowder, 2021), has grown in recent years. Hazardous debris can include parts of fishing gear, such as nets, lines, and ropes, as well as anthropogenic items including plastic bags, tar, styrofoam, and glass. These materials can entangle sea turtles, preventing them from diving to feed or surfacing to breathe. Sea turtles may also ingest debris, which can obstruct their throats or accumulate and affect their digestive systems.

Sea turtles around the world have been noted to ingest plastic debris (Schuyler et al., 2014). Globally, more than half of all sea turtles have been estimated to have ingested plastics, although rates can vary among regions and species (Schuyler et al., 2016). Plastic debris has been found ingested by sea turtles of all life stages, from post-hatchlings to adults (Witherington, 2002; Digka et al., 2020). Oceanic-stage turtles are among those most at-risk to plastic debris ingestion, with the highest regions of risk including the east coasts of the USA, Australia, and South Africa, as well as within waters of the East Indian Ocean, and Southeast Asia (Schuyler et al., 2016). In a study of stranded sea turtles in Australia, Schuyler et al. (2012) found that benthic sea turtles have a stronger selection for clear, soft plastic, while pelagic turtles were less selective but tended to consume more rubber items, such as balloons (Schuyler et al., 2012). Ingestion may also vary by feeding preferences; carnivorous sea turtles have been found to be less likely to ingest debris compared to herbivores and omnivores (Schuyler et al., 2014; Rizzi et al., 2019).

Plastic debris ingestion can have both sublethal and lethal impacts on sea turtles (McCauley and Bjorndal, 1999). Higher concentrations of ingested plastic have been linked to higher probability of mortality, with Wilcox et al. (2018) reporting that 14 pieces of plastic in a sea turtle's gut leads to a 50% probability of mortality. Santos et al. (2015) found that less than one gram of ingested debris can kill juvenile turtles. Even when not lethal, ingested debris may impact sea turtles in other ways, such as reducing swimming capacity, or making turtles more susceptible to bycatch. Sublethal effects of debris ingestion include reduced nutrient gains through dietary dilution (McCauley and Bjorndal, 1999).

Land-based plastics have been found to account for most ingested debris found within sea turtles (Schuyler et al., 2014) and other marine animals (Boerger et al., 2010; Codina-García et al., 2013; De Stephanis et al., 2013). With over 4-12 million tons of plastic estimated to enter the oceans each year (Jambeck et al., 2015), and this significantly increasing (Ostle et al., 2019), plastic pollution is a critical problem that is not going away anytime soon. Better understanding its impacts on sea turtles and their habitats, as well as large-scale solutions to minimize plastic discharge into marine environments, will be important avenues for future research.

Bycatch threats and reduction technologies

Fisheries bycatch is one of the most significant threats to sea turtles around the world (Spotila et al., 2000; Wallace et al., 2013; Lewison et al., 2014; Patel et al., 2021). Accidental engagement in fishing gear, known as bycatch, kills thousands of sea turtles every year (Lewison et al., 2004; Finkbeiner et al., 2011). Various bycatch reduction technologies have been developed to limit the impact of fishing activity on sea turtles. Most efforts have focused on the use of turtle excluder devices in trawl nets (Crowder et al., 1994; Jenkins, 2012) and circle hooks in longlines (Gilman et al., 2006; Pacheco et al., 2011), but more recently gear modifications have been developed for gillnets. Gillnets are used in coastal waters worldwide and engagement in gillnets can be a large source of mortality for sea turtles (Gilman et al., 2010), yet bycatch reduction strategies have been difficult to develop (Žydelis et al., 2013).

Studies suggest that visual cues may be one promising avenue that can be used to alleviate gillnet entanglement with various bycaught species, including sea turtles (Martin and Crawford, 2015). Sea turtles rely on visual cues when foraging (Constantino and Salmon, 2003), and thus illuminating gillnets may be one way to alert the animals of their presence. Equipping gillnets with light-emitting diodes (LEDs) or chemical lightsticks have both been shown to reduce the number of sea turtle and gillnet interactions, without negatively impacting overall catch rates of the target species (Wang et al., 2010; Bielli et al., 2020; Senko et al., 2022). Importantly, other commonly bycaught species, such as seabirds and marine mammals, also rely strongly on visual cues (Schakner and Blumstein, 2013; Martin and Crawford, 2015). Therefore, there is potential for net illumination to be used as a multi-taxa bycatch reduction tool, with species-specific conservation benefits beyond just sea turtles. In addition, researchers are currently building and assessing the use of solar-powered LEDs, which will help reduce battery cost and waste as well as provide a more environmentally friendly option (Senko et al., 2020).

Decision-support tools and dynamic management approaches

With a greater understanding of critical habitats and oceanic movements, efforts to mitigate overlap between fisheries activities and sea turtles is a significant priority. But a key challenge to fisheries management is understanding and planning for species interactions in a dynamic environment (Lewison et al., 2015; Maxwell et al., 2015). This is especially true for highly migratory sea turtles that exploit multiple oceanic habitats across global boundaries.

New approaches to ocean management have begun to incorporate the shifting nature of the ocean, its users, and its inhabitants based on the integration of new biological, environmental, or socioeconomic conditions in near real time (Maxwell et al., 2015; Hazen et al., 2018). 'Dynamic management' approaches are reviewed in detail by Hazen et al. (Chapter 13) and demonstrate great potential as fully operational, data-driven decision-support tools for bycatch avoidance and marine resource management in ways that traditional static spatial management objectives may fall short. For example, TurtleWatch[5] is a tool derived from sea turtle-temperature affinities and uses up-to-date information about the location of thermal habitat to reduce interactions between U.S. Hawaii longline fishers, and sea turtles (Howell et al., 2008; Howell et al., 2015).

Multispecies tools such as EcoCast[6] provide daily predictions to fishers for both target (swordfish, *Xiphias gladius*) and non-target species (leatherback sea turtles, *Dermochelys coriacea*, California sea lions, *Zalophus*

5 https://www.fisheries.noaa.gov/resource/map/turtlewatch
6 https://coastwatch.pfeg.noaa.gov/ecocast/about.html

californianus, and blue sharks, *Prionace glauca*) (Hazen et al., 2018; Welch et al., 2019a) along the U.S. West Coast. Given that species-environment associations predictably change over daily, seasonal, and interannual scales, these tools allow decision-makers to frequently and automatically adjust management approaches in near-real time. However, the built-in flexibility also ensures that these tools are capable of delivering proactive, climate-ready solutions, as species-environment relationships change or break down, and as new threats emerge under anomalous environmental conditions (e.g., NOAA's TOTAL[7] tool, Welch et al. (2019b); also see Hazen et al. (Chapter 13), 2018; Hobday et al., 2018).[8]

Climate impacts and a changing ocean

Warming oceanic temperatures and more frequent marine heat waves are expected to cause unprecedented challenges for marine species (McHenry et al., 2019). As a wide-ranging species that is both circumglobally distributed and highly susceptible to environmental variability (Wallace et al., 2010), the impact of climate change is a forefront issue that touches every age and stage of their life cycle (see Patrício et al., 2021).

An emerging volume of research has observed and predicted impacts of climate change on sea turtles, although for practical and accessibility reasons, most of these studies have focused on the terrestrial life history phase (Witt et al., 2010; Patrício et al., 2021). From these extraordinary efforts, we now understand the direct and indirect effects of climate variables, particularly those associated with air, sand, and ocean temperatures, increased rainfall and storm intensity, and sea level rise, on sex ratios, hatchling success and morphology, nesting phenology and habitat, and reproductive success, to name a few (Hawkes et al., 2009; Poloczanska et al., 2009; Witt et al., 2010; Saba et al., 2012; Patel et al., 2021; Patrício et al., 2021). These studies provide more detailed reviews of impacts than we can cover in this chapter, with key insights by species, habitat, geographical region, and threat, highlighting key priorities for future research and management, and emphasizing the critical gaps that remain in our ability to fully understand the impacts experienced at-sea. Optimal temperature ranges are known to vary among species, but warming temperatures and changing ocean circulation patterns are projected to induce shifts in at-sea movements and distributions, with implications across ontogenetic stages and habitats (Poloczanska et al., 2009; Patrício et al., 2021). Climate-forced changes to productivity and prey availability may shift, altering species' habitat, distribution, reproductive patterns, growth rates, and recruitment (Poloczanska et al., 2009; Ascani et al., 2016; Stubbs et al., 2020). More frequent bouts of anomalous environmental conditions may influence migratory corridors and habitat connectivity, leading to the development of ecological bridges or barriers, connecting or disconnecting animals to preferred habitats under varying ocean conditions (Briscoe et al., 2017). Such changes (whether temporary or permanent) will have lasting effects on population management.

Lesser studied but equally important concerns include resilience against infectious diseases and pathogens, as it is unknown how such stressors may be altered in a warming environment (Harvell et al., 2009; Tracy et al., 2019). The full breadth and depth of climate-related threats are yet to be understood, and despite significant technological and analytical advances, there is still a great need for information across this cryptic at-sea stage. With varying degrees of vulnerability, adaptability, and life history characteristics, resilience to climate change and other stressors (human and environmental) may be easier for some populations than others, but all will require dynamic approaches to successfully manage for the future (Maxwell et al., 2020). Marine turtles have weathered 120 million years and multiple climate change events, but never at such an unprecedented rate of change (IPCC, 2021; Patrício et al., 2021). As global environmental conditions are expected to become more extreme, the implications are significant. Understanding the opportunities for mitigation and intervention on land and at sea is an essential element to the conservation of these charismatic species.

7 https://coastwatch.pfeg.noaa.gov/loggerheads/
8 https://coastwatch.pfeg.noaa.gov/loggerheads/

Limitations

The utilization of these novel methodologies has enabled us to effectively navigate numerous conservation and management challenges inherent to the at-sea stage (Robinson et al., 2023), however there remain several limitations. Although advancement of tagging technologies have allowed for a deeper understanding of the movements and behavior of marine turtles (see Godley et al., 2008; Hays, 2008; Hart and Hyrenbach, 2009; Hussey et al., 2015; Hays and Hawkes, 2018) data gaps still remain, given that most tracking technologies are unable to span the length of life history stages (Hazen et al., 2012; Shillinger et al., 2012b). Logistical challenges and limited access to sea turtles at-sea tends to hinder research efforts of life history characteristics during these life stages, in comparison to when they are in nearshore environments (Hamann et al., 2010). The issue of data availability and data sharing remains a pervasive limitation, given the importance of continued and improved conservation and monitoring efforts (Jeffers and Godley, 2016; Mazaris et al., 2017; Wildermann et al., 2018; Hays et al., 2019; Godley et al., 2020). This is especially true when only a small proportion of animals tend to be tracked, often representing only a fraction of the whole population (Hays and Hawkes, 2018). Although research interest in sea turtles has increased substantially over time (Hamann et al., 2010; Rees et al., 2016), some sea turtle populations tend to be more well-studied than others. In particular, there is a highlighted need to increase scientific understanding on immature leatherback and hawksbill populations, as well as studies on all marine turtle species across the Indian, South Pacific, and South Atlantic Oceans (Wildermann et al., 2018).

Efforts to advance sea turtle knowledge can also be impacted by limited support. Lack of resources, including funding, has been identified as a significant individual barrier hindering research in this field, particularly for experts working in the Atlantic and Mediterranean regions (Wildermann et al., 2018). This is especially true with some of the more advanced technologies and techniques (e.g., equipment, data accessibility and storage, and analytical expertise), which require expendable budgets and specific skill sets. For example, satellite tracking data remains very expensive and difficult to obtain (Hays and Hawkes, 2018), and complex analyses in machine learning and artificial intelligence require a specific level of expertise. There should be targeted attempts to extend access to such technologies and methodologies, distributing resources to the less well funded nations and regions. In instances where data is limited, local ecological knowledge (LEK) can be used to uncover historical trends (Beaudreau and Levin, 2014; Lee et al., 2019) and document baseline data that cannot be acquired solely through natural science methods (Mukherjee et al., 2018; Mason et al., 2019). LEK has been used to produce data to better understand the population trends of Eastern Pacific greens (Early-Capistrán et al., 2020) as well as to support the identification of sea turtle nesting beaches in Panama (Flores et al., 2021). Active and meaningful integration of LEK alongside Western methods of scientific research can facilitate a more holistic view of sea turtle biology. It can also aid in ensuring management decisions are attuned to the cultural and socioeconomic needs of the local communities that sea turtles belong to, maximizing conservation benefits for both humans and animals alike.

Conclusions

In a changing ocean, the utilization of diverse approaches to species conservation in marine management is essential. For many marine species, including sea turtles, transformative advances in technology and monitoring capabilities have bolstered our ability to observe, learn, and protect individuals and their habitats. In this chapter, we reviewed new and emerging research directions that have deepened our ability to study sea turtles during their critical at-sea phases. The studies cited in this chapter are by no means exhaustive, but serve as examples of the rapid pace of scientific discovery in sea turtle biology and conservation. Here, we highlight how several advancements, including innovative approaches in animal telemetry, genetic and molecular technologies, automated data collection, and computation modeling, have been used to address some knowledge gaps in sea turtle habitat, movement, and behavior at sea. In addition to studying sea turtle behavior and movement, these tools also can be used to inform the development of conservation and management approaches. Despite some of the challenges and limitations that still exist with studying these elusive animals, these applications have provided promising new directions for the long-term sustainability of sea turtle populations around the globe.

References

Aarts, G., M. MacKenzie, B. McConnell, M. Fedak and J. Matthiopoulos. (2008). Estimating space-use and habitat preference from wildlife telemetry data. Ecography 31: 140-160.

Ascani, F., K. S. Van Houtan, E. Di Lorenzo, J. J. Polovina and T. T. Jones. (2016). Juvenile recruitment in loggerhead sea turtles linked to decadal changes in ocean circulation. Global Change Biology 22: 3529-3538.

Avens, L., M. D. Ramirez, L. R. Goshe, J. M. Clark, A. B. Meylan, W. Teas, D. J. Shaver, M. H. Godfrey and L. Howell. (2021). Hawksbill sea turtle life-stage durations, somatic growth patterns, and age at maturation. Endangered Species Research 45: 127-145.

Badawy, M. and C. Direkoglu. (2019). Sea turtle detection using faster R-CNN for conservation purpose. In International Conference on Theory and Application of Soft Computing, Computing with Words and Perceptions (pp. 535-541). New York: Springer. https://doi.org/10.1007/978-3-030-35249-3_68

Bailey, H., S. Fossette, S. J. Bograd, G. L. Shillinger, A. M. Swithenbank, J.-Y. Georges, P. Gaspar, K. P. Strömberg, F. V. Paladino and J. R. Spotila. (2012). Movement patterns for a critically endangered species, the leatherback turtle (Dermochelys coriacea), linked to foraging success and population status. PLoS One 7: e36401.

Baker, C. S., D. Steel, S. Nieukirk and H. Klinck. (2018). Environmental DNA (eDNA) from the wake of the whales: Droplet digital PCR for detection and species identification. Frontiers in Marine Science 5: 133.

Baumbach, D. S., E. C. Anger, N. A. Collado and S. G. Dunbar. (2019). Identifying sea turtle home ranges utilizing citizen-science data from novel web-based and smartphone GIS Applications. Chelonian Conservation and Biology: Celebrating 25 Years as the World's Turtle and Tortoise Journal 18: 133-144.

Beaudreau, A. H. and P. S. Levin. (2014). Advancing the use of local ecological knowledge for assessing data-poor species in coastal ecosystems. Ecological Applications 24: 244-256.

Bentley, B. P., T. Carrasco-Valenzuela, E. K. S. Ramos, et al. (2023). Divergent sensory and immune gene evolution in sea turtles with contrasting demographic and life histories. Proc Natl Acad Sci USA 120(7) e2201076120. https://doi.org/10.1073/pnas.2201076120

Bevan, E., T. Wibbels, E. Navarro, M. Rosas, B. M. Najera, L. Sarti, F. Illescas, J. Montano, L. J. Peña and P. Burchfield. (2016). Using unmanned aerial vehicle (UAV) technology for locating, identifying, and monitoring courtship and mating behaviour in the green turtle (Chelonia mydas). Herpetological Review 47: 27-32.

Bielli, A., J. Alfaro-Shigueto, P. D. Doherty, B. J. Godley, C. Ortiz, A. Pasara, J. H. Wang, and J. C. Mangel. (2020). An illuminating idea to reduce bycatch in the Peruvian small-scale gillnet fishery. Biological Conservation 241: 108277.

Bird, K. E., W. J. Nichols and C. R. Tambiah. (2003). The value of local knowledge in sea turtle conservation: a case from Baja California, Mexico. University of British Columbia Fisheries Centre Research Reports 11: 178-183.

Boerger, C. M., G. L. Lattin, S. L. Moore and C. J. Moore. (2010). Plastic ingestion by planktivorous fishes in the North Pacific Central Gyre. Marine Pollution Bulletin 60(12): 2275-2278.

Bousquet, O., M. Dalleau, M. Bocquet, P. Gaspar, S. Bielli, S. Ciccione, E. Remy and A. Vidard. (2020). Sea turtles for ocean research and monitoring: overview and initial results of the STORM project in the Southwest Indian Ocean. Frontiers in Marine Science 7: 859.

Boussarie, G., J. Bakker, O. S. Wangensteen, S. Mariani, L. Bonnin, J. B. Juhel, J. J. Kiszka, M. Kulbicki, S. Manel, W. D. Robbins, L. Vigliola and D. Mouillot. (2018). Environmental DNA illuminates the dark diversity of sharks. Science Advances 4(5): eaap9661.

Briscoe, D., D. Parker, S. Bograd, E. Hazen, K. Scales, G. Balazs, M. Kurita, T. Saito, H. Okamoto and M. Rice. (2016a). Multi-year tracking reveals extensive pelagic phase of juvenile loggerhead sea turtles in the North Pacific. Movement Ecology 4: 1-12.

Briscoe, D., D. Parker, G. Balazs, M. Kurita, T. Saito, H. Okamoto, M. Rice, J. J. Polovina and L. Crowder. (2016b). Active dispersal in loggerhead sea turtles (Caretta caretta) during the 'lost years'. Proceedings of the Royal Society B:

Biological Sciences 283: 20160690.

Briscoe, D. K., A. J. Hobday, A. Carlisle, K. Scales, J. P. Eveson, H. Arrizabalaga, J. N. Druon and J. M. Fromentin. (2017). Ecological bridges and barriers in pelagic ecosystems. Deep Sea Research Part II: Topical Studies in Oceanography 140: 182-192.

Briscoe, D. K., C. N. T. Tomaszewicz, J. A. Seminoff, D. M. Parker, G. H. Balazs, J. J. Polovina, M. Kurita, H. Okamoto, T. Saito, M. R. Rice and L. B. Crowder. (2021). Dynamic thermal corridor may connect endangered loggerhead sea turtles across the Pacific Ocean. Frontiers in Marine Science 8: 630590.

Carr, A. (1980). Some problems of sea turtle ecology. American Zoologist 20: 489-498.

Casale, P., M. Affronte, G. Insacco, D. Freggi, C. Vallini, P. Pino d'Astore, R. Basso, G. Paolillo, G. Abbate and R. Argano. (2010). Sea turtle strandings reveal high anthropogenic mortality in Italian waters. Aquatic Conservation: Marine and Freshwater Ecosystems 20: 611-620.

Ceriani, S. A., Roth, J. D., Evans, D. R., Weishampel, J. F., & Ehrhart, L. M. (2012). Inferring foraging areas of nesting loggerhead turtles using satellite telemetry and stable isotopes. PLoS One, 7, e45335.

Ceriani, S. A., Roth, J. D., Sasso, C. R., McClellan, C. M., James, M. C., Haas, H. L., Smolowitz, R. J., Evans, D. R., Addison, D. A., Bagley, D. A., Ehrhart, L. M., & Weishampel, J. F. (2014). Modeling and mapping isotopic patterns in the Northwest Atlantic derived from loggerhead sea turtles. Ecosphere, 5, art122.

Chaloupka, M., Work, T. M., Balazs, G. H., Murakawa, S. K., & Morris, R. (2008). Cause-specific temporal and spatial trends in green sea turtle strandings in the Hawaiian Archipelago (1982-2003). Marine Biology, 154, 887-898.

Chambault, P., Gaspar, P., & Dell'Amico, F. (2021). Ecological trap or favorable habitat? First evidence that immature sea turtles may survive at their range-limits in the North-East Atlantic. Frontiers in Marine Science, 8, 1553.

Chevis, M. G., Godley, B. J., Lewis, J. P., Lewis, J. J., Scales, K. L., & Graham, R. T. (2017). Movement patterns of juvenile hawksbill turtles Eretmochelys imbricata at a Caribbean coral atoll: long-term tracking using passive acoustic telemetry. Endangered Species Research, 32, 309-319.

Codina-García, M., Militão, T., Moreno, J., & González-Solís, J. (2013). Plastic debris in Mediterranean seabirds. Marine Pollution Bulletin, 77(1-2), 220-226.

Coles, W., & Musick, J. A. (2000). Satellite sea surface temperature analysis and correlation with sea turtle distribution off North Carolina. Copeia, 2000, 551-554.

Constantino, M. A., & Salmon, M. (2003). Role of chemical and visual cues in food recognition by leatherback posthatchlings (Dermochelys coriacea L). Zoology, 106(3), 173-181.

Cook, M., Reneker, J. L., Nero, R. W., Stacy, B. A., Hanisko, D. S., & Wang, Z. (2021). Use of Drift Studies to Understand Seasonal Variability in Sea Turtle Stranding Patterns in Mississippi. Frontiers in Marine Science, 8, 447.

Crouse, D. T., Crowder, L. B., & Caswell, H. (1987). A stage-based population model for loggerhead sea turtles and implications for conservation. Ecology, 68, 1412-1423.

Crowder, L. B., Crouse, D. T., Heppell, S. S., & Martin, T. H. (1994). Predicting the impact of turtle excluder devices on loggerhead sea turtle populations. Ecological Applications, 4, 437-445.

De Stephanis, R., Giménez, J., Carpinelli, E., Gutierrez-Exposito, C., & Cañadas, A. (2013). As main meal for sperm whales: Plastics debris. Marine Pollution Bulletin, 69(1-2), 206-214.

Deiner, K., Bik, H. M., Mächler, E., Seymour, M., Lacoursière-Roussel, A., Altermatt, F., Creer, S., Bista, I., Lodge, D. M., de Vere, N., Pfrender, M. E., & Bernatchez, L. (2017). Environmental DNA metabarcoding: Transforming how we survey animal and plant communities. Molecular Ecology, 26(21), 5872-5895.

Digka, N., Bray, L., Tsangaris, C., Andreanidou, K., Kasimati, E., Kofidou, E., Komnenou, A., & Kaberi, H. (2020). Evidence of ingested plastics in stranded loggerhead sea turtles along the Greek coastline, East Mediterranean Sea. Environmental Pollution, 263, 114596.

Dodge, K. L., Galuardi, B., Miller, T. J., & Lutcavage, M. E. (2014). Leatherback turtle movements, dive behavior, and habitat characteristics in ecoregions of the Northwest Atlantic Ocean. PLoS One, 9(3), e91726.

Doi, T., Storto, A., Fukuoka, T., Suganuma, H., & Sato, K. (2019). Impacts of Temperature Measurements From Sea Turtles on Seasonal Prediction Around the Arafura Sea. Frontiers in Marine Science, 6, 719.

DuBois, M. J., Putman, N. F., & Piacenza, S. E. (2021). A Global Assessment of the Potential for Ocean-Driven Transport in Hatchling Sea Turtles. Water, 13, 757.

Dutton, P. H., Jensen, M. P., Frutchey, K., Frey, A., LaCasella, E., Balazs, G. H., Cruce, J., Tagarino, A., Farman, R., & Tatarata, M. (2014). Genetic Stock Structure of Green Turtle (Chelonia mydas) Nesting Populations Across the Pacific Islands. Pacific Science, 68(4), 451-464.

Dutton, P. H., Komoroske, L., Bejder, L., & Meekan, M. (2019). Integrating emerging technologies into marine megafauna conservation management. Frontiers in Marine Science, 6, 693.

Early-Capistrán, M.-M., Solana-Arellano, E., Abreu-Grobois, F. A., Narchi, N. E., Garibay-Melo, G., Seminoff, J. A., Koch, V., & Saenz-Arroyo, A. (2020). Quantifying local ecological knowledge to model historical abundance of long-lived, heavily-exploited fauna. PeerJ, 8, e9494.

Eguchi, T., McClatchie, S., Wilson, C., Benson, S. R., LeRoux, R. A., & Seminoff, J. A. (2018). Loggerhead turtles (Caretta caretta) along the US west coast: Abundance, distribution, and anomalous warming of the North Pacific. Frontiers in Marine Science, 5, 1-15.

Elith, J., & Leathwick, J. R. (2009). Species distribution models: Ecological explanation and prediction across space and time. Annual review of ecology, evolution, and systematics, 40, 677-697.

Ficetola, G. F., Miaud, C., Pompanon, F., & Taberlet, P. (2008). Species detection using environmental DNA from water samples. Biology Letters, 4(4), 423-425.

Figgener, C., Bernardo, J., & Plotkin, P. T. (2019). MarTurtSI, a global database of stable isotope analyses of marine turtles. Scientific Data, 6(1), 1-6.

Finkbeiner, E. M., Wallace, B. P., Moore, J. E., Lewison, R. L., Crowder, L. B., & Read, A. J. (2011). Cumulative estimates of sea turtle bycatch and mortality in USA fisheries between 1990 and 2007. Biological Conservation, 144, 2719-2727.

Fleming, A. H., Kellar, N. M., Allen, C. D., & Kurle, C. M. (2018). The Utility of Combining Stable Isotope and Hormone Analyses for Marine Megafauna Research. Frontiers in Marine Science, 5, 338.

Flores, E., De La Cruz, J., Seminoff, J., & Urena, L. (2021). Local Ecological Knowledge Supports Identification of Sea Turtle Nesting Beaches in Panama.

Foote, A. D., Thomsen, P. F., Sveegaard, S., Wahlberg, M., Kielgast, J., Kyhn, L. A., Salling, A. B., Galatius, A., Orlando, L., & Gilbert, M. T. P. (2012). Investigating the Potential Use of Environmental DNA (eDNA) for Genetic Monitoring of Marine Mammals. PLoS One, 7, e41781.

Fossette, S., Hobson, V. J., Girard, C., Calmettes, B., Gaspar, P., Georges, J.-Y., & Hays, G. C. (2010). Spatio-temporal foraging patterns of a giant zooplanktivore, the leatherback turtle. Journal of Marine Systems, 81, 225-234.

Fossette, S., Witt, M., Miller, P., Nalovic, M., Albareda, D., Almeida, A., Broderick, A., Chacón-Chaverri, D., Coyne, M., & Domingo, A. (2014). Pan-Atlantic analysis of the overlap of a highly migratory species, the leatherback turtle, with pelagic longline fisheries. Proceedings of the Royal Society B: Biological Sciences, 281, 20133065.

Gaspar, P., Benson, S. R., Dutton, P. H., Réveillère, A., Jacob, G., Meetoo, C., Dehecq, A., & Fossette, S. (2012). Oceanic dispersal of juvenile leatherback turtles: going beyond passive drift modeling. Marine Ecology Progress Series, 457, 265-284.

Gaspar, P., Georges, J.-Y., Fossette, S., Lenoble, A., Ferraroli, S., & Le Maho, Y. (2006). Marine animal behaviour: neglecting ocean currents can lead us up the wrong track. Proceedings of the Royal Society B: Biological Sciences, 273, 2697-2702.

Gilman, E., Gearhart, J., Price, B., Eckert, S., Milliken, H., Wang, J., Swimmer, Y., Shiode, D., Abe, O., Hoyt Peckham, S., Chaloupka, M., Hall, M., Mangel, J., Alfaro-Shigueto, J., Dalzell, P., & Ishizaki, A. (2010). Mitigating sea turtle by-catch in coastal passive net fisheries. Fish and Fisheries, 11(1), 57-88.

Gilman, E., Zollett, E., Beverly, S., Nakano, H., Davis, K., Shiode, D., Dalzell, P., & Kinan, I. (2006). Reducing sea turtle by-catch in pelagic longline fisheries. Fish and Fisheries, 7, 2-23.

Godley, B., Blumenthal, J., Broderick, A., Coyne, M., Godfrey, M., Hawkes, L., & Witt, M. (2008). Satellite tracking of sea turtles: where have we been and where do we go next? Endangered Species Research, 4, 3-22.

Godley, B., Broderick, A., Colman, L., Formia, A., Godfrey, M., Hamann, M., Nuno, A., Omeyer, L., Patrício, A., & Phillott, A. (2020). Reflections on sea turtle conservation. Oryx, 54, 287-289.

Graham, B. S., Koch, P. L., Newsome, S. D., McMahon, K. W., & Aurioles, D. (2010). Using Isoscapes to Trace the Movements and Foraging Behavior of Top Predators in Oceanic Ecosystems. In J. B. West, G. J. Bowen, T. E. Dawson, & K. P. Tu (Eds.), Isoscapes: Understanding movement, pattern, and process on Earth through isotope mapping (pp. 299-318). Springer Netherlands.

Gray, P. C., Fleishman, A. B., Klein, D. J., McKown, M. W., Bezy, V. S., Lohmann, K. J., & Johnston, D. W. (2019). A convolutional neural network for detecting sea turtles in drone imagery. Methods in Ecology and Evolution, 10, 345-355.

Guisan, A., & Thuiller, W. (2005). Predicting species distribution: offering more than simple habitat models. Ecology Letters, 8, 993-1009.

Guisan, A., & Zimmermann, N. E. (2000). Predictive habitat distribution models in ecology. Ecological Modelling, 135, 147-186.

Hamann, M., Godfrey, M. H., Seminoff, J. A., Arthur, K., Barata, P. C. R., Bjorndal, K. A., Bolten, A. B., Broderick, A. C., Campbell, L. M., Carreras, C., Casale, P., Chaloupka, M., Chan, S. K. F., Coyne, M. S., Crowder, L. B., Diez, C. E., Dutton, P. H., Epperly, S. P., FitzSimmons, N. N., Formia, A., Girondot, M., Hays, G. C., I-Jiunn, C., Kaska, Y., Lewison, R., Mortimer, J. A., Nichols, W. J., Reina, R. D., Shanker, K., Spotila, J. R., Tomás, J., Wallace, B. P., Work, T. M., Zbinden, J., & Godley, B. J. (2011). Global research priorities for sea turtles: Informing management and conservation in the 21st century. Endangered Species Research, 11, 245-269.

Hanna, M. E., Chandler, E. M., Semmens, B. X., Eguchi, T., Lemons, G. E., & Seminoff, J. A. (2021). Citizen-sourced sightings and underwater photography reveal novel insights about green sea turtle distribution and ecology in southern California. Frontiers in Marine Science, 8, 500.

Hardin, E. E., & Fuentes, M. M. (2021). A Systematic Review of Acoustic Telemetry as a Tool to Gain Insights Into Marine Turtle Ecology and Aid Their Conservation. Frontiers in Marine Science.

Harper, K. J., Goodwin, K. D., Harper, L. R., LaCasella, E. L., Frey, A., & Dutton, P. H. (2020). Finding Crush: Environmental DNA Analysis as a Tool for Tracking the Green Sea Turtle Chelonia mydas in a Marine Estuary. Frontiers in Marine Science, 6, 810.

Hart, K. M., & Hyrenbach, K. D. (2009). Satellite telemetry of marine megavertebrates: the coming of age of an experimental science. Endangered Species Research, 10, 9-20.

Hart, K. M., Mooreside, P., & Crowder, L. B. (2006). Interpreting the spatio-temporal patterns of sea turtle strandings: Going with the flow. Biological Conservation, 129(2), 283-290.

Harvell, D., Altizer, S., Cattadori, I. M., Harrington, L., & Weil, E. (2009). Climate change and wildlife diseases: When does the host matter the most? Ecology, 90, 912-920.

Hatase, H., Sato, K., Yamaguchi, M., Takahashi, K., & Tsukamoto, K. (2006). Individual variation in feeding habitat use by adult female green sea turtles (Chelonia mydas): Are they obligately neritic herbivores? Oecologia, 149, 52-64.

Hawkes, L. A., Broderick, A. C., Coyne, M. S., Godfrey, M. H., & Godley, B. J. (2007). Only some like it hot - quantifying the environmental niche of the loggerhead sea turtle. Diversity and Distributions, 13, 447-457.

Hawkes, L. A., Broderick, A. C., Godfrey, M. H., & Godley, B. J. (2009). Climate change and marine turtles. Endangered Species Research, 7, 137-154.

Hays, G. C. (2008). Sea turtles: A review of some key recent discoveries and remaining questions. Journal of Experimental Marine Biology and Ecology, 356, 1-7.

Hays, G. C., Bailey, H., Bograd, S. J., Bowen, W. D., Campagna, C., Carmichael, R. H., Casale, P., Chiaradia, A., Costa, D. P., & Cuevas, E. (2019). Translating marine animal tracking data into conservation policy and management. Trends in Ecology & Evolution, 34, 459-473.

Hays, G. C., Fossette, S., Katselidis, K. A., Mariani, P., & Schofield, G. (2010). Ontogenetic development of migration: Lagrangian drift trajectories suggest a new paradigm for sea turtles. Journal of the Royal Society Interface, 7, 1319-1327.

Hays, G. C., & Hawkes, L. A. (2018). Satellite tracking sea turtles: Opportunities and challenges to address key questions. Frontiers in Marine Science, 5, 432.

Haywood, J. C., Fuller, W. J., Godley, B. J., Margaritoulis, D., Shutler, J. D., Snape, R. T., Widdicombe, S., Zbinden, J. A., & Broderick, A. C. (2020). Spatial ecology of loggerhead turtles: Insights from stable isotope markers and satellite telemetry. Diversity and Distributions, 26, 368-381.

Haywood, J. C., Fuller, W. J., Godley, B. J., Shutler, J. D., Widdicombe, S., & Broderick, A. C. (2019). Global review and inventory: How stable isotopes are helping us understand ecology and inform conservation of marine turtles. Marine Ecology Progress Series, 613, 217-245.

Hazen, E. L., Maxwell, S. M., Bailey, H., Bograd, S. J., Hamann, M., Gaspar, P., Godley, B. J., & Shillinger, G. L. (2012). Ontogeny in marine tagging and tracking science: Technologies and data gaps. Marine Ecology Progress Series, 457, 221-240.

Hazen, E. L., Scales, K. L., Maxwell, S. M., Briscoe, D. K., Welch, H., Bograd, S. J., Bailey, H., Benson, S. R., Eguchi, T., Dewar, H., Kohin, S., Costa, D. P., Crowder, L. B., & Lewison, R. L. (2018). A dynamic ocean management tool to reduce bycatch and support sustainable fisheries. Science Advances, 4, eaar3001.

Hobday, A. J., Spillman, C. M., Eveson, J. P., Hartog, J. R., Zhang, X., & Brodie, S. (2018). A framework for combining seasonal forecasts and climate projections to aid risk management for fisheries and aquaculture. Frontiers in Marine Science, 5, 137.

Hoopes, L. A., Landry Jr, A. M., & Stabenau, E. K. (2000). Physiological effects of capturing Kemp's ridley sea turtles, Lepidochelys kempii, in entanglement nets. Canadian Journal of Zoology, 78, 1941-1947.

Hoover, A. L., Shillinger, G. L., Swiggs, J., & Bailey, H. (2017). Comparing acoustic tag attachments designed for mobile tracking of hatchling sea turtles. Frontiers in Marine Science, 4, 225.

Howell, E. A., Hoover, A., Benson, S. R., Bailey, H., Polovina, J. J., Seminoff, J. A., & Dutton, P. H. (2015). Enhancing the TurtleWatch product for leatherback sea turtles, a dynamic habitat model for ecosystem-based management. Fisheries Oceanography, 24, 57-68.

Howell, E. A., Kobayashi, D. R., Parker, D. M., Balazs, G. H., & Polovina, A. (2008). TurtleWatch: A tool to aid in the bycatch reduction of loggerhead turtles Caretta caretta in the Hawaii-based pelagic longline fishery. Endangered Species Research, 5, 267-278.

Hunt, K. E., Innis, C. J., Merigo, C., & Rolland, R. M. (2016). Endocrine responses to diverse stressors of capture, entanglement and stranding in leatherback turtles (Dermochelys coriacea). Conservation Physiology, 4(1), cow022.

IPCC. (2021). Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change; Technical Summary.

Jambeck, J. R., Geyer, R., Wilcox, C., Siegler, T. R., Perryman, M., Andrady, A., Narayan, R., & Law, K. L. (2015). Plastic waste inputs from land into the ocean. Science, 347(6223), 768-771.

Jeffers, V. F., & Godley, B. J. (2016). Satellite tracking in sea turtles: How do we find our way to the conservation dividends? Biological Conservation, 199, 172-184.

Jenkins, L. D. (2012). Reducing sea turtle bycatch in trawl nets: A history of NMFS turtle excluder device (TED) research. Marine Fisheries Review, 74, 26-44.

Jensen, M. P., Allen, C. D., Eguchi, T., Bell, I. P., LaCasella, E. L., Hilton, W. A., Hof, C. A. M., & Dutton, P. H. (2018). Environmental warming and feminization of one of the largest sea turtle populations in the world. Current Biology, 28, 154-159.e154.

Jones, T. T., & Seminoff, J. (2013). Feeding Biology: Advances from Field-Based Observations, Physiological Studies, and Molecular Techniques. In J. Wyneken, K. Lohmann, & J. Musick (Eds.), The Biology of Sea Turtles, Volume III (1st ed., pp. 211-247). CRC Press.

Jonsen, I. D., Myers, R. A., & James, M. C. (2007). Identifying leatherback turtle foraging behaviour from satellite telemetry using a switching state-space model. Marine Ecology Progress Series, 337, 255-264.

Kelly, R. P., Port, J. A., Yamahara, K. M., & Crowder, L. B. (2014a). Using environmental DNA to census marine fishes in a large mesocosm. PLoS One, 9(1), e86175.

Kelly, R. P., Port, J. A., Yamahara, K. M., Martone, R. G., Lowell, N., Thomsen, P. F., Mach, M. E., Bennett, M., Prahler, E., Caldwell, M. R., & Crowder, L. B. (2014b). Harnessing DNA to improve environmental management. Science, 344(6191), 1455-1456.

Koch, V., Peckham, H., Mancini, A., & Eguchi, T. (2013). Estimating at-sea mortality of marine turtles from stranding frequencies and drifter experiments. PLoS One, 8, e56776.

Komoroske, L. M., Jensen, M. P., Stewart, K. R., Shamblin, B. M., & Dutton, P. H. (2017). Advances in the Application of Genetics in Marine Turtle Biology and Conservation. Frontiers in Marine Science, 4, 156.

LaCasella, E. L., Jensen, M. P., Madden Hof, C. A., Bell, I. P., Frey, A., & Dutton, P. H. (2021). Mitochondrial DNA Profiling to Combat the Illegal Trade in Tortoiseshell Products. Frontiers in Marine Science, 7, 595853.

Lalire, M., & Gaspar, P. (2019). Modeling the active dispersal of juvenile leatherback turtles in the North Atlantic Ocean. Movement Ecology, 7, 1-17.

Lamont, M. M., & Iverson, A. R. (2018). Shared habitat use by juveniles of three sea turtle species. Marine Ecology Progress Series, 606, 187-200.Lee, L. C., Thorley, J., Watson, J., Reid, M., & Salomon, A. K. (2019). Diverse knowledge systems reveal social–ecological dynamics that inform species conservation status. Conservation Letters, 12, e12613.

Letessier, T. B., Bouchet, P., Reisser, J., & Meeuwig, J. J. (2014). Baited videography reveals remote foraging and migration behaviour of sea turtles. Marine Biodiversity, 45(4), 609-610.

Lewison, R. L., Hobday, A. J., Maxwell, S. M., Hazen, E. L., Wiley, D., Dunn, D. C., Briscoe, D. K., Fossette, S., O'Keefe, C., Barnes-Mauthe, M., Abecassis, M., Bograd, S. J., Howell, E., Bethoney, N. D., Bailey, H., Hartog, J., Andrews, S., Hazen, L., & Crowder, L. B. (2015). Dynamic ocean management: identifying the critical ingredients of dynamic approaches to ocean resource management. BioScience, 65, 486-498.

Lewison, R. L., Crowder, L. B., Read, A. J., & Freeman, S. A. (2004). Understanding impacts of fisheries bycatch on marine megafauna. Trends in Ecology & Evolution, 19, 598-604.

Lewison, R. L., Crowder, L. B., Wallace, B. P., Moore, J. E., Cox, T., Zydelis, R., McDonald, S., DiMatteo, A., Dunn, D. C., & Kot, C. Y. (2014). Global patterns of marine mammal, seabird, and sea turtle bycatch reveal taxa-specific and cumulative megafauna hotspots. Proceedings of the National Academy of Sciences, 111, 5271-5276.

Liu, X., Manning, J., Prescott, R., Page, F., Zou, H., & Faherty, M. (2019). On simulating cold-stunned sea turtle strandings on Cape Cod, Massachusetts. PLoS One, 14(12), e0204717.

Luschi, P., Benhamou, S., Girard, C., Ciccione, S., Roos, D., Sudre, J., & Benvenuti, S. (2007). Marine turtles use geomagnetic cues during open-sea homing. Current Biology, 17, 126-133.

Luschi, P., Hays, G., Del Seppia, C., Marsh, R., & Papi, F. (1998). The navigational feats of green sea turtles migrating from Ascension Island investigated by satellite telemetry. Proceedings of the Royal Society of London. Series B: Biological Sciences, 265, 2279-2284.

Maki, T., Horimoto, H., Ishihara, T., & Kofuji, K. (2020). Tracking a sea turtle by an AUV with a multibeam imaging sonar: Toward robotic observation of marine life. International Journal of Control, Automation and Systems, 18, 597-604.

Mancini, A., Koch, V., Seminoff, J. A., & Madon, B. (2012). Small-scale gill-net fisheries cause massive green turtle Chelonia mydas mortality in Baja California Sur, Mexico. Oryx, 46(1), 69-77.

Mansfield, K. L., Wyneken, J., & Luo, J. (2021). First Atlantic satellite tracks of 'lost years' green turtles support the importance of the Sargasso Sea as a sea turtle nursery. Proceedings of the Royal Society B, 288, 20210057.

Mansfield, K. L., Wyneken, J., Porter, W. P., & Luo, J. (2014). First satellite tracks of neonate sea turtles redefine the 'lost years' oceanic niche. Proceedings of the Royal Society B: Biological Sciences, 281, 20133039.

Martin, G. R., & Crawford, R. (2015). Reducing bycatch in gillnets: A sensory ecology perspective. Global Ecology and Conservation, 3, 28-50.

Mason, J. G., Alfaro-Shigueto, J., Mangel, J. C., Brodie, S., Bograd, S. J., Crowder, L. B., & Hazen, E. L. (2019). Convergence of fishers' knowledge with a species distribution model in a Peruvian shark fishery. Conservation Science and Practice, 1, e13.

Maxwell, S. M., Breed, G. A., Nickel, B. A., Makanga-Bahouna, J., Pemo-Makaya, E., Parnell, R. J., Formia, A., Ngouessono, S., Godley, B. J., & Costa, D. P. (2011). Using satellite tracking to optimize protection of long-lived marine species: olive ridley sea turtle conservation in Central Africa. PLoS One, 6, e19905.

Maxwell, S. M., Broderick, A. C., Dutton, P. H., Fossette-Halot, S., Fuentes, M. M., & Reina, R. D. (2019). Advances in the biology and conservation of marine turtles. Frontiers in Marine Science, 6, 9.

Maxwell, S. M., Gjerde, K. M., Conners, M. G., & Crowder, L. B. (2020). Mobile protected areas for biodiversity on the high seas. Science, 367, 252-254.

Maxwell, S. M., Hazen, E. L., Lewison, R. L., Dunn, D. C., Bailey, H., Bograd, S. J., Briscoe, D. K., Fossette, S., Hobday, A. J., Bennett, M., Benson, S., Caldwell, M. R., Costa, D. P., Dewar, H., Eguchi, T., Hazen, L., Kohin, S., Sippel, T., & Crowder, L. B. (2015). Dynamic oceans need dynamic management. Marine Policy, 58, 42-50.

Mayne, B., Mustin, W., Baboolal, V., Casella, F., Ballorain, K., Barret, M., Vanderklift, M.A., Tucker, A.D., Korbie, D., Jarman, S. and Berry, O., 2022. Age prediction of green turtles with an epigenetic clock. *Molecular Ecology Resources*, *22*(6), pp.2275-2284.

Mazaris, A. D., Schofield, G., Gkazinou, C., Almpanidou, V., & Hays, G. C. (2017). Global sea turtle conservation successes. Science Advances, 3, e1600730.

McCauley, S. J., & Bjorndal, K. A. (1999). Conservation implications of dietary dilution from debris ingestion: Sublethal effects in post-hatchling loggerhead sea turtles. Conservation Biology, 13(4), 925-929.

McClellan, C. M., Braun-McNeill, J., Avens, L., Wallace, B. P., & Read, A. J. (2010). Stable isotopes confirm a foraging dichotomy in juvenile loggerhead sea turtles. Journal of Experimental Marine Biology and Ecology, 387, 44-51.

McClellan, C. M., & Read, A. J. (2007). Complexity and variation in loggerhead sea turtle life history. Biology Letters, 3, 592-594.

McHenry, J., Welch, H., Lester, S. E., & Saba, V. (2019). Projecting marine species range shifts from only temperature can mask climate vulnerability. Global Change Biology, 25, 4208-4221.

McMahon, K. W., Hamady, L. L., & Thorrold, S. R. (2013). A review of ecogeochemistry approaches to estimating movements of marine animals. Limnology and Oceanography, 58, 697-714.

Mello-Fonseca, J., Cordeiro, C. A., & Ferreira, C. E. (2021). Spatial distribution of sea turtles on South Atlantic subtropical reefs. Marine Ecology Progress Series, 678, 125-138.

Melo-Merino, S. M., Reyes-Bonilla, H., & Lira-Noriega, A. (2020). Ecological niche models and species distribution models in marine environments: A literature review and spatial analysis of evidence. Ecological Modelling, 415, 108837.

Mencacci, R., De Bernardi, E., Sale, A., Lutjeharms, J. R., & Luschi, P. (2010). Influence of oceanic factors on long-distance movements of loggerhead sea turtles displaced in the southwest Indian Ocean. Marine Biology, 157, 339-349.

Monteiro, D. S., Estima, S. C., Gandra, T. B. R., Silva, A. P., Bugoni, L., Swimmer, Y., Seminoff, J. A., & Secchi, E. R. (2016). Long-term spatial and temporal patterns of sea turtle strandings in southern Brazil. Marine Biology, 163(12), 1-19.

Mukherjee, N., Zabala, A., Huge, J., Nyumba, T. O., Esmail, B. A., & Sutherland, W. J. (2018). Comparison of techniques for eliciting views and judgments in decision-making. Methods in Ecology and Evolution, 9, 54-63.

Nichols, W. J., Resendiz, A., Seminoff, J. A., & Resendiz, B. (2000). Transpacific migration of a loggerhead turtle monitored by satellite telemetry. Bulletin of Marine Science, 67, 937-947.

Oliver, E. C. J., Benthuysen, J. A., Darmaraki, S., Donat, M. G., Hobday, A. J., Holbrook, N. J., Schlegel, R. W., & Sen Gupta, A. (2021). Marine Heatwaves. Annual Review of Marine Science, 13, 313-342.

Ostle, C., Thompson, R. C., Broughton, D., Gregory, L., Wootton, M., & Johns, D. G. (2019). The rise in ocean plastics evidenced from a 60-year time series. Nature Communications, 10(1), 1-6.

Pacheco, J. C., Kerstetter, D. W., Hazin, F. H., Hazin, H., Segundo, R. S. S. L., Graves, J. E., Carvalho, F., & Travassos, P. E. (2011). A comparison of circle hook and J hook performance in a western equatorial Atlantic Ocean pelagic longline fishery. Fisheries Research, 107, 39-45.

Pankaew, K., & Milton, S. L. (2018). The effects of extended crawling on the physiology and swim performance of loggerhead and green sea turtle hatchlings. Journal of Experimental Biology, 221, jeb165225.

Papafitsoros, K., Dimitriadis, C., Mazaris, A. D., & Schofield, G. (2022). Photo-identification confirms polyandry in loggerhead sea turtles. Marine Ecology, 43(2), e12696.

Patel, S. H., Dodge, K. L., Haas, H. L., & Smolowitz, R. J. (2016). Videography reveals in-water behavior of loggerhead turtles (Caretta caretta) at a foraging ground. Frontiers in Marine Science, 3, 254.

Patel, S. H., Winton, M. V., Hatch, J. M., Haas, H. L., Saba, V. S., Fay, G., & Smolowitz, R. J. (2021). Projected shifts in loggerhead sea turtle thermal habitat in the Northwest Atlantic Ocean due to climate change. Scientific Reports, 11, 1-12.

Patrício, A. R., Hawkes, L. A., Monsinjon, J. R., Godley, B. J., & Fuentes, M. M. (2021). Climate change and marine turtles: recent advances and future directions. Endangered Species Research, 44, 363-395.

Pearson, R. M., van de Merwe, J. P., Limpus, C. J., & Connolly, R. M. (2017). Realignment of sea turtle isotope studies needed to match conservation priorities. Marine Ecology Progress Series, 583, 259-271.

Peckham, S. H., Maldonado-Diaz, D., Koch, V., Mancini, A., Gaos, A., Tinker, M. T., Nichols, W. J., & Wallace, J. (2008). High mortality of loggerhead turtles due to bycatch, human consumption and strandings at Baja California Sur, Mexico, 2003 to 2007. Endangered Species Research, 5, 171-183.

Piacenza, J., Piacenza, S., Mayoral, S., Kenney, A., & Shields, N. (2018). Design Opportunities for Sea Turtle Satellite Tracking Devices. In International Design Engineering Technical Conferences and Computers and Information in Engineering Conference (pp. V004T005A024). American Society of Mechanical Engineers.

Poloczanska, E. S., Limpus, C. J., & Hays, G. C. (2009). Vulnerability of marine turtles to climate change. Advances in Marine Biology, 56, 151-211.

Polovina, J. J., Kobayashi, D. R., Parker, D. M., Seki, M. P., & Balazs, G. H. (2000). Turtles on the edge: movement of loggerhead turtles (Caretta caretta) along oceanic fronts, spanning longline fishing grounds in the central North Pacific, 1997–1998. Fisheries Oceanography, 9(1), 71-82.

Putman, N. F., Mansfield, K. L., He, R., Shaver, D. J., & Verley, P. (2013). Predicting the distribution of oceanic-stage Kemp's ridley sea turtles. Biology Letters, 9(3), 20130345.

Ramirez, M. D., Miller, J. A., Parks, E., Avens, L., Goshe, L. R., Seminoff, J. A., Snover, M. L., & Heppell, S. S. (2019). Reconstructing sea turtle ontogenetic habitat shifts through trace element analysis of bone tissue. Marine Ecology Progress Series, 608, 247-262.

Reavis, J. L., Demir, H. S., Witherington, B. E., Bresette, M. J., Christen, J. B., Senko, J. F., & Ozev, S. (2021). Revealing Sea Turtle Behavior in Relation to Fishing Gear Using Color-Coded Spatiotemporal Motion Patterns With Deep Neural Networks. Frontiers in Marine Science, 8, 785357.

Rees, A. F., Alfaro-Shigueto, J., Barata, P., Bjorndal, K. A., Bolten, A. B., Bourjea, J., Broderick, A., Campbell, L., Cardona, L., & Carreras, C. (2016). Are we working towards global research priorities for management and conservation of sea turtles? Endangered Species Research, 31, 337-382.

Rees, A. F., Avens, L., Ballorain, K., Bevan, E., Broderick, A. C., Carthy, R. R., Christianen, M. J., Duclos, G., Heithaus, M. R., & Johnston, D. W. (2018). The potential of unmanned aerial systems for sea turtle research and conservation: a review and future directions. Endangered Species Research, 35, 81-100.

Reich, K. J., Bjorndal, K. A., & Bolten, A. B. (2007). The lost years of green turtles: using stable isotopes to study cryptic lifestages. Biology Letters, 3(6), 712-714.

Reneker, J. L., Cook, M., & Nero, R. W. (2018). Preparation of fresh dead sea turtle carcasses for at-sea drift experiments.

Resendiz, A., Resendiz, B., Nichols, W. J., Seminoff, J. A., & Kamezaki, N. (1998). First confirmed east-west transpacific movement of a loggerhead sea turtle, Caretta caretta, released in Baja California, Mexico. Pacific Science, 52(2), 151-153.

Rizzi, M., Rodrigues, F. L., Medeiros, L., Ortega, I., Rodrigues, L., Monteiro, D. S., Kessler, F., & Proietti, M. C. (2019). Ingestion of plastic marine litter by sea turtles in southern Brazil: abundance, characteristics and potential selectivity. Marine Pollution Bulletin, 140, 536-548.

Robinson, N. J., Figgener, C., We, A., McDonal, J., Gomez, V., Maccarthy, A. C., Stuart, D., & Koleff, V. (2015). Plastic Straw Found Inside the Nostril of an Olive Ridley Sea Turtle. Marine Turtle Newsletter, 1-4.

Robinson, N. M., Nelson, W. A., Costello, M. J., Sutherland, J. E., & Lundquist, C. J. (2017). A systematic review of marine-based species distribution models (SDMs) with recommendations for best practice. Frontiers in Marine Science, 4, 421.

Robinson, N.J., Aguzzi, J., Arias, S., Gatto, C., Mills, S.K., Monte, A., Andrews, L.S., Yaney-Keller, A. and Tomillo, P.S., 2023. Global trends in sea turtle research and conservation: Using symposium abstracts to assess past biases and future opportunities. *Global Ecology and Conservation*, *47*, p.e02587.

Robson, N. A., Hetzel, Y., Whiting, S., Wijeratne, S., Pattiaratchi, C. B., Withers, P., & Thums, M. (2017). Use of particle tracking to determine optimal release dates and locations for rehabilitated neonate sea turtles. Frontiers in Marine Science, 4, 173.

Roe, J. H., Morreale, S. J., Paladino, F. V., Shillinger, G. L., Benson, S. R., Eckert, S. A., Bailey, H., Tomillo, P. S., Bograd, S. J., & Eguchi, T. (2014). Predicting bycatch hotspots for endangered leatherback turtles on longlines in the Pacific Ocean. Proceedings of the Royal Society B: Biological Sciences, 281(1778), 20132559.

Roussel, J. M., Paillisson, J. M., Tréguier, A., & Petit, E. (2015). The downside of eDNA as a survey tool in water bodies. Journal of Applied Ecology, 52(3), 823-826.

Rubin, S. A., & Mickle, D. (1982). A simply constructed treadmill for rodent exercise studies. Journal of Applied Physiology, 52(2), 505-507.

Saba, V. S., Shillinger, G. L., Swithenbank, A. M., Block, B. A., Spotila, J. R., Musick, J. A., & Paladino, F. V. (2008). An oceanographic context for the foraging ecology of eastern Pacific leatherback turtles: consequences of ENSO. Deep Sea Research Part I: Oceanographic Research Papers, 55, 646-660.

Saba, V. S., Stock, C. A., Spotila, J. R., Paladino, F. V., & Tomillo, P. S. (2012). Projected response of an endangered marine turtle population to climate change. Nature Climate Change, 2, 814-820.

Samhouri, J. F., Feist, B. E., Fisher, M. C., Liu, O., Woodman, S. M., Abrahms, B., ... Saez, L. E. (2021). Marine heatwave challenges solutions to human–wildlife conflict. Proceedings of the Royal Society B, 288(1964), 20211607.

Santos, B. S., & Crowder, L. B. (2021). Online news media coverage of sea turtles and their conservation. BioScience, 71, 305-313.

Santos, B. S., Friedrichs, M. A. M., Rose, S. A., Barco, S. G., & Kaplan, D. M. (2018a). Likely locations of sea turtle stranding mortality using experimentally-calibrated, time and space-specific drift models. Biological Conservation, 226, 127-143.

Santos, B. S., Kaplan, D. M., Friedrichs, M. A. M., Barco, S. G., Mansfield, K. L., & Manning, J. P. (2018b). Consequences of drift and carcass decomposition for estimating sea turtle mortality hotspots. Ecological Indicators, 84, 319-336.

Santos, R. G., Andrades, R., Boldrini, M. A., & Martins, A. S. (2015). Debris ingestion by juvenile marine turtles: An underestimated problem. Marine Pollution Bulletin, 93.

Schakner, Z. A., & Blumstein, D. T. (2013). Behavioral biology of marine mammal deterrents: A review and prospectus. Biological Conservation, 167, 380-389.

Schofield, G., Papafitsoros, K., Haughey, R., & Katselidis, K. (2017). Aerial and underwater surveys reveal temporal variation in cleaning-station use by sea turtles at a temperate breeding area. Marine Ecology Progress Series, 575, 153-164.

Schuyler, Q., Hardesty, B. D., Wilcox, C., & Townsend, K. (2012). To eat or not to eat? Debris selectivity by marine turtles. PLoS One, 7(7), e40884.

Schuyler, Q., Hardesty, B. D., Wilcox, C., & Townsend, K. (2014). Global Analysis of Anthropogenic Debris Ingestion by Sea Turtles. Conservation Biology, 28(1), 129-139.

Schuyler, Q. A., Wilcox, C., Townsend, K. A., Wedemeyer-Strombel, K. R., Balazs, G., van Sebille, E., & Hardesty, B. D. (2016). Risk analysis reveals global hotspots for marine debris ingestion by sea turtles. Global Change Biology, 22(2), 567-576.

Scott, R., Biastoch, A., Roder, C., Stiebens, V. A., & Eizaguirre, C. (2014a). Nano-tags for neonates and ocean-mediated swimming behaviours linked to rapid dispersal of hatchling sea turtles. Proceedings of the Royal Society B: Biological Sciences, 281, 20141209.

Scott, R., Marsh, R., Hays, G. C. (2014b). Ontogeny of long distance migration. Ecology, 95(10), 2840-2850.

Scott, R., Hodgson, D. J., Witt, M. J., Coyne, M. S., Adnyana, W., Blumenthal, J. M., Broderick, A. C., Canbolat, A. F., Catry, P., Ciccione, S. (2012). Global analysis of satellite tracking data shows that adult green turtles are significantly aggregated in Marine Protected Areas. Global Ecology and Biogeography, 21(10), 1053-1061.

Seminoff, J. A., Abreu-Grobois, F., Alfaro Shigueto, J., Balazs, G., Hatase, H., Jones, T. T., Limpus, C., Mangel, J., Nichols, W. J., Peckham, S. H., Zavala Norzagaray, A., Matsuzawa, Y. (2018). The Pacific Loggerhead, So Excellent a Connector. State of The World's Sea Turtles SWOT.

Seminoff, J. A., Benson, S. R., Arthur, K. E., Eguchi, T., Dutton, P. H., Tapilatu, R. F., Popp, B. N. (2012). Stable isotope tracking of endangered sea turtles: validation with satellite telemetry and δ15N analysis of amino acids. PLoS One, 7(5), e37403.

Seminoff, J. A., Eguchi, T., Carretta, J., Allen, C. D., Prosperi, D., Rangel, R., Gilpatrick, J. W., Forney, K., Peckham, S. H. (2014). Loggerhead sea turtle abundance at a foraging hotspot in the eastern Pacific Ocean: implications for at-sea conservation. Endangered Species Research, 24(3), 207-220.

Seminoff, J. A., Jones, T. T., Marshall, G. J. (2006). Underwater behaviour of green turtles monitored with video-time-depth recorders: what's missing from dive profiles? Marine Ecology Progress Series, 322, 269-280.

Senko, J., Mancini, A., Bailly, M., Christen, J. B., Jenkins, L., Wang, J. (2020). Do Sea Turtles See the Light? Developing Solar-Powered Illuminated Nets to Reduce Sea Turtle Bycatch. State of the World's Sea Turtles SWOT.

Senko, J. F., Peckham, S. H., Aguilar-Ramirez, D., Wang, J. H. (2022). Net illumination reduces fisheries bycatch, maintains catch value, and increases operational efficiency. Current Biology, 32(4), 911-918.

Shaw, K. R., Lynch, J. M., Balazs, G. H., Jones, T. T., Pawloski, J., Rice, M. R., French, A. D., Liu, J., Cobb, G. P., Klein, D. M. (2021). Trace Element Concentrations in Blood and Scute Tissues from Wild and Captive Hawaiian Green Sea Turtles (Chelonia mydas). Environmental Toxicology and Chemistry, 40(1), 208-218.

Shillinger, G. L., Di Lorenzo, E., Luo, H., Bograd, S. J., Hazen, E. L., Bailey, H., & Spotila, J. R. (2012a). On the dispersal of leatherback turtle hatchlings from Mesoamerican nesting beaches. Proceedings of the Royal Society B: Biological Sciences, 279(1743), 2391-2395.

Shillinger, G. L., Bailey, H., Bograd, S. J., Hazen, E. L., Hamann, M., Gaspar, P., Godley, B. J., Wilson, R. P., & Spotila, J. R. (2012b). Tagging through the stages: technical and ecological challenges in observing life histories through biologging. Marine Ecology Progress Series, 457, 165-170.

Shillinger, G. L., Palacios, D. M., Bailey, H., Bograd, S. J., Swithenbank, A. M., Gaspar, P., Wallace, B. P., Spotila, J. R., Paladino, F. V., & Piedra, R. (2008). Persistent leatherback turtle migrations present opportunities for conservation. PLoS Biology, 6(7), e171.

Shimada, T., Jones, R., Limpus, C., Groom, R., Hamann, M. (2016). Long-term and seasonal patterns of sea turtle home ranges in warm coastal foraging habitats: implications for conservation. Marine Ecology Progress Series, 562, 163-179.

Shritika S. Prakash, Monal M. Lal, Peter H. Dutton, Ciro Rico, Susanna Piovano. 2022. Kinship genomics approach to study mating systems in a depleted sea turtle rookery, Regional Studies in Marine Science, Volume 51, 102174, ISSN 2352-4855, https://doi.org/10.1016/j.rsma.2022.102174.

Smith, J. A., Tommasi, D., Welch, H., Hazen, E. L., Sweeney, J., Brodie, S., Muhling, B., Stohs, S. M., Jacox, M. G. (2021). Comparing Dynamic and Static Time-Area Closures for Bycatch Mitigation: A Management Strategy Evaluation of a Swordfish Fishery. Frontiers in Marine Science, 8, 272.

Spotila, J. R., Reina, R. D., Steyermark, A. C., Plotkin, P. T., Paladino, F. V. (2000). Pacific leatherback turtles face extinction. Nature, 405(6785), 529-530.

Stewart, K. R., LaCasella, E. L., Jensen, M. P., Epperly, S. P., Haas, H. L., Stokes, L. W., Dutton, P. H. (2019). Using mixed stock analysis to assess source populations for at-sea bycaught juvenile and adult loggerhead turtles (Caretta caretta) in the north-west Atlantic. Fish and Fisheries, 20(2), 239-254.

Stewart, K. R., LaCasella, E. L., Roden, S. E., Jensen, M. P., Stokes, L. W., Epperly, S. P., Dutton, P. H. (2016). Nesting population origins of leatherback turtles caught as bycatch in the U.S. pelagic longline fishery. Ecosphere, 7(11), e01272.

Stubbs, J. L., Marn, N., Vanderklift, M. A., Fossette, S., Mitchell, N. J. (2020). Simulated growth and reproduction of green turtles (Chelonia mydas) under climate change and marine heatwave scenarios. Ecological Modelling, 431, 109185.

Sykora-Bodie, S. T., Bezy, V., Johnston, D. W., Newton, E., Lohmann, K. J. (2017). Quantifying nearshore sea turtle densities: applications of unmanned aerial systems for population assessments. Scientific Reports, 7(1), 1-7.

Thomsen, P. F., & Willerslev, E. (2015). Environmental DNA - An emerging tool in conservation for monitoring past and present biodiversity. Biological Conservation, 183, 4-18.

Thums, M., Whiting, S. D., Reisser, J. W., Pendoley, K. L., Pattiaratchi, C. B., Harcourt, R. G., McMahon, C. R., & Meekan, M. G. (2013). Tracking sea turtle hatchlings—a pilot study using acoustic telemetry. Journal of Experimental Marine Biology and Ecology, 440, 156-163.

Tracy, A. M., Pielmeier, M. L., Yoshioka, R. M., Heron, S. F., & Harvell, C. D. (2019). Increases and decreases in marine disease reports in an era of global change. Proceedings of the Royal Society B, 286, 20191718.

Turner Tomaszewicz, C. N., Seminoff, J. A., Avens, L., Goshe, L. R., Peckham, S. H., Rguez-Baron, J. M., Bickerman, K., & Kurle, C. M. (2015). Age and residency duration of loggerhead turtles at a North Pacific bycatch hotspot using skeletochronology. Biological Conservation, 186, 134-142.

Turner Tomaszewicz, C. N., Seminoff, J. A., Avens, L., & Kurle, C. M. (2016). Methods for sampling sequential annual bone growth layers for stable isotope analysis. Methods in Ecology and Evolution, 7, 556-564.

Turner Tomaszewicz, C. N., Seminoff, J. A., Peckham, S. H., Avens, L., & Kurle, C. M. (2017). Intrapopulation variability in the timing of ontogenetic habitat shifts in sea turtles revealed using δ15N values from bone growth rings. Journal of Animal Ecology, 86, 694-704.

Tyson, R. B., Piniak, W. E., Domit, C., Mann, D., Hall, M., Nowacek, D. P., & Fuentes, M. M. (2017). Novel bio-logging tool for studying fine-scale behaviors of marine turtles in response to sound. Frontiers in Marine Science, 4, 219.

Vander Zanden, H. B., Bjorndal, K. A., Reich, K. J., & Bolten, A. B. (2010). Individual specialists in a generalist population: results from a long-term stable isotope series. Biology Letters, 6, 711-714.

Vander Zanden, H. B., Tucker, A. D., Hart, K. M., Lamont, M. M., Fujisaki, I., Addison, D. S., Mansfield, K. L., Phillips, K. F., Wunder, M. B., Bowen, G. J., Pajuelo, M., Bolten, A. B., & Bjorndal, K. A. (2015). Determining origin in a migratory marine vertebrate: a novel method to integrate stable isotopes and satellite tracking. Ecological Applications, 25, 320-335.

Varela, M. R., Patrício, A. R., Anderson, K., Broderick, A. C., DeBell, L., Hawkes, L. A., Tilley, D., Snape, R. T., Westoby, M. J., & Godley, B. J. (2019). Assessing climate change associated sea-level rise impacts on sea turtle nesting beaches using drones, photogrammetry and a novel GPS system. Global Change Biology, 25, 753-762.

Varela, M. R., & Rees, A. (2020). Drones in Sea Turtle Conservation: The Sky Is the Limit. State of the World's Sea Turtles SWOT.

Wallace, B. P., DiMatteo, A. D., Hurley, B. J., Finkbeiner, E. M., Bolten, A. B., Chaloupka, M. Y., Hutchinson, B. J., Abreu-Grobois, F. A., Amorocho, D., & Bjorndal, K. A. (2010). Regional management units for marine turtles: a novel framework for prioritizing conservation and research across multiple scales. PLoS One, 5, e15465.

Wallace, B. P., Kot, C. Y., DiMatteo, A. D., Lee, T., Crowder, L. B., & Lewison, R. L. (2013). Impacts of fisheries bycatch on marine turtle populations worldwide: toward conservation and research priorities. Ecosphere, 4, 1-49.

Wallace, B. P., Seminoff, J. A., Kilham, S. S., Spotila, J. R., & Dutton, P. H. (2006). Leatherback turtles as oceanographic indicators: stable isotope analyses reveal a trophic dichotomy between ocean basins. Marine Biology, 149, 953-960.

Wang, J. H., Fisler, S., & Swimmer, Y. (2010). Developing Visual deterrents to reduce sea turtle bycatch in gill net fisheries. Marine Ecology Progress Series, 408.

Welch, H., Hazen, E. L., Bograd, S. J., Jacox, M. G., Brodie, S., Robinson, D., Scales, K. L., Dewitt, L., & Lewison, R. (2019a). Practical considerations for operationalizing dynamic management tools. Journal of Applied Ecology, 56, 459-469.

Welch, H., Hazen, E. L., Briscoe, D. K., Bograd, S. J., Jacox, M. G., Eguchi, T., Benson, S. R., Fahy, C. C., Garfield, T., & Robinson, D. (2019b). Environmental indicators to reduce loggerhead turtle bycatch offshore of Southern California. Ecological Indicators, 98, 657-664.

Wilcox, C., Puckridge, M., Schuyler, Q. A., Townsend, K., & Hardesty, B. D. (2018). A quantitative analysis linking sea turtle mortality and plastic debris ingestion. Scientific Reports, 8, 1-11.

Wildermann, N. E., Gredzens, C., Avens, L., Barrios-Garrido, H. A., Bell, I., Blumenthal, J., Bolten, A. B., McNeill, J. B., Casale, P., & Di Domenico, M. (2018). Informing research priorities for immature sea turtles through expert elicitation. Endangered Species Research, 37, 55-76.

Willis-Norton, E., Hazen, E. L., Fossette, S., Shillinger, G., Rykaczewski, R. R., Foley, D. G., Dunne, J. P., & Bograd, S. J. (2015). Climate change impacts on leatherback turtle pelagic habitat in the Southeast Pacific. Deep Sea Research Part II: Topical Studies in Oceanography, 113, 260-267.

Witherington, B. E. (2002). Ecology of neonate loggerhead turtles inhabiting lines of downwelling near a Gulf Stream front. Marine Biology, 140(4), 843-853.

Witt, M. J., Broderick, A. C., Johns, D. J., Martin, C., Penrose, R., Hoogmoed, M. S., & Godley, B. J. (2007). Prey landscapes help identify potential foraging habitats for leatherback turtles in the NE Atlantic. Marine Ecology Progress Series, 337, 231-243.

Witt, M. J., Hawkes, L. A., Godfrey, M., Godley, B., & Broderick, A. (2010). Predicting the impacts of climate change on a globally distributed species: The case of the loggerhead turtle. Journal of Experimental Biology, 213(6), 901-911.

Zbinden, J. A., Bearhop, S., Bradshaw, P., Gill, B., Margaritoulis, D., Newton, J., & Godley, B. J. (2011). Migratory dichotomy and associated phenotypic variation in marine turtles revealed by satellite tracking and stable isotope analysis. Marine Ecology Progress Series, 421, 291-302.

Zendejas, C. G. (2013). What Do Drones Have to Do with Sea Turtles? The Ocean Foundation. Retrieved from https://oceanfdn.org/what-do-drones-have-to-do-with-sea-turtles/

Žydelis, R., Small, C., & French, G. (2013). The incidental catch of seabirds in gillnet fisheries: A global review. Biological Conservation, 162, 76-88.

Supplemental Bibliography

Additional References for Sections 1.1 and 1.2

Innovations: Advancements in Technology & Monitoring Capabilities

Tagging technology and biologging capabilities

Abecassis, M., Senina, I., Lehodey, P., Gaspar, P., Parker, D., Balazs, G., & Polovina, J. (2013). A model of loggerhead sea turtle (Caretta caretta) habitat and movement in the oceanic North Pacific. PLoS One, 8(4), e73274.

Åkesson, S., Broderick, A., Glen, F., Godley, B., Luschi, P., Papi, F., & Hays, G. (2003). Navigation by green turtles: which strategy do displaced adults use to find Ascension Island? Oikos, 103(2), 363-372.

Benhamou, S., Sudre, J., Bourjea, J., Ciccione, S., De Santis, A., & Luschi, P. (2011). The role of geomagnetic cues in green turtle open sea navigation. PLoS One, 6(10), e26672.

Benson, S. R., Dutton, P. H., Hitipeuw, C., Samber, B., Bakarbessy, J., & Parker, D. (2007). Post-nesting migrations of leatherback turtles (Dermochelys coriacea) from Jamursba-Medi, Bird's Head Peninsula, Indonesia. Chelonian Conservation and Biology, 6(1), 150-154.

Broderick, A. C., Coyne, M. S., Fuller, W. J., Glen, F., & Godley, B. J. (2007). Fidelity and over-wintering of sea turtles. Proceedings of the Royal Society B: Biological Sciences, 274(1617), 1533-1539.

Casale, P., Broderick, A. C., Freggi, D., Mencacci, R., Fuller, W. J., Godley, B. J., & Luschi, P. (2012). Long-term residence of juvenile loggerhead turtles to foraging grounds: a potential conservation hotspot in the Mediterranean. Aquatic Conservation: Marine and Freshwater Ecosystems, 22(2), 144-154.

Cuevas, E., Putman, N. F., Uribe-Martínez, A., López-Castro, M. C., Guzmán-Hernández, V., Gallegos-Fernández, S. A., Liceaga-Correa, M. d. l. Á., Trujillo-Córdova, J. A., González-Díaz-Mirón, R. d. J., Negrete-Phillipe, A., Acosta-Sánchez, H. H., Martínez-Portugal, R. C., López-Hernández, M., Huerta-Rodríguez, P., & Silver, J. (2020). First Spatial Distribution Analysis of Male Sea Turtles in the Southern Gulf of Mexico. Frontiers in Marine Science, 7.

DiMatteo, A., Lockhart, G., & Barco, S. (2022). Habitat models and assessment of habitat partitioning for Kemp's ridley and loggerhead marine turtles foraging in Chesapeake Bay (USA). Endangered Species Research, 47, 91-107.

Dodge, K. L., Galuardi, B., & Lutcavage, M. E. (2015). Orientation behaviour of leatherback sea turtles within the North Atlantic subtropical gyre. Proceedings of the Royal Society B: Biological Sciences, 282, 20143129.

Doherty, P. D., Broderick, A. C., Godley, B. J., Hart, K., Phillips, Q., Sanghera, A., Stringell, T. B., Walker, J., & Richardson, P. B. (2020). Spatial Ecology of Sub-Adult Green Turtles in Coastal Waters of the Turks and Caicos Islands: Implications for Conservation Management. Frontiers in Marine Science, 7, 690.

Eckert, S. A. (2006). High-use oceanic areas for Atlantic leatherback sea turtles (Dermochelys coriacea) as identified using satellite telemetered location and dive information. Marine Biology, 149, 1257-1267.

Gaos, A. R., Lewison, R. L., Yañez, I. L., Wallace, B. P., Liles, M. J., Nichols, W. J., Baquero, A., Hasbún, C. R., Vasquez, M., & Urteaga, J. (2012). Shifting the life-history paradigm: discovery of novel habitat use by hawksbill turtles. Biology Letters, 8, 54-56.

Gredzens, C., & Shaver, D. J. (2020). Satellite tracking can inform population-level dispersal to foraging grounds of post-nesting Kemp's ridley sea turtles. Frontiers in Marine Science, 7, 559.

Godley, B., Richardson, S., Broderick, A., Coyne, M., Glen, F., & Hays, G. (2002). Long-term satellite telemetry of the movements and habitat utilisation by green turtles in the Mediterranean. Ecography, 25, 352-362.

Harcourt, R., Sequeira, A. M., Zhang, X., Roquet, F., Komatsu, K., Heupel, M., McMahon, C., Whoriskey, F., Meekan, M., & Carroll, G. (2019). Animal-borne telemetry: an integral component of the ocean observing toolkit. Frontiers in Marine Science, 6, 326.

Hart, K. M., Sartain, A. R., Fujisaki, I., Pratt Jr, H. L., Morley, D., & Feeley, M. W. (2012). Home range, habitat use, and migrations of hawksbill turtles tracked from Dry Tortugas National Park, Florida, USA. Marine Ecology Progress Series, 457, 193-207.

Hart, K. M., Iverson, A. R., Fujisaki, I., Lamont, M. M., Bucklin, D., & Shaver, D. J. (2018). Marine threats overlap key foraging habitat for two imperiled sea turtle species in the Gulf of Mexico. Frontiers in Marine Science, 5, 336.

Hays, G. C., Hobson, V. J., Metcalfe, J. D., Righton, D., & Sims, D. W. (2006). Flexible foraging movements of leatherback turtles across the North Atlantic Ocean. Ecology, 87, 2647-2656.

Hays, G. C., & Scott, R. (2013). Global patterns for upper ceilings on migration distance in sea turtles and comparisons with fish, birds, and mammals. Functional Ecology, 27, 748-756.

Hays, G. C., Bailey, H., Bograd, S. J., Bowen, W. D., Campagna, C., Carmichael, R. H., Casale, P., Chiaradia, A., Costa, D. P., & Cuevas, E. (2019). Translating marine animal tracking data into conservation policy and management. Trends in Ecology & Evolution, 34, 459-473.

Hazen, E. L., Scales, K. L., Maxwell, S. M., Briscoe, D. K., Welch, H., Bograd, S. J., Bailey, H., Benson, S. R., Eguchi, T., & Dewar, H. (2018). A dynamic ocean management tool to reduce bycatch and support sustainable fisheries. Science advances, 4, eaar3001.

Hill, J. E., Robinson, N. J., King, C. M., & Paladino, F. V. (2017). Diving behavior and thermal habitats of gravid hawksbill turtles at St. Croix, USA. Marine Biology, 164, 1-9.

Hoover, A. L., Shillinger, G. L., Williamson, S. A., Reina, R. D., & Bailey, H. (2020). Nearshore neonate dispersal of Atlantic leatherback turtles (Dermochelys coriacea) from a non-recovering subpopulation. Scientific Reports, 10, 1-10.

Howell, E. A., Hoover, A., Benson, S. R., Bailey, H., Polovina, J. J., Seminoff, J. A., & Dutton, P. H. (2015). Enhancing the TurtleWatch product for leatherback sea turtles, a dynamic habitat model for ecosystem-based management. Fisheries oceanography, 24, 57-68.

Howell, E. A., Kobayashi, D. R., Parker, D. M., Balazs, G. H., & Polovina, A. (2008). TurtleWatch: a tool to aid in the bycatch reduction of loggerhead turtles Caretta caretta in the Hawaii-based pelagic longline fishery. Endang Species Res, 5, 267-278.

Hussey, N. E., Kessel, S. T., Aarestrup, K., Cooke, S. J., Cowley, P. D., Fisk, A. T., Harcourt, R. G., Holland, K. N., Iverson, S. J., Kocik, J. F., & Mills Flemming, J. E. (2015). Aquatic animal telemetry: a panoramic window into the underwater world. Science, 348(6240), 1255642.

Klinges, D. (2018). Drone 3D models help assess risk of turtle nesting beaches to sea level rise. Retrieved from https://news.mongabay.com/.

Kobayashi, D. R., Polovina, J. J., Parker, D. M., Kamezaki, N., Cheng, I. J., Uchida, I., Dutton, P. H., & Balazs, G. H. (2008). Pelagic habitat characterization of loggerhead sea turtles, Caretta caretta, in the North Pacific Ocean (1997–2006): Insights from satellite tag tracking and remotely sensed data. Journal of Experimental Marine Biology and Ecology, 356, 96-114.

Luschi, P., Sale, A., Mencacci, R., Hughes, G., Lutjeharms, J., & Papi, F. (2003). Current transport of leatherback sea turtles (Dermochelys coriacea) in the ocean. Proceedings of the Royal Society of London. Series B: Biological Sciences, 270, S129-S132.

Luschi, P. (2013). Long-distance animal migrations in the oceanic environment: orientation and navigation correlates. International Scholarly Research Notices, 2013.

Luschi, P., & Casale, P. (2014). Movement patterns of marine turtles in the Mediterranean Sea: a review. Italian Journal of Zoology, 81, 478-495.

Marcovaldi, M. Â., Lopez, G. G., Soares, L. S., & López-Mendilaharsu, M. (2012). Satellite tracking of hawksbill turtles Eretmochelys imbricata nesting in northern Bahia, Brazil: turtle movements and foraging destinations. Endangered Species Research, 17, 123-132.

Maxwell, S. M., Breed, G. A., Nickel, B. A., Makanga-Bahouna, J., Pemo-Makaya, E., Parnell, R. J., Formia, A., Ngouessono, S., Godley, B. J., & Costa, D. P. (2011). Using satellite tracking to optimize protection of long-lived marine species: olive ridley sea turtle conservation in Central Africa. PLoS One, 6, e19905.

Nero, R. W., Cook, M., Coleman, A. T., Solangi, M., & Hardy, R. (2013). Using an ocean model to predict likely drift tracks of sea turtle carcasses in the north central Gulf of Mexico. Endangered Species Research, 21.

Nichols, W. J., Resendiz, A., Seminoff, J. A., & Resendiz, B. (2000). Transpacific migration of a loggerhead turtle monitored by satellite telemetry. Bull Mar Sci, 67, 937-947.

Papi, F., Luschi, P., Akesson, S., Capogrossi, S., & Hays, G. (2000). Open-sea migration of magnetically disturbed sea turtles. Journal of Experimental Biology, 203, 3435-3443.

Pendoley, K. L., Schofield, G., Whittock, P. A., Ierodiaconou, D., & Hays, G. C. (2014). Protected species use of a coastal marine migratory corridor connecting marine protected areas. Marine Biology, 161, 1455-1466.

Piacenza, J., Piacenza, S., Mayoral, S., Kenney, A., & Shields, N. (2018, August). Design opportunities for sea turtle satellite tracking devices. In International Design Engineering Technical Conferences and Computers and Information in Engineering Conference (Vol. 51791, p. V004T05A024). American Society of Mechanical Engineers.

Pilcher, N. J., Antonopoulou, M., Perry, L., Abdel-Moati, M. A., Al Abdessalaam, T. Z., Albeldawi, M., Al Ansi, M., Al-Mohannadi, S. F., Al Zahlawi, N., & Baldwin, R. (2014). Identification of important sea turtle areas (ITAs) for hawksbill turtles in the Arabian region. Journal of Experimental Marine Biology and Ecology, 460, 89-99.

Plotkin, P., Lutz, P., Musick, J., & Wyneken, J. (2002). Adult migrations and habitat use. The biology of sea turtles 2, 225-241.

Plotkin, P. T. (2010). Nomadic behaviour of the highly migratory olive ridley sea turtle Lepidochelys olivacea in the eastern tropical Pacific Ocean. Endangered Species Research, 13, 33-40.

Polovina, J., Uchida, I., Balazs, G., Howell, E. A., Parker, D., & Dutton, P. (2006). The Kuroshio Extension Bifurcation Region: A pelagic hotspot for juvenile loggerhead sea turtles. Deep Sea Research II, 53, 326-339.

Polovina, J. J., Balazs, G. H., Howell, E. A., Parker, D. M., Seki, M. P., & Dutton, P. H. (2004). Forage and migration habitat of loggerhead (Caretta caretta) and olive ridley (Lepidochelys olivacea) sea turtles in the central North Pacific Ocean. Fish Oceanog, 13, 36-51.

Rees, A. F., Al Saady, S., Broderick, A. C., Coyne, M. S., Papathanasopoulou, N., & Godley, B. J. (2010). Behavioural polymorphism in one of the world's largest populations of loggerhead sea turtles Caretta caretta. Marine Ecology Progress Series, 418, 201-212.

Rees, A. F., Carreras, C., Broderick, A. C., Margaritoulis, D., Stringell, T. B., & Godley, B. J. (2017). Linking loggerhead locations: using multiple methods to determine the origin of sea turtles in feeding grounds. Marine Biology, 164, 1-14.

Santos, E. A., Silva, A. C., Sforza, R., Oliveira, F. L., Weber, M. I., Castilhos, J. C., López-Mendilaharsu, M., Marcovaldi, M. A., Ramos, R. M., & DiMatteo, A. (2019). Olive ridley inter-nesting and post-nesting movements along the Brazilian coast and Atlantic Ocean. Endangered Species Research, 40, 149-162.

Schofield, G., Dimadi, A., Fossette, S., Katselidis, K. A., Koutsoubas, D., Lilley, M. K., Luckman, A., Pantis, J. D., Karagouni, A. D., & Hays, G. C. (2013). Satellite tracking large numbers of individuals to infer population level dispersal and core areas for the protection of an endangered species. Diversity and Distributions, 19, 834-844.

Shaver, D. J., & Rubio, C. (2008). Post-nesting movement of wild and head-started Kemp's ridley sea turtles Lepidochelys kempii in the Gulf of Mexico. Endangered Species Research, 4, 43-55.

Stokes, K., Broderick, A., Canbolat, A., Candan, O., Fuller, W., Glen, F., Levy, Y., Rees, A., Rilov, G., & Snape, R. (2015). Migratory corridors and foraging hotspots: critical habitats identified for Mediterranean green turtles. Diversity and Distributions, 21, 665-674.

Swimmer, Y., McNaughton, L., Foley, D., Moxey, L., & Nielsen, A. (2009). Movements of olive ridley sea turtles Lepidochelys olivacea and associated oceanographic features as determined by improved light-based geolocation. Endangered Species Research, 10, 245-254.

Taquet, C., Taquet, M., Dempster, T., Soria, M., Ciccione, S., Roos, D., & Dagorn, L. (2006). Foraging of the green sea turtle Chelonia mydas on seagrass beds at Mayotte Island (Indian Ocean), determined by acoustic transmitters. Marine Ecology Progress Series, 306, 295-302.

Thomson, J. A., & Heithaus, M. R. (2014). Animal-borne video reveals seasonal activity patterns of green sea turtles and the importance of accounting for capture stress in short-term biologging. Journal of Experimental Marine Biology and Ecology, 450, 15-20.

Troeng, S., Evans, D. R., Harrison, E., & Lagueux, C. J. (2005). Migration of green turtles Chelonia mydas from Tortuguero, Costa Rica. Marine Biology, 148, 435-447.

Tucker, A. D. (2010). Nest site fidelity and clutch frequency of loggerhead turtles are better elucidated by satellite telemetry than by nocturnal tagging efforts: implications for stock estimation. Journal of Experimental Marine Biology and Ecology, 383, 48-55.

Varo-Cruz, N., Hawkes, L. A., Cejudo, D., López, P., Coyne, M. S., Godley, B. J., & López-Jurado, L. F. (2013). Satellite tracking derived insights into migration and foraging strategies of male loggerhead turtles in the eastern Atlantic. Journal of Experimental Marine Biology and Ecology, 443, 134-140.

Whiting, S., Long, J., & Coyne, M. (2007). Migration routes and foraging behaviour of olive ridley turtles Lepidochelys olivacea in northern Australia. Endangered Species Research, 3, 1-9.

Whittock, P. A., Pendoley, K. L., & Hamann, M. (2014). Inter-nesting distribution of flatback turtles Natator depressus and industrial development in Western Australia. Endangered Species Research, 26, 25-38.

Coupling environmental data, ocean physics, and computer simulations to simulate sea turtle movements and strandings

Allen, C. D., Robbins, M. N., Eguchi, T., Owens, D. W., Meylan, A. B., Meylan, P. A., Kellar, N. M., Schwenter, J. A., Nollens, H. H., LeRoux, R. A., Dutton, P. H., & Seminoff, J. A. (2015). First Assessment of the Sex Ratio for an East Pacific Green Sea Turtle Foraging Aggregation: Validation and Application of a Testosterone ELISA. PLoS One, 10, e0138861.

Auster, P. J., Campanella, F., Kurth, R., Muñoz, R. C., & Taylor, J. C. (2020). Identifying Habitat Associations of Sea Turtles within an Area of Offshore Sub-Tropical Reefs (NW Atlantic). Southeastern Naturalist, 19, 460-471.

Bevan, E., Wibbels, T., Najera, B. M., Martinez, M. A., Martinez, L. A., Martinez, F. I., Cuevas, J. M., Anderson, T., Bonka, A., & Hernandez, M. H. (2015). Unmanned aerial vehicles (UAVs) for monitoring sea turtles in near-shore waters. Marine Turtle Newsletter, 145, 19-22.

Chambault, P., de Thoisy, B., Huguin, M., Martin, J., Bonola, M., Etienne, D., Gresser, J., Hiélard, G., Mailles, J., Védie, F., Barnerias, C., Sutter, E., Guillemot, B., Dumont-Dayot, É., Régis, S., Lecerf, N., Lefebvre, F., Frouin, C., Aubert, N., Guimera, C., Bordes, R., Thieulle, L., Duru, M., Bouaziz, M., Pinson, A., Flora, F., Queneherve, P., Woignier, T., Allenou, J.-P., Cimiterra, N., Benhalilou, A., Murgale, C., Maillet, T., Rangon, L., Chanteux, N., Chanteur, B., Béranger, C., Le Maho, Y., Petit, O., & Chevallier, D. (2018). Connecting paths between juvenile and adult habitats in the Atlantic green turtle using genetics and satellite tracking. Ecology and Evolution, 8, 12790-12802.

Christiansen, F., Putman, N., Farman, R., Parker, D., Rice, M., Polovina, J., Balazs, G., & Hays, G. (2016). Spatial variation in directional swimming enables juvenile sea turtles to reach and remain in productive waters. Marine Ecology Progress Series, 557, 247-259.

Dalleau, M., Kramer-Schadt, S., Gangat, Y., Bourjea, J., Lajoie, G., & Grimm, V. (2019). Modeling the emergence of migratory corridors and foraging hot spots of the green sea turtle. Ecology and Evolution, 9, 10317-10342.

Fujisaki, I., Hart, K. M., Bucklin, D., Iverson, A. R., Rubio, C., Lamont, M. M., Miron, R. d. J. G. D., Burchfield, P. M., Peña, J., & Shaver, D. J. (2020). Predicting multi-species foraging hotspots for marine turtles in the Gulf of Mexico. Endangered Species Research, 43, 253-266.

Gaspar, P., & Lalire, M. (2017). A model for simulating the active dispersal of juvenile sea turtles with a case study on western Pacific leatherback turtles. PLoS One, 12, e0181595.

Hatase, H., Sato, K., Yamaguchi, M., Takahashi, K., & Tsukamoto, K. (2006). Individual variation in feeding habitat use by adult female green sea turtles (Chelonia mydas): are they obligately neritic herbivores? Oecologia, 149, 52-64.

Hazen, E. L., Jorgensen, S., Rykaczewski, R. R., Bograd, S. J., Foley, D. G., Jonsen, I. D., Shaffer, S. A., Dunne, J. P., Costa, D. P., & Crowder, L. B. (2013). Predicted habitat shifts of Pacific top predators in a changing climate. Nature Climate Change, 3, 234-238.

Hamann, M., Grech, A., Wolanski, E., & Lambrechts, J. (2011). Modelling the fate of marine turtle hatchlings. Ecological Modelling, 222, 1515-1521.

Harrison, C. S., Luo, J. Y., Putman, N. F., Li, Q., Sheevam, P., Krumhardt, K., Stevens, J., & Long, M. C. (2021). Identifying global favourable habitat for early juvenile loggerhead sea turtles. Journal of the Royal Society Interface, 18(175), 20200799.

Kobayashi, D. R., Polovina, J. J., Parker, D. M., Kamezaki, N., Cheng, I. J., Uchida, I., Dutton, P. H., & Balazs, G. H. (2008). Pelagic habitat characterization of loggerhead sea turtles, Caretta caretta, in the North Pacific Ocean (1997–2006): Insights from satellite tag tracking and remotely sensed data. Journal of Experimental Marine Biology and Ecology, 356, 96-114.

Kobayashi, D. R., Farman, R., Polovina, J. J., Parker, D. M., Rice, M., & Balazs, G. H. (2014). “Going with the flow” or not: evidence of positive rheotaxis in oceanic juvenile loggerhead turtles (Caretta caretta) in the South Pacific Ocean using satellite tags and ocean circulation data. PLoS One, 9, e103701.

Lohmann, K., Hester, J., & Lohmann, C. (1999). Long-distance navigation in sea turtles. Ethology Ecology & Evolution, 11, 1-23.

Lohmann, K., & Lohmann, C. (1994). Detection of magnetic inclination angle by sea turtles: a possible mechanism for determining latitude. The Journal of experimental biology, 194, 23-32.

Lopez-Mendilaharsu, M., Sales, G., Coluchi, R., Marcovaldi, M. Â., & Giffoni, B. (2019). At-sea distribution of juvenile leatherback turtles: new insights from bycatch data in the Atlantic Ocean. Marine Ecology Progress Series, 621, 199-208.

Luschi, P., Sale, A., Mencacci, R., Hughes, G., Lutjeharms, J., & Papi, F. (2003). Current transport of leatherback sea turtles (Dermochelys coriacea) in the ocean. Proceedings of the Royal Society of London. Series B: Biological Sciences, 270, S129-S132.

McMahon, C. R., & Hays, G. C. (2006). Thermal niche, large-scale movements and implications of climate change for a critically endangered marine vertebrate. Global Change Biology, 12, 1330-1338.

Murray, K. T., & Orphanides, C. D. (2013). Estimating the risk of loggerhead turtle Caretta caretta bycatch in the US mid-Atlantic using fishery-independent and-dependent data. Marine Ecology Progress Series, 477, 259-270.

Neeman, N., Robinson, N. J., Paladino, F. V., Spotila, J. R., & O'Connor, M. P. (2015). Phenology shifts in leatherback turtles (Dermochelys coriacea) due to changes in sea surface temperature. Journal of Experimental Marine Biology and Ecology, 462, 113-120.

Pikesley, S. K., Maxwell, S. M., Pendoley, K., Costa, D. P., Coyne, M. S., Formia, A., Godley, B. J., Klein, W., Makanga-Bahouna, J., & Maruca, S. (2013). On the front line: integrated habitat mapping for olive ridley sea turtles in the southeast Atlantic. Diversity and Distributions, 19, 1518-1530.

Putman, N. F., Scott, R., Verley, P., Marsh, R., & Hays, G. C. (2012a). Natal site and offshore swimming influence fitness and long-distance ocean transport in young sea turtles. Marine Biology, 159, 2117-2126.

Putman, N. F., Verley, P., Shay, T. J., & Lohmann, K. J. (2012b). Simulating transoceanic migrations of young loggerhead sea turtles: merging magnetic navigation behavior with an ocean circulation model. Journal of Experimental Biology, 215, 1863-1870.

Rees, A. F., Carreras, C., Broderick, A. C., Margaritoulis, D., Stringell, T. B., & Godley, B. J. (2017). Linking loggerhead locations: using multiple methods to determine the origin of sea turtles in feeding grounds. Marine Biology, 164, 1-14.

Revelles, M., Isern-Fontanet, J., Cardona, L., San Félix, M., Carreras, C., & Aguilar, A. (2007). Mesoscale eddies, surface circulation and the scale of habitat selection by immature loggerhead sea turtles. Journal of Experimental Marine Biology and Ecology, 347, 41-57.

Robson, N. A., Hetzel, Y., Whiting, S., Wijeratne, S., Pattiaratchi, C. B., Withers, P., & Thums, M. (2017). Use of particle tracking to determine optimal release dates and locations for rehabilitated neonate sea turtles. Frontiers in Marine Science, 4, 173.

Sales, G., Giffoni, B. B., Fiedler, F. N., Azevedo, V. N. G., Kotas, J. E., Swimmer, Y., & Bugoni, L. (2010). Circle hook effectiveness for the mitigation of sea turtle bycatch and capture of target species in a Brazilian pelagic longline fishery. Aquatic Conservation: Marine and Freshwater Ecosystems, 20, 428-436.

Smolowitz, R. J., Patel, S. H., Haas, H. L., & Miller, S. A. (2015). Using a remotely operated vehicle (ROV) to observe loggerhead sea turtle (Caretta caretta) behavior on foraging grounds off the mid-Atlantic United States. Journal of Experimental Marine Biology and Ecology, 471, 84-91.

Turner Tomaszewicz, C. N., Seminoff, J. A., Avens, L., & Kurle, C. M. (2016). Methods for sampling sequential annual bone growth layers for stable isotope analysis. Methods in Ecology and Evolution, 7, 556-564.

Winton, M. V., Fay, G., Haas, H. L., Arendt, M., Barco, S., James, M. C., Sasso, C., & Smolowitz, R. (2018). Estimating the distribution and relative density of satellite-tagged loggerhead sea turtles using geostatistical mixed effects models. Marine Ecology Progress Series, 586, 217-232.

Witt, M. J., Bonguno, E. A., Broderick, A. C., Coyne, M. S., Formia, A., Gibudi, A., Mounguengui Mounguengui, G. A., Moussounda, C., NSafou, M., & Nougessono, S. (2011). Tracking leatherback turtles from the world's largest rookery: assessing threats across the South Atlantic. Proceedings of the Royal Society B: Biological Sciences, 278, 2338-2347. Sales, G., B. B. Giffoni, F. N. Fiedler, V. N. G. Azevedo, J. E. Kotas, Y. Swimmer, and L. Bugoni. 2010. Circle hook effectiveness for the mitigation of sea turtle bycatch and capture of target species in a Brazilian pelagic longline fishery. Aquatic Conservation: Marine and Freshwater Ecosystems **20**:428-436.

Smolowitz, R. J., S. H. Patel, H. L. Haas, and S. A. Miller. 2015. Using a remotely operated vehicle (ROV) to observe loggerhead sea turtle (*Caretta caretta*) behavior on foraging grounds off the mid-Atlantic United States. Journal of Experimental Marine Biology and Ecology **471**:84-91.

Turner Tomaszewicz, C. N., J. A. Seminoff, L. Avens, and C. M. Kurle. 2016. Methods for sampling sequential annual bone growth layers for stable isotope analysis. Methods in Ecology and Evolution **7**:556-564.

Winton, M. V., G. Fay, H. L. Haas, M. Arendt, S. Barco, M. C. James, C. Sasso, and R. Smolowitz. 2018. Estimating the distribution and relative density of satellite-tagged loggerhead sea turtles using geostatistical mixed effects models. Marine Ecology Progress Series **586**:217-232.

Witt, M. J., E. Augowet Bonguno, A. C. Broderick, M. S. Coyne, A. Formia, A. Gibudi, G. A. Mounguengui Mounguengui, C. Moussounda, M. NSafou, and S. Nougessono. 2011. Tracking leatherback turtles from the world's largest rookery: assessing threats across the South Atlantic. Proceedings of the Royal Society B: Biological Sciences **278**:2338-2347.

Interdisciplinary approaches to marine ecosystems

Over time, marine conservation has shifted from a primary focus on protecting biodiversity and species of concern, toward conserving whole ecosystems, including species and ecosystem function. This thinking includes all aspects of the biophysical ecosystem as well as the relationship of people to marine ecosystems. The protectionist perspective has been that people are generally harmful actors and if one is going to protect marine biodiversity, the best ocean is one that excludes people. This thinking led the efforts to promote marine protected areas (MPAs) and totally protected marine reserves, which persist to this day. But given that the human population is now over 8 billion and climate change has global impacts, it is difficult to make the case that effectively excluding the harmful impacts of people is even possible on a global scale. For 20 years now, the definition of ecosystem-based management has acknowledged that people are fully a part of marine ecosystems. And while humans can damage ecosystem structure and function, humans are also the major actors that can restore ecosystem function and provide outcomes that people want and need. In this section of the book, we focus on recent efforts to transition toward this broader ecosystem perspective.

Alam Lubna, Mazlin Bin Mokhtar, and Ussif Rashid Sumaila detail the effects of climate change on fisheries and aquaculture. This case study, focused on Malaysia, characterizes the shift from constraining human actors to harmonizing human needs with maintaining functional marine ecosystems. Small-scale fisheries provide 90% of the jobs in fisheries and half the protein for human consumption. As wild-capture fisheries have continued to decline, aquaculture has been on the rise to meet the nutritional demands of a growing human population. This combination of enterprises is occurring globally, but as this case study shows, the way forward must be shaped by the history, culture, and governance approaches appropriate for each country.

Stefan Gelcich, C. Josh Donlan, Benjamin Lagos, Rodrigo Sanchez Grez, and Rodrigo A. Estévez present the case for voluntary marine conservation programs in which local fishers are granted property rights to manage their local fisheries. This case is classic in marine conservation and related to TURF-Reserves in Chile. Territorial use rights fisheries grant local fishing communities rights to assess and manage their own fisheries and to benefit from more sustainable management decisions. This case and other like cases around the globe have been most often applied to relatively sedentary benthic resources like mollusks and crustaceans. This and other cases show the power of Elinor Ostrom's theories and the flaws in Garrett Hardin's tragedy of the commons.

Cassandra Brooks and John Weller, take these arguments to a global scale by addressing ecosystem-based approaches to management in the Antarctic Ocean. This ocean is the least impacted by people in the world but is vulnerable to growing human impacts due to fisheries, climate change, tourism, and more. It is also home to a unique biota, and an even more unique governance structure. Under the Antarctic Treaty, the entire continent and surrounding waters are internationally-managed—with no national holdings or Exclusive Economic Zones. The Convention on the Conservation of Antarctic Living Marine Resources (CCAMLR) includes 26 nations and the EU. This body decides by consensus how various international waters will be used or protected. These authors describe the leadership in these global commons that led to the implementation of the Ross Sea Marine Protected Area.

Catarina Frazão Santos, Tundi Agardy, and Elena Gissi, extend the approach of managing marine ecosystems to include full cross-sectoral marine spatial planning (MSP), which has been in intensive development for just over 20 years. This approach goes beyond protection for biodiversity to spatial planning for conservation as well as all human uses, initially in the EEZs of nations. This approach to spatial planning is well established on land, but more recently applied to the sea. Over the last 20 years, MSP has been elaborated to some degree in about 80 countries. But one limitation has been that the spatial plots have been static (as on land). MSP in the age of climate change requires much more dynamic thinking because marine habitats, organisms, and the people who use them move around with variation in ocean climate. Current work led by this group is seeking to extend thinking around climate-ready MSP to the open sea (outside EEZs where governance is more uncertain)—in the Southern Ocean.

5. Climate change impacts on the fisheries and aquaculture sectors with a focus on Malaysia

Lubna Alam,[1] *Mazlin Bin Mokhtar, and Ussif Rashid Sumaila*

Fisheries and aquaculture play critical roles in food supply, food security, and income generation on a local, regional, and global scale (Sumaila et al., 2012; FAO, 2020). According to the Food and Agriculture Organization, in recent decades the fisheries and aquaculture sector has expanded considerably, and total production, trade and consumption have reached a record all-time level in 2018 (Figure 5.1; FAO, 2020). Since the early 1990s, aquaculture has experienced the greatest increase in production in the sector, while fish capture has been relatively stable or even declining (Pauly and Zeller, 2016), with some modest growth in domestic capture. Global fish production was estimated to have reached approximately 179 million tons in 2018, with aquaculture production accounting for 82 million tons. Humans consumed 156 million tons of the total, while the remaining 22 million tons were used for non-food purposes, primarily the production of fishmeal and fish oil (FAO, 2020). Overall, between 1990 and 2018, global capture fisheries increased by 14%, aquaculture production increased by 527%, and total food fish consumption increased by 120% (FAO, 2020). In 2018, an estimated 59.5 million people worked (full-time, part-time, or irregularly) in the primary sector of capture fisheries (39.0 million people) and aquaculture (20.5 million people) (FAO, 2020). The majority of those who are engaged in production are in developing countries, and most are small-scale, craftsmen and aquaculture workers. Asia employs the most people (85%), followed by Africa (9%), the Americas (4%), Europe (1%), and Oceana (1%).

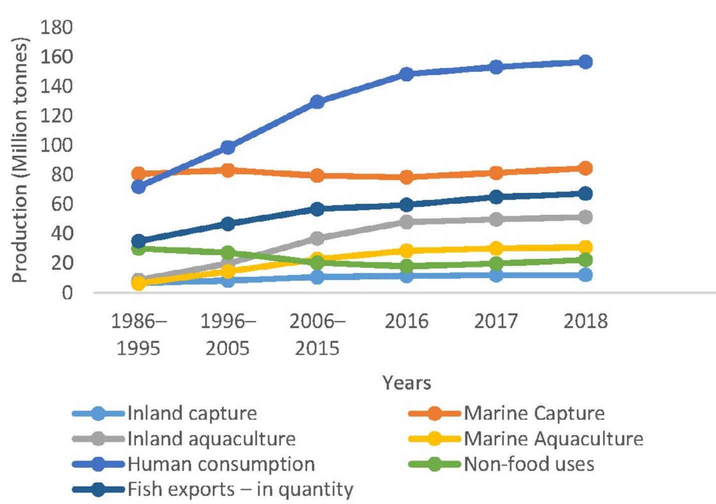


Fig. 5.1 World capture fisheries and aquaculture production, utilization, and trade. 1986–1995 1996–2005 2006–2015: Average per year (Data Source: FAO, 2020).

1 Institute for the Ocean and Fisheries, The University of British Columbia, https://orcid.org/0000-0002-0910-2391

https://doi.org/10.11647/OBP.0395.05

However, the world's fisheries and aquaculture sectors are largely impacted by anthropogenic climate change, one of the greatest environmental challenges the world faces today (Barange et al., 2018). Climate change has already begun to alter ocean conditions, most notably water temperature and biogeochemistry, and is expected to have an effect on marine fisheries productivity (Kim & Kim, 2021; Holdsworth et al., 2021). Studies also estimate that climate change will result in economic losses in many regions (Lam et al., 2016; Suh and Pomeroy, 2020), although some countries and/or regions may benefit from increased fisheries production (Guerra et al., 2021; Pawluk et al., 2021).

At the national level, seasonal variation, high temperatures, irregular rainfall, and cyclones have been identified as the major climate change threats affecting coastal aquaculture in brackish and freshwater farming areas at Andhra Pradesh, India (Muralidhar et al., 2013). Here, alterations in water quality (e.g., increase and decrease in salinity and temperature) and changes in dissolved oxygen are the most relevant climate-related impacts on shrimp farming (Muralidhar et al., 2013). Another example pertains to vulnerability assessments of mangroves to climate change and sea-level rise in Cameroon, Tanzania, and Fiji (Ellison, 2015). These assessments found the most critical components to be exposure to relative sea level trends and sediment supply, and sensitivity components of forest health, recent spatial changes, and net accretion rates (Ellison, 2015). A risk-based approach was also conducted to evaluate the vulnerability to climate change of the northeast United States fish community (Gaichas and Hare, 2014). Finally, in a study carried out by Barton et al. (2012), the Pacific oyster (*Crassostrea gigas*) showed negative correlation to naturally elevated carbon dioxide levels and provided implications for near-term ocean acidification effects.

In Malaysia, the fisheries and aquaculture sectors are important sub-sectors, contributing 60-70% of the national animal protein intake (Sallehudin et al., 2017). However, it is not surprising that this sector would be influenced by climate change, as the National Hydraulic Research Institute of Malaysia reported that many of Malaysia's coastlines were being affected by rising sea levels, which is directly linked to an increasing trend in ocean temperature. Despite the importance of the fisheries sector for the economy and food security in Malaysia, insufficient information or studies exist on climate change and its effects on fisheries. The present chapter is intended to address this gap by reviewing the impact of climatic factors on the global fish sector with a special focus on Malaysia, identifying factors influencing adaptation to climate change, and highlighting recommended adaptation strategies. Knowledge on climate change impacts and adaptation strategies is the foundation for developing interdisciplinary solutions that address the complex interplay between ecological, social, and economic systems within marine ecosystems. This knowledge is essential for fostering resilience, promoting sustainability, and safeguarding the wellbeing of both the ecosystems, and the communities that depend on them.

Climate change impacts on fish species

There is strong evidence that the ocean became warmer, more stratified, and more acidic during the 20th century, and with less sea ice (IPCC, 2019). As predicted by the Intergovernmental Panel on Climate Change (IPCC), these trends are expected to continue into the next century (IPCC, 2019). Climate change caused by humans is already affecting marine ecosystems through long-term changes in atmospheric and oceanographic conditions. Temperature, sea level, and salinity are all affected by climate change, which can have an impact on fish production and distributions (Pawluk et al., 2021). For instance, a comparison of temperature-stock-recruitment relationships between different populations of Atlantic cod (*Gadus morhua*) reveals a unimodal relationship with an optimal recruitment temperature (Drinkwater, 2005). Together, these factors are expected to have an effect on the distribution of marine species, including those targeted by fisheries, directly and/or indirectly (Davis et al., 2020). Moreover, increases in temperature are leading to changes in the distribution of marine fisheries and community interactions (Parry et al., 2005). Brackish water species from delicate estuarine ecosystems are particularly sensitive to temperature and salinity changes (Smyth and Elliott, 2016). Regional changes in the distribution and productivity of certain fish species are expected due to continued warming, and local extinctions will occur at the edges of ranges, particularly in freshwater and diadromous species such as salmon or sturgeon (Easterling et al., 2007). Global warming will confound the impacts of natural variation on fishing activity (Suh and Pomeroy, 2020), and further complicate management. Another study showed that a rise in temperature (of 4°C) reduced the productivity of fisheries (Das et al., 2020). Concurrent theory and experimental findings both indicated that temperature and ocean chemistry influenced organism's physiology, growth, and reproduction (Pörtner and Knust, 2007; Pauly, 1981). On the other hand, increased abundance of warmer-water species such as sea bass (*Dicentrarchus labrax*) and red mullet (*Mullus surmuletus*) in the North Sea has opened up new fishing opportunities (Pinnegar et al., 2010). Changes in the location of straddling stocks may result in increased conflict between countries in some cases (Sumaila et al., 2011; Mendenhall et al., 2020; Abrante et al., 2020; Sumaila et al., 2020). Furthermore, some fish species will likely benefit from climate change, with an increase in their occurrence area in coastal regions in the Americas, particularly as temperatures rise and salinity increases (Guerra et al., 2021).

In the case of freshwater fish species, the thermal regime of the river is a significant element impacting the onset of spawning and breeding success; because freshwater fish species are ectothermic river organisms, their metabolic rates, growth, development, and survival, as well as their distribution and abundance within fluvial environments, are all affected by the thermal regime (Kedra and Wiejaczka, 2018). Therefore, altering the thermal regime can produce numerous adverse effects, such as decreases in larval and juvenile fish growth and survival (Pörtner and Farrell, 2008), delays in migrations and spawning, and native fish declines (Hari et al., 2006; Olden and Naiman, 2010). Moreover, water temperature has an especially strong influence on reproductive processes in all stages of fish life (Pankhurst and Munday, 2011)

The climate of the future may result in reduced habitat and worse spawning conditions due to flow reduction. For instance, a study compared the effects of observed climate conditions on Chinook salmon (*Oncorhynchus tshawytscha*) spawning and rearing habitats, as well as growth responses to the local climate, to predicted responses to climate change. The findings concluded that the future quality of spawning habitat may be diminished in the seasonal period to which Chinook have become adapted (Reeder et al., 2021). Moreover, the study projected an increase in the size of Chinook salmon in the future due to rising water temperatures. On the other hand, climate change has been linked to the expansion of oxygen minimum zones (Stramma et al., 2010), which will likely affect the physiological performance and distribution of pelagic marine organisms, with far-reaching consequences for fisheries (Pörtner, 2010).

Fish diversity response to climate variables was modelled to estimate the effects of climate change on Texas' marine fish populations (Pawluk et al., 2021). Using rarefaction analysis, asymptotic Shannon diversity was computed for each bay, season, and year using 33 years of gillnet survey data from eight major bays along the Texas coast. Temperature, salinity, and sea level emerged as the most important influences driving the increase in fish diversity. Mangrove expansion and warmer winters are likely enabling tropical species to expand their ranges, contributing to the observed increase in fish diversity. Likewise, climate change is predicted to disrupt existing stressors, but the ways in which this occurs remain poorly understood in freshwater systems worldwide. Using data from over 300 catchments across a broad 250,000 square kilometer region, Murdoch (2020) examined the combined and interacting effects of various stressors (including land use) on boreal stream fishes. Land use changes did not lead to overall community impoverishment and productivity. In contrast, sensitive species, such as valued salmonids, showed declines that depended on local climate, land use, and stream type.

Climate change impacts on fisheries, food security and livelihoods

Climate change's environmental consequences are expected to have a significant impact on fisheries and associated economies, posing a significant challenge for policymakers. Therefore, impacts on countries heavily reliant on fisheries can be linked to vulnerability, given the sectors' critical contribution to employment, supply, income, and nutrition (Vannuccini et al., 2018). Concerns about the impact of ocean warming on fisheries yields are particularly prevalent. For instance, one study confirmed that ocean warming has altered the composition of fisheries landings (of warmer and colder species) in three regions along the Portuguese coast, highlighting the importance and urgency in fisheries management of the temperature-induced shift in species distribution (Leitão et al., 2018).

Using Monte Carlo models, Arnason (2006) calculated the impact of global warming on fish supplies in Iceland and Greenland. In Iceland and Greenland, the study reveals a positive influence on GDP. Ibarra et al. (2013) investigated the economic impacts of climate change on Mexican coastal fisheries, focusing on shrimp and sardine. They have found that climate change causes a decline in shrimp production and a high degree of sardine fishery variability and uncertainty. A study described the contribution of small pelagic fish to the food safety and identified the knowledge gaps to be filled to improve the fishery's resilience to the effects of climate change (Sekadende et al., 2020). The study proposed the following six critical research questions in order to enhance current capability for predicting climate change impacts on the Pemba Channel's small pelagic fishery, including local and regional environmental drivers, biomass, species composition and exploitation rate, adaptation to changes in biomass, and prediction of small pelagic bivalves. Climate change has the likelihood to exert substantial and challenging impacts on fisheries as a whole, thereby influencing livelihoods, food security, and overall wellbeing of communities reliant on fisheries.

Applying a dynamic bioclimate envelope model, Cheung et al. (2010) presented the maximum exploitable catch of a species under climate change. They show that climate change has a significant impact on the distribution of catch potential, which in turn affects potential fisheries productivity. According to their calculations, catch potentials will decline in many coastal places, particularly in the tropics and along the southern margins of semi-enclosed seas, as species are projected to migrate away from the areas as ocean temperatures rise (Suh and Pomeroy, 2020). The analysis of trends in the landings of the most important fishing métiers along the Portuguese coast, as well as the vulnerability and adaptability of Portuguese fisheries to climate change, revealed that sardine is extremely sensitive to the effects of climate change, making purse-seine fisheries particularly vulnerable (Gamito et al., 2016). If additional fishing and processing capital is required to adapt to the impact of climate change on the quantity, composition, and distribution of fisheries resources, this would be affecting the cost of vessels, fishing gear, processing plants, etc. and eventually the fisheries livelihood (Pauly et al., 2005; Sumaila et al., 2019; Lam et al., 2020). The catch per unit effort of the reef fisheries in the Philippines was influenced by factors such as fishing costs, monthly income, weather conditions, and coral bleaching (Macusi et al., 2020).

Many studies have been conducted to identify the impact of climate change on fisheries because of changes in biomass, species mix, and potential catches (Alam et al. 2023; Begum et al., 2022). However, understanding how climate change is likely to affect maritime countries' fisheries revenues is critical for developing effective socioeconomic policies and food sustainability strategies to mitigate and adapt to climate change. The economic consequences of climate change for fisheries could be seen in changes in the price and value of catches, fisheries costs, fishers' income, fishing company income, discount rates and economic rents as well as across the entire global economy. Lam et al. (2016) show how climate change affects worldwide fisheries income. They suggest that climate change will have a detrimental influence on most fishing countries' maximal revenue potential. It was shown that coastal low-income food deficit countries (LIFDCs) rely heavily on fish catches to meet their nutritional needs, but that practically every coastal LIFDC is at risk of losing their maximum revenue potential from fisheries (Suh and Pomeroy, 2020).

According to a study that used climate-living marine resource simulation models, global fisheries revenues could decline by 35% more than the projected decline in catches by the 2050s under high CO_2 emission scenarios (Lam et al., 2016). Under climate change, landed values and costs will change, affecting fishing companies' earnings and the resource rent generated by fishing, with the direction and magnitude of change varying across regional fishing zones (Sumaila et al., 2011). In some cases, the profits earned by fisheries in Canada and the United States would change both in absolute and relative terms as a result of climate change, resulting in relative changes in threat points (Sumaila et al., 2020).

Merino et al. (2011) investigated the synergistic effect of climate variability and fish production, with the goal of determining the maximum sustainable yield. They emphasized global management techniques to ensure an optimum worldwide supply of marine products, implying that interactions between global markets and regional climate may be a factor in resource depletion and successive overexploitation. Seafood demand in Pacific countries is expected to increase significantly between now and 2050, and climate change is projected to reduce the supply of fish from coastal fisheries (Dey et al., 2016). Warmer waters, changes in food availability, and a density-dependent growth of the population have all been connected to recent changes in Atlantic mackerel distribution and the repercussions for fisheries quota allocation. The North Sea's primary productivity has declined significantly over the last 25 years, which has been linked to a general drop in the recruitment of key commercial fish stocks (Pinnegar et al., 2020).

A recent study examined the livelihoods and vulnerability of marine fishing space units in the coastal and marine ecosystems of India, and most marine fishing spatial units were found to be severely vulnerable based on cumulative vulnerability indices (Jeevamani et al., 2021). Additionally, shifts in stock distribution and fish abundance because of climate change may have a significant impact on fish supply, jeopardizing the livelihoods and food security of some British Columbia residents (Talloni-Álvarez et al., 2019). Furthermore, Alava et al. (2017) recognized the importance of developing comprehensive policies to address the ecological and socioeconomic risks posed by greenhouse gases and marine pollutants. The overall reduction in catch potential, combined with stock-share changes, will exacerbate trade-offs between species catch potential changes (Palacios-Abrantes et al., 2020). Climate change may enhance the conditions that may lead to fisheries conflict, posing new problems for existing fisheries management organizations (Mendenhall et al., 2020). However, implementing the Paris Agreement, which aims to mitigate the effects of climate change on ecological and social systems, may prove critical for the future of the world's ocean ecosystems and economies (Sumaila et al., 2019). Addressing the impacts of climate change on fisheries requires a holistic approach, involving sustainable fisheries management, international cooperation, and efforts to reduce greenhouse gas emissions to mitigate further climate change effects. Sustainable and adaptive measures are essential to safeguard the wellbeing of communities dependent on fisheries for food security and livelihoods.

Malaysia's fisheries and aquaculture sectors

The fisheries sector in Malaysia is not only significant at a national level, but also plays a role in the broader Southeast Asian region. Malaysia collaborates with neighboring countries on issues related to fisheries management and shares common marine ecosystems with other nations in the region. For decades, the fisheries sector has been a major source of animal protein for Malaysia's population. In 2019, the country's overall fishery production was of 1.9 million tons, the vast majority from capture (c. 1.5 million tons) and about a fourth from aquaculture (0.4 million tons; Department of Statistics Malaysia, 2021). The supply of fish in the country has fluctuated dramatically over the last two decades (Figure 5.2).

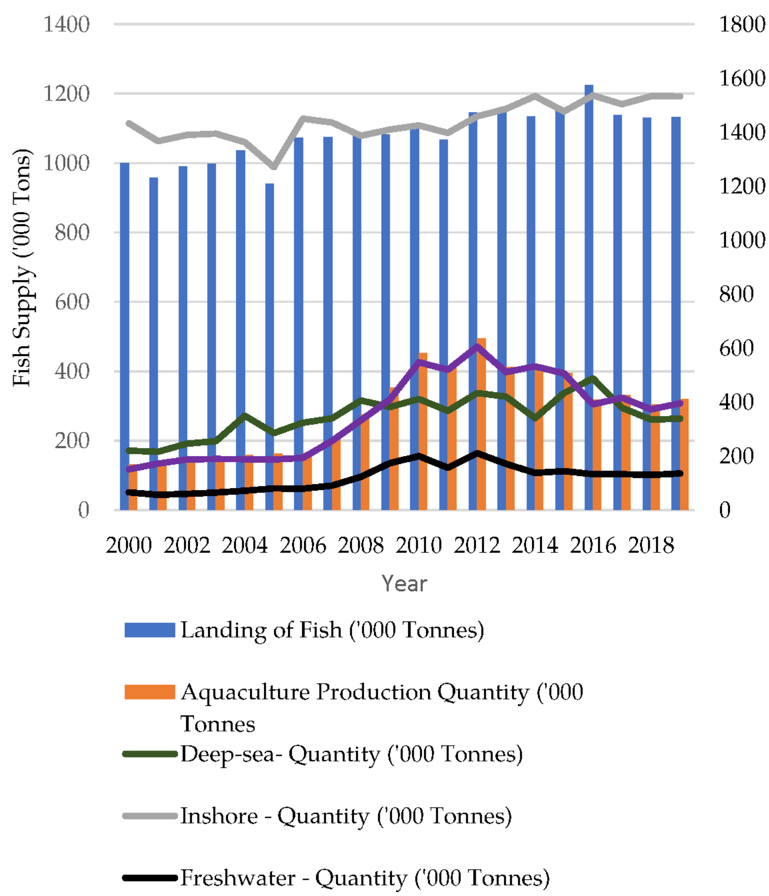


Fig. 5.2 The supply of fish in Malaysia between the years 2000 to 2019 (Data Source: Department of Fisheries, Malaysia, 2021).

For example, total marine fish landings showed a decrease of 2.5% between 2013 and 2014 (from 1,483 to 1,458 thousand tons), an increase of 6.6% between 2015 and 2016 (from 1,486 to 1,584 thousand tons), and another decrease of 7.5% between 2017 and 2018 (from 1,574 to 1,475 thousand tons) (Figures 5.2 and 5.3).

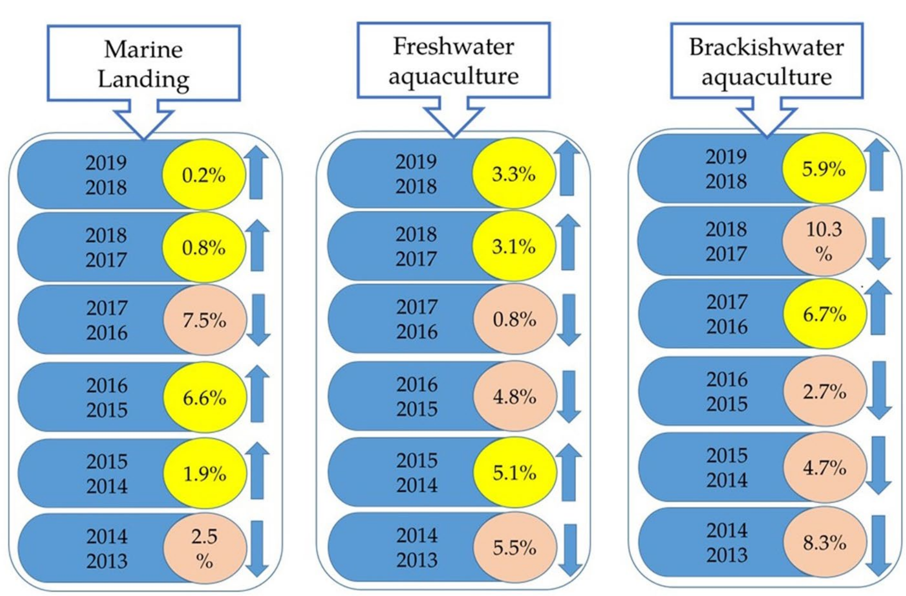


Fig. 5.3 Scenario of marine fish landing, freshwater aquaculture, and brackish water aquaculture production in Malaysia indicating the yearly percentage of changes (Source: department of statistics Malaysia, 2021).

The highest annual increase in freshwater production was 5.1% between 2014 and 2015, with a total production of 112 thousand tons in 2015. On the other hand, the greatest decline in freshwater production occurred between 2013 and 2014, accounting for a 5.5% decline in total production, with 112.8 thousand tons produced in 2013 and 106.6 thousand tons produced in 2014. Minimal variations were found between 2016 and 2017 in annual production of the freshwater with a production decline of 0.8%. Brackishwater production declined at an alarming rate from 2013 to 2016, with the highest decrease (8.3%) occurring in the years 2013 to 2014, when the production of 38.6 thousand tons was recorded. The least drop was noticed during the years 2015 to 2016 (383 thousand tons), and it has since increased to a maximum of 10.3% (290.9 thousand tons) over the years 2017 and 2018. A further decrease in brackish water production was noted between the production records of 2018 and 2019 (5.9%).

In 2019, the total number of fishers was estimated to be around 126,595, with an additional 20,149 people working full-time in aquaculture (DOF, 2021). During the years 2000 to 2019, there was a gradual increase in the number of people involved in marine capture fisheries, but the number of aquaculturists remained comparatively stable (Figure 5.4). Over the period from 2000 to 2019, the value of marine fish landings steadily increased from 4 billion to 11 billion Malaysian Ringgit (approximately 0.9 to 2.5 billion USD).

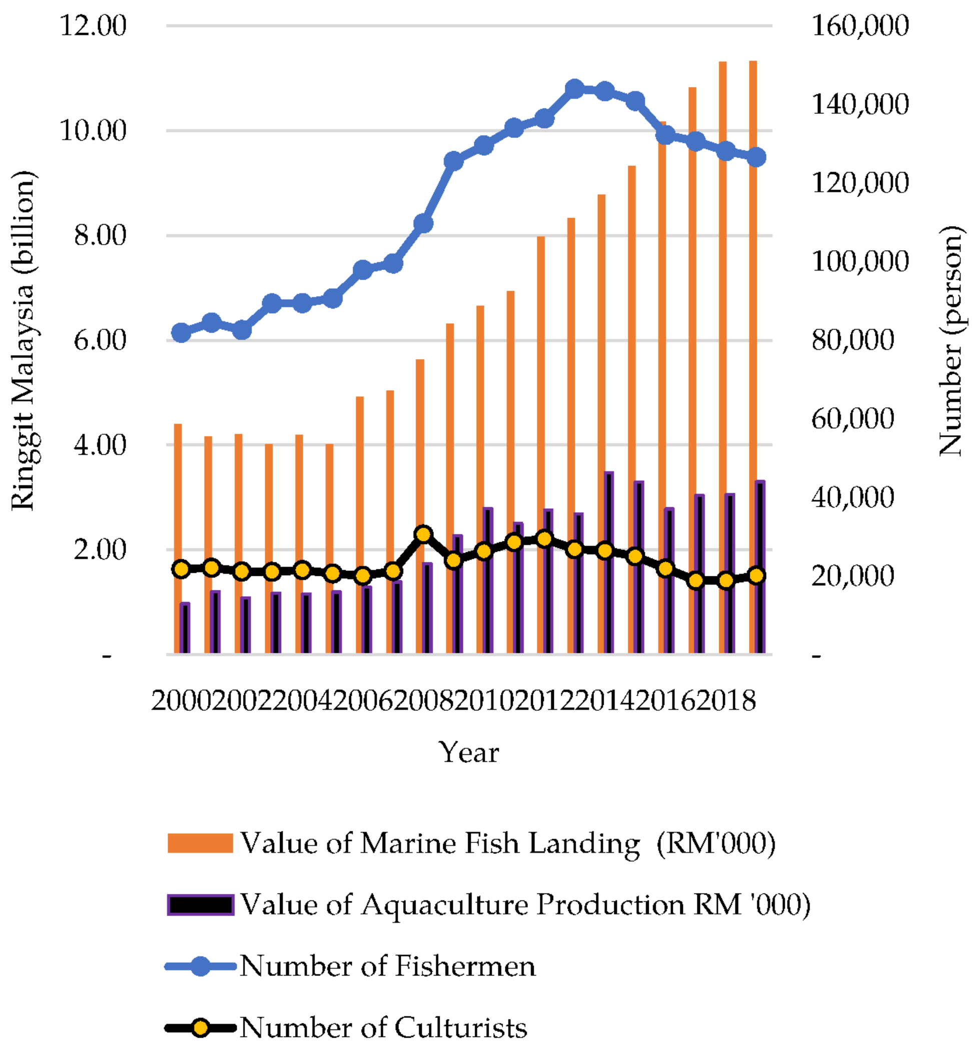
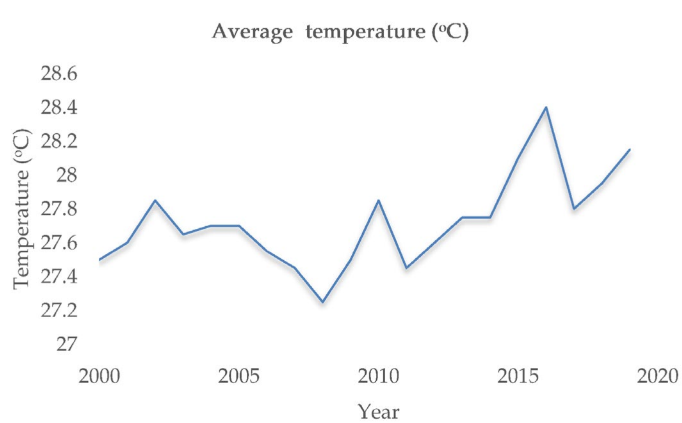


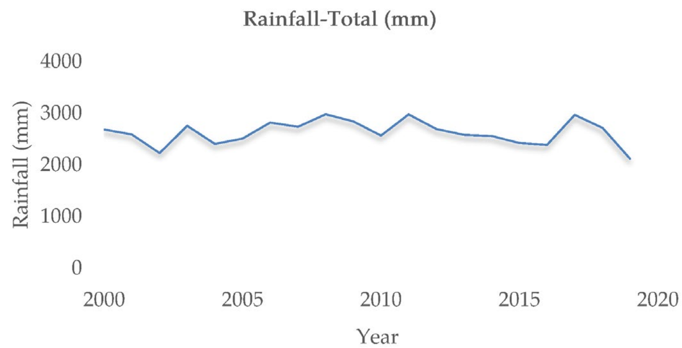
Fig. 5.4 Yearly values of marine fish landing and aquaculture production along with the number of fishermen and culturists in Malaysia (Data Source: Department of Fisheries, Malaysia, 2021).

In the case of aquaculture production, the price of fish has steadily increased from 2000 to 2019. With a contribution of 12.0% from the fishing sector in 2019, the agricultural sector contributed 7.1% (RM 101.50 billion) to the Gross Domestic Product (GDP) (DOSM, 2021). The contribution of fishing to GDP in 2018 was somewhat higher than in 2017, at 12.5% (DOSM, 2021). In the previous three years, the contribution of fisheries was significantly lower. The majority of fish caught in the marine capture sector are sold fresh or chilled, whereas those raised in aquaculture are sold live, directly to restaurants, at a premium price compared to other markets (FAO, 2019). Demand for fish is increasing as wealth and awareness of the health benefits of fish grow. Fish consumption per capita is quite high, at around 59 kg in 2016, making it one of the highest in the world (FAO, 2019). Despite experiencing fluctuations in fisheries production in Malaysia over the past decade, the sector has continued to be in high demand, as evidenced by the steady growth in the number of fishers, the value of marine fish landings, and aquaculture production. Gaining insight into the state of the fisheries sector and continuous monitoring of fisheries trends is vital for economic planning, particularly for countries like Malaysia that rely significantly on the fishing industry.

Climate change impacts on Malaysia

Climate variability is a significant environmental factor affecting the fisheries sector. The effects of climate damage are evident throughout the world and no country is immune to the effects of climate change. Temperature and precipitation variance, flood and drought seasons and water degradation and stratification are events in Malaysia that indicate climate variability (Hamdan et al., 2011). The most obvious impact is the rise in temperature and Malaysia has experienced significant warming and precipitation irregularities over the last two decades (Tang, 2019). Wai et al. (2005) discovered that over a 50-year period (1951–2000), several areas in Malaysia experienced temperature increases ranging from 1.75 to 2.69°C, while the Special Report on Global Warming of 1.5°C, released by IPCC has predicted that changes in rain patterns, rising mean sea levels and consequent coastal floods, and more frequent extreme weather events would all be negative consequences for Malaysia (IPCC, 2018). According to Figure 5.5A, Malaysia's annual mean temperature has been fluctuating between 27.5°C and 28.2°C. Temperature increases in 2015–2016 were caused by a strong El Nino event, one of the strongest on record (Tang, 2019). Numerous studies have confirmed Malaysia's warming trend. For instance, according to the Ministry of Natural Resources and Environment, Malaysia's study on rising temperatures, peninsular Malaysia is experiencing a 0.25°C increase per decade, Sabah is experiencing a 0.20°C increase per decade, and Sarawak is experiencing a 0.14°C increase per decade (NRE, 2015). A number of areas near the sea in Malaysia, which are home to many fishermen, have been identified as undergoing considerable temperature shifts (Kwan et al., 2013). For example, Kota Bharu, Kuala Terengganu, Kuantan, Mersing, and Setiawan are experiencing a 45.3−67.21% rise in warmer days and a 45.8−90.81% increase in warmer nights.





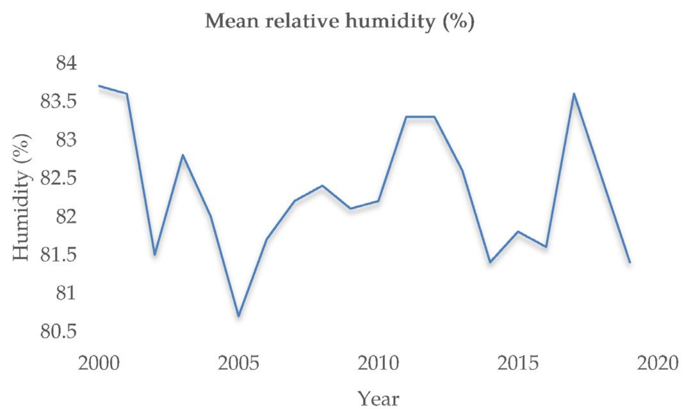


Fig. 5.5 Annual mean temperature, total rainfall, and humidity variation in Malaysia (2000-2019). Data Source: Malaysian Meteorological Department, 2021.

Malaysia's average annual rainfall was generally less than 2,500mm from 2000 to 2019, with the exception of 2008 and 2017, when rainfall exceeded 2,900mm (Figure 5.5B). The historical precipitation data show a high degree of variability that is consistent with current research (Malaysian Meteorological Department, 2009; Sammathuria and Ling, 2009; Loh et al., 2016). This study examines the mean relative humidity of 13 states across the country from 2000 to 2019 (Figure 5.5C). The relative humidity fluctuated between 80.7 and 83.7%, with the lowest value recorded in 2005. In general, the humidity trended downward.

Sea level rise is another concern associated with climate change in Malaysia; in general, Malaysia's regional sea level rise is projected to be higher than the global average. For example, according to an analysis of tidal data from 1984 to 2013 (Kamaruddin et al., 2016), the total average sea level in Malaysia has been rising at a rate of $3.67\pm$ 0.15 millimeters per year (mm/year), which is greater than the projected global sea level rise of 1.7–3.1 mm/year due to local climate and topographical conditions. Furthermore, a more recent study by Izzati et al. (2018) noted an upward rate trend in the Malaysian sea levels between 3.27 ± 0.12 mm/year from eastern Malaysia, and 4.95 ± 0.15 mm/year in the west, which is also higher than the global level. Moreover, low-lying areas with high population and socioeconomic activity are vulnerable to being inundated. Therefore, another study raised additional concerns by identifying three locations in Malaysia where the sea level increased by more than 3 millimeters per year between 1993 and 2008, namely Sandakan (3.45 mm/year), Chendering (3.20 mm/year), and Kukup (3.02 mm/year) (Din & Omar, 2012). Several sectors in Malaysia have been identified as vulnerable to climate change impacts, including agriculture, forestry, biodiversity, water resources, coastal and marine resources, public health, and energy (Tang, 2019). Nonetheless, most existing research focuses on the agricultural impacts of climate change, particularly on rice production, while studies on the fisheries and aquaculture sector remain scarce. One plausible reason for the increased focus on the effects of climate change on agriculture sector in Malaysia is its importance as a major contributor to the country's Gross Domestic Product (GDP) (Department of Statistics Malaysia, 2021). While research on the impact of climate change on the fisheries sector is limited, it has been established that small-scale fishers in Malaysia have been affected by climate change related factors such as rising temperatures, unstable North-East monsoon patterns, sea level rise, and extreme winds and waves (Shaffril et al., 2013). The following section addresses these impacts, together with needed adaptation measures.

Climate change impacts and adaptations in the fisheries sector in Malaysia

Shaffril et al. (2015) and D'Silva et al. (2012) have both investigated the effects of climate change on fishing communities. Climate change impacts have reduced the number of fishing days per year in Malaysia (Shaffril et al., 2016) and resulted in a 32% decrease in fishermen's catches (Yaakob and Quah, 2005). According to Kamaruzzaman et al. (2021), the projected increases in sea surface temperature due to climate change influence the spatial and temporal distributions of *Rastrelliger kanagurta*. Elevated temperatures of 2.6°C and 3.3°C indicated a decrease in potential *Rastrelliger kanagurta* catch areas in the Exclusive Economic Zone (EEZ) of Malaysia. Moreover, the study has predicted a loss in most fishing grounds and a shift in the distribution of fishing grounds outside the Exclusive Economic Zone of the South China Sea. Correlations between pelagic fish landings and rainfall, temperature, wind, and Southern Oscillation Index (SOI) values suggested that fish abundance and diversity are weather-dependent (Ho et al., 2013). Similarly, Hamdan et al. (2011) established a significant link between climate variability and production loss, particularly when water temperatures fluctuate, and pandemic disease outbreaks occur.

Due to the predicted escalation of climate change's effects, small-scale fishers are expected to be particularly hard hit. The best response is therefore to strengthen the adaptation practices of this sector to climate change. Abu Samah et al. (2019) examined the influence of individual differences on climate change adaptation practices of small-scale fishermen in Malaysia. These authors revealed that demographic parameters such as age and experience had a substantial negative association with climate change adaptation practices, whereas income had a large positive link with climate change adaptation practices. Furthermore, small-scale fishermen who used fisheries technologies, had alternative jobs, and had a higher education level, developed better climate change adaptation practices than non-users of technologies, full-time fishermen, and less educated fishermen (Abu Samah et al., 2019). On the other hand, awareness of the consequences of climate change is another issue among Malaysia's small-scale fishermen. For instance, a recent study indicated that small-scale fishers in Kota Belud, Sabah, one of the largest producers to Malaysia's national fisheries industry, were ignorant about the influence of climate change on their survival. Additionally, most of them have demonstrated limited resilience to the effects of climate change (Osman et al., 2021). Shaffril et al. (2017a) highlighted and analyzed six main adaptation strategies: reduction of the risks associated with fishing routines, reinforcement of social connections, management of fishing knowledge about climate change, facilitating community learning of alternatives, involving fishers in the planning of climate change adaptation, and improving fishers access to credit. These recommendations could serve as a starting point for the development of other adaptation strategies that are tailored to the needs, abilities, and interests of small-scale fishers. Furthermore, small-scale fishermen living in coastal areas of Malaysia that are particularly vulnerable to climate change, possess adaptive strength in two areas: formal and informal networks, as well as environmental awareness, values, and attitudes (Shaffril et al., 2017b). Moreover, the potential for alternative skills, managed retreat, housing and protection, information management, periodic assessment, and access to credit to help small-scale fishermen in Malaysia may develop progressive adaptive capacity (Shaffril et al., 2017b).

On the other hand, regional variation might be an important factor influencing the adaptive capacity of fishermen. Considering this, a recent study attempted to explore the level of adaptation of small-scale fishermen on the mainland and on islands towards climate change to further identify any important differences in their potential for adaptation (Samah et al., 2020). The ability to adapt varied among small-scale fishermen on Malaysia's east and west coasts (Samah et al., 2016). In this respect, several substantive differences between islanders and mainland fishermen have been detected in 10 out of 16 adaptability variables including monetary and emotional adaptability, the level of interest in adapting to change, the ability to plan, the ability to reorganize and attachment to work. Fishermen in Peninsular Malaysia demonstrated a high level of adaptation in terms of attitude toward climate change, while their level of education, catching area, fishing technology, vessel type, and income were confirmed as influential factors (Muhammad et al., 2018). Likewise, fishermen in Peninsular Malaysia's East Coast Region proved a high level of adaptation in two areas: first, environmental awareness, attitudes, and beliefs; and second, indigenous environmental knowledge (Shaffril et al., 2013). A previous study had also examined the effects of income, age, and work experience on the climate change adaptation practices of Malaysian deep sea and coastal fishermen (D'Silva et al., 2012). Here, the authors concluded that income had no discernible effect on fisher's adaptation practices, but that older, more experienced fishers had more effective adaptation practices when compared to younger, less experienced ones. Adequate training and financial support are recommended for the local fishers so that they are prepared mentally and financially to cope with the calamities of climate change (Jeffrey et al., 2012). The overview of impact of climate change in Malaysia's fisheries, factors affecting community adaptation and suggested strategies extracted from this review are highlighted in Figure 5.6.

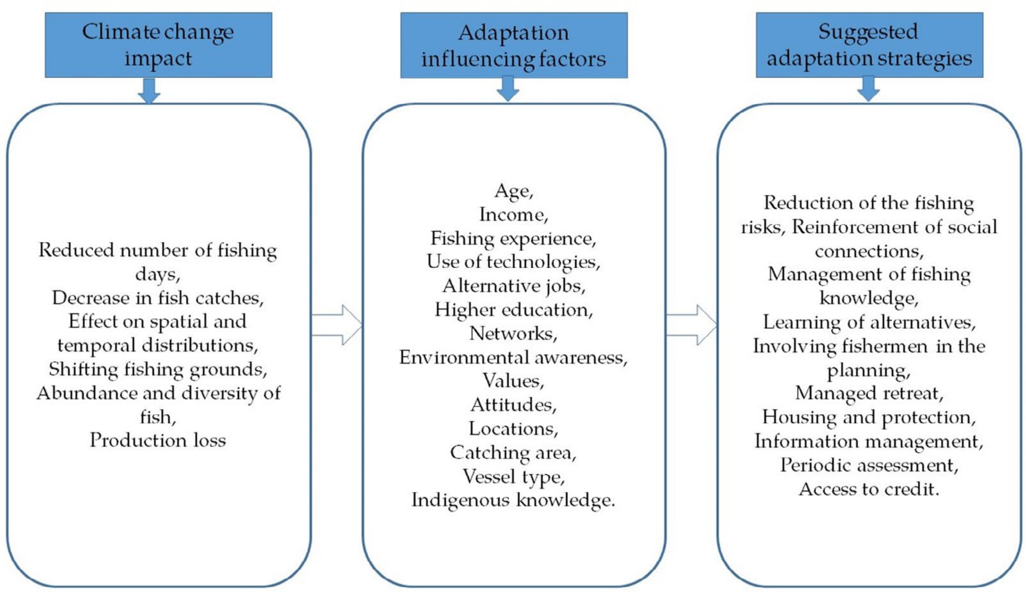


Fig. 5.6 The observed impact of climate change in fisheries, factors affecting community adaptation and recommended adaptation strategies in the context of Malaysia.

Conclusion

Interdisciplinary solutions for marine ecosystems involve integrating knowledge, methods, and perspectives from various disciplines to address the complex challenges posed by climate change, human activities, and other environmental stressors. This chapter aims to fill a gap in our understanding by reviewing the literature on the effects of climate change on the fish industry worldwide, with a particular emphasis on Malaysia. This information is crucial for developing interdisciplinary solutions for marine ecosystems. Fish populations, marine habitats, and fisheries are all predicted to be impacted by climate change. Although significant progress has been made in recent years, there are still substantial knowledge gaps that prevent a comprehensive understanding of the full range of impacts that climate change could have on the fisheries sector and food security. Some of these gaps include insufficient data on species-specific impacts, the cumulative effects of multiple stressors on fisheries, and the impact of interconnections with other sectors. Currently, studies on the impact of climate change on the fisheries sector at the regional level are scarce. Considering this, the present review focused on Malaysia's fisheries sector, comprising the impact of climate change and adaptation measures. Numerous local studies have identified indicators of climate change in the country, which are expected to worsen, further negatively affecting fishing communities. However, while the situation is likely to worsen, efforts at the individual level may be made to diminish and delay impacts, and these focus on reinforcing fishermen's adaptive capabilities. The findings of the study include a list of the factors that influence the ability of the fishing community to adapt to the effects of climate change, as well as highlighting recommended adaptation strategies in Malaysia. Efforts to develop a more precise adaptation strategy for dealing with the potential effects of climate variability on the fisheries sector in Malaysia need to be further refined. The results indicated a greater need for research on community adaptation, particularly for low-awareness and poorly adapted communities who are especially vulnerable to the effects of climate change. This research also revealed that studies were limited to only small-scale fishermen in Malaysia. Therefore, future research should concentrate on other fishing communities, particularly deep-sea fishing communities, taking into account fishermen's age, experience, income level, and other potential factors. There is a need for possible initiatives to improve the adaptive capacity of less adaptive fishermen, such as the elderly and poorly trained community. Simultaneously, fishing technology advancements (like better fishing boats) and radio signaling will assist in the adaptation processes. Additionally, the government and/or non-governmental organizations (NGOs) should support or provide alternative sources of income generation for fishing communities in order to mitigate their livelihood vulnerability. Although this study attempted to integrate knowledge about climate change impacts and adaptation practices at the regional level, more in-depth research on fishermen's responses to adaptation strategies is required. This may involve investigating the indigenous knowledge and perspectives on climate change among fisherman, as well as analyzing the particular adaptation measures that fishermen are currently implementing. It would also be essential to identify the barriers and challenges that fisherman encounter while putting adaptation strategies into practice. However, despite our lack of knowledge about how climate change affects the fishing industry, there is enough evidence to support the implementation of mitigation and adaptation policies. Adapting to climate change in the fishing industry will require dynamic and flexible management, which can be accomplished by aligning management policies with regional scales of climate change and socioeconomic responses. This may include enforcing catch quotas, adjusting fishing seasons, and implementing real-time monitoring systems to respond promptly to climate-induced changes. Involving local fishing communities in the decision-making process, and implementing adaptive co-management approaches that involve collaboration between government authorities, fishing communities, and other stakeholders, are crucial. Furthermore, engaging with neighboring nations and international organizations to solve common concerns and foster regional cooperation, will be beneficial in dealing with the impact of climate change on the fisheries industry at the regional level.

References

Abu Samah, A., Shaffril, H. A. M., Hamzah, A., & Abu Samah, B. (2019). Factors affecting small-scale fishermen's adaptation toward the impacts of climate change: Reflections from Malaysian fishers. *SAGE Open*, *9*(3), 2158244019864204.

Abu Samah, A., Hamdan, M. E., Abu Samah, B., Hamzah, A., & Shaffril, H. A. M. (2016). Adaptation towards climate change among small scale fishermen: A comparison between the East Coast and West Coast fishermen in Peninsular Malaysia. *The Social Sciences*, *11*, 3458-3462.

Alam, L., Zolkaply, S.Z., Sumaila, U.R. et al. Risk of extinction, variability in fish species composition, and factors influencing fish biodiversity in the Malacca Strait. Environ Sci Pollut Res (2023). https://doi.org/10.1007/s11356-023-27101-2

Alava, J. J., Cheung, W. W., Ross, P. S., & Sumaila, U. R. (2017). Climate change–contaminant interactions in marine food webs: Toward a conceptual framework. *Global change biology*, *23*(10), 3984-4001.

Arnason, R. (2006). "Global warming, small pelagic fisheries and risk," in Climate Change and the Economics of the World's Fisheri'es: Examples of Small Pelagic Stocks, eds R. Hannesson, M. Barange, and S. Herrick (Northampton, MA: Edward Elgar), 1–32.

Barange, M., Bahri, T., Beveridge, M. C., Cochrane, K. L., Funge-Smith, S., & Poulain, F. (2018). Impacts of climate change on fisheries and aquaculture: synthesis of currrent knowledge, adaptation and mitigation options. FAO.

Barton, A., Hales, B., Waldbusser, G. G., Langdon, C., & Feely, R. A. (2012). The Pacific oyster, Crassostrea gigas, shows negative correlation to naturally elevated carbon dioxide levels: Implications for near-term ocean acidification effects. *Limnology and oceanography*, *57*(3), 698-710.

Begum, M., Masud, M.M., Alam, L. et al. The impact of climate variables on marine fish production: an empirical evidence from Bangladesh based on autoregressive distributed lag (ARDL) approach. Environ Sci Pollut Res 29, 87923–87937 (2022). https://doi.org/10.1007/s11356-022-21845-z

Cheung, W. W., Lam, V. W., Sarmiento, J. L., Kearney, K., Watson, R. E. G., Zeller, D., et al. (2010). Large-scale redistribution of maximum fisheries catch potential in the global ocean under climate change. Glob. Change Biol. 16, 24–35. https://doi.org/10.1111/j.1365-2486.2009.01995.x

Cooley, S. R. & Doney, S. C. (2009) Anticipating ocean acidification's economic consequences for commercial fisheries. Environ. Res. Lett. 4, 024007.

Das, I., Lauria, V., Kay, S., Cazcarro, I., Arto, I., Fernandes, J. A., & Hazra, S. (2020). Effects of climate change and management policies on marine fisheries productivity in the north-east coast of India. *Science of The Total Environment*, *724*, 138082.

Department of Fisheries, Malaysia, 2021, https://www.dof.gov.my/

Department of Statistics Malaysia. (2021). Indicators: Agriculture.

Dey, M. M., Rosegrant, M. W., Gosh, K., Chen, O. L., & Valmonte-Santos, R. (2016). Analysis of the economic impact of climate change and climate change adaptation strategies for fisheries sector in Pacific coral triangle countries: Model, estimation strategy, and baseline results. *Marine Policy*, *67*, 156-163.

Din, A. H. M., Omar, K. M., Naeije, M., & Ses, S. (2012). Long-term sea level change in the Malaysian seas from multi-mission altimetry data. *International Journal of Physical Sciences*, *7*(10), 1694-1712.Drinkwater, K. F. (2005). The response of Atlantic cod (*Gadus morhua*) to future climate change. ICES J. Mar. Sci. 62, 1327–1337

D'Silva, J. L., Shaffril, H. A. M., Samah, B. A., & Uli, J. (2012). Assessment of social adaptation capacity of Malaysian fishermen to climate change. Journal of Applied Science, 12, 876-881.

Easterling, W. E., Aggarwal, P. K., Batima, P., Brander, K. M., Erda, L., Howden, S. M., ... & Tubiello, F. N. (2007). Food, fibre and forest products. *Climate change*, *2007*, 273-313.

Eide, A. (2007).Economic impacts of global warming: The case of the Barents Sea fisheries. Nat. Resour. Model. 20, 199–221

Ellison, J. C. (2015). "Vulnerability assessment of mangroves to climate change and sea-level rise impacts." Wetlands Ecology and Management 23(2): 115-137.

FAO (2019). Fishery and Aquaculture Country Profiles Malaysia. http://www.fao.org/fishery/facp/mys/en

FAO (2020), The State of World Fisheries and Aquaculture (SOFIA), Food and Agriculture Organization of the United Nations, Rome

Gaichas, S., J. Link, et al. (2014). "A risk-based approach to evaluating northeast US fish community vulnerability to climate change." ICES Journal of Marine Science: Journal du Conseil 71(8): 2323-2342.

Gamito, R., Pita, C., Teixeira, C., Costa, M. J., & Cabral, H. N. (2016). Trends in landings and vulnerability to climate change in different fleet components in the Portuguese coast. *Fisheries Research*, *181*, 93-101.

Guerra, T. P., dos Santos, J. M. F. F., Pennino, M. G., & Lopes, P. F. M. (2021). Damage or benefit? How future scenarios of climate change may affect the distribution of small pelagic fishes in the coastal seas of the Americas. *Fisheries Research*, *234*, 105815.

Hamdan, R., Kari, F., & Othman, A. (2011). Climate variability and socioeconomic vulnerability of aquaculture farmers in malaysia. In *International Conference on Business and Economics Research. Singapore* (pp. 47-52).

Hari, R.E., Livingstone, D.M., Siber, R., Burkhardt-Holm, P., Güttinger, H., 2006.

Consequences of climatic change for water temperature and brown trout populations

in Alpine rivers and streams. Glob. Change Biol. 12, 10–26.

Ho, D. J., Maryam, D. S., Jafar-Sidik, M., & Aung, T. (2013). Influence of weather condition on pelagic fish landings in Kota Kinabalu, Sabah, Malaysia. *Journal of Tropical Biology & Conservation* (*JTBC*).

Holdsworth, A. M., Zhai, L., Lu, Y., & Christian, J. R. (2021). Future Changes in Oceanography and Biogeochemistry Along the Canadian Pacific Continental Margin. *Frontiers in Marine Science*, *8*, 190.

Ibarra, A. A., Vargas, A. S., and Lopez, B. M. (2013). Economic impacts of climate change on twoMexican coastal fisheries: implications for food security. Economics 7, 1–38. https://doi.org/10.5018/economics-ejournal.ja.2013-36.

IPCC (2018). Global warming of 1.5° C: an IPCC special report on the impacts of global warming of 1.5° C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty. Intergovernmental Panel on Climate Change.

IPCC (2019). SROCCC: IPCC Special Report on the Ocean and Cryosphere in a Changing Climate H.-O. Pörtner, D.C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, A. Alegría, M. Nicolai, A. Okem, J. Petzold, B. Rama, N.M. Weyer (eds.).

Izzati, A., Hamid, A., Hassan, A., Hwang, C., Fadila, N., Tugi, A., & Mohd, K. (2018). Contemporary sea level rise rates around Malaysia: Altimeter data optimization for assessing coastal impact. Journal of Asian Earth Sciences, 166, 247-259

Jeevamani, J., Priya, P., Infantina, J. A., Abhilash, K. R., Behera, D. P., Samuel, V. D., Soundararajan, R., Purvaja, R., & Ramesh, R. (2021). An integrated approach to assess coastal vulnerability versus fisheries livelihood sustainability: Strategies for climate change adaptation in Sindhudurg, west coast of India. *Environment, Development & Sustainability*, *23*(3).

Jeffrey, L., Hayrolazril, M. S., Bahaman, A. S., & Jegak, U. (2012). Assessment of social adaptation capacity of Malaysian fishermen to climate change. *Journal of Applied Sciences*, *12*(9), 876-881.

Kamaruddin, A. H., Din, A. H. M., Pa'suya, M. F., & Omar, K. M. (2016, August). Long-term sea level trend from tidal data in Malaysia. In 2016 7th IEEE Control and System Graduate Research Colloquium (ICSGRC) (pp. 187-192). IEEE.

Kamaruzzaman, Y. N., Mustapha, M. A., & Abd Ghaffar, M. (2021). Determination of Fishing Grounds Distribution of the Indian Mackerel in Malaysia's Exclusive Economic Zone Off South China Sea Using Boosted Regression Trees Model. *Thalassas: An International Journal of Marine Sciences*, *37*(1), 147-161.

Kedra, M., Wiejaczka, L., 2018. Climatic and dam-induced impacts on river water temperature: Assessment and management implications. The Science of the total environment 626, 1474–1483.

Kim, S. U., & Kim, K. Y. (2021). Impact of climate change on the primary production and related biogeochemical cycles in the coastal and sea ice zone of the Southern Ocean. *Science of The Total Environment*, *751*, 141678.

Kwan, M. S., Tangang, F. T., & Juneng, L. (2013). Projected changes of future climate extremes in Malaysia. *Sains Malaysiana*, *42*(8), 1051-1059.

Lam, Vicky WY, Edward H. Allison, Johann D. Bell, Jessica Blythe, William WL Cheung, Thomas L. Frölicher, Maria A. Gasalla, and U. Rashid Sumaila. (2020) "Climate change, tropical fisheries and prospects for sustainable development." *Nature Reviews Earth & Environment* 1, no. 9, 440-454.

Lam, V. W., Cheung, W. W., Reygondeau, G., & Sumaila, U. R. (2016). Projected change in global fisheries revenues under climate change. *Scientific Reports*, *6*(1), 1-8.

Leitão, F., Maharaj, R. R., Vieira, V. M., Teodósio, A., & Cheung, W. W. (2018). The effect of regional sea surface temperature rise on fisheries along the Portuguese Iberian Atlantic coast. *Aquatic Conservation: Marine and Freshwater Ecosystems*, *28*(6), 1351-1359.

Loh, J.L., Tangang, F., Liew, J., Hein, D., Lee, D., (2016) Projected rainfall and temperature changes over Malaysia at the end of the 21st century based on PRECIS modelling system. Asia-Pac. J. Atmos. Sci. 52 (2), 191–208.

Macusi, E. D., Macusi, E. S., Jimenez, L. A., & Catam-isan, J. P. (2020). Climate change vulnerability and perceived impacts on small-scale fisheries in eastern Mindanao. *Ocean & Coastal Management*, *189*, 105143.

Malaysian Meteorological Department. (2009). Climate Change Scenarios for Malaysia 2001–2099. Malaysia Meteorological Department, Kuala Lumpur.

Malaysian Meteorological Department. (2021). https://www.met.gov.my/

Mendenhall, E., Hendrix, C., Nyman, E., Roberts, P. M., Hoopes, J. R., Watson, J. R., & Sumaila, U. R. (2020). Climate change increases the risk of fisheries conflict. *Marine Policy*, *117*, 103954.

Merino, G., Barange, M., Rodwell, L., and Mullon, C. (2011). Modelling the sequential geographical exploitation and potential collapse of marine fisheries through economic globalization, climate change and management alternatives. Sci. Mar. 75, 779–790. https://doi.org/10.3989/scimar.2011.75n4779

Ministry of Natural Resources and Environment Malaysia. (2015). Malaysia: Biennial update report to the UNFCC. Putrajaya: Author.

Muralidhar, M., Kumaran, M., Kumar, J. A., Dayal, J. S., Jayanthi, M., Saraswathy, R., & Murugan, P. (2013). Climate change and coastal aquaculture in West Godavari District, Andhra Pradesh: Impacts, vulnerability, adaptations and mitigations for resilience. *Journal of Agrometeorology*, *15*, 116-122.

Muhammad, M., Idris, K., Shaffril, H. A. M., Sulaiman, A. H., Samah, B. A., & Suandi, T. (2018). Attitude of Small-Scale Fishermen Towards Adaptation to Climate Change. *Pertanika Journal of Social Sciences & Humanities*.

Mohamed Shaffril, H. A., Hamzah, A., D'Silva, J. L., Abu Samah, B., & Abu Samah, A. (2017). Individual adaptive capacity of small-scale fishermen living in vulnerable areas towards the climate change in Malaysia. *Climate and Development*, *9*(4), 313-324.

Murdoch, A., Mantyka-Pringle, C., & Sharma, S. (2020). The interactive effects of climate change and land use on boreal stream fish communities. *Science of the Total Environment*, *700*, 134518.

NRE, 2015. Malaysia Biennial Update Report to the UNFCC. Ministry of Natural Resources and Environment Malaysia, Putrajaya, Malaysia.

Olden, J.D., Naiman, R.J., (2010). Incorporating thermal regimes into environmental flows assessments: modifying dam operations to restore freshwater ecosystem integrity. Freshw. Biol. 55, 86–107.

Osman, N. F., Yassin, J., Gabir, J., & Bakrin, S. (2021). Impact of The Climate Change to The Small-Scale Fisheries and Their Adaptation in Kota Belud, Sabah. International Journal of Academic Research in Business and Social Sciences, 11(6), 240–252.

Palacios-Abrantes, J., Sumaila, U. R., & Cheung, W. (2020). Challenges to transboundary fisheries management in North America under climate change. *Ecology and Society*, *25*(4).

Pankhurst, N.W., Munday, P.L., (2011) Effects of climate change on fish reproduction and early life history stages. Mar. Freshw. Res. 62, 1015–1026.

Parry, M., Rosenzweig, C., & Livermore, M. (2005). Climate change, global food supply and risk of hunger. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *360*(1463), 2125-2138.

Pauly, D. (1981). The relationships between gill surface area and growth performance in fish: a generalization of von Bertalanffy's theory of growth.

Pauly, D., Watson, R., & Alder, J. (2005). Global trends in world fisheries: impacts on marine ecosystems and food security. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *360*(1453), 5-12.

Pauly, D., & Zeller, D. (2016). Catch reconstructions reveal that global marine fisheries catches are higher than reported and declining. *Nature communications*, *7*(1), 1-9.

Pawluk, M., Fujiwara, M., & Martinez-Andrade, F. (2021). Climate effects on fish diversity in the subtropical bays of Texas. *Estuarine, Coastal and Shelf Science*, *249*, 107121.

Pinnegar, J. K., Cheung, W. W. L. & Heath, M. in Marine Climate Change Impacts Partnership Annual Report Card Science Review 2010–11 (MCCIP, 2010); available at http://www.mccip.org.uk/arc

Pinnegar, J. K., Wright, P. J., Maltby, K., & Garrett, A. (2020). The impacts of climate change on fisheries, relevant to the coastal and marine environment around the UK. *MCCIP Sci. Rev*, *2020*, 456-581.

Pörtner, H. O. & Knust, R. Climate change affects marine fishes through the oxygen limitation of thermal tolerance. Science 315, 95–97 (2007).

Pörtner, H-O. Oxygen- and capacity-limitation of thermal tolerance: a matrix for integrating climate-related stressor effects in marine ecosystems. J. Exp. Biol. 213, 881–893 (2010).

Reeder, W. J., Gariglio, F., Carnie, R., Tang, C., Isaak, D., Chen, Q., ... & Tonina, D. (2021). Some (fish might) like it hot: Habitat quality and fish growth from past to future climates. *Science of The Total Environment*, *787*, 147532.

Sallehudin, J., Samsudin, B., Effarina, M.F. and Nor Azlin, M. (2017), Understanding the role of Malaysian Fisheries Management in the fisheries data collection. Working Party on Data Collection and Statistics (WPDCS), IOTC-2017-WPDCS13-18.

Samah, A. A., & Shaffril, H. A. M. (2020). A comparative study between mainland and islander small-scale fishermen's adaptation towards climate change. *Environmental Science and Pollution Research*, 1-13.

Sammathuria, M.K., Ling, L.K., (2009). "Regional Climate Observation And Simulation Of Extreme Temperature and Precipitation Trends", Paper Presented at the 14th International Rainwater Catchment Systems Conference, 3–6 August. PWTC, Kuala Lumpur available at. http://www.eng.warwick.ac.uk/ircsa/pdf/14th/papers/P1-3%20 Sammathuria.pdf
Sekadende, B., Scott, L., Anderson, J., Aswani, S., Francis, J., Jacobs, Z., ... & Popova, E. (2020). The small pelagic fishery of the Pemba Channel, Tanzania: What we know and what we need to know for management under climate change. *Ocean & Coastal Management*, *197*, 105322.

Shaffril, H. A. M, Hamzah, A., D'Silva, J. L., Abu Samah, B., & Abu Samah, A. (2017). Individual adaptive capacity of small-scale fishermen living in vulnerable areas towards the climate change in Malaysia. *Climate and Development*, *9*(4), 313-324.

Shaffril, H. A. M., Abu Samah, B., D'Silva, J. L., & Yassin, S. M. (2013). The process of social adaptation towards climate change among Malaysian fishermen. International Journal of Climate Change Strategies and Management, 5, 38-52.

Shaffril, H. A. M., D'Silva, J. L., Kamaruddin, N., Omar, S. Z., & Bolong, J. (2015). The coastal community awareness towards the climate change in Malaysia. *International Journal of Climate Change Strategies and Management*, *7*, 516-533.

Shaffril, H. A. M., Samah, A. A., & D'Silva, J. L. (2017). Adapting towards climate change impacts: Strategies for small-scale fishermen in Malaysia. *Marine Policy*, *81*, 196-201.

Smyth, K., & Elliott, M. (2016). Effects of changing salinity on the ecology of the marine environment. Stressors in the Marine Environment: Physiological and Ecological Responses; Societal Implications, 161-174.

Stramma, L., Schmidtko, S., Levin, L. A., & Johnson, G. C. (2010). Ocean oxygen minima expansions and their biological impacts. *Deep Sea Research Part I: Oceanographic Research Papers*, *57*(4), 587-595.

Suh, D., & Pomeroy, R. (2020). Projected economic impact of climate change on marine capture fisheries in the Philippines. *Frontiers in Marine Science*, *7*, 232.

Sumaila, U. R. & Cheung, W. W. L. Cost of Adapting Fisheries to Climate Change World Bank Discussion Paper 5 (International Bank for Reconstruction and Development/World Bank, 2010).

Sumaila, U. R., Cheung, W. W., Lam, V. W., Pauly, D., & Herrick, S. (2011). Climate change impacts on the biophysics and economics of world fisheries. *Nature climate change*, *1*(9), 449-456.

Sumaila, U. R., Palacios-Abrantes, J., & Cheung, W. (2020). Climate change, shifting threat points, and the management of transboundary fish stocks. *Ecology and Society*, *25*(4).

Sumaila, U. R., Tai, T. C., Lam, V. W., Cheung, W. W., Bailey, M., Cisneros-Montemayor, A. M., Chen, O.L., & Gulati, S. S. (2019). Benefits of the Paris Agreement to ocean life, economies, and people. *Science advances*, *5*(2), eaau3855.

Sumaila, Ussif Rashid, William Cheung, Andrew Dyck, Kamal Gueye, Ling Huang, Vicky Lam, Daniel Pauly et al. "Benefits of rebuilding global marine fisheries outweigh costs." *PloS one* 7, no. 7 (2012): e40542.

Talloni-Álvarez, N. E., Sumaila, U. R., Le Billon, P., & Cheung, W. W. (2019). Climate change impact on Canada's Pacific marine ecosystem: The current state of knowledge. *Marine Policy*, *104*, 163-176.

Tang, K. H. D. (2019). Climate change in Malaysia: Trends, contributors, impacts, mitigation and adaptations. *Science of the Total Environment*, *650*, 1858-1871.

Vannuccini, S., Kavallari, A., Bellù, L. G., Müller, M., and Wisser, D. (2018). "Understanding the impacts of climate change for fisheries and aquaculture: global and regional supply and demand trends and prospects," in Impacts of Climate Change on Fisheries and Aquaculture, ed M. Barange (Rome: FAO), 41–62

Wai, N. M., Camerlengo, A., Khairi, A., & Wahab, A. (2005). A study of global warming in Malaysia.

Yaakob, O., & Quah, P. C. (2005). Weather downtime and its effect on fishing operation in Peninsular Malaysia. *Jurnal Teknologi*, *42*, 13-26. https://doi.org/10.11113/jt.v42.730

Zubaidi, J., (2010). Climate change: Potential impacts on water resources and adaptation strategies in Malaysia. Paper presented at in: Proceedings of the 1st WEPA International Workshop, 8–9 March, Hanoi, Vietnam, 2010.

6. Mainstreaming voluntary marine conservation programs: Insights from TURF-Reserves

Stefan Gelcich,[1] *C. Josh Donlan, Benjamin Lagos, Rodrigo Sanchez Grez, and Rodrigo A. Estévez*

We dedicate this chapter to Benjamin Lagos who was the CEO of Fundacion Capital Azul and spent his life pushing for marine conservation with communities. He left us in May 2022 at 31. We will never forget your push and legacy.

The goal to create a sustainable world cannot be achieved without recognition of the pivotal roles of the oceans (United Nations Sustainable Development Goal 14 – Life under water). They regulate the Earth's climate and are a primary source of food, wellbeing, and spiritual connection for humans (Costello et al., 2020; Rudolph et al., 2020; IPCC, 2019). Increasing anthropogenic impacts, however, are compromising the ability of oceans to provide these services, which has motivated important discussions on the role that Marine Protected Areas (MPAs) can play in supporting healthy oceans (Edgar et al., 2014; Giakoumi et al., 2018). Key topics have included implementation, effectiveness, enforcement, and representation of current MPA systems, in addition to proposals for expanding the world's networks of MPAs (Sala et al., 2021; Barreto et al., 2020; Weekers et al., 2021; Fernandez et al., 2021).

While MPAs can be effective tools to protect and restore ocean biodiversity and associated services, only around 7% of the oceans have been designated or proposed as MPAs, and less than 3% of the ocean can be considered as fully or highly protected (Sala et al., 2021). Unfortunately, of all MPAs, many are considered 'paper parks': they have been legally designated but are not supplied with effective protection and stewardship, and efforts are falling considerably short of marine conservation targets (Fernandez et al., 2021). Low levels of effective protection and representation can be explained, in part, by conflict between protection and extraction stemming from perceived trade-offs (Langton et al., 2020; Grip and Blomqvist, 2020). Accordingly, increased buy-in is needed from local stakeholders for MPAs to be successful and scale up. Yet, communities are often reluctant to support new initiatives that promote MPAs, particularly if those initiatives are driven by top-down regulatory approaches (Bennett and Dearden, 2014; Gelcich et al., 2009; Oyanedel et al., 2016).

As MPAs have been established widely, it has become clear that incremental improvements in their implementation frameworks (e.g., increasing enforcement) may not be sufficient to achieve their goals (Edgar et al., 2014). New approaches are needed that enhance marine conservation, while also providing an important complement to MPA designation (Cudney-Bueno and Basurto, 2009; Gelcich and Donlan, 2015). If novel approaches are to be effective, they must be embedded within transformative processes that challenge pre-existing views on the relationships between humanity and the ocean (Gunderson and Holling, 2002; Olsson et al., 2008; Gelcich et al., 2010). New approaches must move beyond the dichotomy of protection versus extraction and provide marine conservation pathways to secure the continuity of plans to protect and restore our seas (Rudolph et al., 2020).

1 Pontificia Universidad Católica de Chile, https://orcid.org/0000-0002-5976-9311

 https://doi.org/10.11647/OBP.0395.06

Over the last decade, important insights into the processes and phases of social change have emerged from research focused on sustainable transitions (hereafter transitions; Turnheim et al., 2015) and social-ecological transformations (hereafter transformations; Gunderson and Holling, 2002). These insights, which draw from complex adaptive systems theory, can inform the development and mainstreaming of new approaches to marine conservation (Levin 1998; Preiser et al., 2018). From a social-ecological perspective, a transformation entails the capacity to create new governance systems when ecological, economic, or social structures make the existing system untenable (Walker et al., 2004; Gelcich et al., 2010; Table 6.1). Transitions can emerge when landscape pressures (e.g., population growth, technological change) result in the realization that existing regimes are inappropriate to address destructive pressures or achieve a set of broader goals that previously did not exist (e.g., effective and enforced coastal MPAs; Loorbach et al., 2017; Table 6.1). Despite differences, both concepts can aid in understanding and developing novel marine conservation approaches. Transformations and transitions highlight the key role of enabling conditions as a prerequisite for change (Herrfahrdt-Pähle et al., 2020; Olsson et al., 2006). In addition, a preparation phase is common in which niche innovations can arise as networks of innovators respond to changing conditions by designing systems that aim to respond to emerging pressures (e.g., non-compliance with top-down MPAs or lack of MPA representation; Table 6.1). Understanding the conditions for the scalability of niche innovations in the wider landscape is critical, as are the presence of windows of opportunity that can aid in the institutionalization of a new regime or approach.

Table 6.1 Working definitions of key concepts.

Concept	**Working Definition**	**Supporting References**
Social-ecological Transformation	The capacity to create fundamentally new systems of human–environmental interactions and feedbacks when ecological, economic, or social structures make the continuation of the existing system untenable. It involves multiple elements, including agency, practices, behaviors, incentives, institutions, beliefs, values, and world views and their leverage points at multiple levels.	Folke et al., 2010; Moore and Milkoreit 2020.
Socio-technical transition	A multi-dimensional shift from one socio-technical system to another involving changes in both technological and social systems that are intrinsically linked in a feedback loop. Transitions emerge from a specific constellation of conditions that interact in complex ways when landscape pressures result in a realization that existing socio-technical regimes are inappropriate to address potentially destructive pressures or achieve a set of broader goals that previously did not exist.	Geels and Schot, 2007; Geels, 2010.
Niche Innovation	Novel approaches through which sectors or stakeholder communities interact with or produce goods from a social-ecological system in response to landscape pressures.	Rudolph et al., 2020
Environmental Stewardship	Actions taken by individuals, groups, or networks of actors to protect, care for, or responsibly use the environment in pursuit of environmental and/or social outcomes in diverse social and ecological contexts.	Bennett et al., 2018

In this chapter, we explore elements of enabling conditions, scalability, institutionalization and mainstreaming of a niche innovation associated with an initiative aimed at improving MPA representation and effectiveness in coastal zones. By examining the factors and processes that underlie transformations/transitions, we present a heuristic for supporting new marine conservation approaches. This heuristic is an approach to problem solving that uses a practical method or various shortcuts in order to produce solutions and allow learning. We ground our analysis in the implementation of TURF-reserves (Costello and Kaffine, 2010).[2] As a pathway toward marine stewardship and improved economic opportunities for artisanal fisher communities, TURF-reserves spatially integrate two widely used management and conservation strategies: Territorial Use Rights for Fisheries (TURFs) and fully protected MPAs. We use a TURF-reserve program in Chile as a case study to provide empirical evidence on the benefits of the approach. Like other conservation interventions (e.g., MPAs or development funds), TURF-reserves can change fishers' short-term behavior. Without a deeper understanding of the conditions that lead to transformational change, however, there is a risk that the system might revert to less desirable and sustainable behavioral patterns in the event of social or environmental shocks. Based on transition and transformation theory, our heuristic can aid in developing resilient TURF-reserve networks or alternative pathways to those of MPAs decreed and managed by a government. In the following section, we discuss the key elements of our proposed heuristic, which is aimed at supporting the development and implementation of novel marine conservation initiatives.

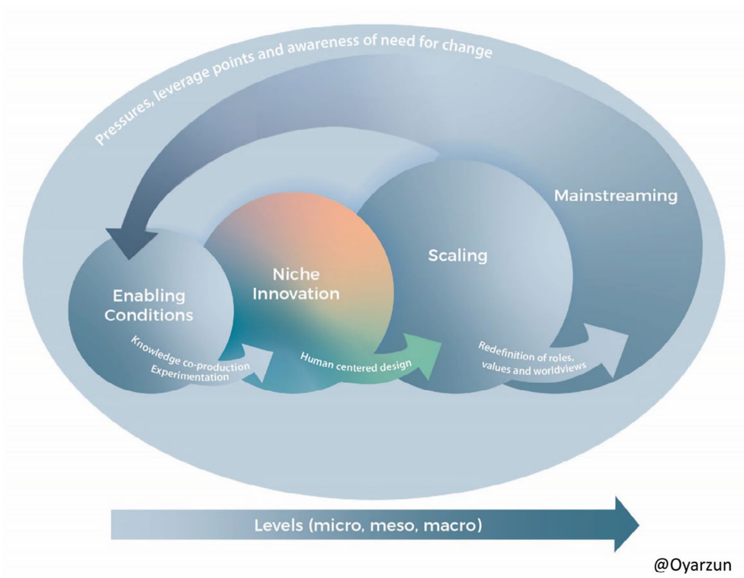


Fig. 6.1 Heuristic to support the development and implementation of transitions to mainstream novel marine conservation initiatives such as TURF-Reserves. The heuristic draws on Transformations and Transition theoretical insights (Table 6.1).

Niche innovation: TURF-reserve

Research on transitions and transformations emphasize the importance of fostering diverse forms of novelty and innovation at the micro level, supported by the creation of *transformative spaces*. These niche innovations allow for experimentation with new mental models, ideas, and practices that could help shift societies towards more desirable pathways (Loorbach et al., 2017; Pereira et al., 2018). Fishers, practitioners and scientists have

2 Territorial Use Rights for Fisheries (TURFs) are a spatial form of property rights in which individuals or a collective group of fishers are granted exclusive access to harvest resources within a geographically defined area (Christy, 1982). We define a TURF-reserve as a marine reserve (i.e., no-take zone) established within a TURF.

been promoting the creation of TURF-reserves along coastal zones (Costello and Kaffine, 2010; Gelcich and Donlan 2015). The establishment of TURF-reserves could increase artisanal fishers' livelihood opportunities and support for MPAs by allowing them to become active participants in conservation, as well as to benefit from potential dividends associated with the creation of a reserve within their exclusive access rights. For example, fishers could capture the benefits of adult spillover or larval dispersal, depending on species and the size of the area (Barner et al., 2015; Lester et al., 2017). TURF-reserves could also generate opportunities to develop new business models (Gelcich and Donlan, 2015). Specific place-based design and implementation of TURF-reserve programs represent niche innovations that challenge and complement mainstream MPA conservation strategies.

Modelling suggests there is potential for improved fishery management outcomes and higher profits with TURF-reserves under certain circumstances (Costello and Kaffine, 2010; Oyanedel et al., 2018). For instance, TURF-reserves could be more effective than TURFs alone to balance fisheries and conservation goals, depending on species mobility, TURF size, and fishing intensity outside the TURF-reserve (Lester et al., 2017). An important caveat is that dispersal of target species will often be greater than the scale of the management of the TURF-reserve (Costello, Quérou, and Tomini, 2015). Nonetheless, bioeconomic modeling suggests TURF-reserves could aid in recovering economic and conservation targets (Yamazaki et al., 2015).

Practitioners are implementing TURF-reserves across many geographies. A review of 27 existing TURF-reserves suggests that they can be developed under a wide range of artisanal fishery settings (Afflerbach et al., 2014). In some places, they have been implemented where no previous rights-based system exists and, therefore, its establishment creates strong incentives for engagement (Smallhorn-West et al., 2020). In many other areas, reserves are being implemented in previously established TURF systems. Irrespective of history and geography, it is critical to understand the transition towards fishers' new role in conservation, to anticipate their capacity to deal with new associated challenges, such as increased enforcement costs, conflicts from poaching, lack of enforcement support, or ineffective sanctions to outsiders (Davis et al., 2017).

Enabling conditions

Simply specifying spatial access rights alone will not provide all the enabling conditions for TURF-reserves to scale (Gelcich and Donlan, 2015). Rather, TURF-reserves must be designed within a setting that has the necessary social and ecological conditions that can allow the approach to be successful (Sorice et al., 2018). For example, the combination of fishing associations and TURF policy creates use rights, strong local governance, and a stewardship ethic. That same combination creates the opportunity to increase biodiversity by boosting enforcement and creating marine reserves inside TURFs. In addition, the level of coordination among fishers will likely influence the performance and acceptance of a program. Active participation and empowerment within small-scale fishers are also enabling conditions (Herrfahrdt-Pähle et al., 2020).

If biodiversity benefits are an explicit objective of TURF-reserves, then latent biodiversity outcomes must exist that can be realized through behavioral changes, and those benefits must be protected against external pressures (Gelcich and Donlan, 2015). In TURF-reserves, fishing associations will often need to regularly conduct surveillance and enforcement activities to prevent poaching (Oyanedel et al., 2018). Enforced MPAs often achieve conservation goals, and, in some cases, may also increase the resilience of surrounding fisheries and enhance local catches (Lester et al., 2009). Latent biodiversity benefits are likely in many TURF-reserve systems, which can be realized through programs that incentivize behavioral changes by participating fishers.

In sum, it is important to understand the foundations on which levels of governance, coordination, participation, and empowerment can create the enabling conditions to design, prototype, and mainstream TURF-reserves (Figure 6.1). Methodologies from social and ecological science can help assess and understand key gaps in enabling conditions. Biodiversity assessments and impact evaluations based on counterfactual thinking and the study of actors' perceptions can provide insights from an ecological and social perspective, respectively. Perceptions is an umbrella term that includes interests, social values, experiences, interpretation, and evaluation (Gelcich and O`Keeffe, 2016; Bennett, 2016). Although perceptions are not necessarily objective, individuals' subjective perceptions can become their truths (Munhall, 2008). Accordingly, considerations of perceptions towards TURF-reserves become more important as marine conservation increasingly depends on the actions of interested groups of actors (de Groot and Steg, 2009).

Scalability and sustainability

Receiving less attention than implementation, scaling and sustaining TURF-reserves will require integrating needs and preferences of fishers whose behavioral change will result in sustainable outcomes (Sorice et al., 2018). The value of a TURF-reserve program will depend on participants' perception of benefits. Because TURF-reserve programs most often rely on voluntary engagement, they will only be successful if individuals choose to participate. Understanding the preferences of potential participants can enhance program design by specifically addressing place and culture (Manzini 2015). In addition to external rewards (e.g., income), program desirability can increase when it incorporates aspects such as trust and belonging, as well as supporting basic human needs (Chan et al., 2015, Deci and Ryan 2008). A greater focus on program desirability can help understand the potential of TURF-reserves to scale and increase participation by engendering feelings of empowerment and serve as a motivator for sustained environmental stewardship (Bennett et al., 2018; Fig 1).

Although addressing the scalability of programs beyond single communities is key to achieving sustainability, it is still rare in marine conservation and TURF-reserve design. In Chile, researchers explored scalability as a predicted probability of fishers to participate in TURF-reserve programs, focusing specifically on different program factors and beliefs such as contract characteristics, expected resource increases, and enforcement requirements (Sorice et al., 2018). Results demonstrate the importance of small design choices for scalability. However, it also stresses the need to advance research from the program user's perspective, in order to assess and inform the broader program design.

Scalability of TURF-reserves depends on the ability to understand the social values associated with biodiversity, as well as resolving potential trade-offs between different interests (Scarano 2017). The importance of understanding stakeholders' values associated with marine reserves and integrating them into decision-making is widely recognized (Barreto, et al., 2020, Rasheed & Abdull, 2020). Therefore, scalability depends not only on social, economic and ecological priorities in specific areas, but also on how conservation programs align with social values at regional and national scales. For example, lack of political or public support for financial schemes for conservation programs could undermine the scaling of successful local projects (Kettunen et al., 2017).

Mainstreaming and institutionalizing a new program

TURF-reserves can emerge as isolated niche innovations which can then scale (Smallhorn-West et al., 2020, Gelcich and Donlan, 2015). However, for a transformative process to occur, TURF-reserve programs must be mainstreamed and become a well-supported complementary alternative to government-managed MPAs (Barner et al., 2015). That support must not come only from local coastal communities, but also from government agencies. This dynamic process must be informed by changes in wider values, frames, and worldviews of wellbeing, sustainability, and the role of civil society in coastal conservation. As such, it must replace less effective political, economic, and social institutions. The list of challenges to mainstreaming TURF-reserves is a long one: resolving coherence between regulatory frameworks, coordination, clarity, outdated regulatory assumptions, conflict over allocation of space and rights of access to resources, inadequate monitoring and enforcement (Sorice et al., 2018; Davis et al., 2017), lack of inclusivity, and inequity in the distribution of ecosystem service benefits (Brain et al., 2020; Sorice & Donlan 2015). Tackling these challenges will require capacity-building and alternative narratives. A purposeful shift towards governance for TURF-reserves is required to address these challenges and mainstream programs (Figure 6.1).

In practical terms, mainstreaming new governance models for TURF-reserves will entail a process in which decisions are taken by new or reformed actors in novel settings (Afflerbach et al., 2014). Accordingly, new social-ecological feedbacks will become established (Moore et al., 2014) and the implementation of novel governance regimes must be monitored and fine-tuned to ensure legitimacy and avoid unintended consequences (Westley et al., 2013). Key aspects to consider include exploring the changing role of existing actors and the inclusion of new actors within a TURF-reserve system, as well new decision-making processes.

Application of the heuristic: The Chilean TURF-reserve pilot

In Chile, a TURF policy has been in place for over three decades and there are hundreds of active TURFs along the coast (Gelcich et al., 2019; Figure 6.2a). They form a substantial part of the coastal seascape in Chile: they tend be ~100 hectares in size, surrounded by open access areas, and ~2-5 kilometers away from the next adjacent TURF (Gelcich et al., 2010). To be granted a TURF, artisanal fisher associations must undertake a baseline study of the area and develop management plans that need to be approved by the government (Aburto et al., 2013). Surveillance and enforcement by the association is required, and it is forbidden to extract any benthic species not included in the management plan. The use of TURF fishing associations is part-time. That is, diving for benthic resources is usually restricted to a few times a month and the extracted resources are around 10–30% of total income for an association (Gelcich et al., 2017).

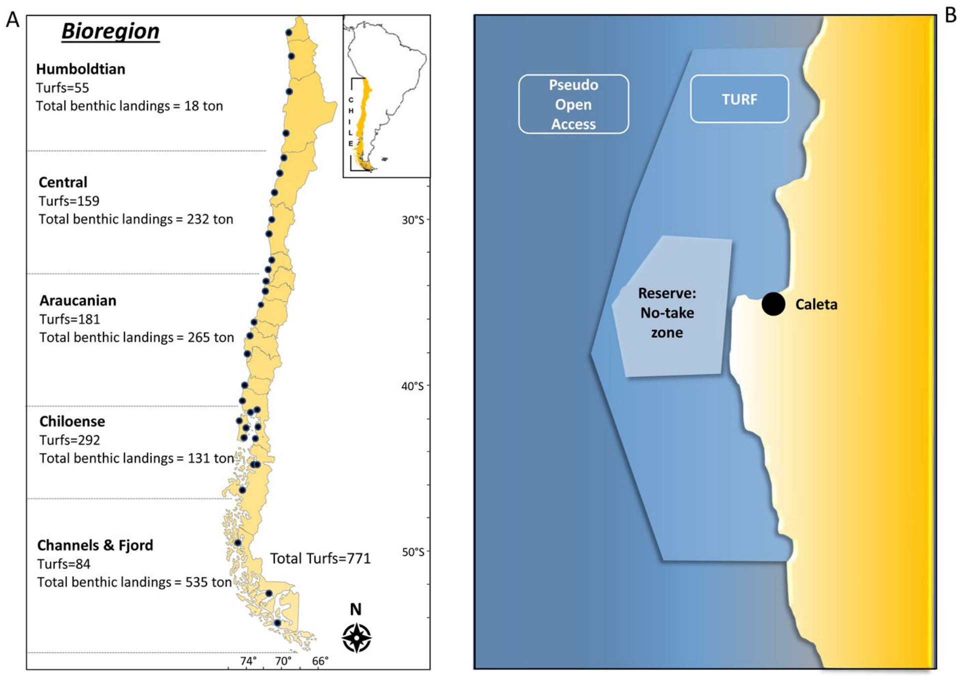


Fig. 6.2 (A) Some of the over 700 TURFs along the coastline of Chile showing coverage and benthic resource landings of all bioregions in Chile. (B) TURF-reserve niche innovation which compensates Chilean fishing associations annually for setting aside a portion of their formal fishing grounds as a no-take reserve alongside their landing port, known as "caleta" (Adapted from Sorice et al., 2018).

A series of studies have assessed both the social and ecological enabling conditions necessary to design a voluntary conservation program that could incentivize additional biodiversity benefits through TURF-reserves (Villaseñor-Derbez et al., 2019, Gelcich and Donlan 2015; Figure 6.2B). In essence, existing TURF policy creates use rights, governance structures, and a stewardship ethic (Crona et al., 2017). That same combination creates latent biodiversity and enforcement benefits. That is, increasing enforcement and creating a marine reserve within a TURF should produce marine conservation benefits and associated ecosystem services (Gelcich et al., 2019). Research also documents the presence of enabling conditions in the form of increased social capital (Marin et al., 2012; Crona et al., 2017). TURFs alone already facilitate conditions for the development of enforcement capacity and the internalization of social norms (Gelcich et al., 2013). Further, participation in TURF programs create positive shifts in fishers' environmental perceptions (Gelcich et al., 2008). It is also common in Chile for fishers to design and implement surveillance programs and rules for resource management, both of which are sustained by active stakeholder participation. The resulting benefits are both perceived and valued by TURF members (Gelcich et al., 2009). In sum, empirical evidence suggests that additional biodiversity benefits would be generated if a fishing association enters into agreement to set aside at least 15 hectares of its TURF as a no-take marine reserve and agrees to conduct anti-poaching surveillance (Gelcich et al., 2012). The enabling conditions are often present for such a program to be successful.

Recognizing that enabling conditions were in place, a conceptual model for a voluntary incentive program associated with TURF-reserves was developed (Gelcich and Donlan, 2015). A pilot of the program was co-produced with two fishing communities in an iterative learning process which was context-based, pluralistic, goal-oriented, and interactive (Nostrom et al., 2020; Figure 6.3A–B). Early on, a key aspect of the program that needed to be developed related to enforcement technology. A Chilean technology company provided land-based surveillance cameras, technology, and data which is shared by fishing communities. This provides the community with an additional surveillance tool, while providing the program with a means of assessing compliance. A biodiversity and fishing monitoring program to track the impact of the program, which included control sites, was implemented with the fishing associations (Figure 6.2C). With funding from U.S. foundations, the niche innovation was piloted for several years while social science research was conducted to make design changes so as to better align fishers' perspectives and needs in order to begin address the scalability challenge.

To address the challenge of scaling, a human-centered approach was used to design the program (Sorice and Donlan 2015). Focus groups, surveys, and stated-choice experiments helped understand and quantify fishers' preferences on different aspects of a TURF-reserve program, such as the contract length, payments, perceived benefits, types of surveillance systems (e.g., land-based video surveillance), and biodiversity monitoring requirements. Doing so allowed the design of a program that was highly desirable, as well as to identify highly undesirable program structures. For example, while financial incentives serve as a relatively strong factor to encourage a fisher to opt-in to a TURF-reserve program, their ability to do so substantively diminishes as attitudes become negative, trust decreases, and dependence on fishing decreases. In fact, results suggest that those financial incentives alone are insufficient to attract enough participation by Chilean fishers to scale the program and deliver significant environmental benefits (Sorice et al., 2018). In addition, fishers' willingness to participate differs if program funding comes from revenue generated from sustainable seafood, industry interested in offsetting their environmental impacts, or the philanthropic sector. Fishers prefer programs that are funded by offsets or philanthropy compared to sustainable seafood sales. Participation also differs, by as much as 30%, by how familiar fishers are with TURF-reserves programs. These results help to define programmatic design changes that may improve program desirability and thus participation as the program scales. In parallel to designing the program through the lens of the users, research was conducted around assessing sustainable financing models to be able to better scale the program.

In 2019, efforts towards mainstreaming TURF-reserves were formally established through the creation of the Chilean NGO Capital Azul. The NGO is focused on managing, scaling and mainstreaming the TURF-reserve program in Chile. Supported by a board and program partners, Capital Azul maintains new and existing relationships with fishing communities, supports surveillance activities, and conducts the annual monitoring of the reserves alongside fisher association divers. The marine reserve program currently consists of a network of five reserves in central Chile. Only 200km from the capital Santiago, this region is one of the mostly densely populated in the country, with no national marine protected areas. Thus, the network informally complements the existing national protected area network and serves as a high-visibility example of a voluntary conservation program to the hundreds of thousands of Chilean tourists that visit the region during the summer months.

While results from surveys of over 250 fishers demonstrate general support about the benefits of the program, there is still little quantitative evidence of wide changes in ecosystem state and, ultimately, coastal fisheries resources. Annual monitoring of the areas (and control sites) is underway to examine the impacts of the TURF-reserve program, and preliminary results suggest positive impacts. But TURF-reserves are still too young for strongly discernible changes in species richness and abundance to have occurred.

In parallel with the Capital Azul program, the institutionalization of TURF-reserves is underway in Chile (Fig 6.3C). With the support of university academics and Foundation Costa Humboldt, Capital Azul recently recommended, through the formal recommendation channels, a series of revisions to the proposed bill that will modify the General Law of Fishing and Aquaculture for Benthic Resources (Boletín N°12.535; Capital Azul, 2021). Recommendations were included in the new bill proposal, which now formally acknowledges actions geared toward conservation and allows for the establishment of reserves within TURF areas:

> Among the allowed management actions, the establishment of buffer zones will be considered in which extractive fishing activity on benthic resources will be restricted to agreements for the established purposes in the respective management plan, where duly justified research, monitoring, and other management actions may be carried out to ensure the sustainability of resources and their ecosystem. (Boletín N°12.535).

While the new bill proposal has not yet been passed by Congress, the above language is an important step in mainstreaming TURF-reserves in Chile (Figure 6.3D).

The scaling of the TURF-reserve program in Chile has allowed government to trigger changes about marine conservation. It is helping to produce a shift from species-centered to people-centered marine conservation approaches, and has given opportunities for civil society, beyond fisher communities, to connect with alternative ways in which conservation can be achieved. Accordingly, a vision of how positive biodiversity impacts can support the local economy have begun to transcend public resistance and civil society is slowly becoming a protagonist. Considering this, scientists, fishers, NGOs, local authorities, and other actors can subscribe to the same coastal conservation project, which is leading to the creation of wider networks of participation, a key aspect in legitimizing and mainstreaming novel marine conservation approaches.

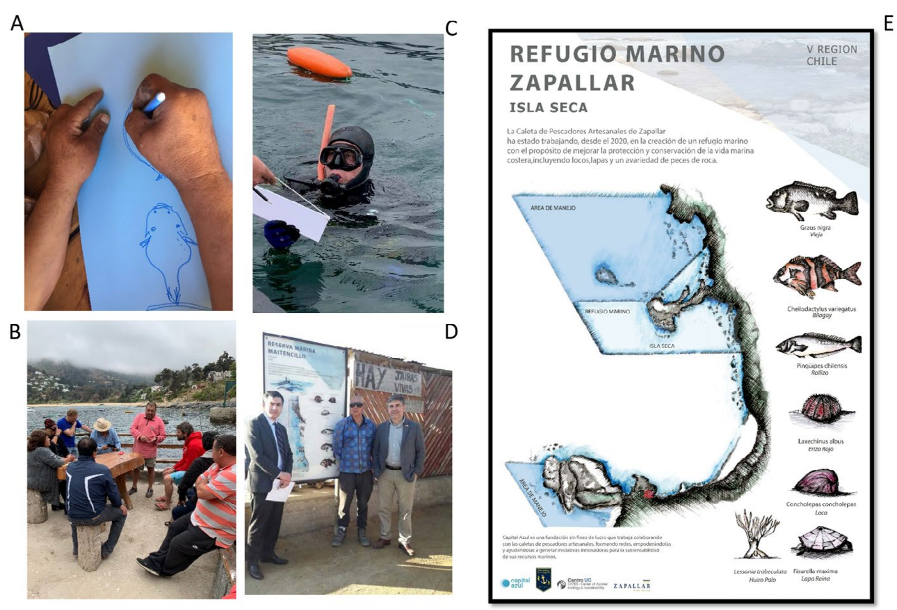


Fig. 6.3 A) Participatory narrative building workshop drawing led by Capital Azul, B) Fisher leaders and Capital Azul TURF-Reserve co-design team meeting at Zapallar, Chile in 2019, C) Subtidal diversity monitoring, jointly between academics, practitioners and fishers in 2020 D) Meeting with government authorities in Maitencillo fishing cove as a way to address institutionalization and mainstreaming challenges E) TURF-Reserve model diagram used to inform the general public at each location.

Conclusion

Understanding transitions and transformations implies identifying capacities that tend to reduce the resilience of systems, and supporting the emergence of new, more desirable systems that confront path-dependencies, build capacities, and promote shifts towards sustainable pathways (Elmqvist et al., 2019; Olsson et al., 2017). More sustainable ocean systems will require other approaches that complement government-managed MPA approaches. TURF-reserves or other novel approaches should avoid the path dependency created by many MPA models. Our heuristic provides an approach to specify the dynamics of TURF-reserves by signaling key elements necessary for transformational change.

For alternative conservation approaches to be successful, many complex system components need to be dismantled and re-organized (Folke et al., 2021). This includes enabling conditions, capacities for change, and access to new knowledge. Without these components, niche innovations will not emerge, scale, or catalyze alternative pathways to MPAs. Consideration of the characteristics presented in our heuristic can support decision-makers and stakeholders in implementing TURF-reserves successfully. Institutionalizing TURF-reserves requires strengthening governance models at multiple levels (Herrfahrdt-Pähle et al., 2020). Local programs, with successful niche innovations, require organizing institutional arrangements and structural features for scalability (Carlsson & Berkes 2005, Ostrom 2005, Folke et al., 2005). In the case of Chile, the mainstreaming of successful TURF-reserve programs requires formal recognition and widespread changes in values and worldviews to accept TURF-reserves. Otherwise, niche innovations may be blocked by bureaucratic-administrative processes.

Thinking through the enabling conditions, scalability, and mainstreaming of TURF-reserve programs can provide key insights into mechanisms by which to avoid known pitfalls in the expansion of protected areas. First, enabling conditions allow the development of local communities' commitments in the management of MPAs (Collier et al., 2020). This promotes the establishment of learning networks that allow the concatenation of transforming experiences from one case to another (Berkes 2009). Second, ensuring that programs are designed with a fisher-centered approach entices associations to participate and protect areas in ways they would likely not do so otherwise. Third, thinking through mainstreaming TURF-reserves is critical, especially considering the real-world constraints of many governance contexts such as fragmented institutions, contested policy processes, and poorly delineated roles and capabilities of policymakers and administrators (Patterson et al., 2017). Applying this heuristic successfully to other settings will rely on understanding the specific conditions that will ultimately foster the greatest long-term engagement in management and conservation.

Acknowledgements

We thank artisanal fishers who have engaged and co-produced the TURF-reserve niche innovation. We acknowledge funding from Financiamiento ANID PIA/Basal FB0002, Millennium Initiative ICN 2019_015, and FONDECYT 1190109.

References

Aburto, J., Gallardo, G., Stotz, W., Cerda, C., Mondaca-Schachermayer, C., Vera, K.Y. (2013). Territorial user rights for artisanal fisheries in Chile—Intended and unintended outcomes. Ocean & Coastal Management 71: 284–295.

Afflerbach, J.C., Lester, S.E., Dougherty, D.T., Poon, S.E. (2014). A global survey of "TURF-reserves", Territorial Use Rights for Fisheries coupled with marine reserves. Global Ecology and Conservation 2: 97–106.

Barner, A.K., Lubchenco, J., Costello, C., Gaines, S.D., Leland, A., Jenks, B., Murawski, S., Schwaab, E., & Spring, M. (2015). Solutions for recovering and sustaining the bounty of the ocean: combining fishery reforms, rights-based fisheries management, and marine reserves. Oceanography 28(2): 252–263.

Barreto, G.C., Di Domenico, M., Medeiros, R.P. (2020). Human dimensions of marine protected areas and small-scale fisheries management: A review of the interpretations. Marine Policy 119: 104040.

Bennett, E.M., Solan, M., Biggs, R., McPhearson, T., Norström, A.V., Olsson, P., Pereira, L., Peterson, G., Raudsepp-Hearne, C., Biermann, F., Carpenter, S., Ellis, E., Hichert, T., Galaz, V., Lahsen, M., Milkoreit, M., Martin López, B., Nicholas, K., Preiser, R., Vince, G., Vervoort, J., & Xu, J. (2016). Bright spots: Seeds of a good anthropocene. Frontiers in Ecology and the Environment 14: 441–448.

Bennett, N.J., Dearden, P. (2014). Why local people do not support conservation: community perceptions of marine protected area livelihood impacts, governance and management in Thailand. Marine Policy 44: 107–116. https://doi.org/10.1016/j.marpol.2013.

Bennett, N.J., Whitty, T.S., Finkbeiner, E., Pittman, J., Bassett, H., Gelcich., S., Allison, E.H. (2018). Environmental Stewardship: A Conceptual Review and Analytical Framework. Environmental Management 61: 597–614. https://doi.org/10.1007/s00267-017-0993-2.08.017

Berkes, F. (2009). Evolution of co-management: Role of knowledge generation, bridging organizations and social learning. Journal of Environmental Management 90: 1692–1702.

Brain M.J., Nahuelhual, L., Gelcich, S., Bozzeda, F. (2020). Marine conservation may not deliver ecosystem services and benefits to all: Insights from Chilean Patagonia. Ecosystem Services 45: 101170. https://doi.org/10.1016/j.ecoser.2020.101170

Chan, K.M.A., Balvanera, P., Benessaiah, K., Chapman, M., Díaz, S., Gómez-Baggethun, E., Gould, R., Hannahs, N., Jax, K., Klain, S., Luck, G.W., Martín-López, B., Muraca, B., Norton, B., Ott, K., Pascual, U., Satterfield, T., Tadaki, M., Taggart, J., & Turner, N. (2016). Opinion: Why protect nature? Rethinking values and the environment. Proceedings of the National Academy of Sciences 113(6): 1462–1465.

Carlsson, L., Berkes, F. (2005). Co-Management: Concepts and Methodological Implications. Journal of Environmental Management 75: 65–76. 10.1016/j.jenvman.2004.11.008.

Capital Azul. (2021). https://capitalazul.cl/

Collier, C.E. (2020). Enabling conditions for community-based comanagement of marine protected areas in the United States. Marine Policy 122: 104244.

Crona, B., Gelcich, S., Bodin, Ö. (2017). The Importance of Interplay Between Leadership and Social Capital in Shaping Outcomes of Rights-Based Fisheries Governance. World Development 91: 70–83.

Costello, C., Kaffine, D.T. (2010). Marine protected areas in spatial property-rights fisheries. Australian Journal of Agricultural and Resource Economics 54: 321–341. https://doi.org/10.1111/j.1467-8489.2010.00495.x

Costello, C., Cao, L., Gelcich, S., Cisneros-Mata, M.A., Free, C.M., Froehlich, H.E., Golden, C.D., Ishimura, G., Maier, J., Macadam-Somer, I., Mangin, T., Melnychuk, M.C., Miyahara, M., de Moor, C.L., Naylor, R., Nøstbakken, L., Ojea, E., O'Reilly, E., Parma, A.M., Plantinga, A.J., Thilsted, S.H., Lubchenco, J. (2020). The future of food from the sea. Nature. https://doi.org/10.1038/s41586-020-2616-y. https://rdcu.be/b7a4q

Costello, C., Quérou, N., Tomini, A. (2015). Partial enclosure of the commons. Journal of Public Economics 121: 69–78. https://doi.org.10.1016/J.Jpubeco.2014.11.011

Cudney-Bueno, R., Basurto, X. (2009). Lack of Cross-Scale Linkages Reduces Robustness of Community-Based Fisheries Management. PLOS ONE 4(7): e6253. https://doi.org/10.1371/journal.pone.0006253

Davis, K.J., Kragt, M.E., Gelcich, S., Burton, M., Schilizzi, S., & Pannell, D.J. (2017). Why are fishers not enforcing their marine user rights? Environmental and Resource Economics 67: 661–681. https://doi.org/10.1007/s10640-015-9992-z

De Groot, J.I., & Steg, L. (2009). Mean or green: which values can promote stable pro-environmental behavior?. Conservation Letters 2(2): 61–66.

Edgar, G.J., Stuart-Smith, R.D., Willis, T.J., Kininmonth, S., Baker, S.C., Banks, S., Barrett, N.S., Becerro, M.A., Bernard, A.T.F., Berkhout, J., Buxton, C.D., Campbell, S.J., Cooper, A.T., Davey, M., Edgar, S.C., Forsterra, G., Galvan, D.E., Irigoyen, A.J., Kushner, D.J., Moura, R., Parnell, P.E., Shears, N.T., Soler, G., Strain, E.M.A., Thomson, R.J. (2014). Global conservation outcomes depend on marine protected areas with five key features. Nature 506: 216.

Elmqvist, T., E. Andersson, N. Frantzeskaki, T. McPhearson, P. Olsson, O. Gaffney, K. Takeuchi, and C. Folke. (2019). Sustainability and resilience for transformation in the urban century. Nature Sustainability 2: 267–273.

Fernández, M., Rodríguez-Ruiz, M., Gelcich, S., Hiriart-Bertrand, L., Castilla, J.C. (2021). Advances and challenges in marine conservation in Chile: A regional and global comparison. Aquatic Conservation: Marine and Freshwater Ecosystems. https://doi.org/10.1002/aqc.3570

Folke, C., Hahn, T., Olsson, P., Norberg, J. (2005). Adaptive governance of social–ecological systems. Annual Review of Environmental Resources 30: 441–473.

Folke, C., Polasky, S., Rockström, J., Galaz, V., Westley, F., Lamont, M., Scheffer, M., Österblom, H., Carpenter, S.R., Chapin, F.S. and Seto, K.C., Weber, E., Crona, B., Daily, G., Dasgupta, D., Gaffney, O., Gordon, L., Hoff, H., Levin, S., Lubchencho, J., Steffen, W., & Walker, B.H. (2021). Our future in the Anthropocene biosphere. Ambio: 1–36.

Geels, F.W., and Schot, J. (2007). Typology of Sociotechnical Transition Pathways. Research Policy 36(3): 399–417. https://doi.org/10.1016/j.respol.2007.01.003

Geels, F.W. (2010). Ontologies, Socio-technical Transitions (to Sustainability), and the Multi-level Perspective. Research Policy 39(4): 495–510. https://doi.org/10.1016/j.respol.2010.01.022

Gelcich, S., O'Keeffe, J. (2016). Emerging frontiers in perceptions research for aquatic conservation. Aquatic Conservation: Marine and Freshwater Ecosystems 26: 986–994. https://doi.org/10.1002/aqc.2714

Gelcich, S., Kaiser, M.J., Castilla, J.C., & Edwards-Jones, G. (2008). Engagement in co-management of marine benthic resources influences environmental perceptions of artisanal fishers. Environmental Conservation 35(1): 36–45.

Gelcich, S., Godoy, N., & Castilla, J.C. (2009). Artisanal fishers' perceptions regarding coastal co-management policies in Chile and their potentials to scale-up marine biodiversity conservation. Ocean & Coastal Management 52(8): 424–432.

Gelcich, S., Hughes, T.P., Olsson, P., Folke, C., Defeo, O., Fernandez, M., Foale, S., Gunderson, L.H., Rodriguez-Sickert, C., Scheffer, M., Steneck, R.S., & Castilla, J.C. (2010). Navigating transformations in governance of Chilean marine coastal resources. Proceedings of the National Academy of Sciences of the United States of America 107: 16794–16799.

Gelcich, S., Fernandez, M., Godoy, N., Canepa, A., Prado, L., & Castilla, J.C. (2012). Territorial User Rights for Fisheries as Ancillary Instruments for Marine Coastal Conservation in Chile. Conservation Biology 26: 1005–1015.

Gelcich, S., Guzman, R., Rodriguez-Sickert, J., Castilla, J.C., & Cardenas, J.C. (2013). Exploring External Validity of Common Pool Resource Experiments: Insights from Artisanal Benthic Fisheries in Chile. Ecology and Society: 18.

Gelcich, S., & Donlan, C. (2015). Incentivizing biodiversity conservation in artisanal fishing communities through territorial user rights and business model innovation. Conservation Biology: The Journal of the Society for Conservation Biology 29.

Gelcich, S., Cinner, J., Donlan, C.J., Tapia-Lewin, S., Godoy, N., & Castilla, J.C. (2017). Fishers' perceptions on the Chilean coastal TURF system after two decades: problems, benefits, and emerging needs. Bulletin of Marine Science 93(1): 53–67. http://dx.doi.org/10.5343/bms.2015.1082

Gelcich, S., Martínez-Harms, M.J., Tapia-Lewin, S., Vasquez-Lavin, F., & Ruano-Chamorro, C. (2019). Comanagement of small-scale fisheries and ecosystem services. Conservation Letters 12: e12637.

Giakoumi, S., McGowan, J., Mills, M., Beger, M., Bustamante, R.H., Charles, A., Christie, P., Fox, M., Garcia-Borboroglu, P., Gelcich, S., Guidetti, P., Mackelworth, P., Maina, J.M., McCook, L., Micheli, F., Morgan, L.E., Mumby, P.J., Reyes, L.M., White, A., Grorud-Colvert, K., & Possingham, H.P. (2018). Revisiting "Success" and "Failure" Marine Protected Areas: A Conservation Scientist Perspective. Frontiers in Marine Science 5: 5.

Grip, K., Blomqvist, S. (2020). Marine nature conservation and conflicts with fisheries. Ambio 49: 1328–1340.

Gunderson, L.H., and Holling, C.S. (2002). Panarchy: understanding transformations in human and natural systems. Washington: Island Press.

Herrfahrdt-Pähle, E., Schlüter, M., Olsson, P., Folke, C., Gelcich, S., Pahl-Wostl, C. (2020). Sustainability transformations: socio-political shocks as opportunities for governance transitions. Global Environmental Change 63: 102097.

IPCC. (2019). Summary for Policy Makers. In H.O. Pörtner et al. (eds.), Special Report on the Ocean and Cryosphere. IPCC.

Kettunen, M., Illes, A., Rayment, M., Primmer, E., Verstraeten, Y., Rekola, A., Ring, I., Tucker, G., Baldock, D., Droste, N., Santos, R., Rantala, S., Ebrahim, N. and ten Brink, P. (2017). Summary report—Integration approach to EU biodiversity financing: evaluation of results and analysis of options for the future. Final report for the European Commission (DG ENV) (Project ENV.B.3/ETU/2015/0014). Brussels / London: Institute for European Policy (IEEP).

Langton, R., Stirling, D.A., Boulcott, P., Wright, P.J. (2020). Are MPAs effective in removing fishing pressure from benthic species and habitats? Biological Conservation 247: 108511.

Lester, S.E., Halpern, B. Grorud-Colvert, S.K., Lubchenco, J., Ruttenberg, B.I., Gaines, S.D., Airame, S.& Warner, R.R. (2009). Biological effects within no-take marine reserves: a global synthesis. Marine Ecology Progress Series 384: 33–46.

Lester, S.E., McDonald, G., Clemence, M., Dougherty, D.T., & Szuwalski, C.S. (2017). Impacts of TURFs and marine reserves on fisheries and conservation goals: theory, empirical evidence, and modeling. Bulletin of Marine Science 93(1): 173–198.

Levin, S. (1998). Ecosystems and the Biosphere as Complex Adaptive Systems. Ecosystems 1 (May): 431–36. doi.org/10.1007/s100219900037

Loorbach, D., Frantzeskaki, N., Avelino, F. (2017). Sustainability Transitions Research: Transforming Science and Practice for Societal Change. In A. Gadgil, T.P. Tomich (eds.), Annual Review of Environment and Resources, Vol 42 (pp. 599–626). Palo Alto: Annual Reviews.

Manzini, E. (2015). Design, when everybody designs: An introduction to design for social innovation. Cambridge, MA: MIT Press.

Marin, A., Gelcich, S., Castilla, J.C., & Berkes, F. (2012). Exploring social capital in Chile's coastal benthic comanagement system using a network approach. Ecology and Society 17: 13.

Moore, M.L., Tjornbo, O., Enfors, E., Knapp, C., Hodbod, J., Baggio, J.A., Norström, A., Olsson, P., & Biggs, D. (2014). Studying the complexity of change: Toward an analytical framework for understanding deliberate social-ecological transformations. Ecology and Society 19(4): 54. http://dx.doi.org/10.5751/ES-06966-190454

Norström, A.V., Cvitanovic, C., Löf, M.F., West, S., Wyborn, C., Balvanera, P., Bednarek, A.T., Bennett, E.M., Biggs, R., de Bremond, A., Campbell, B.M., Canadell, J.G., Carpenter, S.R., Folke, C., Fulton, E.A., Gaffney, O., Gelcich, S., Jouffray, J.B., Leach, M., Le Tissier, M., Martín-López, B., Louder, E., Loutre, M.F., Meadow, A.M., Nagendra, H., Payne, D., Peterson, G.D., Reyers, B., Scholes, R., Speranza, C.I., Spierenburg, M., Stafford-Smith, M., Tengö, M., van der Hel, S., van Putten, I., & Österblom, H. (2020). Principles for knowledge co-production in sustainability research. Nature Sustainability. https://doi.org/10.1038/s41893-019-0448-2

Olsson, P., C. Folke, and T.P. Hughes. (2008). Navigating the transition to ecosystem-based management of the Great Barrier Reef, Australia. Proceedings of the National Academy of Sciences of the United States of America 105: 9489–9494. http://dx.doi.org/10.1073/pnas.0706905105

Olsson, P., Gunderson, L.H., Carpenter, S.R., Ryan, P., Lebel, L., Folke, C., Holling, C.S., (2006). Shooting the rapids: navigating transitions to adaptive governance of social-ecological systems. Ecology and Society 11: 21.

Olsson, P., Moore, M.-L., Westley, F.R., & McCarthy, D.D.P. (2017). The concept of the Anthropocene as a game-changer: A new context for social innovation and transformations to sustainability. Ecology and Society 22: 31.

Ostrom, E. (2005). Understanding institutional diversity. Princeton, NJ: Princeton University Press.

Oyanedel, R., Marín, A., Castilla, J.C., Gelcich, S. (2016). Establishing marine protected areas through bottom-up processes: insights from two contrasting initiatives in Chile. Aquatic Conservation: Marine and Freshwater Ecosystems 26(1): 184–195. https://doi.org/10.1002/aqc.2546

Oyanedel, R., Keim, A., Castilla, J.C., Gelcich, S. (2018). Illegal fishing and territorial user rights in Chile. Conservation Biology 32(3): 619–627. https://doi.org/10.1111/cobi.13048

Patterson, J., K. Schulz, J. Vervoort, S. van der Hel, O. Widerberg, C. Adler, M. Hurlbert, K. Anderton, M. Sethi, and A. Barau. (2017). Exploring the governance and politics of transformations towards sustainability. Environmental Innovation and Societal Transitions 24: 1–16. http://dx.doi.org/10.1016/j.eist.2016.09.001

Pereira, L. M., Karpouzoglou, T., Frantzeskaki, N., & Olsson, P. (2018). Designing transformative spaces for sustainability in social-ecological systems. Ecology and Society 23(4).

Preiser, R., Biggs, R., De Vos, A., & Folke, C. (2018). Social-ecological systems as complex adaptive systems. Ecology and Society 23(4).

Rasheed, A.R., Abdulla, A. (2020). Evaluating stakeholder participatory processes in policy development for Marine Protected Areas. Marine Policy 112: 103737.

Rudolph, T.B., Ruckelshaus, M., Swilling, M., Allison, E.H., Österblom, H., Gelcich, S., Mbatha, P., (2020). A transition to sustainable ocean governance. Nature Communications 11: 3600.

Sala, E., Mayorga, J., Bradley, D., Cabral, R.B., Atwood, T.B., Auber, A., Cheung, W., Costello, C., Ferretti, F., Friedlander, A.M., Gaines, S.D., Garilao, C., Goodell, W., Halpern, B.S., Hinson, A., Kaschner, K., Kesner-Reyes, K., Leprieur, F., McGowan, J., Morgan, L.E., Mouillot, D., Palacios-Abrantes, J., Possingham, H.P., Rechberger, K.D., Worm, B., & Lubchenco, J. (2021). Protecting the global ocean for biodiversity, food and climate. Nature 592(7854): 397–402.

Scarano, F.R. (2017). Ecosystem-based adaptation to climate change: concept, scalability and a role for conservation science. Perspectives in Ecology and Conservation 15: 65–73.

Smallhorn-West, P.F., Sheehan, J., Malimali, S., Halafihi, T., Bridge, T.C., Pressey, R.L., Jones, G.P. (2020a). Incentivizing co-management for impact: mechanisms driving the successful national expansion of Tonga's Special Management Area program. Conservation Letters. https://doi.org/10.1111/conl.12742

Sorice, M.G., Donlan, C.J. (2015). A human-centered framework for innovation in conservation incentive programs. Ambio 44: 788–792.

Sorice, M.G., Oh, C.O., Gartner, T., Snieckus, M., Johnson, R., Donlan, C.J. (2013). Increasing participation in incentive programs for biodiversity conservation. Ecol Appl 23: 1146–1155.

Sorice, M. G., Donlan, C. J., Boyle, K. J., Xu, W., & Gelcich, S. (2018). Scaling participation in payments for ecosystem services programs. PLOS ONE 13(3): e0192211.

Turnheim, B., Berkhout, F., Geels, F.W., Hof, A., McMeekin, A., Nykvist, B., van Vuuren, D.P. (2015). Evaluating sustainability transitions pathways: Bridging analytical approaches to address governance challenges. Global Environmental Change-Human and Policy Dimensions 35: 239–253.

Villaseñor-Derbez, J., Aceves-Bueno, E., Fulton, S., Suárez, A., Hernández-Velasco, A., Torre, J., Micheli, F. (2019). An interdisciplinary evaluation of community-based TURF-reserves. PLOS ONE 14: e0221660.

Walker, B., Holling, C.S., Carpenter, S.R., & Kinzig, A. (2004). Resilience, adaptability and transformability in social–ecological systems. Ecology and Society 9(2).

Weekers, D., Petrossian, G., Thiault, L. (2021). Illegal fishing and compliance management in marine protected areas: a situational approach. Crime Sci 10: 14.

Westley, F. R., O. Tjornbo, L. Schultz, P. Olsson, C. Folke, B. Crona, and Ö. Bodin. (2013). A theory of transformative agency in linked social-ecological systems. Ecology and Society 18(3): 27. http://dx.doi.org/10.5751/ES-05072-180327

Yamazaki, S., Jennings, S., Grafton, R.Q., & Kompas, T. (2015). Are marine reserves and harvest control rules substitutes or complements for rebuilding fisheries?. Resource and Energy Economics 40: 1–18.

7. Leadership in the global commons: Protecting the Ross Sea, Antarctica

Cassandra Brooks[1] *and John Weller*

Positionality statement

John Weller and Cassandra Brooks were closely involved in the international campaign to protect the Ross Sea, Antarctica. In 2004, after reading a science paper by Dr. David Ainley in which the Ross Sea was described as perhaps the last intact marine ecosystem left in the world—and one threatened by growing commercial fishing for Antarctic toothfish—John Weller committed to bringing the Ross Sea to the world. He, along with Ainley and filmmaker Peter Young, founded the Last Ocean Trust and *The Last Ocean* project. *The Last Ocean* was a grand-scale global media campaign which sought to bring the Ross Sea to the world, and included an award-winning book and documentary of the same title. *The Last Ocean* project contributed to what would become a global coalition of organizations, scientists, diplomats, and eventually entrained the attention of world leaders. This pursuit brought John to the Ross Sea four times. His images became the face of Antarctic conservation efforts worldwide, reaching a global audience of nearly 1 billion people, including the policymakers who eventually adopted a marine protected area in the Ross Sea under the umbrella of the Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR).

Cassandra Brooks began studying aspects of the Antarctic toothfish's little-known life history in 2004 for her Master's degree program. Like many fish species in the deeper depths of the ocean, this one, too, with its delayed maturation evident in her results, was vulnerable to overexploitation. With hopes of contributing to protecting toothfish and the greater Ross Sea ecosystem, in 2009, Cassandra joined *The Last Ocean* team. In the midst of the Ross Sea effort, Cassandra began a PhD at Stanford University to study the policy process around adopting Antarctic marine protected areas. In 2012, she began attending the closed-door meetings of CCAMLR– the multi-national body tasked with managing the Southern Ocean.

Twelve years after their Antarctic journey began, Cassandra and John were both in the room on 28 October 2016, when CCAMLR delegates came to unanimous consensus to adopt the world's largest marine protected area in the region containing the Ross Sea, Antarctica. They seek to share lessons learned from this story.

***

On 28 October 2016, in a stone fortress in the center of Hobart, Tasmania, Nation States made history by adopting the world's largest marine protected area (MPA) in the Ross Sea, Antarctica—one of the last large intact marine ecosystems left in the world. This feat demanded the dogged efforts of scientists, diplomats, conservationists, and involved global citizens over the course of more than a decade. In the end, it required

1 Institute of Arctic and Alpine Research (INSTAAR), University of Colorado Boulder, https://orcid.org/0000-0002-1397-0394

 https://doi.org/10.11647/OBP.0395.07

the consensus of all the States comprising the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR). In that moment when consensus was finally achieved, the room exploded in applause, national representatives were hugging one another. It became clear that this was not just an environmental win, or a gift to future generations, though it was both. Like the signing of the Antarctic Treaty in the height of the Cold War, this was also a diplomatic win showing that despite tensions among some countries, the adoption of the Ross Sea Regional MPA exemplified that the Antarctic continues to be an exceptional space dedicated to peace and science (Figure 7.1). Further, in adopting a large MPA, CCAMLR members demonstrated what is possible through international collaboration. Here we share the story of the Ross Sea campaign, with the hope of providing valuable lessons for conservation elsewhere in the Southern Ocean and beyond.

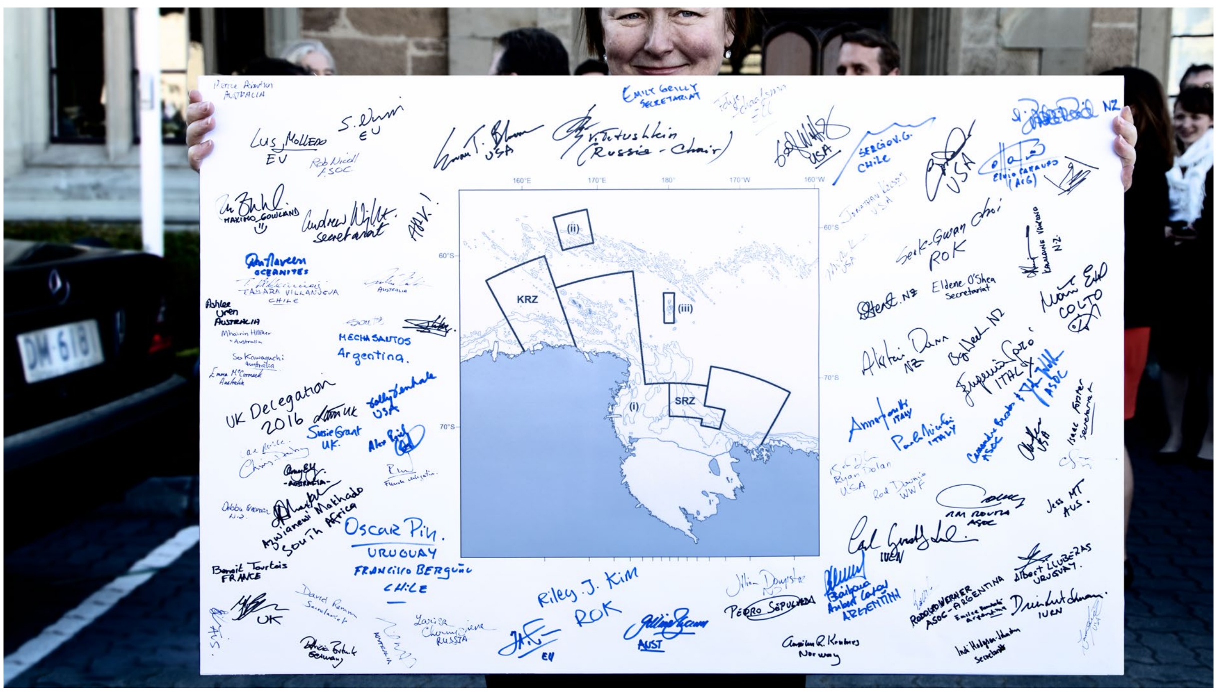


Fig. 7.1 Signed map of Ross Sea region Marine Protected Area (MPA). New Zealand Head of Delegation Jillian Dempster holding map of the newly adopted Ross Sea region MPA, with the signatures of CCAMLR delegates who were there at adoption. The MPA was an immediate source of pride for CCAMLR, and this signed map remains framed on display in CCAMLR's office in Hobart, Tasmania (photo credit: John B. Weller).

Antarctic governance

Antarctica is exceptional. The coldest, windiest, iciest, driest, and most remote of continents is critical to the Earth's system—driving global ocean circulation, regulating weather, and storing the majority of the world's freshwater (Pertierra et al., 2021). It is widely celebrated for its history of exploration and science, for its exceptional beauty, and for its exemplary governance (Berkman et al., 2011). Beginning in the 1800s and into the first half of the 1900s, countries were dividing the Antarctic continent like a pie, and at the height of the Cold War, the USA and USSR both sought their share (Shapley, 1986). Other countries were already exploiting and depleting its marine resources (Hofman, 2017; Koch, 1992). Then something unexpected happened: scientific collaboration led to a political breakthrough. The International Geophysical Year (IGY) of 1957/58 focused on the polar regions, including the Antarctic. It demanded that the 12 countries participating in Antarctic research, including those that had made Antarctic claims, set up a formal agreement of scientific collaboration. The IGY led directly to the signing of the Antarctic Treaty in 1959. The Treaty suspended sovereignty and banned military operations and nuclear activity (Antarctic Treaty, 1959). Along with associated Conventions, the Antarctic Treaty System (ATS) collectively also prohibits mining (including in the surrounding seabed) and sets aside the continent as a natural reserve, devoted to peace and science (Protocol, 1991). As such, the ATS has been celebrated as perhaps the world's most successful peace and environmental treaty and is a model for international collaboration (Beck, 2010; Berkman et al., 2011).

Under the ATS, the Convention on the Conservation of Antarctic Marine Living Resources (hereafter Convention), has jurisdiction over the waters around Antarctica, i.e., those of the Southern Ocean, defined by the Antarctic Polar Front (APF: CCAMLR, 1980; Figure 7.2). In the late 1970s, this Convention was negotiated in response to expanding fisheries for Antarctic krill (*Euphausia superba*)—a key prey species of the Southern Ocean food web, with the fishery threatening the recovery of the near-extirpated baleen whales which were dependent upon krill (Hofman, 2017). In accordance with principles of peace, science, and environmental preservation embodied in the ATS, the Convention's explicit objective was to *conserve* marine living resources. While conservation includes "rational use," scientific and commercial harvesting of living resources are subject to clearly articulated conservation principles that strive to avoid significant changes in harvested, related and dependent populations, or significant adverse effects on their associated ecosystems that are not reversible in 20–30 years (CCAMLR 1980, Article II). This approach has been recognized, at least for that time, to be far-sighted, by enlisting an ecosystem approach to marine resource management (Diz Pereira Pinto, 2012; Miller and Slicer, 2014).

Additionally adding to CCAMLR's efficacy, the Southern Ocean represents a well-defined social-ecological system (Berkes and Folke, 1998). While most governance arrangements face the challenges of a poor fit between political and ecological boundaries (Young, 2002; Crowder et al., 2006), the Convention designates the entire Southern Ocean as its jurisdiction, thereby facilitating the implementation of their ecosystem-based mandate (see Figure 7.2). In this way, the Convention's jurisdictional boundaries are clearly defined (Dietz et al., 2003) and the rules that the Commission makes to govern the region are congruent with an ecological boundary, the APF (Brooks et al., 2014). Further, the Convention is a relatively small international regime, most recently having only 25 Member States plus the European Union in its Commission. The latter meets annually and has done so for the 40 years of its regime. In addition, representatives have met annually throughout the year in a variety of working groups. These meetings, in relatively small group settings, provide the opportunity for long-term face-to-face cooperation, which enhances conditions for trust and reciprocity (Ostrom and Walker, 2003; Österblom and Folke, 2013). Indeed, the Commission has demonstrated an ability to overcome severe collective action problems in the past, such as dramatically reducing illegal, unregulated, and unreported fishing, banning benthic trawling, fisheries for sharks, and other measures (see, e.g., Österblom and Sumaila, 2011). CCAMLR's policy decisions require consensus of all Member States and must be based on the best available science, as advised by the working groups and Scientific Committee (CCAMLR, 1980; 1982). All of these institutional characteristics eventually played a critical role in facilitating the adoption of the Ross Sea Region MPA.

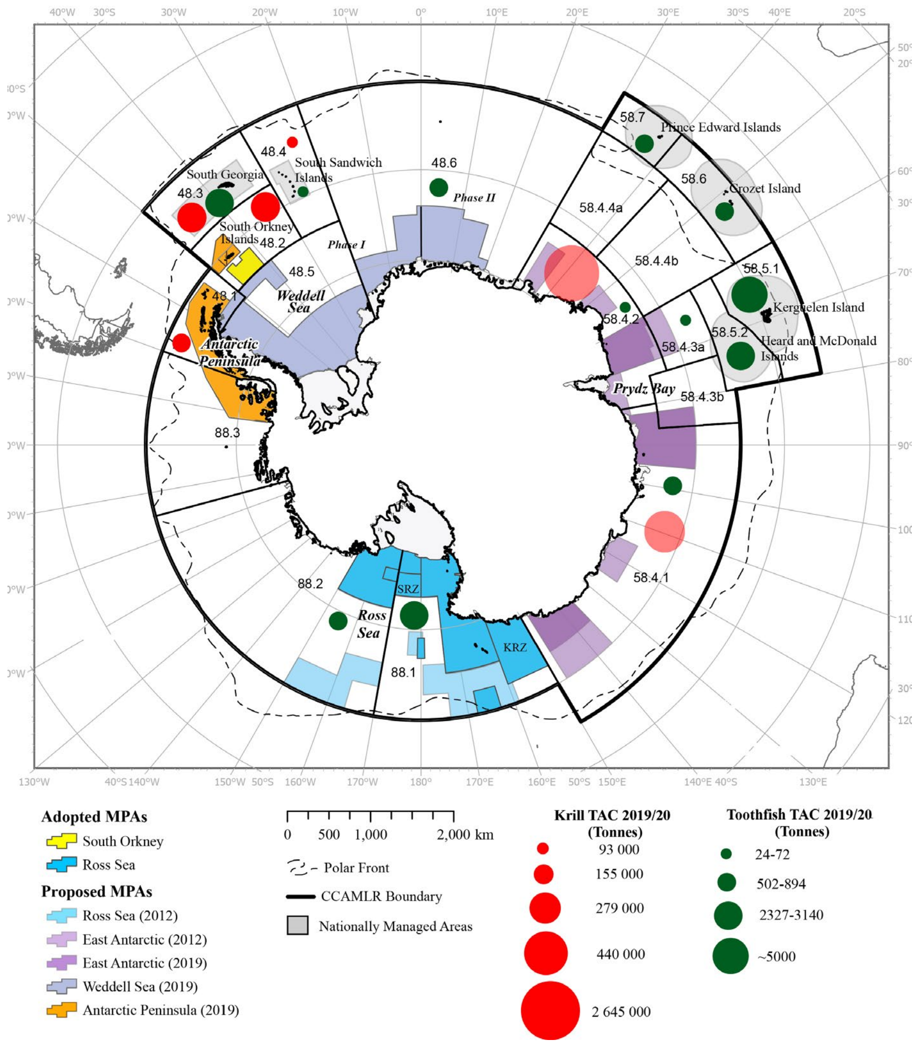


Fig. 7.2 CCAMLR fisheries and marine protected areas (MPAs). CCAMLR area boundary (thick black line) and UN FAO management areas (thin black lines with numerical labels). CCAMLR's adopted and proposed MPAs from 2012 to 2019, including the South Orkney Islands Southern Shelf MPA (yellow), Ross Sea Region MPA (blue), East Antarctic (violet), Weddell Sea (purple) and the Western Antarctic Peninsula (orange). Total Allowable Catch (TAC) for toothfish (green) and krill (red) in the CCAMLR management area; circles proportional to respective TAC (tonnes in 2019/20), transparency indicates underutilization. Shaded circles around subantarctic islands reflect delineated Exclusive Economic Zone boundaries generated prior to the signing of the CAMLR Convention (from Brooks et al. 2020).

Increasing threat: Moving towards Southern Ocean MPAs

Pressure on Antarctic commercial fisheries has amplified in recent years (see Figure 7.2), as have the potential impacts from a changing climate affecting the fishery rules (Brooks et al., 2018). There are currently two main commercial fisheries in the Southern Ocean. Antarctic krill continues to be exploited, along with Patagonian and Antarctic toothfishes (*Dissostichus eleginoides* & *D. mawsoni*), the top fish predators in the Southern Ocean (Figure 7.2). Antarctic krill reached the unprecedented high catch of more than 440,000 tons in the 2020 season (SC-CAMLR, 2020), increasingly exploited for omega-3 pills and fishmeal (Nicol et al., 2012). Toothfishes, exploited across the region since the mid to late 1990s, are sold as the lucrative Chilean Sea Bass and experience rising demand (Grilly et al., 2015). Meanwhile, regions of the Antarctic are among the most rapidly changing on the planet, facing global repercussions of sea level rise, along with altered ocean circulation and climate regulation (IPCC, 2019). In FAO/CCAMLR Area 48, climate change is driving loss of sea ice cover, shifts in marine population distributions and decreases in primary productivity (Schofield et al., 2010; Ducklow et al., 2013). Potential declines in ice-dependent Antarctic krill could lead to ecological disruptions throughout that region (Rintoul et al., 2018). Impacts of climate change on toothfish remain unstudied and unknown. Importantly, the combined impacts of fishing and climate change are likely to have greater effect than either impact alone (Pinsky and Mantua, 2014; Fu et al., 2017).

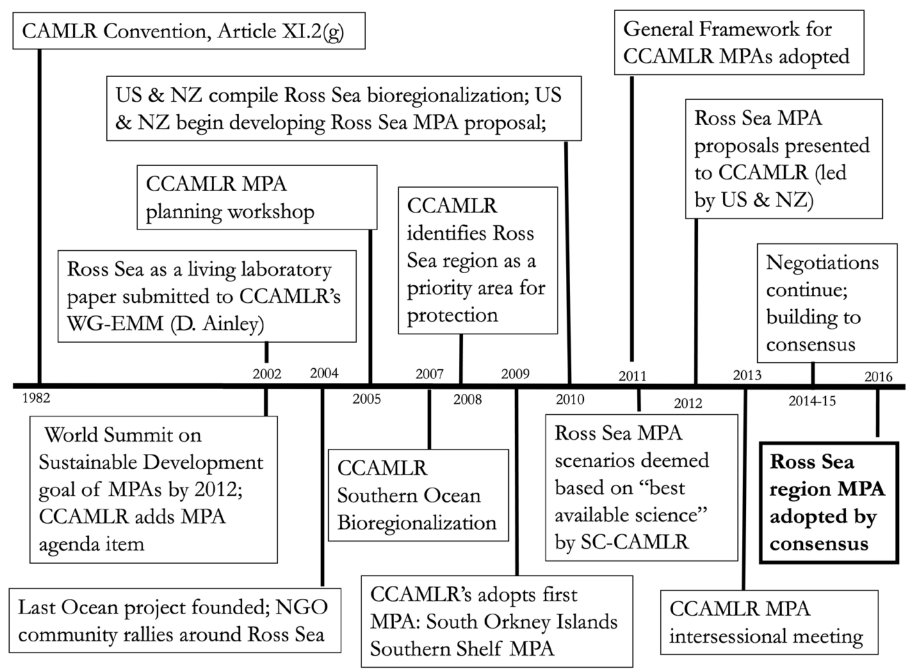


Fig. 7.3 Timeline of key CCAMLR MPA events and initiatives related to the Ross Sea region MPA (modified after Brooks et al. 2020).

The Ross Sea

The Ross Sea—a large embayment and the largest Antarctic continental shelf between west and east Antarctica about 4,000km south of New Zealand (see Figure 7.2)—was a priority area for protection, not only for CCAMLR, but also for international scientists and conservation organizations. Largely protected by ice and remoteness, the Ross Sea was deemed the least anthropogenically affected stretch of the world ocean (Halpern et al., 2008). The effort to formally protect the Ross Sea largely began in 2002, when Antarctic ecologist David Ainley began writing science papers directly to CCAMLR calling for the protection of the Ross Sea as a living laboratory (e.g., Ainley, 2002, 2004). Among attributes reviewed, the Ross Sea is the most productive stretch of the Southern Ocean (Arrigo et al., 1998), supporting disproportionate amounts of marine life (Smith et al. 2007, 2012, 2014). While the waters of the Ross Sea shelf and slope comprise only 3.2% of the Southern Ocean, they harbor ~25% of the world's Emperor Penguins (*Aptenodytes forsteri*), ~38% of the world's Adélie Penguins (*Pygoscelis adeliae*), 30% of Antarctic Petrels (*Thalassoica antarctica*) 40% of Weddell seals (*Leptonychotes weddellii*), and 50% of South Polar Skuas (*Stercorarious maccormicki*) (see Figure 7.4). They also harbor a large population of Antarctic toothfish and a distinct population of Killer Whale (*Orcinus orca*) that feeds primarily on toothfish (Lauriano et al., 2020). The Ross Sea is also the best studied Antarctic continental shelf system with datasets spanning 170 years and more than 500 species first described from Ross Sea specimens (Ainley et al., 2010; Ballard et al., 2010).

Antarctic science, conservation and diplomatic communities rallied around protecting the Ross Sea. Antarctic scientists, both outside of and inside of CCAMLR, worked to compile more than a century's worth of data on the Ross Sea ecosystem. They identified priority areas for biodiversity, and for the diverse array of predators and prey that live there (Ainley et al., 2010; Ballard et al., 2010). Some of these scientists actively advocated and petitioned on behalf of protecting the Ross Sea, noting its remarkable ecological value, and its scientific value as a living laboratory for studying how a healthy marine ecosystem functions, including under the stressors of climate change (ASOC, 2010). Meanwhile, the Ross Sea ecosystem was also under increasing threat from an international commercial fishery for Antarctic toothfish which takes roughly 3000 tons a year (see Figure 7.2). Up to a dozen countries have participated in the Ross Sea toothfish fishery (CCAMLR, 2019), which, being the furthest south a vessel can travel on the ocean, is the most remote fishery on Earth. Conservation organizations and foundations across the world advocated intensely for Ross Sea protection, branding it as "The Last Ocean" due to its assessment as perhaps the last large intact marine ecosystem left in the world (Young, 2012; Weller, 2013). They worked extensively across the world, but with targeted efforts in New Zealand and the United States. The United States and New Zealand both had political motivations to take leadership. Owing to its logistical attributes the region has long been central to the United States' Antarctic Program (USAP), with decades of research since the International Geophysical Year was driven from its large science logistics base in McMurdo Sound. New Zealand has historic sovereignty claims in the Ross Sea region, i.e., the Ross Dependency, and out of commercial interest led development of the toothfish fishery there. While these two nation states ended up leading the charge, adopting the MPA demanded consensus among all CCAMLR's Member States, as is true of all CCAMLR Conservation Measures. Consensus can be a powerful form of decision-making, as, once it is achieved, you have a situation where all Member States have actually come to agreement. However, building consensus moves slowly, often requires conservation trade-offs, and, in the case of the Ross Sea, demanded diplomacy at the highest level.

Fig. 7.4 The Ross Sea region. Images representing the Ross Sea region biodiversity and ecosystem, including (from top left to bottom right) Ross Sea killer whales, Emperor penguins, Adélie penguins, Antarctic Minke whale, Emerald Rockcod, Weddell seal, isopod on a glass sponge, and the benthic seafloor (photo credits: John B. Weller).

Building consensus

Getting CCAMLR Member States to agree to adopt a Ross Sea MPA proved difficult and demanded many years of scientific planning followed by five years of intensive negotiations. In 2010, the United States and New Zealand began formally working to develop a proposal for a Ross Sea MPA, compiling extensive data into bioregionalizations (Ainley et al., 2010; Ballard et al., 2010; Sharp et al., 2010). In 2011, both States submitted unique scenarios for a Ross Sea MPA to CCAMLR's scientific advisory body—the Scientific Committee—for evaluation (USA, 2011; New Zealand, 2011). After extensive discussion over boundaries, size, and potential impact on fishing, both the United States and New Zealand's Ross Sea scenarios were deemed to be based on the best available science, meaning the proposals could be advanced to the Commission for formal negotiation (SC-CAMLR, 2011). A proposal for an East Antarctic MPA was also being negotiated at this time (see Figure 7.2), but discussion of this MPA (which was still under negotiation as of 2022) is outside the scope of this chapter.

In 2012, United States and New Zealand delegations each brought proposals for a Ross Sea MPA to the Commission (USA, 2012; New Zealand, 2012). Both proposals had objectives to protect the ecological structure and function of the ecosystem. The proposals included areas important for the life history of birds, mammals and fish as well as reference areas aimed at improving current understanding of the potential impacts from fishing and climate change. Both proposals also drew their boundaries to exclude the main commercial fishing grounds on the continental slope, centered on Iselin Bank (roughly the location of the green circle in the Ross Sea on Figure 7.2). However, the proposal put forward by New Zealand, who has historically led and dominated the Ross Sea fishery, also accommodated some fishing of the Ross Sea shelf and other portions of the slope. The major point of contention between the two proposals was the 'Special Research Zone' (see SRZ in Figure 7.2). The USA wanted to close much of this highly productive area to provide a reference zone for measuring the ecosystem impacts of the Ross Sea fishery, by comparing this area with the heavily fished areas located just outside the proposed MPA. However, this area is also a prime toothfish fishing ground and New Zealand emphasized that this region was essential to maintain the continuity and integrity of their tagging program (see discussion in (Brooks, 2013b)). After intensive after-hours work during the 2012 CCAMLR meeting and much urging from the other Commission Members, the two countries forged a compromise (CCAMLR, 2012) (see original 2012 proposal boundaries in Figure 7.2). In 2012, more than half of CCAMLR Member States supported this joint proposal (Figure 7.5), noting both the value of the Ross Sea and CCAMLR's commitment to adopting a network of MPAs by 2012 in line with international targets (e.g., WSSD 2012 deadline) (CCAMLR, 2012).

Since consensus was not achieved in 2012, CCAMLR called a special and high-profile intersessional meeting in 2013 (CCAMLR, 2012), which came with immense pressure from civil society on CCAMLR to make progress. This intersessional meeting was fraught with geopolitical tensions and economic concerns regarding fishing access potentially being compromised by MPA proposals. Many Member States questioned the science supporting the large northern area included in the Ross Sea MPA proposal to protect purported spawning grounds for Antarctic toothfish (see Figure 7.2, original Ross Sea MPA proposal) and the Scientific Committee agreed that there was insufficient evidence to support the spawning objective for the northern area (SC-CAMLR, 2013). During the Scientific Committee meeting, Russia in particular criticized the boundaries of the proposed Ross Sea MPA as being political (e.g., based on historic sovereignty claims). Russia also highlighted how the Ross Sea remains the only area with a large toothfish fishery that all CCAMLR Member States can access (other large fisheries are embodied in subantarctic EEZs, see Figure 7.2). The Russian and Ukrainian delegations also commented on the need to expand toothfish fishing areas to make up for displaced toothfish catch due to the potential adoption of MPAs (SC-CAMLR, 2013). The breadth and extent of their convictions were extensive. The adoption of the report was contentious and carried on until 5:30am (Brooks, 2013a). These tensions, apparent at the Scientific Committee, carried over into the Commission meeting, which commenced a day later. Early in negotiating the MPA proposals, Russia made an extensive statement questioning CCAMLR's legal capacity to adopt MPAs, which effectively halted negotiations. Many closing statements voiced disappointment, stressing that the purpose of the intersessional meeting was to make progress on MPAs (CCAMLR, 2013b) (see also discussion in Brooks et al., 2019).

Despite disappointments raised at the close of the 2013 intersessional meeting, CCAMLR had made real progress towards consensus. Even in failure, high-profile meetings can help open political windows of opportunity to achieve solid commitments (Young, 1999; Keohane and Nye, 2011). After incorporating concerns made during the intersessional meeting, the United States and New Zealand made modifications to the Ross Sea MPA proposal, reducing it in size by 40% (including removal of the data deficient northern areas) (CCAMLR, 2013a). Coming into the 2013 CCAMLR annual meeting just over three months later, with these modifications made, all but three countries supported the Ross Sea proposal (Brooks et al., 2019) (Figure 7.5).

In 2014, the Ross Sea proposal was negotiated for the fourth time (CCAMLR, 2014). Shared past interactions and anticipation of a shared future should lead to higher levels of trust and cooperation (Axelrod, 1984; Cox et al., 2010), but positions can also become entrenched (Ostrom and Walker, 2003). The MPA process divided CCAMLR, breaking trust – some Member States accused the MPA of being politically motivated, while others argued that some Member States were not negotiating in good faith (Brooks, 2019; Brooks et al., 2019). For some fishing Member States, MPAs presented a threat to current and future access that could also set precedent for other regions (e.g., high seas and Arctic). Member States also seem to have widely divergent views on the Convention's purpose—some arguing for a right to fish while others emphasizing the responsibility to conserve (Brooks, 2019; Brooks et al., 2019). Lack of a clear policy process also compromised trust. Further, while the Antarctic is physically isolated, negotiations did not occur in political isolation. In 2014, tensions between Russia and the United States were remarkably high—stemming from Russia's annexation of the Crimean Peninsula from Ukraine—and spilled into CCAMLR negotiations (Brooks et al., 2019). Thus in 2014, Russia would not negotiate the Ross Sea MPA proposal. In contrast, Ukraine was far less vocal in its opposition to MPAs in 2014 (Figure 7.5), thus CCAMLR inched further towards consensus. By the meeting's end, Russia and China remained the only countries opposing a Ross Sea MPA (Brooks et al., 2019) (Figure 7.5).

The Ross Sea proposal was negotiated for the fifth time in 2015 (CCAMLR, 2015). The proposed MPA had been further reduced in size, and the SRZ had been expanded, intended to appease Russian research fishing interests (Brooks et al., 2019). Further, the proposal included a sunset clause—requested by multiple Member States—that the MPA should expire after 50 years. Despite the expanded SRZ, Russia remained opposed. China also continued to voice concerns, wanting larger levels of fishing and a shorter MPA duration (Brooks et al., 2019). Negotiations stalled until the final morning of the meeting, when a revised version of the Ross Sea MPA with a ~322,000km^2 krill fishing zone (KRZ) west of the Ross Sea (Figure 7.2), was produced from trilateral negotiations with China. The United States and New Zealand noted the revision was "to meet the concerns of a particular Member...We want to thank China for its constructive approach...and spirit of cooperation" (CCAMLR, 2015) (para 8.107). China formally thanked the United States and New Zealand for their "endeavors to accommodate" (CCAMLR, 2015) (para 8.108). With the meeting closing, parties agreed to engage intersessionally on the updated proposal (CCAMLR, 2015). China's sudden support likely came from the addition of the KRZ, but also from high-level political meetings between the United States and China during 2015 leading up to the Paris Agreement (Tang, 2017; Liu and Brooks, 2018). This left Russia as the last Member State that had not joined the consensus on the Ross Sea MPA.

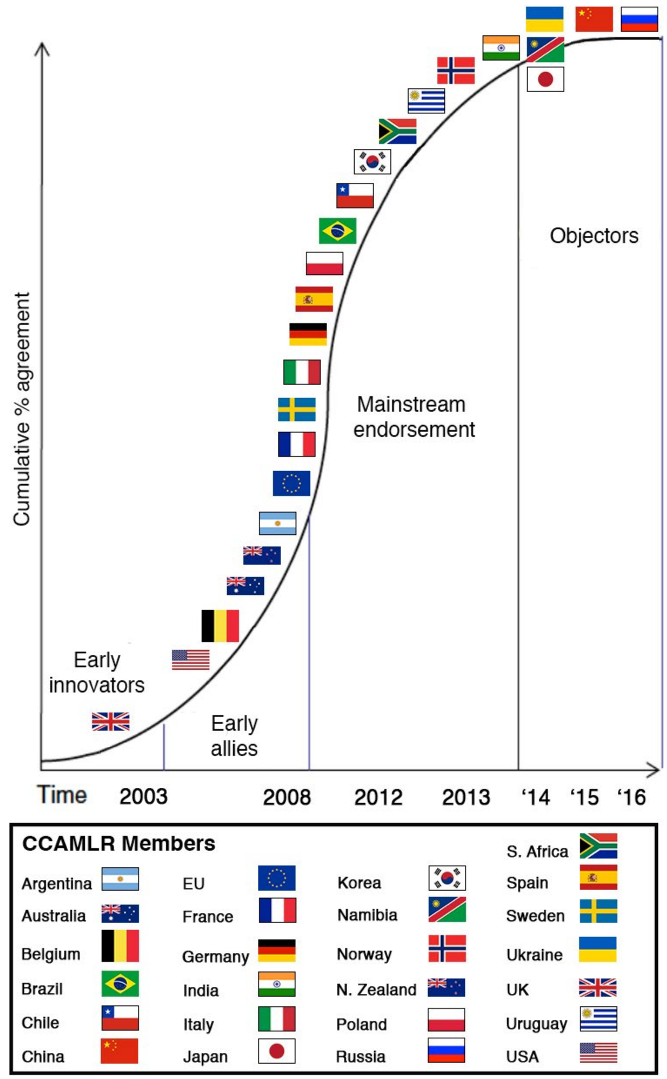


Fig. 7.5 Building to consensus towards CCAMLR marine protected areas (MPAs). The process of building to consensus for adopting CCAMLR MPAs, with particular focus on the Ross Sea region MPA (from Brooks et al., 2020).

Stepping outside the room

Inside the CCAMLR negotiation room, individuals representing governments must work across three levels—international, national and individual—seeking to meet competing interests. At the international level, diplomats must balance international diplomatic relations; at the national level, this includes economic and domestic interests; and at the individual level, this includes managing relationships as well as personal values. The chief negotiator (e.g., the Head of Delegation) negotiates all levels simultaneously, trying to find agreements that can be considered a win in both the domestic and international arenas (Putnam, 1988). Indeed, international relations were critically important throughout the process—with tensions between some countries (United States and Russia) stalling the process, while national-level interests also drove the process at times (e.g., fishing interests). Meanwhile, the role of individuals cannot be understated. Trust is built between individual people, and the key role of building and reinforcing trust was evident throughout the process for diplomats, scientists and others who were involved in the long road towards adopting a Ross Sea region MPA (Figure 7.6). Much of this work occurred in the CCAMLR meeting room, but much of it happened in the sidelines, outside the room, and throughout the year.

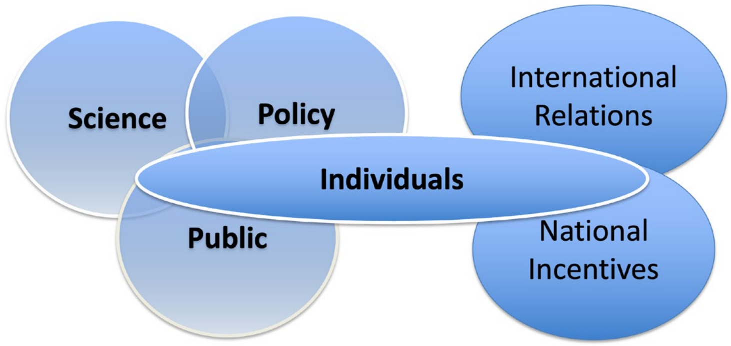


Fig. 7.6 Multi-level governance in CCAMLR. The role of individuals working across the science-policy-public space in CCAMLR, and working between the International and National level, cannot be understated.

Individuals working across the science-policy-public spheres were putting pressure on CCAMLR. Scientists worked to produce a flood of science over the years before and during negotiations in support of protecting the Ross Sea (e.g., (Ainley, 2004, 2007, 2010; Smith et al., 2007, 2012, 2014; Ainley and Ballard, 2012; Ainley et al., 2012a; Ainley et al., 2012b; Ballard et al., 2012; Ainley and Brooks, 2013; Ainley and Pauly, 2013). Conservation non-governmental organizations (through the Antarctic and Southern Ocean Coalition) worked inside and outside the room, informing and facilitating the process at all levels. They brought the story to life with compelling media (e.g., Young, 2012; Weller, 2013); engaged journalists across the globe (e.g., White, 2010); entrained support from the public, celebrities, and high-level government officials (e.g., Howard, 2013); and, delivered policy reports directly to decision-makers (e.g., AOA, 2012). They harnessed the collective voice of global civil society, representing millions of citizens calling for protection of the Ross Sea (e.g., Avaaz, 2012). The public, led by certain NGOs, also began to publicly protest outside the doors of CCAMLR (Figure 7.7). These conservation organizations got the attention of former Secretary of State John Kerry in 2013 when Pew Charitable Trusts hosted an event with National Geographic and showed a version of the award winning *The Last Ocean* documentary (Young, 2012; Howard, 2013). United States Secretary of State John Kerry started urging support for the Ross Sea, committing to making protection of the Ross Sea part of his legacy during his term. His engagement at the highest political level was one of the fundamental drivers towards getting China and Russia to come to consensus on adopting a Ross Sea region MPA.

A political window of opportunity

Coming into 2016, Russia was the last hold-out, but all the years of science, public, and policy work would finally result in a political window of opportunity for the Ross Sea. First, Russia was isolated as the last State opposing the MPA. Russian President Vladimir Putin had declared 2017 as a Year of Ecology, appointing a new Special Representative for Ecology. Russia was also chairing the 2016 CCAMLR meeting and preparing to celebrate the 200th anniversary of Russia's contested discovery of Antarctica. Finally, Senator Kerry, wanting his legacy to include a Ross Sea MPA, had been liaising with his counterparts in Russia, applying high-level political pressure throughout 2016. The stage was set for Russian leadership.

In 2016, formal Ross Sea MPA negotiations were sparse, occurring primarily in private meetings between the top diplomats from each Member State, or in informal consultations. Russia negotiated for more toothfish fishing in the Ross Sea MPA's SRZ and to open some previously closed areas outside the MPA. The proposal called for a 50-year duration, but other States, like Japan and China, had requested a 20-year duration. Eventually, a compromise of 35 years was agreed to. Finally, in the final hour of the two-week meeting, on 28 October 2016, after 14 years of effort (Figure 7.4), the Ross Sea region MPA was adopted by consensus. The

CCAMLR Secretariat printed a map of the MPA and invited all delegations to sign it; most did, including China and Russia. Almost every Member State made substantial closing remarks highlighting the success and the adoption of the Ross Sea region MPA, and immediately made headlines across the world. At more than 2 million km^2, and >70% no-take, the Ross Sea region MPA was and continues to be the largest MPA in the world.

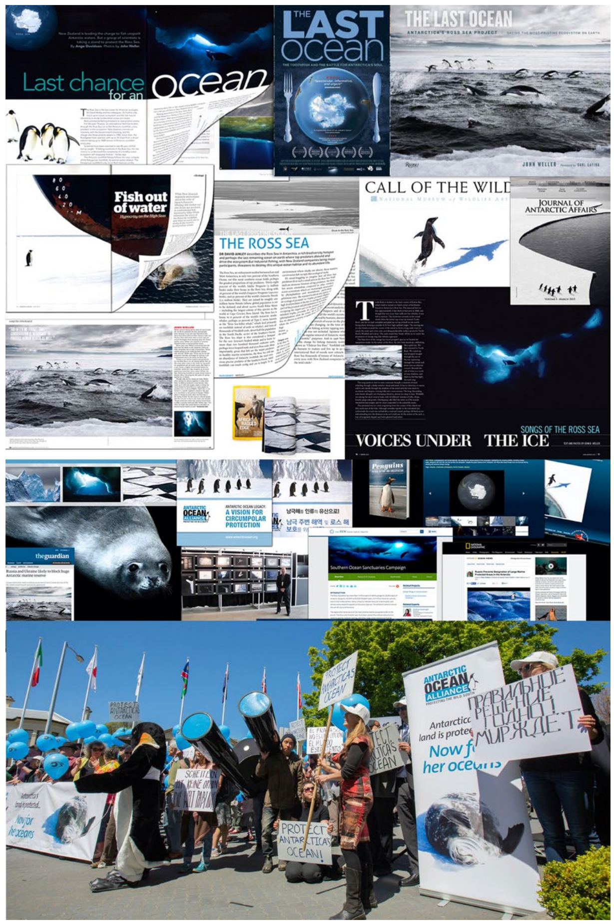


Fig. 7.7 Montage of Ross Sea media. An array of media and outreach materials (including photography, film and policy reports) was produced and widely distributed in support of the Ross Sea region MPA. The bottom image shows a public protest outside the CCAMLR building during the annual meeting.

Looking forward

CCAMLR has a long history of conservation successes (Österblom et al., 2015), but MPAs posed a new collective action challenge (Brooks et al., 2016). Consensus-based decision making allows any party to block a measure, and individual Member State interests can undermine international cooperation (Miller and Slicer, 2014). Thus, achieving consensus on protecting the Ross Sea was slow, exacerbated by the lack of a clear and transparent process and degradation of trust owing to geopolitics within and outside of CCAMLR. A fundamental driver was CCAMLR's existing provision to declare closed areas (CCAMLR, 1980, Article IX), offering a legal mechanism and legitimacy for MPAs. Early on, the adoption of global targets influenced CCAMLR's discussions. The extensive science underpinning the Ross Sea MPA, derived largely from 60 years of research led by the United States, New Zealand and Italy, as well as having scientists involved throughout, helped drive the process. Compelling media and public engagement also simultaneously inspired and pressured diplomats to make progress. Ultimately, consensus for the Ross Sea region MPA required levers of influence with diverse Member

States. While accommodation of fishing interests was a key incentive, high-level diplomacy and opportunities for leadership potentially proved the most influential drivers (Brooks et al. 2019).

CCAMLR is the only management body to have adopted no-take MPAs within international waters. Their process may prove influential in informing the ongoing United Nations negotiations to develop other high seas MPAs within a new International Legally Binding Instrument for the Management of Biodiversity in Areas Beyond National Jurisdiction (i.e., the High Seas Treaty). Though CCAMLR's membership is relatively small, and the diversity of industries and stakeholders potentially limited compared with other international bodies (making consensus easier to achieve), the Ross Sea MPA process reveals both potential pathways and impediments. In these international spaces, science, leadership and high-level political engagement will be critical, as well as engagement with all participants, including conservation organizations, scientists, industry, and the public. Furthermore, the Ross Sea region MPA highlighted an important lesson for large-scale conservation initiatives: they must work across institutional boundaries. Global initiatives, such as the Aichi Targets or the United Nations Sustainable Development Goal 14 (Life Below Water), will fail in isolation. What we learned from the example of the Ross Sea is that when we work across the science, policy and public interfaces, we can achieve consensus to protect large important marine spaces. We also learned that while it can be difficult to know when a political window of opportunity will open, we need to have our science, outreach, and diplomacy in place, so that when that window opens, we can push through it. This will also be the case for future MPAs implemented through the High Seas Treaty.

While the Ross Sea was a great step towards conserving the Southern Ocean, CCAMLR's work is not done. At the time of writing, there are three MPAs still under negotiation, including in the Weddell Sea, East Antarctic and Antarctic Peninsula—all of which would contribute to a representative network of Southern Ocean protected areas (Brooks et al., 2020). There is strong science in place supporting the proposals, and extensive public engagement, but political barriers (and ongoing economic interests) have hindered adoption. Yet, in 2022, there was renewed leadership and potential for high-level diplomacy. The United States has become a co-proponent on the Weddell Sea and East Antarctic MPAs, joining the European Union, Australia, India, New Zealand, Uruguay, South Korea, the United Kingdom and Norway. Chile and Argentina lead on the Antarctic Peninsula MPA proposal. This collective force will need to work across the diverse CCAMLR member states, to build support and ultimately, consensus. Furthermore, CCAMLR has agreed to another intersessional meeting in 2023 to make progress on MPAs (CCAMLR, 2022). The story of the Ross Sea shows that the international community can overcome differences to protect a globally important space. And CCAMLR can do it again. We look forward to seeing action in future years.

References

Ainley, D. (2002). The Ross Sea, Antarctica, where all ecosystem processes still remain for study. CCAMLR WG-EMM-02/60.

Ainley, D.G. (2004). "Acquiring a 'Base datum of normality' for a marine ecosystem: The Ross Sea, Antarctica", in: WG-EMM-04/20. (Hobart, Australia: CCAMLR).

Ainley D.G. 2007. Insights from study of the last intact neritic marine ecosystem. Trends in Ecology & Evolution 22: 444-445.

Ainley, D.G. 2010. A history of the exploitation of the Ross Sea, Antarctica. Polar Record 46 (238): 233–243.

Ainley, D., and Ballard, G. (2012). Trophic Interactions and the decrease in Killer Whale (Orcinus orca) prevalence with reduced availability of large fish in the southern Ross Sea. Aquatic Mammals 38(2), 153-160. https://doi.org/10.1578/AM.38.2.2012.153.

Ainley, D., Ballard, G., and Weller, J.B. (2010). Ross Sea Bioregionalization Part I CCAMLR WG-EMM-10/11.

Ainley, D.G., and Blight, L.K. (2009). Ecological repercussions of historical fish extraction from the Southern Ocean. Fish and Fisheries 10(1), 13-38. https://doi.org/10.1111/j.1467-2979.2008.00293.x.

Ainley, D., and Brooks, C. (2013). "Exploiting the Southern Ocean: Rational use or reversion to tragedy of the Commons?," in Exploring Antarctic Values, eds. D. Liggett & A. Hemmings. (Christchurch, NZ: University of Canterbury), 143-154.

Ainley, D., Brooks, C.M., Eastman, J., and Massaro, M. (2012a). "Unnatural selection of Antarctic Toothfish in the Ross Sea, Antarctica," in Protection of the Three Poles, ed. F. Huettmann. (Tokyo: Springer), 53-75

Ainley, D., Nur, N., Eastman, J., Ballard, G., Parkinson, C., Evans, C., et al. (2012b). Decadal trends in abundance, size and condition of Antarctic toothfish in McMurdo Sound, Antarctica, 1972-2011. Fish and Fisheries 14, 343-363.

Ainley, D.G., and Pauly, D. (2013). Fishing down the food web of the Antarctic continental shelf and slope. Polar Record 50(01), 92-107. https://doi.org/10.1017/s0032247412000757.

Antarctic Treaty. (1959). "The Antarctic Treaty". (Washington, D.C.).

AOA (2012). "Antarctic Ocean Legacy: A Vision for Circumpolar Protection.". Antarctic Ocean Alliance).

Arrigo, K.R., Worthen, D.L., Schnell, A. & Lizotte, M.P. 1998. Primary production in Southern Ocean waters. Journal of Geophysical Research 103, 15,587–15,600.

Arrigo, K.R., van Dijken, G.L., and Strong, A.L. (2015). Environmental controls of marine productivity hot spots around Antarctica. Journal of Geophysical Research: Oceans 120(8), 5545-5565. https://doi.org/10.1002/2015jc010888.

ASOC (2010). "Scientists' Consensus Statement on Protection of the Ross Sea". (Washington, D.C.: Antarctic and Southern Ocean Coalition.).

Avaaz (2012). Days to save the Antarctic ocean [Online]. Available: http://www.avaaz.org/en/save_the_southern_ocean_5/?pv=59

Axelrod, R. (1984). The Evolution of Cooperation. Cambridge, MA: Basic Books.

Ballard, G., Jongsomjit, D., and Ainley, D. (2010). Ross Sea Bioregionalization, Part II: Patterns of co-occurence of mesopredators in an intact polar ocean ecosystem. CCAMLR WG-EMM-10/12.

Ballard, G., Jongsomjit, D., Veloz, S.D., and Ainley, D.G. (2012). Coexistence of mesopredators in an intact polar ocean ecosystem: The basis for defining a Ross Sea marine protected area. Biological Conservation 156, 72-82. https://doi.org/10.1016/j.biocon.2011.11.017.

Beck, P. (2010). Fifty years on: putting the Antarctic Treaty into the history books. The Polar Record 46(1), 4-7.

Berkes, F., and Folke, C. (1998). Linking Social and Ecological Systems. Cambridge, UK: Cambridge University Press.

Berkman, P., Lang, M., Walton, W., and Young, O. (2011). Science Diplomacy: Antarctica, Science and the Governance of International Spaces. Washington, DC: Smithsonian Institute Scholarly Press.

Brooks, C., Crowder, L.B., Curran, L., Dunbar, R., Ainley, D., Dodds, K., et al. (2016). Science-based management in decline in the Southern Ocean. Science 354(6309), 185-187.

Brooks, C., Weller, J.B., Gjerde, K.M., Sumaila, R., Ardron, J., Ban, N.C., et al. (2014). Challenging the 'Right to Fish' in a Fast-Changing Ocean. Stanford Environmental Law Journal 33(3), 289-324.

Brooks, C.M. (2013a). Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR): 2nd Intersessional Meeting, preceded by the 1st Intersessional Meeting of the Scientific Committee. The Polar Journal 3(1), 5-7.

Brooks, C.M. (2013b). Competing values on the Antarctic high seas: CCAMLR and the challenge of marine-protected areas. The Polar Journal 3(2), 277-300. https://doi.org/10.1080/2154896x.2013.854597.

Brooks, C.M. (2019). "Geopolitical complexity at the bottom of the world: CCAMLR's ongoing challenge of adopting marine protected areas. ," in Governing marine living resources in the polar regions., eds. N. Liu, C.M. Brooks & T. Qin. (Cheltenham, UK: Edward Elgar Publishing), 43-65.

Brooks, C.M., Ainley, D.G., Abrams, P.A., Dayton, P., Hofman, R., Jacquet, J., et al. (2018). Watch over Antarctic waters. Nature, 177-180.

Brooks, C.M., Chown, S.L., Douglass, L.L., Raymond, B.P., Shaw, J.D., Sylvester, Z.T., et al. (2020). Progress towards a representative network of Southern Ocean protected areas. PLoS One 15(4), e0231361. https://doi.org/10.1371/journal.pone.0231361.

Brooks, C.M., Crowder, L.B., Osterblom, H., and Strong, A.L. (2019). Reaching consensus for conserving the global commons: The case of the Ross Sea, Antarctica. Conservation Letters. ;e12676. https://doi.org/10.1111/conl.12676

CCAMLR (1980). The Convention on the Conservation of Marine Living Resources.

CCAMLR (1982). Rules of Procedure.

CCAMLR (2002). "Report of the XXI Meeting of the Commission".).

CCAMLR (2009). Conservation Measure 91-03. Protection of the South Orkney Islands southern shelf.

CCAMLR (2011). Conservation Measure 91-04. General Framework for the establishment of CCAMLR Marine Protected Areas.

CCAMLR (2012). Report of the XXXI Meeting of the Commission.

CCAMLR (2013a). Report of the XXXII Meeting of the Commission.

CCAMLR (2013b). Second meeting of the Commission in Bremerhaven.

CCAMLR (2014). Report of the XXXIII Meeting of the Commission.

CCAMLR (2015). Report of the XXXIV Meeting of the Commission.

CCAMLR (2019). Statistical Bulletin 31 (2009-2018).

CCAMLR (2022). Report of the Fourty-first Meeting of the Commission.

Cox, M., Arnold, G., and Tomas, V. (2010). A Review of Design Principles for Community-based Natural Resource Management. Ecology and Society 15(4), 38.

Crowder, L.B., Osherenko, G., Young, O.R., Airame, S., Norse, E.A., Baron, N., et al. (2006). Resolving Mismatches in U.S. Ocean Governance. Science 313, 617-618.

Dietz, T., Ostrom, E., and Stern, P. (2003). The Struggle to Govern the Commons. Science 302, 1907-1912.

Diz Pereira Pinto, D. (2012). Fisheries Management in areas beyond national jurisdiction. Netherlands: Martinus Nijhoff

Ducklow, H., Fraser, W., Meredith, M., Stammerjohn, S., Doney, S., Martinson, D., et al. (2013). West Antarctic Peninsula: An Ice-Dependent Coastal Marine Ecosystem in Transition. Oceanography 26(3), 190-203.

Fu, C., Travers-Troletb, M., Velezc, L., Grüsse, A., Bundyh, A., Shannoni, L.J., et al. (2017). Risky business: The combined effects of fishing and changes in primary productivity on fish communities. Ecological Modelling 368, 265-276. https://doi.org/10.1016/j.ecolmodel.2017.12.003.

Grilly, E., Reid, K., Lenel, S., and Jabour, J. (2015). The price of fish: A global trade analysis of Patagonian (Dissostichus eleginoides) and Antarctic toothfish (Dissostichus mawsoni). Marine Policy 60, 186-196. https://doi.org/10.1016/j.marpol.2015.06.006.

Halpern, B.S., Walbridge, S., Selkoe, K.A., Kappel, C.V., Micheli, F., D'Agrosa, C., et al. (2008). A global map of human impact on marine ecosystems. Science 319(5865), 948-952. https://doi.org/10.1126/science.1149345.

Hofman, R. (2017). Historical Overview of Sealing, Whaling and the Krill Fishery in the Southern Ocean. Polar Record 53(1), 88-99.

Howard, B. (2013). John Kerry Urges Support for Ross Sea Antarctic Ocean Reserve. National Geographic Voices.

IPCC (2019). IPCC Special Report on the Ocean and Cryosphere in a Changing Climate, (eds.) H.-O. Pörtner, D.C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, A. Alegría, M. Nicolai, A. Okem, J. Petzold, B. Rama & N.M. Weyer.

Keohane, R., and Nye, J. (2011). Power and Interdependence Pearson.

Kock, K.-H. 1992. Antarctic Fish and Fisheries. Cambridge University Press, UK.

Liu, N., and Brooks, C.M. (2018). China's changing position towards marine protected areas in the Southern Ocean: Implications for future Antarctic governance. Marine Policy 94, 189-195. https://doi.org/10.1016/j.marpol.2018.05.011.

Miller, D., and Slicer, N.M. (2014). CCAMLR and Antarctic conservation: The leader to follow?, in Governance of Marine Fisheries and Biodiversity Conservation: Interaction and Coevolution, eds. S.M. Garcia, J. Rice & A. Charles. (West Sussex, UK: John Wiley & Sons, Ltd.).

New Zealand, Delegation of D.o.N. (2011). A Marine Protected Area Scenario by New Zealand for the Ross Sea Region. SC-CAMLR-XXX/10.

New Zealand, Delegation ofD.o.N. (2012). A proposal for the establishment of a Ross Sea region Marine Protected Area. CCAMLR-XXXI/16.

Nicol, S., Foster, J., and Kawaguchi, S. (2012). The fishery for Antarctic krill - recent developments. Fish and Fisheries 13(1), 30-40. https://doi.org/10.1111/j.1467-2979.2011.00406.x.

Olds, A.D., Pitt, K.A., Maxwell, P.S., Babcock, R.C., Rissik, D., and Connolly, R.M. (2014). Marine reserves help coastal ecosystems cope with extreme weather. Glob Chang Biol 20(10), 3050-3058. https://doi.org/10.1111/gcb.12606.

Österblom, H., Bodin, O., Sumaila, R., and Press, A.J. (2015). Reducing Illegal Fishing in the Southern Ocean: A Global Effort. Solutions 4(5), 72-79.

Österblom, H., and Folke, C. (2013). Emergence of Global Adaptive Governance for Stewardship of Regional Marine Resources. Ecology and Society 18(2). https://doi.org/10.5751/es-05373-180204.

Österblom, H., and Sumaila, U.R. (2011). Toothfish crises, actor diversity and the emergence of compliance mechanisms in the Southern Ocean. Global Environmental Change 21(3), 972-982. https://doi.org/10.1016/j.gloenvcha.2011.04.013.

Ostrom, E., and Walker, J. (2003). Trust & Reciprocity. New York: Russell Sage Foundation.

Pertierra, L.R., Santos-Martin, F., Hughes, K.A., Avila, C., Caceres, J.O., De Filippo, D., et al. (2021). Ecosystem services in Antarctica: Global assessment of the current state, future challenges and managing opportunities>. Ecosystem Services 49. https://doi.org/10.1016/j.ecoser.2021.101299.

Pinsky, M.L., and Mantua, N.J. (2014). Emerging adaptation approaches for climate-ready fisheries management. Oceanography 27(4), 146-159.

Protocol, E. (1991). The Protocol on Environmental Protection to the Antarctic Treaty.

Putnam, R.D. (1988). Diplomacy and Domestic Politics: The Logic of Two-Level Games. International Organization 42, 427-460.

Rintoul, S.R., Chown, S.L., DeConto, R.M., England, M.H., Fricker, H.A., Masson-Delmotte, V., et al. (2018). Choosing the future of Antarctica. Nature 558(7709), 233-241. https://doi.org/10.1038/s41586-018-0173-4.

Roberts, C.M., O'Leary, B.C., McCauley, D.J., Cury, P.M., Duarte, C.M., Lubchenco, J., et al. (2017). Marine reserves can mitigate and promote adaptation to climate change. Proc Natl Acad Sci U S A 114(24), 6167-6175. https://doi.org/10.1073/pnas.1701262114.

SC-CAMLR (2011). Report of the XXX Meeting of the CAMLR Scientific Committee.

SC-CAMLR (2013). Report of the First Intersessional Meeting of the Scientific Committee.

SC-CAMLR (2020). Report of the Thirty-Ninth Meeting of the CAMLR Scientific Committee.

Schofield, O., Ducklow, H., Martinson, D., Meredith, M., Moline, M., and Fraser, W. (2010). How do polar marine ecosystems respond to rapid climate change? Science 328(1520-1523), 1520-1523.

Shapley, D. (1986). The seventh continent: Antarctica in a resource age. Washington DC: Resources for the future, Inc.

Sharp, B.R., Parker, S., and Pinkerton, M. (2010). Bioregionalisation and Spatial Ecosystem Processes in the Ross Sea Region. CCAMLR-WG-EMM-10/30.

Smith, W.O., Ainley, D.G., and Cattaneo-Vietti, R. (2007). Trophic interactions within the Ross Sea continental shelf ecosystem. Philosophical Transactions of the Royal Society B: Biological Sciences 362(1477), 95-111. https://doi.org/10.1098/rstb.2006.1956.

Smith, W.O. Jr., D.G. Ainley, R. Cattaneo-Vietti and E.E. Hofmann. 2012. The Ross Sea continental shelf: Regional biogeochemical cycles, trophic interactions, and potential future changes. In: Antarctic Ecosystems: An Extreme Environment in a Changing World (A.D. Rogers, N.M. Johnston, E.J. Murphy and A. Clarke, Eds.). Chapter 7, Blackwell Publishing, London, pp. 213-242.

Smith, W.O. Jr., D.G. Ainley, K.R. Arrigo & M.S. Dinniman. 2014. The oceanography and ecology of the Ross Sea. Annual Review of Marine Science 6:469–487.

Tang, J. (2017). China's engagement in the establishment of marine protected areas in the Southern Ocean: From reactive to active. Marine Policy 75, 68-74. https://doi.org/10.1016/j.marpol.2016.10.010.

USA, Delegation of the (2011). An MPA Scenario for the Ross Sea Region. SC-CAMLR-XXX/9.

USA, Delegation of the (2012). A proposal for the Ross Sea region Marine Protected Area. CCAMLR-XXXI/40.

Weller, J.B. (2013). The Last Ocean. New York: Rizzoli.

White, M. (2010). 'Fish out of water: Hypocrisy on the high seas'. North & South July, 56-65.

Young, O. (2002). The Institutional Dilemmas of Environmental Change: Fit, Interplay and Scale. Cambridge, MA: MIT Press.

Young, O.R. (1999). The Effectiveness of International Environmental Regimes. Cambridge, MA: MIT Press.

Young, P. 2012. The Last Ocean. Fisheye Films, NZ.

8. Marine spatial planning in the age of climate change

Catarina Frazão Santos,[1] *Tundi Agardy, and Elena Gissi*

Marine spatial planning (MSP) is not a recent concept. The need to plan the use of the ocean emerged almost 40 years ago, in the 1980s, in both Australia and China. In 1981, the original zoning plan of the Great Barrier Reef Marine Park (GBRMP) in Australia was developed to regulate human activities and ensure the conservation of key marine areas (Day, 2002). Shortly after, in 1989, China started developing the idea of "marine functional zoning", a tool to address sea-use conflicts in national coastal and marine waters (Teng et al., 2019). Since then, the concept and practice of MSP have spread widely around the world. Formal MSP initiatives, extending from coastal waters to the open ocean, are under development in over 75 countries, from high to low latitudes and across almost all ocean basins (Ehler, 2021; Frazão Santos et al., 2019). On top of such global uptake, MSP will keep expanding in the coming decade, supported by a myriad of regional and international initiatives—e.g., the UNESCO MSP global program, the MACBIO project, or the European Union Directive on MSP (EU, 2014; MACBIO, 2018; UNESCO, 2021).

Because of the diversity of settings in which it is developed, MSP takes many forms and names depending on context—e.g., ocean planning, marine spatial management, comprehensive ocean zoning—each with nuanced meanings (Agardy, 2010; Katona et al., 2017). Still, MSP is commonly described as "a public process of analyzing and allocating the spatial and temporal distribution of human activities in marine areas to achieve ecological, economic, and social objectives that are usually specified through a political process" (Ehler & Douvere, 2009). Planning the ocean is indeed a continuous and interactive, future-oriented process that can offer the best means to address conflicts among ocean uses (such as fisheries, aquaculture, or shipping), and between uses and the ability of marine ecosystems to provide multiple goods and services (Agardy, 2010; Ehler & Douvere, 2009). For this reason, MSP has been increasingly highlighted as a vital tool to support ocean sustainability. It can also play a key role in supporting the achievement of global ocean governance goals, in particular the United Nations (UN) Sustainable Development Goals (Gissi et al., 2022; Ntona & Morgera, 2018), or the Aichi Biodiversity Targets from the UN Convention on Biological Diversity for those countries engaged in systematic conservation planning for marine protected areas (MPAs) site selection (UNEP, 2010).

Several conceptual and practical challenges, however, limit the effectiveness of developing and implementing MSP initiatives around the world (Frazão Santos et al., 2021). These range from *realpolitik* factors hindering MSP implementation, to the lack of integration of the social dimension, constraints in proper engagement of stakeholders, or challenges in achieving ocean health as opposed to simply allocating ocean space (Flannery et al., 2020; Kidd et al., 2020; Trouillet, 2020; Trouillet & Jay, 2021; Vaughan & Agardy, 2020). On top of all these challenges, and with a high potential to significantly exacerbate them, there is global climate change (Frazão Santos et al., 2016, 2020). As ocean warming keeps accelerating and the vulnerability of marine organisms

1 Departamento de Biologia Animal, Ciências ULisboa, Faculdade de Ciências da Universidade de Lisboa, https://orcid.org/0000-0001-6988-253X

 https://doi.org/10.11647/OBP.0395.08

keeps increasing (Duarte et al., 2020; IPCC, 2019, 2022), the benefits provided by the ocean will keep changing, and causing change in the way humans use the ocean. Areas that are most amenable to human activities today will likely be modified due to climate change in the near future, thus challenging established marine spatial plans. In order to respond to these changes and effectively support a sustainable and equitable use of the ocean, MSP will need to integrate climate-related knowledge and foresee adaptation pathways (Frazão Santos et al., 2020; Gissi et al., 2019). Under a changing ocean, we also need to ensure a paradigm shift towards MSP initiatives that truly support a healthy ocean, as without healthy and productive marine ecosystems we will not be able to ensure long-term socio-economic development and human wellbeing (Allison et al., 2020).

In this chapter, we aim to propose interdisciplinary solutions to marine conservation by exploring the opportunities and benefits of developing sustainable, equitable, and climate-smart MSP. To this purpose, here we highlight how the challenge of supporting marine conservation through MSP must be revised considering climate change; provide a glimpse on how MSP can be affected by changing marine social-ecological systems; and point ways to move towards the development of climate-smart marine spatial plans.

Making ocean use truly sustainable

Finding the right balance between socioeconomic development and environmental protection is not straightforward and has been one of the most striking and widespread challenges in MSP development (Frazão Santos et al., 2021; UNEP & GEF-STAP, 2014). It has been long acknowledged that MSP can lead to ocean sustainability by putting ecosystem-based management into practice at large scales (Ansong et al., 2017; Foley et al., 2010; Kirkfeldt, 2019). "Ecosystem-based" MSP processes begin by developing a plan to ensure ecosystem health; that is, establishing how to manage human uses to maintain biodiversity and ecosystem processes to the maximum extent possible. Only then do they move to the allocation of different maritime uses and activities in space and time (Frazão Santos et al., 2019). These initiatives consider environmental sustainability at the core of the entire planning process (Qiu & Jones, 2013) being based on a deep understanding of ecological processes, functions, value, and the delivery of ecosystem goods and services (Agardy, 2018; White et al., 2012). They look at marine ecosystems in a holistic way, linking them to coasts, estuaries, and watersheds (Kerr et al., 2014), and seek to find integrated solutions.

Ecosystem-based MSP also bears specific opportunities for marine conservation (Fraschetti et al., 2018; Katsanevakis et al., 2020). New instruments and regimes can be developed and implemented within the planning area, such as new MPAs (Agardy, 2018; Vaughan & Agardy, 2020). Indeed, applying systematic conservation planning tools in MSP can support the expansion of existing MPAs, or the creation of MPA networks that are "coherent, representative, and more robust at multiple spatial scales" (Rilov et al., 2020). Additionally, environmental assessments can be performed to understand the spatial distribution of the combined effects of multiple stressors on the marine environment (e.g., cumulative impact assessments) (Stelzenmüller et al., 2020).

However, in reality, all around the world MSP processes are more focused on nourishing the ocean economy than on incorporating ecological objectives or ensuring marine ecosystem health (Ansong et al., 2017; Fraschetti et al., 2018; Trouillet, 2020; Trouillet & Jay, 2021). Marine conservation is commonly perceived as one use of the ocean space—similar to fisheries or shipping—many times being a "weak voice" at the decision-making table and being limited to the inclusion of opportunistic MPAs in the planning area (Frazão Santos et al., 2019).

Links to non-marine systems are also largely ignored by marine planners, who fail to provide an integrated approach with strong connections between MSP, integrated coastal management, and watershed management (Kerr et al., 2014). Discussions on the long-term sustainability of these "integrated-use" approaches to MSP (Qiu & Jones, 2013) are old and far from being resolved, with a plethora of different interpretations and views on the topic (Agardy, 2010; Kyriazi et al., 2013). Yet, in light of the challenges from a changing climate (Duarte et al., 2020; IPCC, 2019, 2022), marine managers, planners and policymakers should take the chance to revisit the need for MSP initiatives that effectively support ocean health.

Under a changing ocean, we can no longer pretend to separate socioeconomic development from environmental protection, or coastal areas from the open ocean. An integrated approach, based on ecosystem health and with adaptive management driving constant amendment and improvement, is the only way forward to face climate-induced changes and reduce their impacts (IPCC, 2019; Tittensor et al., 2019). If they fail to ensure the ability of marine ecosystems to provide goods and services under a changing climate, or to consider land-based threats and solutions in ocean planning (e.g., agriculture run-off, nature-based solutions such as mangroves), MSP initiatives will consequently fail to support economic growth and sustainable development in the long term.

The need to go back to MSP inception and regain the original focus on ecosystem-based approaches (Merrie & Olsson, 2014; Rilov et al., 2020) is therefore unavoidable. This need has already been recognized internationally, for example, by the Marine Spatial Planning in Practice initiative convened by UNEP and the Secretariat of the Convention on Biological Diversity (UNEP & GEF-STAP, 2014) or, more recently, by the UNESCO's MSP Global Program, which aims to support the implementation of ecosystem-based MSP in practice (UNESCO, 2021). Still, a more generalized effort towards a paradigm shift is needed if we want to effectively move towards (truly) ecosystem-based, climate-smart MSP.

Combined effects of climate change on marine ecosystems, ocean uses and ocean planning

Anthropogenic climate change affects the ocean at global and local scales (Coll et al., 2020; IPCC, 2019), with climate-related impacts being felt all around the world (Halpern et al., 2015, 2019). Climate-related drivers such as ocean warming, acidification, or deoxygenation, are altering the physical, chemical and biological conditions of the ocean, affecting the composition, spatial structure, and functioning of entire marine ecosystems (IPCC, 2019; Sampaio et al., 2021). These changes in biotic and abiotic conditions will modify the delivery of the goods and services provided by marine ecosystems, in terms of both their spatial-temporal distribution and intensity, and this will in turn affect human wellbeing and livelihoods (Allison et al., 2020; Gattuso et al., 2015; Pecl et al., 2017). Indeed, human uses of the ocean that rely on such goods and services—such as fisheries, aquaculture, or tourism (Box 8.1 and Figure 8.1)—will be directly impacted by a changing ocean (Barange et al., 2018; Scott et al., 2019). For example, tourism is a major economic driver in more and more coastal areas worldwide, being a use that directly links a healthy environment to a healthy economy—especially any sort of nature-based tourism or development. It will be significantly affected by climate impacts depending on both the activity itself (e.g., whale watching, snorkeling, surfing) and the destination (e.g., temperate or tropical zones), with multiple social and economic consequences (Jones & Phillips, 2018; Scott et al., 2019).

Simultaneously, ocean uses that do not rely on marine species and habitats—such as shipping, renewable energy, or seabed mining—will also be affected by changing ocean conditions (Box 8.1 and Figure 8.1). This is the case when considering increased danger at sea (from extreme weather events) to both humans and infrastructures, changes in circulation patterns of winds and currents, or the opening up of new navigation routes and areas for exploitation (due to reduced ice cover) (Hauser et al., 2018; Heij & Knapp, 2015).

Box 1. Overview of climate change impacts on main ocean uses

Fisheries

From ocean warming to deoxygenation, changes in ocean currents and sea level rise, climate impacts will lead to shifts in the distribution, composition and productivity of fish stocks at a global scale, with considerable regional variations, which will induce changes in fisheries planning and management. The direct effect of warming on fish stocks, for example, results from physiological changes at individual level that ultimately affect populations, communities, and the functioning of ecosystems. At the same time, increased frequency of storms and other extreme weather events is expected not only to promote the loss of important breeding/nursery habitats, but also to intensify danger at sea, increasing vulnerability of fishing communities and fishing infrastructures (e.g., (Barange et al., 2014, 2018; Poloczanska et al., 2016; Rutterford et al., 2015; Somero, 2012).

Marine conservation

All drivers of change can affect ocean conservation. For example, distributional shifts may lead priority habitats and species to move beyond the limits of current protected areas (either inside, across or outside national borders). As well, cumulative impacts of ocean warming and acidification, together with changes in circulation patterns, are expected to alter the spatial scale of marine ecological connectivity. Conservation areas will thus need to be reorganized and redesigned if they are to ensure effectiveness and efficiency of ecosystems protection measures—e.g., areas that are closer together or larger in size, or with dynamic boundaries. Ocean warming, sea level rise and increased frequency of hurricanes and storms, are also expected to induce loss of key shallow-water habitats such as coral reefs (e.g., (Ainsworth et al., 2016; Coleman et al., 2017; Gormley et al., 2015; Keppel et al., 2015; Maxwell et al., 2020).

Aquaculture

This is another use that can be significantly affected by all climate drivers of change. Migration of optimal thermal conditions due to ocean warming can benefit cultivated species with wider optimal temperature ranges and higher thermal limits (e.g., increased metabolism and growth rates), while species with narrower optimal ranges and lower thermal limits are expected to suffer enhanced mortalities and a decline in productivity. As well, background conditions for particular cultures can be significantly affected by changes in food webs due to distributional shifts in primary production. Because aquaculture is limited to relatively "small" areas when compared to other ocean uses, and has unnaturally higher host densities, increased occurrence of infectious diseases (parasites, bacteria, viruses) can have significant deleterious impacts. Because of this narrower spatial scale, effects of harmful algal blooms in caged stocks will also be more severe than in fisheries which is of special relevance due to human health issues. Damage of infrastructures (e.g., rafts, lines or cages) and stock losses can also derive from more intense and frequent extreme events (e.g., Barange et al., 2014, 2018; Froehlich et al., 2018; Galappaththi et al., 2020; Reid et al., 2019).

Tourism

The extent to which marine tourism is dependent on climate change impacts is highly variable, depending on both the activity (e.g., whale watching, diving, snorkeling, surfing, sailing and recreational fishing) and the destination. Ocean warming effects in marine ecosystems, such as bleaching of coral reefs in tropical regions, can decrease demand for diving, snorkeling or underwater photography activities. Concomitantly small island nations (e.g., Caribbean region), being highly dependent on tourism as their major source of income, are significantly vulnerable to sea level rise and increased extreme events. Changes in circulation patterns (that affect surfing, windsurfing, kitesurfing, and sailing activities) or the increased emergence of new diseases (which can limit diving and swimming due to human health issues) are also expected to impact tourism (e.g., Jones & Phillips, 2018; Scott et al., 2012, 2019).

Shipping

Marine transportation is expected to be highly affected by modifications in the extent and thickness of sea-ice cover due to ocean warming. As a consequence, new navigable routes will be opened in the poles and shipping patterns will be globally modified. International transportation networks are also expected to be affected by relocation of seaports due to sea level rise, as well as by changes in circulation patterns (wind strength and wave height) and increased frequency of storms and other extreme events, which will influence the risk of shipping incidents (e.g., Becker et al., 2018; Heij & Knapp, 2015; Ng et al., 2018; Sardain et al., 2019).

Renewable energy

Ocean warming will open new areas for wind energy development, particularly in Arctic latitudes (due to declines in icing frequency and drifting sea ice), while sea level rise is expected to affect devices (wave or wind) that are moored in shallow waters. However, major impacts to marine renewable energy will come from changes in wind (speed and energy density) and wave patterns expected under future climate scenarios. Alongside, increased storm activity and other extreme events are likely to increase infrastructures survival risk and to limit maintenance procedures (e.g., Gernaat et al., 2021; Mróz et al., 2008; Sierra et al., 2017).

Seabed mining

Mining is directly vulnerable to extreme events (increased frequency of storms and hurricanes is expected to threaten mining infrastructures and increase danger at sea (limiting operational procedures). Infrastructures survival risk is of especial importance when hazardous substances are being drilled (e.g., oil products). Here, damaged infrastructures may represent major environmental disasters with widespread long-lasting effects. Mining will also be affected by the opening of new areas due to ocean warming, with corresponding social and ecological challenges (e.g., Edwards & Evans, 2017; Girard & Fisher, 2018; Ismail et al., 2014; Petrick et al., 2017).

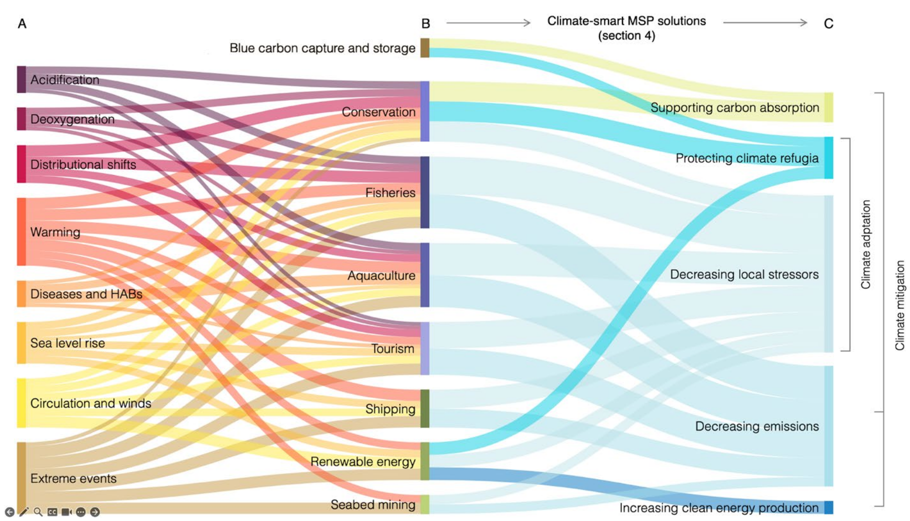


Fig. 8.1 Sankey diagram representing the links between (A) climate-related drivers of change, (B) key uses of the ocean space, and (C) climate adaptation and mitigation actions supported by applying climate-smart solutions to marine spatial planning (MSP).[2]

2 Climate-related drivers will affect key ocean uses through multiple pathways; some uses will be globally more affected than others, as summarized in Box 8.1. Simultaneously, when managed through MSP, ocean uses can contribute to several actions that promote both climate adaptation and climate mitigation (C), as detailed in Box 8.2. To ensure the operationalization of these pathways and actions, MSP must be developed within a climate-smart framework, as highlighted in Section 4. Weighting of A-B pathways is based on direct impact estimates from Frazão-Santos et al. (2016). B-C pathways are equally weighted per ocean use.

It is clear from Figure 8.1 that not all ocean uses will be affected in the same way, some being globally more sensitive to a changing ocean (e.g., fisheries, tourism) than others (e.g., renewable energy, mining). At the same time, we acknowledge that there will be considerable regional variations, as the same ocean use will have different socioeconomic importance and will be differently affected by climate factors depending on social, economic and geographical contexts (Frazão Santos et al., 2016). Finally, we need to acknowledge both "affected and affecting parties", that is, uses that have impacts on impact ecosystems or ecosystem flows, and those that depend on them.

Because allocating the distribution of ocean uses is at the core of MSP, together with managing conflicts and fostering compatibilities among such uses, MSP will be strongly affected by a changing climate—both directly and indirectly, at multiple scales and to varying degrees (Figure 8.2 and 8.3) (Frazão Santos et al., 2020).

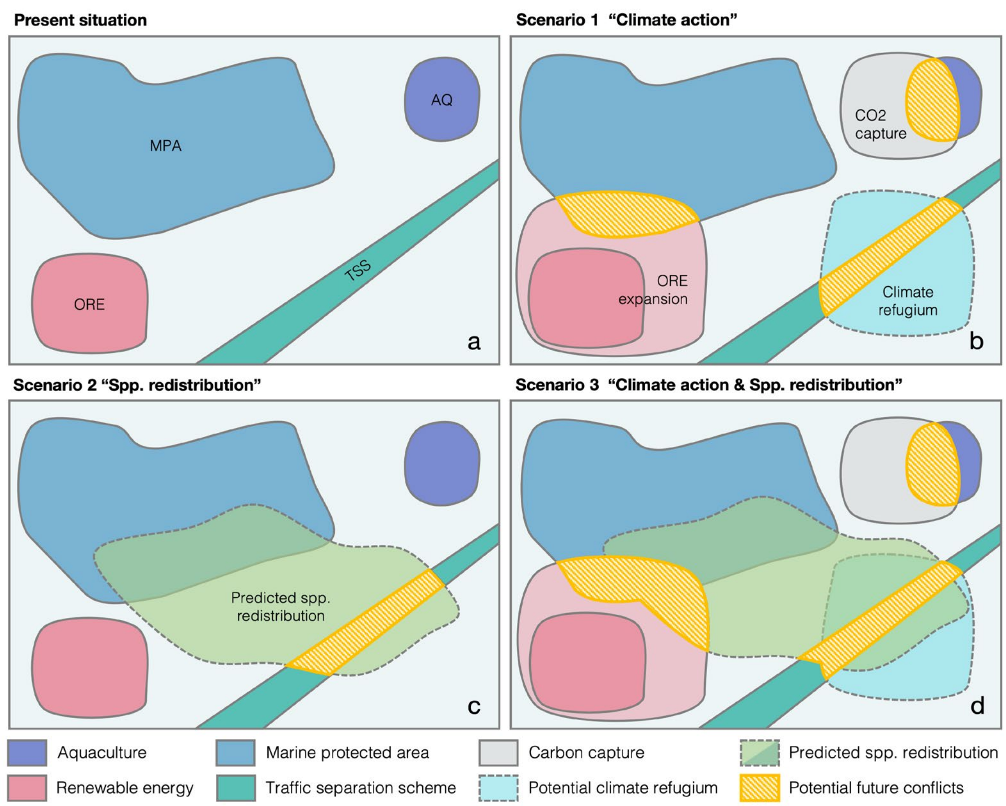


Fig. 8.2 Three imagined future spatial scenarios showcase how climate-related shifts and changing conditions may affect marine spatial plans.[3]

3 Here, there is no proposed preferred spatial scenario; scenarios are meant to highlight a range of potential futures, emphasizing the need to integrate climate knowledge and consider the dynamic nature of the ocean (and its users) to the maximum possible extent. New potential overlaps and spatial conflicts need to be assessed along the evolving future to identify the solutions that better balance trade-offs and respond to planning objectives and the policy context. (a) Present situation: Imagined present spatial use of a marine management area, with a marine protected area (MPA), aquaculture (AQ) and offshore renewable energy (ORE) developments, and a traffic separation scheme (TSS). (b) Scenario 1 "Climate action": New areas are assigned for renewable energy development and carbon capture and storage to support climate mitigation goals. Based on new evidence, scientists also identify a new area as a climate refugium, which can be later designated as an MPA. These changes can lead to potential spatial conflicts between existing and intended uses; yet, new synergies can also arise depending on the type of use/technology/ecosystem (e.g., floating ORE plants may not impact benthic ecosystems; seaweed culture operations may have productivity spillovers to the neighboring carbon capture area). (c) Scenario 2 "Species redistribution": Due to climate-induced shifts and changing ocean conditions, scientists anticipate that protected species will move beyond the boundaries of the existing MPA. The latter may lead to the loss of MPA effectiveness and potential new conflicts with maritime transportation. (d) Scenario 3 "Climate action & Species redistribution": In this imagined future, new uses are established, a potential climate refugium is identified, and

Fig. 8.3 Cartoons illustrating some of the challenges of adaptive, climate-smart marine spatial planning. The need for (a) dynamic conservation areas that change in space and time in response to changes in marine species and habitats, and (b) adaptive law and governance that respond to species on the move. (c) Multiple uses moving to previously unexploited areas. Cartoons by visual artist Bas Köhler (www.studiobaskohler.nl) originally published at PICES (2018) and Frazão Santos et al. (2020).

But the impacts of climate change will not act alone. They will be combined with local human stressors deriving from multiple human activities, both from terrestrial and marine origins, giving place to additive, synergistic, or antagonistic effects in marine ecosystems (Coll et al., 2020; Gissi et al., 2021; Stockbridge et al., 2020). A recent study reviewed these combined effects (Gissi et al., 2021), depicting over 50 local human stressors (e.g., land-based pollution, marine litter, ocean mining, industrial fisheries) and almost 30 climate-related factors (e.g., ocean acidification, sea level rise, temperature changes). Multiple combinations were considered, and results suggested that combined effects were context-dependent and variable among and within ecosystems. The study also showed that results vary with the level of ecological complexity. For example, while climate

protected species are projected to shift. Potential future conflicts are, thus, aggravated, highlighting the need for climate-smart marine spatial plans.

change generally intensifies the effects of local stressors at the species level, at the level of both trophic groups and ecosystems it can either intensify or mitigate the effects of local stressors—depending on the environmental conditions and the trophic groups involved (Gissi et al., 2021).

While understanding these combined effects can be complex, such understanding is fundamental to inform sustainable MSP processes. As stated in the IPCC special report on the ocean and the cryosphere (IPCC, 2019), there are medium levels of confidence that climate-induced changes in the ocean will "occur on spatial and temporal scales that may not align within existing governance structures and practices". There is thus a need for transformative governance, that is, approaches that are "integrative, inclusive, adaptive and pluralist" and address both the direct and indirect drivers of sustainability "including through transdisciplinary research and knowledge coproduction" (Lombard et al., 2023). At the same time, there is a pressing need to empower local communities (by co-developing and co-creating visions, knowledge, capacities, and solutions) to overcome drivers of unsustainability—and sustainable climate-smart MSP can play an important role in such transformations.

Moving towards adaptive, climate-smart MSP

It has been advocated that, when developed with explicit climate-related considerations, MSP can notably contribute to minimizing climate impacts, support adaptation actions and play a role in climate mitigation (Frazão Santos et al., 2020) (Box 8.2 and Figure 8.1). By contrast, excluding climate effects from the MSP agenda would certainly lead to plans that are maladaptive and inefficient in sustaining marine ecosystems and their use under climate change (Frazão Santos et al., 2020). Recent studies also show that while providing substantial benefits, climate-smart ocean plans may require a few trade-offs (Pinsky et al., 2020). Authors showed that myopic "present-only" plans (i.e., considering only the current geographic distribution of species) suffered substantial declines in effectiveness when evaluated against projections of future species habitat distributions. By contrast, proactive plans developed to meet conservation, fishing, and energy goals under both current and future species habitat distributions included only marginally more area (0% to 7%), representing small opportunity costs (Pinsky et al., 2020). As MSP operates in a changing ocean, properly addressing and integrating climate effects is therefore vital, not only to support a healthy ocean but to keep plans viable, relevant, and useful in the long term.

To date, climate change has been neglected as a key factor in the majority of MSP initiatives, with only few plans addressing its impacts in an operational way (Gissi et al., 2019; Rilov et al., 2020). While this might be the case for a variety of reasons (e.g., jurisdictional frameworks, initial costs, uncertainty), several pathways have already been pointed out as potential solutions to climate-proofing MSP (Frazão Santos et al., 2020).

In the Netherlands and the United Kingdom, for example, climate change is considered throughout the entire planning process, from setting planning objectives to monitoring (Rilov et al., 2020). In the Netherlands, sand extraction for coastal defense against sea level rise is a priority (climate adaptation), climate effects on fishing and aquaculture are being considered (re-distribution of species, fishing quotas, opportunities and threats with new species appearing), space is being allocated to wind energy and carbon storage (supporting mitigation), and weather extremes and rising sea levels will be taken into account when installing turbines. In the United Kingdom, MSP is also expected to help to mitigate climate change, and to support the implementation of adaptation measures. For example, MSP supports the diversification of the fishing industry to increase resilience, manage risks and maximize opportunities under a changing climate; and flexibility in planning is ensured by supporting boundary changes to improve resilience of MPAs when there is evidence that protected resources are moving or changing due to climate change (Rilov et al., 2020).

It is clear from these examples that a combination of key approaches is needed (Figure 8.4 and Box 8.2): first, knowledge of climate impacts is integrated to support the development of robust marine spatial plans; second, knowledge is used to take measures that support climate adaptation and mitigation actions; third, MSP is designed in ways that ensure adaptability and flexibility in the planning process itself. While these approaches (integrating climate knowledge, taking relevant actions, and promoting flexibility) are closely linked, they are not one and the same, and must be simultaneously pursued to effectively support climate-smart MSP (Figure 8.4 and Box 8.2).

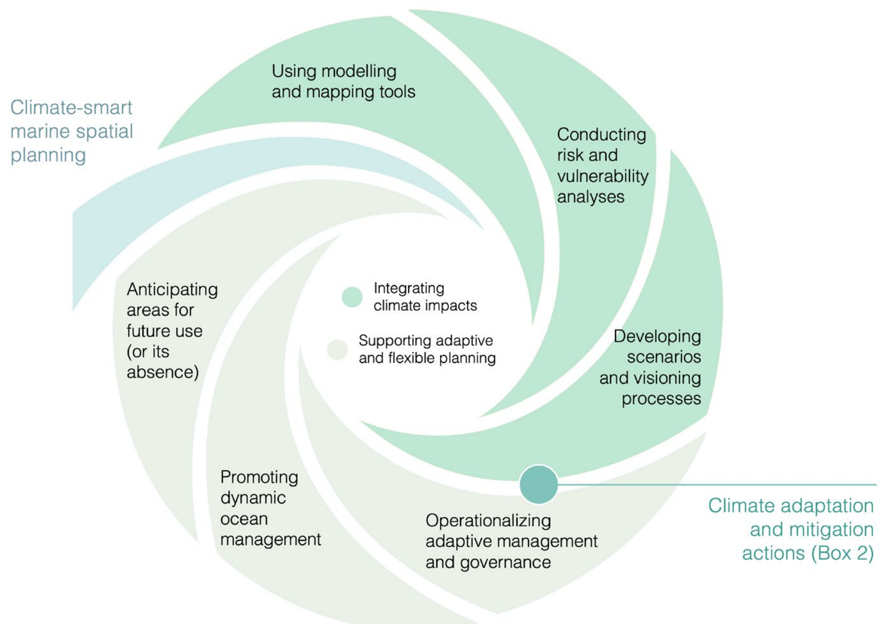


Fig. 8.4 Climate-smart solutions for marine spatial planning (MSP).[4]

Box 2. Implementing climate-smart solutions for Marine Spatial Planning

I. Integrating knowledge on climate impacts

Several mapping and modelling tools can be used to identify changes in ecosystem goods and services, and related human activities, over space and time. These can range from sectoral ones focused on a particular activity – such as aquaculture, shipping, or renewable energy (e.g., Froehlich et al., 2018; Pınarbaşı et al., 2019; Queirós et al., 2016; Sardain et al., 2019) – to more comprehensive, integrated ones. The latter include, for example, the Symphony tool or the ACCESS Program, designed specifically to support MSP in Sweden and in the Arctic, respectively (Edwards & Evans, 2017; Hammar et al., 2020). The benefits of using species distribution modelling to identify future areas to be included in MSP has also been recently demonstrated, and play a very important role in designing climate-smart ocean plans(Pinsky et al., 2020).

Knowledge on where the consequences of climate-induced spatial-temporal changes are most significant is also vital to inform MSP design under a changing ocean. This allows for the identification of key problematic areas, where climate adaptation and mitigation actions will be most needed. Practical examples of risk and vulnerability analyses include the analysis of social-ecological vulnerability of small-scale fisheries in Moorea (Thiault et al., 2018), the assessment of cumulative risk of human activities in

4 The climate-smart MSP cycle needs to articulate two main phases, the integration of knowledge on climate-related impacts into the planning process (e.g., condition review, scenario planning), and the subsequent promotion of adaptive and flexible planning (e.g., dynamic zoning, adaptive governance) to respond to identified changes. Between these two cyclically interconnected phases, sits the opportunity to support and implement climate adaptation and mitigation measures (Box 8.2 and Fig. 8.1). For example, knowledge gathered in the first phase can be used to establish the need to protect climate refugia, or the designation of areas for blue carbon ecosystems, while adaptive mechanisms can support the implementation of such actions, for instance through anticipatory zoning.

two planning regions in the United States (Wyatt et al., 2017), or the vulnerability of MSP and the blue economy to climate change in European coastal countries (Fernandes, 2021).

Results from all these analyses can be further used to support the development of sea-use scenarios and visioning processes in MSP, anticipating related conflicts and opportunities and allowing for more informed decision-making (Ehler & Douvere, 2009; Rilov et al., 2020). For example, in the Netherlands spatial-use scenarios were developed and integrated with alternative sea level rise scenarios, while the spatial vision experiment of Flanders Bays aimed to ensure protection against sea level rise (Ehler & Douvere, 2009; Rilov et al., 2020). Another example pertains to the western tropical Pacific Ocean, where optimistic and catastrophic climate scenarios were developed by stakeholders while establishing visions for MSP (Littaye et al., 2016).

II. Supporting climate adaptation and mitigation actions

Climate adaptation

When developed with explicit climate-related considerations, marine spatial planning can notably contribute to minimize climate impacts, and play an important role in supporting climate adaptation. First, MSP can provide for an integrated, cross-sectoral, systems approach to manage ocean use (Ehler & Douvere, 2009). Such approach is fundamental to deliver a holistic view of the management area, which is in turn essential to support climate adaptation actions, that is the adjustment of a system to current or expected climate impacts in order to increase its resilience and reduce adverse effects (IPCC, 2019, 2022).

Second, as human activities can be spatially managed through MSP to control local human stressors and pressures (e.g., pollution, over-fishing, habitat loss), MSP can support marine ecosystems resilience by regulating exacerbating effects from the combination of climate impacts and other local human stressors (Gissi et al., 2021). For example, spatially managing fisheries can help to counteract climate-related effects by reducing the risk of stock collapse (Voss et al., 2019), or by controlling catches on climate-induced shifting commercial species (Pinsky et al., 2020).

MSP can also support ecosystems resilience by allocating space to the protection of important marine species and habitats (Vaughan & Agardy, 2020), or by identifying and protecting areas that are relatively buffered from climate impacts, known as climate-change refugia (Johnson & Kenchington, 2019; Morelli et al., 2020). Indeed, including climate-change refugia in ocean plans has been identified as a promising approach to minimize climate impacts (Rilov et al., 2020).

Another pathway on how MSP can contribute to climate adaptation is by empowering human populations and increasing their social resilience to climate change. There is a need for transformative governance, and a greater empowerment of local communities to overcome identified challenges from climate change (IPCC, 2019). MSP can contribute to the latter by raising awareness on climate impacts, and fostering stakeholder's participation in identifying solutions (Littaye et al., 2016; Noble et al., 2019).

Climate mitigation

MSP can also contribute to reducing greenhouse gas emissions and, therefore, to climate mitigation. One of the ways it can do so is by supporting the expansion of marine renewable energy – promoting a more efficient allocation of space to the installation of wind, wave, and current energy developments, and decreasing conflicts and fostering compatibilities with other maritime activities – while controlling its environmental impacts (Kyriazi et al., 2016; Schupp et al., 2021; Yates & Bradshaw, 2018).

MSP can also contribute to climate mitigation by supporting blue carbon capture and storage (Ehler & Douvere, 2009). This can be done by allocating space to the conservation of blue carbon ecosystems, such as seagrass beds or kelp forests (Hoegh-Guldberg & et al., 2019; Smale et al., 2018), or by designating areas for ocean-based carbon dioxide removal initiatives (Ocean Visions, 2021; World Resources Institute, 2020).

Finally, as an area-based management tool, MSP could prioritize the attribution of spatial permits to ocean uses and activities that use eco-efficient technologies and power sources that tend toward zero emissions (Frazão Santos et al., 2020). Indeed, recent research highlights the potential for developing new propellers for shipping based on renewable energy (e.g., wind, hydrogen), or using alternative fuels and propulsion systems in fishing vessels (Cutcher, 2020; Gabrielii & Jafarzadeh, 2020; Julià et al., 2020). Ultimately, MSP could even limit the available space to polluting activities that do not engage in decreasing the rate of greenhouse gas emissions (Frazão Santos et al., 2020).

III. Promoting flexibility and adaptability

Using near real-time data, dynamic ocean management allows for the designation of management areas whose boundaries change in space and time in response to shifts in ocean resources and ocean uses (Maxwell et al., 2015, 2020) (Fig. 4). It provides flexibility, promotes increased adequacy and efficiency in ocean use (by supporting the development of human activities in more appropriate places) and narrows spatial-temporal requirements. Practical examples tend to be sectoral, such as fisheries management in the United States and Australia, offshore aquaculture operations in Tasmania, marine mammal protection in Canada and the United States, or mobile protected areas in the High Seas (e.g., Craig, 2012; Hazen et al., 2018; Maxwell et al., 2015, 2020).

Another way to foster flexibility is through anticipatory zoning. The a priori allocation of areas to particular ocean uses in the future (or their exclusion) in anticipation of climate effects allows responsible entities to avoid political and legal problems, and minimize conflicts beforehand (Coleman et al., 2017; Craig, 2012). For example, particular areas in the Arctic Ocean were closed to commercial fishing in anticipation of sea-ice loss, and preferred sand extraction zones were established in the Netherlands to support the protection of low-lying coastal areas against sea level rise (Edwards & Evans, 2017; Ehler & Douvere, 2009).

Other pathways include broader adaptive management and governance frameworks, where actions and strategies are continuously revised based on results that are obtained through performance monitoring and evaluation(Ehler, 2014; Stelzenmüller et al., 2021). Implementing these adaptive frameworks, however, implies the ability to incorporate change in governance and jurisdictional frameworks, which is not always straightforward (Craig et al., 2017). Still, a number of MSP initiatives have already undertaken one or more revision processes thus effectively completing the adaptive management cycle (e.g., Australia, Belgium, China) (Frazão Santos et al., 2020).

For example, species distribution modeling can determine that certain fish stocks will disappear from a planning area, causing the potential collapse of a particular fishery (Pinsky et al., 2018) (Step 1). Based on such knowledge, MSP may (or may not) take measures to foster adaptation mechanisms (Step 2), such as highlighting the need to engage fishermen in alternative livelihoods and allocating space to them (Step 3) — thus supporting social resilience and adaptive capacity to climate change (Thiault et al., 2020). Similarly, an analysis of the risk of coastal flooding can identify particularly sensitive areas, where no infrastructures should be installed (Step 1). Climate-smart MSP could further designate such areas to the development of nature-based solutions (e.g., mangroves or reefs), which not only minimize the risk of flooding and sea level rise, but also support carbon absorption (Menéndez et al., 2020; UNEP, 2014) (Steps 2 and 3).

In practice, solutions to integrate knowledge on climate change impacts into MSP include: (1) modeling and mapping tools, (2) risk and vulnerability assessments, and (3) sea-use scenarios (Box 8.2 and Figure 8.4).

These solutions can be integrated into the planning process in particular when defining and analyzing future conditions (Step 6 of the UNESCO guide on MSP), when developing the zoning plan (within Step 7), and during monitoring and evaluation stages (Step 9) (Ehler & Douvere, 2009).

As for promoting flexibility in planning, a number of practical solutions can also be implemented, namely: (1) dynamic ocean management, (2) anticipatory zoning, or (3) adaptive management and governance (Frazão Santos et al., 2020) (Box 8.2 and Figure 8.4). These should be integrated into the planning process from the very beginning, when organizing the process through pre-planning (e.g., setting boundaries, defining objectives and goals, developing contingency plans; Step 3 of the UNESCO guide on MSP), and especially when adapting the entire marine management process (Step 10) (Ehler & Douvere, 2009).

Climate adaptation and mitigation actions that can be supported through MSP range from measures to address ecosystem resilience, social resilience, the expansion of marine renewable energy developments, blue carbon capture and storage, or the use of alternative power sources in ocean uses such as shipping and fishing (Box 8.2 and Figure 8.1).

Final considerations

While the need to integrate climate change is far from being sufficiently considered and addressed in existing marine spatial plans, the benefits of developing MSP with "climate change in mind" are becoming increasingly evident (Frazão Santos et al., 2020; Pinsky et al., 2020; UNESCO and European Commission, 2022).

Since the ocean is changing, revisiting the role of marine conservation in MSP is also essential to support a healthy ocean and sustainable economic growth. MSP must prioritize ocean health objectives, understand ecological processes that support the delivery of ecosystem goods and services, recognize interlinkages, and implement suitable monitoring programs to evaluate not only environmental changes, but changes in human activities in the long-term (Rilov et al., 2020; Stelzenmüller et al., 2021). Indeed, the integration of climate-related knowledge into MSP will be a continuous, never-ending process (as planning itself is intended to be), requiring periodic assessments, re-visioning, and revised (adaptive) management—as new knowledge is acquired, or unforeseeable situations and unexpected challenges arise. Because climate-related impacts are accelerating change, it is also expected that the periodicity of such revisions and amendments will need to be more frequent.

Finally, as climate change affects all ecosystems on the planet (IPCC, 2019, 2022), the ocean will not be affected by marine drivers of change alone (e.g., ocean warming and acidification). It will also be strongly impacted by the degradation of linked habitats and ecological communities from transitional, coastal, freshwater, and land environments (e.g., climate change will affect run-off and hydrological balances, pollution inputs, and human demographic pressures in coastal areas, affecting ocean uses and the ability to plan for them sustainably). To be truly sustainable and climate-smart, MSP thus needs to adopt a true ecosystem-based management approach with a "systems-view", allowing decision-makers to perceive the "full picture" of what the ocean entails. This type of truly transformative thinking, and acting, is an imperative if we are to sustain oceans and secure human wellbeing in a climate-changed future.

As US Secretary of State John Kerry said, "You cannot protect the oceans without solving climate change and you can't solve climate change without protecting the oceans" (Kerry, 2021).

Acknowledgements

C.F.S. acknowledges funding from the Portuguese Foundation for Science and Technology under grant agreements No 2020.03704.CEECIND, PTDC/CTA-AMB/30226/2017, 2022.09067.PTDC, UIDB/04292/2020 and LA/P/0069/2020. E.G. acknowledges funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 893614-4. The study reflects only the authors' view. The Research Executive Agency and the European Commission are not responsible for any use that may be made of the information it contains.

References

Agardy, T. (2010). Ocean zoning: Making marine management more effective. Earthscan.

Agardy, T. (2018). Marine Protected Areas and Marine Spatial Planning. In Routledge handbook of ocean resources and management.

Ainsworth, T. D., Heron, S. F., Ortiz, J. C., Mumby, P. J., Grech, A., Ogawa, D., Eakin, C. M., & Leggat, W. (2016). Climate change disables coral bleaching protection on the Great Barrier Reef. Science, 352(6283), 338–342. https://doi.org/10.1126/science.aac7125

Allison, E., Kurien, J., Ota, Y., & et al. (2020). The Human Relationship with Our Ocean Planet. World Resources Institute.

Ansong, J., Gissi, E., & Calado, H. (2017). An approach to ecosystem-based management in maritime spatial planning process. Ocean & Coastal Management, 141, 65–81. https://doi.org/10.1016/j.ocecoaman.2017.03.005

Barange, M., Bahri, T., Beveridge, M., Cochrane, K., Funge-Smith, S., & Poulain, F. (2018). Impacts of climate change on fisheries and aquaculture: Synthesis of current knowledge, adaptation and mitigation options. FAO Technical Paper 627. Food and Agriculture Organization of the United Nations.

Barange, M., Merino, G., Blanchard, J. L., Scholtens, J., Harle, J., Allison, E. H., Allen, J. I., Holt, J., & Jennings, S. (2014). Impacts of climate change on marine ecosystem production in societies dependent on fisheries. Nature Climate Change, 4(3), 211–216. https://doi.org/10.1038/nclimate2119

Becker, A., Ng, A. K. Y., McEvoy, D., & Mullett, J. (2018). Implications of climate change for shipping: Ports and supply chains. WIREs Climate Change, 9(2). https://doi.org/10.1002/wcc.508

Coleman, M. A., Cetina-Heredia, P., Roughan, M., Feng, M., Sebille, E., & Kelaher, B. P. (2017). Anticipating changes to future connectivity within a network of marine protected areas. Global Change Biology, 23(9), 3533–3542. https://doi.org/10.1111/gcb.13634

Coll, M., Steenbeek, J., Pennino, M. G., Buszowski, J., Kaschner, K., Lotze, H. K., Rousseau, Y., Tittensor, D. P., Walters, C., Watson, R. A., & Christensen, V. (2020). Advancing Global Ecological Modeling Capabilities to Simulate Future Trajectories of Change in Marine Ecosystems. Frontiers in Marine Science, 7, 567877. https://doi.org/10.3389/fmars.2020.567877

Craig, R. K. (2012). Ocean governance for the 21st century: Making marine zoning climate change adaptable. Harvard Environmental Law Review, 36(2), 305–350.

Craig, R. K., Ruhl, J. B., Brown, E. D., & Williams, B. K. (2017). A proposal for amending administrative law to facilitate adaptive management. Environmental Research Letters, 12(7), 074018. https://doi.org/10.1088/1748-9326/aa7037

Cutcher, N. (2020). Winds of Trade: Passage to Zero-Emission Shipping. American Journal of Economics and Sociology, 79(3), 967–979. https://doi.org/10.1111/ajes.12331

Day, J. C. (2002). Zoning—Lessons from the Great Barrier Reef Marine Park. Ocean & Coastal Management, 45(2–3), 139–156. https://doi.org/10.1016/S0964-5691(02)00052-2

Duarte, C. M., Agusti, S., Barbier, E., Britten, G. L., Castilla, J. C., Gattuso, J.-P., Fulweiler, R. W., Hughes, T. P., Knowlton, N., Lovelock, C. E., Lotze, H. K., Predragovic, M., Poloczanska, E., Roberts, C., & Worm, B. (2020). Rebuilding marine life. Nature, 580(7801), 39–51. https://doi.org/10.1038/s41586-020-2146-7

Edwards, R., & Evans, A. (2017). The challenges of marine spatial planning in the Arctic: Results from the ACCESS programme. Ambio, 46(S3), 486–496. https://doi.org/10.1007/s13280-017-0959-x

Ehler, C. N. (2014). A Guide to Evaluating Marine Spatial Plans. UNESCO.

Ehler, C. N. (2021). Two decades of progress in Marine Spatial Planning. Marine Policy, 132, 104134. https://doi.org/10.1016/j.marpol.2020.104134

Ehler, C. N., & Douvere, F. (2009). Marine Spatial Planning: A step-by-step approach toward ecosystem-based management. Intergovernmental Oceanographic Commission and Man and the Biosphere Programme, UNESCO.

EU. (2014). Directive 2014/89/EU of the European Parliament and of the Council of 23 July 2014, Establishing a Framework for Maritime Spatial Planning. European Union.

Fernandes, M. (2021). The impact of climate change on marine spatial planning and the blue economy: Vulnerability assessment and implications for a sustainable use of the ocean services. Master of Science dissertation, University of Lisbon.

Flannery, W., Toonen, H., Jay, S., & Vince, J. (2020). A critical turn in marine spatial planning. Maritime Studies, 19(3), 223–228. https://doi.org/10.1007/s40152-020-00198-8

Foley, M. M., Halpern, B. S., Micheli, F., Armsby, M. H., Caldwell, M. R., Crain, C. M., Prahler, E., Rohr, N., Sivas, D., Beck, M. W., Carr, M. H., Crowder, L. B., Emmett Duffy, J., Hacker, S. D., McLeod, K. L., Palumbi, S. R., Peterson, C. H., Regan, H. M., Ruckelshaus, M. H., … Steneck, R. S. (2010). Guiding ecological principles for marine spatial planning. Marine Policy, 34(5), 955–966. https://doi.org/10.1016/j.marpol.2010.02.001

Fraschetti, S., Pipitone, C., Mazaris, A. D., Rilov, G., Badalamenti, F., Bevilacqua, S., Claudet, J., Carić, H., Dahl, K., D'Anna, G., Daunys, D., Frost, M., Gissi, E., Göke, C., Goriup, P., Guarnieri, G., Holcer, D., Lazar, B., Mackelworth, P., … Katsanevakis, S. (2018). Light and Shade in Marine Conservation Across European and Contiguous Seas. Frontiers in Marine Science, 5, 420. https://doi.org/10.3389/fmars.2018.00420

Frazão Santos, C., Agardy, T., Andrade, F., Barange, M., Crowder, L. B., Ehler, C. N., Orbach, M. K., & Rosa, R. (2016). Ocean planning in a changing climate. Nature Geoscience, 9(10), 730–730. https://doi.org/10.1038/ngeo2821

Frazão Santos, C., Agardy, T., Andrade, F., Calado, H., Crowder, L. B., Ehler, C. N., García-Morales, S., Gissi, E., Halpern, B. S., Orbach, M. K., Pörtner, H.-O., & Rosa, R. (2020). Integrating climate change in ocean planning. Nature Sustainability, 3(7), 505–516. https://doi.org/10.1038/s41893-020-0513-x

Frazão Santos, C., Agardy, T., Andrade, F., Crowder, L. B., Ehler, C. N., & Orbach, M. K. (2021). Major challenges in developing marine spatial planning. Marine Policy, 132, 103248. https://doi.org/10.1016/j.marpol.2018.08.032

Frazão Santos, C., Ehler, C. N., Agardy, T., Andrade, F., Orbach, M. K., & Crowder, L. B. (2019). Marine Spatial Planning. In World Seas: An Environmental Evaluation (pp. 571–592). Elsevier. https://doi.org/10.1016/B978-0-12-805052-1.00033-4

Froehlich, H. E., Gentry, R. R., & Halpern, B. S. (2018). Global change in marine aquaculture production potential under climate change. Nature Ecology & Evolution, 2(11), 1745–1750. https://doi.org/10.1038/s41559-018-0669-1

Gabrielii, C. H., & Jafarzadeh, S. (2020). Alternative fuels and propulsion systems for fishing vessels. SINTEF Energi AS.

Galappaththi, E. K., Ichien, S. T., Hyman, A. A., Aubrac, C. J., & Ford, J. D. (2020). Climate change adaptation in aquaculture. Reviews in Aquaculture, 12(4), 2160–2176. https://doi.org/10.1111/raq.12427

Gattuso, J.-P., Magnan, A., Billé, R., Cheung, W. W. L., Howes, E. L., Joos, F., Allemand, D., Bopp, L., Cooley, S. R., Eakin, C. M., Hoegh-Guldberg, O., Kelly, R. P., Pörtner, H.-O., Rogers, A. D., Baxter, J. M., Laffoley, D., Osborn, D., Rankovic, A., Rochette, J., … Turley, C. (2015). Contrasting futures for ocean and society from different anthropogenic CO_2 emissions scenarios. Science, 349(6243), aac4722. https://doi.org/10.1126/science.aac4722

Gernaat, D. E. H. J., de Boer, H. S., Daioglou, V., Yalew, S. G., Müller, C., & van Vuuren, D. P. (2021). Climate change impacts on renewable energy supply. Nature Climate Change, 11(2), 119–125. https://doi.org/10.1038/s41558-020-00949-9

Girard, F., & Fisher, C. R. (2018). Long-term impact of the Deepwater Horizon oil spill on deep-sea corals detected after seven years of monitoring. Biological Conservation, 225, 117–127. https://doi.org/10.1016/j.biocon.2018.06.028

Gissi, E., Fraschetti, S., & Micheli, F. (2019). Incorporating change in marine spatial planning: A review. Environmental Science & Policy, 92, 191–200. https://doi.org/10.1016/j.envsci.2018.12.002

Gissi, E., Maes, F., Kyriazi, Z., Ruiz-Frau, A., Santos, C. F., Neumann, B., Quintela, A., Alves, F. L., Borg, S., Chen, W., da Luz Fernandes, M., Hadjimichael, M., Manea, E., Marques, M., Platjouw, F. M., Portman, M. E., Sousa, L. P., Bolognini, L., Flannery, W., … Unger, S. (2022). Contributions of marine area-based management tools to the UN sustainable development goals. Journal of Cleaner Production, 330, 129910. https://doi.org/10.1016/j.jclepro.2021.129910

Gissi, E., Manea, E., Mazaris, A. D., Fraschetti, S., Almpanidou, V., Bevilacqua, S., Coll, M., Guarnieri, G., Lloret-Lloret, E., Pascual, M., Petza, D., Rilov, G., Schonwald, M., Stelzenmüller, V., & Katsanevakis, S. (2021). A review of the combined effects of climate change and other local human stressors on the marine environment. Science of The Total Environment, 755, 142564. https://doi.org/10.1016/j.scitotenv.2020.142564

Gormley, K. S. G., Hull, A. D., Porter, J. S., Bell, M. C., & Sanderson, W. G. (2015). Adaptive management, international co-operation and planning for marine conservation hotspots in a changing climate. Marine Policy, 53, 54–66. https://doi.org/10.1016/j.marpol.2014.11.017

Halpern, B. S., Frazier, M., Afflerbach, J., Lowndes, J. S., Micheli, F., O'Hara, C., Scarborough, C., & Selkoe, K. A. (2019). Recent pace of change in human impact on the world's ocean. Scientific Reports, 9(1), 11609. https://doi.org/10.1038/s41598-019-47201-9

Halpern, B. S., Frazier, M., Potapenko, J., Casey, K. S., Koenig, K., Longo, C., Lowndes, J. S., Rockwood, R. C., Selig, E. R., Selkoe, K. A., & Walbridge, S. (2015). Spatial and temporal changes in cumulative human impacts on the world's ocean. Nature Communications, 6(1), 7615. https://doi.org/10.1038/ncomms8615

Hammar, L., Molander, S., Pålsson, J., Schmidtbauer Crona, J., Carneiro, G., Johansson, T., Hume, D., Kågesten, G., Mattsson, D., Törnqvist, O., Zillén, L., Mattsson, M., Bergström, U., Perry, D., Caldow, C., & Andersen, J. H. (2020). Cumulative impact assessment for ecosystem-based marine spatial planning. Science of The Total Environment, 734, 139024. https://doi.org/10.1016/j.scitotenv.2020.139024

Hauser, D. D. W., Laidre, K. L., & Stern, H. L. (2018). Vulnerability of Arctic marine mammals to vessel traffic in the increasingly ice-free Northwest Passage and Northern Sea Route. Proceedings of the National Academy of Sciences, 115(29), 7617–7622. https://doi.org/10.1073/pnas.1803543115

Hazen, E. L., Scales, K. L., Maxwell, S. M., Briscoe, D. K., Welch, H., Bograd, S. J., Bailey, H., Benson, S. R., Eguchi, T., Dewar, H., Kohin, S., Costa, D. P., Crowder, L. B., & Lewison, R. L. (2018). A dynamic ocean management tool to reduce bycatch and support sustainable fisheries. Science Advances, 4(5), eaar3001. https://doi.org/10.1126/sciadv.aar3001

Heij, C., & Knapp, S. (2015). Effects of wind strength and wave height on ship incident risk: Regional trends and seasonality. Transportation Research Part D: Transport and Environment, 37, 29–39. https://doi.org/10.1016/j.trd.2015.04.016

Hoegh-Guldberg, O., & et al. (2019). The Ocean as a Solution to Climate Change: Five Opportunities for Action. World Resources Institute.

IPCC. (2019). Special Report on the Ocean and Cryosphere in a Changing Climate. Intergovernmental Panel on Climate Change.

IPCC. (2022). Climate Change Sixth Assessment Report 2022: Impacts, Adaptation and Vulnerability.

Ismail, Z., Kong, K. K., Othman, S. Z., Law, K. H., Khoo, S. Y., Ong, Z. C., & Shirazi, S. M. (2014). Evaluating accidents in the offshore drilling of petroleum: Regional picture and reducing impact. Measurement, 51, 18–33. https://doi.org/10.1016/j.measurement.2014.01.027

Johnson, D. E., & Kenchington, E. L. (2019). Should potential for climate change refugia be mainstreamed into the criteria for describing EBSAs? Conservation Letters, 12(4), e12634. https://doi.org/10.1111/conl.12634

Jones, A., & Phillips, M. (2018). Global climate change and coastal tourism: Recognizing problems, managing solutions, future expectations. CAB International.

Julià, E., Tillig, F., & Ringsberg, J. W. (2020). Concept Design and Performance Evaluation of a Fossil-Free Operated Cargo Ship with Unlimited Range. Sustainability, 12(16), 6609. https://doi.org/10.3390/su12166609

Katona, S., Polsenberg, J., Lowndes, J., Halpern, B. S., Pacheco, E., Mosher, L., Kilponen, A., Papacostas, K., Mora, A. G. G.-, Farmer, G., Mori, L., Andrews, O., Taei, S., & Carr, S. (2017). Navigating the seascape of ocean management: Waypoints on the voyage toward sustainable use [Preprint]. MarXiv. https://doi.org/10.31230/osf.io/79w2d

Katsanevakis, S., Coll, M., Fraschetti, S., Giakoumi, S., Goldsborough, D., Mačić, V., Mackelworth, P., Rilov, G., Stelzenmüller, V., Albano, P. G., Bates, A. E., Bevilacqua, S., Gissi, E., Hermoso, V., Mazaris, A. D., Pita, C., Rossi, V., Teff-Seker, Y., & Yates, K. (2020). Twelve Recommendations for Advancing Marine Conservation in European and Contiguous Seas. Frontiers in Marine Science, 7, 565968. https://doi.org/10.3389/fmars.2020.565968

Keppel, G., Mokany, K., Wardell-Johnson, G. W., Phillips, B. L., Welbergen, J. A., & Reside, A. E. (2015). The capacity of refugia for conservation planning under climate change. Frontiers in Ecology and the Environment, 13(2), 106–112. https://doi.org/10.1890/140055

Kerr, S., Johnson, K., & Side, J. C. (2014). Planning at the edge: Integrating across the land sea divide. Marine Policy, 47, 118–125. https://doi.org/10.1016/j.marpol.2014.01.023

Kerry, J. (2021). Special Guest Remarks at Ocean-climate Ambition Summit. https://www.state.gov/special-guest-remarks-at-ocean-climate-ambition-summit/.

Kidd, S., Calado, H., Gee, K., Gilek, M., & Saunders, F. (2020). Marine Spatial Planning and sustainability: Examining the roles of integration - Scale, policies, stakeholders and knowledge. Ocean & Coastal Management, 191, 105182. https://doi.org/10.1016/j.ocecoaman.2020.105182

Kirkfeldt, T. S. (2019). An ocean of concepts: Why choosing between ecosystem-based management, ecosystem-based approach and ecosystem approach makes a difference. Marine Policy, 106, 103541. https://doi.org/10.1016/j.marpol.2019.103541

Kyriazi, Z., Maes, F., & Degraer, S. (2016). Coexistence dilemmas in European marine spatial planning practices. The case of marine renewables and marine protected areas. Energy Policy, 97, 391–399. https://doi.org/10.1016/j.enpol.2016.07.018

Kyriazi, Z., Maes, F., Rabaut, M., Vincx, M., & Degraer, S. (2013). The integration of nature conservation into the marine spatial planning process. Marine Policy, 38, 133–139. https://doi.org/10.1016/j.marpol.2012.05.029

Littaye, A., Lardon, S., & Alloncle, N. (2016). Stakeholders' collective drawing reveals significant differences in the vision of marine spatial planning of the western tropical Pacific. Ocean & Coastal Management, 130, 260–276. https://doi.org/10.1016/j.ocecoaman.2016.06.017

Lombard, M., Clifford-Holmes, J., Goodall, V., Snow, B., Truter, H., Vrancken, P., Jones, P. J. S., Cochrane, K., Flannery, W., Hicks, C., Gipperth, L., Allison, E. H., Diz, D., Peters, K., Erinosho, B., Levin, P., Holthus, P., Nube Szephegyi, M., Awad, A., Golo, H. & Morgera, E. Principles for transformative ocean governance. Nature Sustainability, 6, 1587–1599 (2023). https://doi.org/10.1038/s41893-023-01210-9

MACBIO. (2018). Marine and Coastal Biodiversity Management in Pacific Island Countries. Http://macbio-pacific.info.

Maxwell, S. M., Gjerde, K. M., Conners, M. G., & Crowder, L. B. (2020). Mobile protected areas for biodiversity on the high seas. Science, 367(6475), 252–254. https://doi.org/10.1126/science.aaz9327

Maxwell, S. M., Hazen, E. L., Lewison, R. L., Dunn, D. C., Bailey, H., Bograd, S. J., Briscoe, D. K., Fossette, S., Hobday, A. J., Bennett, M., Benson, S., Caldwell, M. R., Costa, D. P., Dewar, H., Eguchi, T., Hazen, L., Kohin, S., Sippel, T., & Crowder, L. B. (2015). Dynamic ocean management: Defining and conceptualizing real-time management of the ocean. Marine Policy, 58, 42–50. https://doi.org/10.1016/j.marpol.2015.03.014

Menéndez, P., Losada, I. J., Torres-Ortega, S., Narayan, S., & Beck, M. W. (2020). The Global Flood Protection Benefits of Mangroves. Scientific Reports, 10(1), 4404. https://doi.org/10.1038/s41598-020-61136-6

Merrie, A., & Olsson, P. (2014). An innovation and agency perspective on the emergence and spread of Marine Spatial Planning. Marine Policy, 44, 366–374. https://doi.org/10.1016/j.marpol.2013.10.006

Morelli, T. L., Barrows, C. W., Ramirez, A. R., Cartwright, J. M., Ackerly, D. D., Eaves, T. D., Ebersole, J. L., Krawchuk, M. A., Letcher, B. H., Mahalovich, M. F., Meigs, G. W., Michalak, J. L., Millar, C. I., Quiñones, R. M., Stralberg, D., & Thorne, J. H. (2020). Climate-change refugia: Biodiversity in the slow lane. Frontiers in Ecology and the Environment, 18(5), 228–234. https://doi.org/10.1002/fee.2189

Mróz, A., Holnicki-Szulc, J., & Kärnä, T. (2008). Mitigation of ice loading on off-shore wind turbines: Feasibility study of a semi-active solution. Computers & Structures, 86(3–5), 217–226. https://doi.org/10.1016/j.compstruc.2007.01.039

Ng, A. K. Y., Andrews, J., Babb, D., Lin, Y., & Becker, A. (2018). Implications of climate change for shipping: Opening the Arctic seas. WIREs Climate Change, 9(2). https://doi.org/10.1002/wcc.507

Noble, M. M., Harasti, D., Pittock, J., & Doran, B. (2019). Linking the social to the ecological using GIS methods in marine spatial planning and management to support resilience: A review. Marine Policy, 108, 103657. https://doi.org/10.1016/j.marpol.2019.103657

Ntona, M., & Morgera, E. (2018). Connecting SDG 14 with the other Sustainable Development Goals through marine spatial planning. Marine Policy, 93, 214–222. https://doi.org/10.1016/j.marpol.2017.06.020

Ocean Visions. (2021). Ocean-Based Carbon Dioxide Removal. www.oceanvisions.org/task-force-ocean-cdr.

Pecl, G. T., Araújo, M. B., Bell, J. D., Blanchard, J., Bonebrake, T. C., Chen, I.-C., Clark, T. D., Colwell, R. K., Danielsen, F., Evengård, B., Falconi, L., Ferrier, S., Frusher, S., Garcia, R. A., Griffis, R. B., Hobday, A. J., Janion-Scheepers, C., Jarzyna, M. A., Jennings, S., … Williams, S. E. (2017). Biodiversity redistribution under climate change: Impacts on ecosystems and human well-being. Science, 355(6332), eaai9214. https://doi.org/10.1126/science.aai9214

Petrick, S., Riemann-Campe, K., Hoog, S., Growitsch, C., Schwind, H., Gerdes, R., & Rehdanz, K. (2017). Climate change, future Arctic Sea ice, and the competitiveness of European Arctic offshore oil and gas production on world markets. Ambio, 46(S3), 410–422. https://doi.org/10.1007/s13280-017-0957-z

PICES. (2018). The Effects of Climate Change on the World's Oceans – ECCWO-2018 Cartoons. https://meetings.pices.int/meetings/international/2018/climate-change.

Pinsky, M. L., Reygondeau, G., Caddell, R., Palacios-Abrantes, J., Spijkers, J., & Cheung, W. W. L. (2018). Preparing ocean governance for species on the move. Science, 360(6394), 1189–1191. https://doi.org/10.1126/science.aat2360

Pinsky, M. L., Rogers, L. A., Morley, J. W., & Frölicher, T. L. (2020). Ocean planning for species on the move provides substantial benefits and requires few trade-offs. Science Advances, 6(50), eabb8428. https://doi.org/10.1126/sciadv.abb8428

Pınarbaşı, K., Galparsoro, I., Depellegrin, D., Bald, J., Pérez-Morán, G., & Borja, Á. (2019). A modelling approach for offshore wind farm feasibility with respect to ecosystem-based marine spatial planning. Science of The Total Environment, 667, 306–317. https://doi.org/10.1016/j.scitotenv.2019.02.268

Poloczanska, E. S., Burrows, M. T., Brown, C. J., García Molinos, J., Halpern, B. S., Hoegh-Guldberg, O., Kappel, C. V., Moore, P. J., Richardson, A. J., Schoeman, D. S., & Sydeman, W. J. (2016). Responses of Marine Organisms to Climate Change across Oceans. Frontiers in Marine Science, 3. https://doi.org/10.3389/fmars.2016.00062

Qiu, W., & Jones, P. J. S. (2013). The emerging policy landscape for marine spatial planning in Europe. Marine Policy, 39, 182–190. https://doi.org/10.1016/j.marpol.2012.10.010

Queirós, A. M., Huebert, K. B., Keyl, F., Fernandes, J. A., Stolte, W., Maar, M., Kay, S., Jones, M. C., Hamon, K. G., Hendriksen, G., Vermard, Y., Marchal, P., Teal, L. R., Somerfield, P. J., Austen, M. C., Barange, M., Sell, A. F., Allen, I., & Peck, M. A. (2016). Solutions for ecosystem-level protection of ocean systems under climate change. Global Change Biology, 22(12), 3927–3936. https://doi.org/10.1111/gcb.13423

Reid, G., Gurney-Smith, H., Marcogliese, D., Knowler, D., Benfey, T., Garber, A., Forster, I., Chopin, T., Brewer-Dalton, K., Moccia, R., Flaherty, M., Smith, C., & De Silva, S. (2019). Climate change and aquaculture: Considering biological response and resources. Aquaculture Environment Interactions, 11, 569–602. https://doi.org/10.3354/aei00332

Rilov, G., Fraschetti, S., Gissi, E., Pipitone, C., Badalamenti, F., Tamburello, L., Menini, E., Goriup, P., Mazaris, A. D., Garrabou, J., Benedetti-Cecchi, L., Danovaro, R., Loiseau, C., Claudet, J., & Katsanevakis, S. (2020). A fast-moving target: Achieving marine conservation goals under shifting climate and policies. Ecological Applications, 30(1). https://doi.org/10.1002/eap.2009

Rutterford, L. A., Simpson, S. D., Jennings, S., Johnson, M. P., Blanchard, J. L., Schön, P.-J., Sims, D. W., Tinker, J., & Genner, M. J. (2015). Future fish distributions constrained by depth in warming seas. Nature Climate Change, 5(6), 569–573. https://doi.org/10.1038/nclimate2607

Sampaio, E., Santos, C., Rosa, I. C., Ferreira, V., Pörtner, H.-O., Duarte, C. M., Levin, L. A., & Rosa, R. (2021). Impacts of hypoxic events surpass those of future ocean warming and acidification. Nature Ecology & Evolution, 5(3), 311–321. https://doi.org/10.1038/s41559-020-01370-3

Sardain, A., Sardain, E., & Leung, B. (2019). Global forecasts of shipping traffic and biological invasions to 2050. Nature Sustainability, 2(4), 274–282. https://doi.org/10.1038/s41893-019-0245-y

Schupp, M. F., Kafas, A., Buck, B. H., Krause, G., Onyango, V., Stelzenmüller, V., Davies, I., & Scott, B. E. (2021). Fishing within offshore wind farms in the North Sea: Stakeholder perspectives for multi-use from Scotland and Germany. Journal of Environmental Management, 279, 111762. https://doi.org/10.1016/j.jenvman.2020.111762

Scott, D., Hall, C. M., & Gössling, S. (2019). Global tourism vulnerability to climate change. Annals of Tourism Research, 77, 49–61. https://doi.org/10.1016/j.annals.2019.05.007

Scott, D., Simpson, M. C., & Sim, R. (2012). The vulnerability of Caribbean coastal tourism to scenarios of climate change related sea level rise. Journal of Sustainable Tourism, 20(6), 883–898. https://doi.org/10.1080/09669582.2012.699063

Sierra, J. P., Casas-Prat, M., & Campins, E. (2017). Impact of climate change on wave energy resource: The case of Menorca (Spain). Renewable Energy, 101, 275–285. https://doi.org/10.1016/j.renene.2016.08.060

Smale, D. A., Moore, P. J., Queirós, A. M., Higgs, N. D., & Burrows, M. T. (2018). Appreciating interconnectivity between habitats is key to blue carbon management. Frontiers in Ecology and the Environment, 16(2), 71–73. https://doi.org/10.1002/fee.1765

Somero, G. N. (2012). The Physiology of Global Change: Linking Patterns to Mechanisms. Annual Review of Marine Science, 4(1), 39–61. https://doi.org/10.1146/annurev-marine-120710-100935

Stelzenmüller, V., Coll, M., Cormier, R., Mazaris, A. D., Pascual, M., Loiseau, C., Claudet, J., Katsanevakis, S., Gissi, E., Evagelopoulos, A., Rumes, B., Degraer, S., Ojaveer, H., Moller, T., Giménez, J., Piroddi, C., Markantonatou, V., & Dimitriadis, C. (2020). Operationalizing risk-based cumulative effect assessments in the marine environment. Science of The Total Environment, 724, 138118. https://doi.org/10.1016/j.scitotenv.2020.138118

Stelzenmüller, V., Cormier, R., Gee, K., Shucksmith, R., Gubbins, M., Yates, K. L., Morf, A., Nic Aonghusa, C., Mikkelsen, E., Tweddle, J. F., Pecceu, E., Kannen, A., & Clarke, S. A. (2021). Evaluation of marine spatial planning requires fit for purpose monitoring strategies. Journal of Environmental Management, 278, 111545. https://doi.org/10.1016/j.jenvman.2020.111545

Stockbridge, J., Jones, A. R., & Gillanders, B. M. (2020). A meta-analysis of multiple stressors on seagrasses in the context of marine spatial cumulative impacts assessment. Scientific Reports, 10(1), 11934. https://doi.org/10.1038/s41598-020-68801-w

Teng, X., Zhao, Q., Zhang, P., Liu, L., Dong, Y., Hu, H., Yue, Q., Ou, L., & Xu, W. (2019). Implementing marine functional zoning in China. Marine Policy, 103484. https://doi.org/10.1016/j.marpol.2019.02.055

Thiault, L., Gelcich, S., Marshall, N., Marshall, P., Chlous, F., & Claudet, J. (2020). Operationalizing vulnerability for social–ecological integration in conservation and natural resource management. Conservation Letters, 13(1). https://doi.org/10.1111/conl.12677

Thiault, L., Marshall, P., Gelcich, S., Collin, A., Chlous, F., & Claudet, J. (2018). Space and time matter in social-ecological vulnerability assessments. Marine Policy, 88, 213–221. https://doi.org/10.1016/j.marpol.2017.11.027

Tittensor, D. P., Beger, M., Boerder, K., Boyce, D. G., Cavanagh, R. D., Cosandey-Godin, A., Crespo, G. O., Dunn, D. C., Ghiffary, W., Grant, S. M., Hannah, L., Halpin, P. N., Harfoot, M., Heaslip, S. G., Jeffery, N. W., Kingston, N., Lotze, H. K., McGowan, J., McLeod, E., … Worm, B. (2019). Integrating climate adaptation and biodiversity conservation in the global ocean. Science Advances, 5(11), eaay9969. https://doi.org/10.1126/sciadv.aay9969

Trouillet, B. (2020). Reinventing marine spatial planning: A critical review of initiatives worldwide. Journal of Environmental Policy & Planning, 22(4), 441–459. https://doi.org/10.1080/1523908X.2020.1751605

Trouillet, B., & Jay, S. (2021). The complex relationships between marine protected areas and marine spatial planning: Towards an analytical framework. Marine Policy, 127, 104441. https://doi.org/10.1016/j.marpol.2021.104441

UNEP. (2010). The Strategic Plan for Biodiversity 2011-2020 and the Aichi Biodiversity Targets. UNEP/CBD/COP/DEC/X/2. United Nations Environment Programme, Conference of the Parties to the Convention on Biological Diversity.

UNEP. (2014). The importance of mangroves to people: A call to action. United Nations Environment Programme World Conservation Monitoring Centre.

UNEP, & GEF-STAP. (2014). Marine Spatial Planning in Practice – Transitioning from Planning to Implementation. An Analysis of Global Marine Spatial Planning Experiences. United Nations Environment Programme, Scientific and Technical Advisory Panel of the Global Environment Facility.

UNESCO. (2021). MSPglobal Program. Intergovernmental Oceanographic Commission, United Nations Educational, Scientific and Cultural Organization. www.mspglobal2030.org.

UNESCO and European Commission. (2022). Updated Joint Roadmap to accelerate Marine/Maritime Spatial Planning processes worldwide: MSProadmap (2022-2027). Intergovernmental Oceanographic Commission, United Nations Educational, Scientific and Cultural Organization.

Vaughan, D., & Agardy, T. (2020). Marine protected areas and marine spatial planning – allocation of resource use and environmental protection. In Marine Protected Areas (pp. 13–35). Elsevier. https://doi.org/10.1016/B978-0-08-102698-4.00002-2

Voss, R., Quaas, M. F., Stiasny, M. H., Hänsel, M., Stecher Justiniano Pinto, G. A., Lehmann, A., Reusch, T. B. H., & Schmidt, J. O. (2019). Ecological-economic sustainability of the Baltic cod fisheries under ocean warming and acidification. Journal of Environmental Management, 238, 110–118. https://doi.org/10.1016/j.jenvman.2019.02.105

White, C., Halpern, B. S., & Kappel, C. V. (2012). Ecosystem service tradeoff analysis reveals the value of marine spatial planning for multiple ocean uses. Proceedings of the National Academy of Sciences, 109(12), 4696–4701. https://doi.org/10.1073/pnas.1114215109

World Resources Institute. (2020). Leveraging the Ocean's Carbon Removal Potential. www.wri.org/insights/leveraging-oceans-carbon-removal-potential.

Wyatt, K. H., Griffin, R., Guerry, A. D., Ruckelshaus, M., Fogarty, M., & Arkema, K. K. (2017). Habitat risk assessment for regional ocean planning in the U.S. Northeast and Mid-Atlantic. PLOS ONE, 12(12), e0188776. https://doi.org/10.1371/journal.pone.0188776

Yates, K. L., & Bradshaw, C. (2018). Offshore energy and marine spatial planning. Routledge.

Innovative Pathways to Solutions

In this portion of the book, we sample emerging approaches to *Navigating Our Way to Solutions in Marine Conservation*. These chapters present innovative approaches that emerge from the social sciences and natural sciences, but often combine the two perspectives to propose novel pathways. Most of what appears in the following chapters is less than ten years in development and is still rapidly evolving. But these ideas are already being widely adopted as ways to understand fundamental dynamics and provide innovative solutions.

Nicole M. Ardoin, Ryan J. O'Connor, and Alison W. Bowers. In the social sciences, the concept of "place" plays a large role in how humans relate to their environment. History and culture, as well as nuances of human behavior, often revolve around a person's sense of place and belonging. Rather than assuming people are separate from nature, as is common in western science, this approach views people as fully engaged in nature. By probing these connections between people and place, one can foster the engagement of individuals and their communities in characterizing problems and in framing pathways to solutions that can promote sustainability in marine socio-ecological systems. Deep scholarship and well-developed case studies, presented here, support this emerging thinking.

Xavier Basurto outlines the current thinking and empirical data supporting this innovative field. He recently led *Illuminating Hidden Harvests* for the Food and Agriculture Organization of the United Nations (FAO). This approach fully integrates natural science, social science, and governance to map pathways to solutions in these complex social-ecological systems.

Collin J. Closek, Louw Claassens, and Helen J. Killeen. Over the last 10+ years, rapid increases in technological approaches to the assessment of environmental DNA (eDNA), and even more rapid declines in costs for sampling and sequencing eDNA and eRNA, have opened a whole new door for employing this amazing molecular technology to assess biodiversity and dynamics. Closek et al. walk us through these developments and point to how these ever more available methods could accelerate key research and allow many scholars and practitioners to address questions that were previously inaccessible. Research into environmental DNA opens new fundamental science doors and allows us to probe key conservation issues with speed and accuracy. The authors detail the current methods and point to potential future applications.

Stephanie J. Green. Understanding the dynamics of marine food webs—who eats whom and where—is challenging science. Historically, it has been primarily empirical, sampling prey distributions and characterizing diets of predators through tedious and slow sample processing. We usually describe what food webs used to be like and how we think they functioned in the past. But to predict the structure and function of marine food webs under climate change, this post-hoc approach is doomed to failure. We know both predators and prey are on the move, so when and under what circumstances they will encounter each other is challenging. And knowing what novel predators will eat from novel prey assemblages is a challenge. Here, Green offers new trait-based tools to aid conservation planning for predicted predator range shifts.

Elliott L. Hazen, Briana Abrahms, Hannah Blondin, Kylie Scales and Heather Welch also address managing marine ecosystems under climate variation from seasonal cycles, such as the El Niño-La Niña cycles and directional climate change. In pelagic systems, predators and prey move, but so also do people, including fishermen and shippers. Because all this movement overlays an "ocean in motion", we must recognize these dynamics in order to reduce spatio-temporal conflicts. Bycatch of marine megafauna in fisheries, or ship strikes on whales, require a deep understanding of the relationship between environmental variation and animal movement. But we must also understand how environmental variation alters the behavior of people pursuing their living on the sea. The authors introduce exciting new scientific and analytical frameworks that set the stage for the emerging field of dynamic ocean management.

9. Exploring how place connections support sustainability solutions in marine socio-ecological systems

Nicole M. Ardoin,[1] *Ryan J. O'Connor, Alison W. Bowers*

Marine conservation plays a vital role in creating a future where people and nature thrive. The ocean drives life-sustaining water cycles, serves as a direct carbon sink, protects coastal areas, and offers shelter and habitat to countless plants and animals. As a venue for the global economy, the ocean provides food, medicine, resources, minerals, transportation, and recreational opportunities (Sandifer & Sutton-Grier, 2014). The global ocean system also bears cultural importance and, for many communities, is a critical part of their history, identity, mythology, and daily customs (Rock et al., 2020). Given that 71% of the planet's surface is covered by seawater and more than 40% of the global population lives within 200km of a coast (Visbeck, 2018), our collective work toward a sustainable future cannot ignore the global ocean, the many ways people interact with it, and how those interactions are under threat.

The changing climate will alter ocean circulation patterns at large scales (Meehl et al., 2007), shifting how marine ecosystems are connected and potentially limiting the effectiveness of human institutions at protecting them (Lima et al., 2021). Similar risks exist beyond ocean-climate interactions: pollution, biodiversity loss, spread of invasive species, and overfishing threaten the sustainability of future ocean ecosystem services. In response, global leaders and decision makers have highlighted the need to protect and conserve marine environments. In 2022, representatives from 188 governments approved the Kunming-Montreal Global Biodiversity Framework, which includes a goal to protect 30% of degraded coastal and marine ecosystems by 2030 (UN Environment Programme, 2022). The World Database on Protected Areas (UNEP-WCMC & IUCN, 2024) estimates 8.16% of the global ocean is currently protected—a long way from the goal of 30% protection by 2030.

To meet goals such as those set by the international community, marine conservationists apply knowledge of marine environments to protect the global ocean and its inhabitants from exploitation and harm. Traditionally, marine conservation has prioritized knowledge and approaches from conventional natural sciences (Arbo et al., 2018; Bennett, 2019) over social science methodologies that center human experience. For example, while researchers and managers of marine protected areas (MPAs) have attempted to involve various perspectives through community participation, conventional science and management often retain power in these processes, and local perspectives rarely get an equal voice (O'Connor et al., 2024).

Mirroring a trend in related fields such as terrestrial biological conservation, environmental management, and sustainability science, some marine conservationists have adopted broader, interdisciplinary perspectives

1 Woods Institute for the Environment at Stanford University, https://orcid.org/0000-0002-3290-8211

 https://doi.org/10.11647/OBP.0395.09

and engaged in synthesis-driven research that emphasizes the interdependence of human societies and the natural environment (Bennett, 2019; Halpern et al., 2023). Socio-ecological systems (SES) framing represents one way that scientists and practitioners have worked to bridge the ecological and social dimensions (Anderies et al., 2004; Berkes & Folke, 1998; Ostrom, 2009). Employed in an array of related fields (e.g., environmental sciences, biology, agriculture, economics, and engineering [Colding & Barthel, 2019]), including marine conservation (Drakou et al., 2017; Refulio-Coronado et al., 2021), the SES framework emphasizes that the interdependence of society and nature requires problem solving that explores, understands, and engages with people, ecosystems, and the interactions among them.

Some researchers, however, have voiced concern related to the difficulty of applying the SES framework in practice and the lack of standardization and operationalization among its constituent variables (Colding & Barthel, 2019; Herrero-Jáuregui et al., 2018). Rather than rejecting the SES framework or emphasizing what is missing, in this chapter we build on its underlying philosophy by joining other researchers who have highlighted the concept of sense of place in socio-ecological systems (Duggan et al., 2024; Masterson et al., 2017). In reference to ocean environments, however, van Putten et al. (2018, p. 1) has suggested, "marine research and management have until recently largely neglected the critically important role of 'sense of place,' and its role in influencing the success and efficacy of management interventions." Drawing from the SES framework, we champion the emerging and novel pathway of exploring the construct of "place" as a vehicle for integrating the social and ecological dimensions of marine environments to enhance marine conservation (Masterson et al., 2017). We present a conceptual model suggesting how place connections can be leveraged and enhanced to help navigate toward sustainability solutions in marine conservation.

Research on place connections in marine conservation

Although the definition of place is often tied to the physical environment—the New Oxford American Dictionary (McKean, 2005), for example, defines place as "a particular position or point in space"—social scientists frequently envisage place as socially constructed (Masterson et al., 2017; Stedman, 2003). It is through this vantage point that place begins to take on meaning exceeding the biophysical and is imbued with a connection by and to the people who interact with it (Tuan, 1977; Cresswell, 2015). When place is interpreted beyond physical boundaries to include people's perceptions, relationships, histories, values, desires, emotions, and more, it provides a powerful opportunity to acknowledge and leverage socio-ecological integration and promote place-protective behaviors.

Social scientists (e.g., psychologists, sociologists, anthropologists, political scientists, geographers) have a rich history with the construct of place (see Box 9.1). Reflecting an interdisciplinary grounding, place theories have been applied to research and practice in natural resources and environmental management, among other fields (Williams, 2008). One fruitful strand of such work has examined the ways in which place connections, via constructs such as place attachment, sense of place, and place identity (Lewicka, 2011), impact environmental attitudes, values, and behaviors (Ardoin, 2014). Several research reviews have documented support for the idea that higher levels of place attachment may lead to pro-environmental behaviors (Dang & Weiss, 2021; Daryanto & Song, 2021). In a review of how the study of sense of place relates to SES research, Masterson et al. (2017) discuss the role of sense of place in ecosystem stewardship and adaptation to changes in socio-ecological systems. This research offers implications for those involved with the conservation and management of natural areas as they work to educate, communicate, and engage with the people in those places.

Box 9.1

Defining Place and Related Terms

The academic discussion around place crosses many fields and, although rich and thought-provoking, can be difficult to follow, understand, and synthesize. While exploring the nuance and debates of place research is beyond the scope of this chapter, we encourage readers to delve into the subject through the many the foundational and summative works on place (e.g., Altman & Low, 1992; Cresswell, 2015; Lewicka, 2011; Masterson et al., 2017; Raymond et al., 2017; Stedman, 2002; Tuan, 1977). For the purposes of this chapter, we conceptualize **place** as any physical space given meaning through its relationships with living things (Cresswell, 2015). Places in marine environments may include a coral reef frequented by divers, a coastal fishing village, or a popular surf spot. As Tuan (1977, p. 6) writes, "What starts as undifferentiated space becomes place as we get to know it better and endow it with value." **Sense of place** is often used as a term to describe human connections to place (Raymond et al., 2017) and is seen as subsuming overlapping yet distinct constructs such as place attachment, place identity, and place meaning (Masterson et al., 2017). Surfers may develop a strong sense of place for their favorite surf spot due to the feelings they get when surfing there, the relationships they develop with fellow surfers, their knowledge of the place's geography, and their appreciation for its beauty. When we refer to research on place attachment, we invoke a broad definition of that term, envisioning **place attachment** as the emotional connections between a person and a place (Raymond et al., 2017). A person who has grown up in a coastal town may demonstrate positive place attachment based on strong emotional bonds they develop with their local community and place. Throughout this chapter, we use the term **place connections** to refer to any of the relationships people develop with a place. We conceptualize place connections and sense of place as similar concepts, but use the term "place connections" for simplicity and to avoid delving into more theoretical discussions about differentiations among terms.

Although the study of place is a large area of research spanning many fields, researchers have noted a tendency to focus on terrestrial environments (Wynveen et al., 2012). Despite this narrow focus, some place-based research does exist related to marine environments, audiences, and topics. Researchers, for example, have investigated the role of place in island and coastal geographies. Cheng and Wu (2015) surveyed visitors to the Penghu Islands in Taiwan to explore the relationship among environmental knowledge, environmental sensitivity, place attachment, and environmental behavior. After developing and administering a place attachment index in flood-prone coastal communities in the United States, Bukvic et al. (2022) reported higher levels of place attachment in rural coastal areas when compared to urban coastal areas and discussed the implications for the relocation of communities at risk of flooding. To explore the link between scale of environmental action and scale of place connections, Ardoin (2014) conducted case-study research at three sites, including an island ecoregion (the Galápagos Islands) and a coastal ecoregion (Chesapeake Bay in the United States). Researchers have also focused on specific human populations in marine environments. Interview data with fishers and non-fishers helped Urquhart and Acott (2013) investigate place attachment and place identity in an English coastal town, with the authors suggesting place connections have implications for fisheries and marine policies. Waiti and Awatere (2019) used survey and interview data to understand Māori surfers' sense of place and also highlighted important implications for marine conservation. Place-related research in marine and coastal environments continues to expand (e.g., Buchan et al., 2024; Conley & Diamond, 2024; Fudge et al., 2023; Leviston et al., 2023; O'Neill & Graham, 2016; Reineman & Ardoin, 2018) providing a foundation for research and practice predicated on the SES perspective that honors the interdependence of the biophysical and social dimensions.

Place-based approaches in marine conservation frequently emphasize spatial dimensions, as demonstrated in approaches such as MPAs, place-based ecosystem management, marine spatial planning (Frazão Santos et al. Chapter 8), and other effective area-based conservation measures (OECMs; di Sciara et al., 2016; Diz et al., 2018; Young et al., 2007). Adopting place-based approaches with a more integrated view of place, one that considers the physical and social space, can help address obstacles in marine conservation research and practice. One of the challenges in studying the global ocean system, for example, is its vastness and remoteness. Additionally, the ocean's ecological connectivity often defies clear, stable, and political boundaries (Carr et al., 2017; O'Leary & Roberts, 2018). These factors, among others, can make data collection, scientific learning, and development of solutions expensive, tedious, and, at times, potentially irrelevant to local communities. As a result, research and solutions implementation may be available only to those with access to well-resourced institutions.

Place connections, and the pro-environmental behaviors they have been shown to support, offer a way to expand what research means, increase local capacity, and encourage engagement in support of marine conservation; these strengths of a place-based approach can lead to a remaking, via protection and improvement, of the place (in this case, the marine environment). In the next section, we explore how participation in marine conservation interacts with and strengthens place connections, and we highlight examples of approaches that incorporate considerations of place to improve marine conservation research and practice.

Tapping into the power of place in marine environments

Place connections grow organically and are theorized to arise from, and reflect, multiple dimensions: biophysical, sociocultural, political-economic, and psychological (Ardoin et al., 2012; Ardoin, 2014). As noted in the previous section, research suggests a link between place connections (e.g., place attachment and sense of place) and increased pro-environmental behaviors. Expanding on this research and drawing on ideas of tacit knowledge (Collins & Evans, 2007) and remade places (Lukacs & Ardoin, 2014), we propose a conceptual model showing pathways from place connections to improved marine environments. As seen in Figure 9.1, our model is an amplifying feedback loop, indicating an additive process occurs between place connections and marine environments.

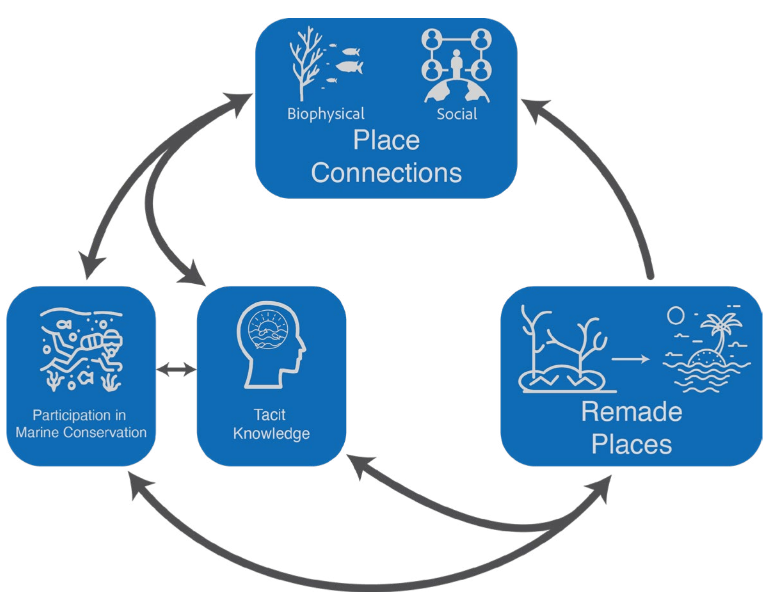


Fig. 9.1 Incorporating ideas of tacit knowledge and remade places, this figure demonstrates the feedback loop that can occur as a result of supporting place connections. Stemming from strong place connections, increased engagement in marine conservation activities and a greater sense of place-based tacit knowledge (including local ecological knowledge) contribute to positive changes in the marine environment. In turn, remade places impact place connections, creating an additive process of connection, engagement, and conservation.

Place connections form the heart of this model, wherein the relationships between people and place are captured in various conceptualizations, such as sense of place, place identity, and place attachment (Ardoin, 2014). In our model, we highlight the biophysical and social dimensions of place as they align with the SES framing that emphasizes ecological (represented in the model via the biophysical dimension) and social elements of a system. Biophysical features include the physical attributes of the ocean place (e.g., water quality, bathymetry, and substrate type), along with the plants and animals interacting within the system. Social aspects focus on the people in that place and the relationships and networks among them.

Place connections—whether conceptualized or measured as sense of place, place attachment, or a related construct—vary in their level of intensity. The bonds between people and a particular place can be strong, weak, or somewhere in between; moreover, those bonds can be dynamic and shifting over time. Research suggests those with deeper and more intense place connections are more likely to engage in pro-environmental behaviors, represented in the model by participation in marine conservation. These behaviors include activities such as volunteering with a marine conservation organization, learning about local issues and the environment, removing litter from a beach, or becoming involved in participatory marine governance and research (e.g., taking part in interviews, workshops, mapping exercises; Friedrich et al., 2020). While participation in these activities may certainly impact and benefit marine conservation, it may also impact the people themselves in a recursive manner: place-based learning and participation in place–protective behaviors can foster stronger place connections (Lukacs & Ardoin, 2014). As part of an additive process, those increased connections can heighten awareness of and sense of belonging to the socio-ecological system while strengthening a sense of responsibility and stewardship.

Place connections also contribute to tacit knowledge, the unspoken understanding of life-governing rules that a person accumulates through everyday experiences and a social upbringing in a place or culture. Drawing on the "periodic table of expertise" put forth by Collins and Evans (2007), our model highlights how individuals, embedded in a place, develop a place-specific body of tacit knowledge. We view tacit knowledge as including local ecological knowledge (LEK). Like tacit knowledge, LEK develops throughout a person's lifetime, but explicitly focuses on a local scale and emphasizes place connections (Carrasquilla-Henao et al., 2019). Researchers have argued LEK is critical for effective marine conservation (Brook & McLachlan, 2008). Our model shows a bidirectional link between place connections and tacit knowledge: strengthened and deepened place connections contribute to enhanced tacit knowledge and, likewise, tacit knowledge (often in the form of LEK) strengthens place connections (Garavito-Bermúdez & Lundholm, 2017).

Our model recognizes interplay between these two highlighted results of place connections: participation in marine conservation activities and tacit knowledge. People may become engaged in stewardship of marine environments for a host of reasons, which can include influence from the rules and cultures governing their local place (i.e., tacit knowledge and LEK). As part of a feedback loop, those engaged in place-protective behaviors may then strengthen their locally situated body of tacit knowledge as they learn more about their environment (biophysical dimension of place) and build and strengthen relationships with other people (social dimension of place). Participation in place-protective behaviors (in this case, in activities supporting marine conservation) and improved connection to tacit knowledge (as other stakeholders and decision makers are exposed to LEK) leads to greater stewardship and responsiveness to changes in the system. Ultimately, the local place is remade, environments are improved and protected. Closing the loop of our model, the remade places go on to impact place connections (Lukacs & Ardoin, 2014)—the improved and protected places strengthen people's connections to their local places and the amplifying feedback loop continues.

Implications for research and practice

Statistician George Box wrote, "All models are wrong, but some are useful" (1979, p. 202). In the case of our model, countless other factors influence place connections, participation in conservation activities, tacit and local ecological knowledge, and successful protection and conservation of marine environments. What we hope this model demonstrates is that place connections are integral to engagement in marine conservation. Supporting place connections is a worthwhile endeavor as studying, understanding, acknowledging, and leveraging place connections can improve marine conservation. These efforts begin with realizing place connections exist wherever people live and work, and thus one goal for marine conservationists is to support—and, where possible, work to enhance—positive relationships between people and the ocean.

Place connections can be strengthened in many ways, and much of this work involves engaging with local people and place-based organizations through avenues such as participatory governance, participatory research, and place-based education (see Figure 9.2). In marine conservation research, a range of participatory approaches can tap into the power of place connections and nourish existing connections, while simultaneously yielding other benefits. Conventional research practices in the marine sciences are traditionally designed, implemented, and shared in ways that limit the involvement of the local community. This way of doing research claims objectivity and relies on broadly accepted rigor, fitting into the expectations of contemporary Western science, offering empirical and carefully crafted insights into the system of study. Yet those practices may fall victim to logistical challenges such as time and funding constraints as well as carbon-intensive travel to field locations. Moreover, conventional research is prone to a lack of situational context—tacit knowledge—that potentially erodes its ability to effectively address evolving questions and challenges facing the global ocean system of today and tomorrow.

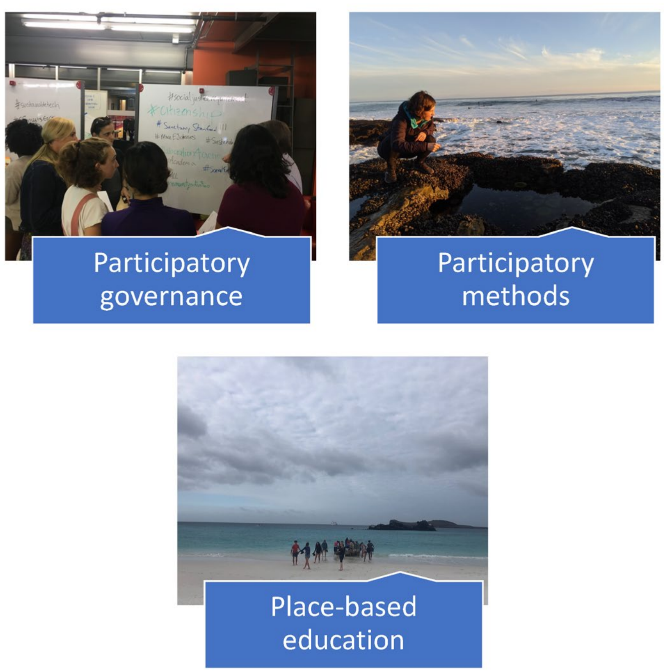


Fig. 9.2 Examples of marine conservation activities that support place connections. (Photos courtesy of Nicole M. Ardoin and Meghan Shea).

Place-based approaches such as fostering local research capacity through participatory methods and the inclusion of LEK present as both a solution and an opportunity to address these challenges. To address a given ecological question, for example, a specific dataset may be required. With the data being equal, it is presumably more efficient and effective, in the short and long term, to foster data-collection capacity among researchers who live and work in the study locale. Such an approach not only saves travel time, expense, and emissions, but also—and perhaps more importantly—it centers the voices and experiences of local people and communities, building capacity closer to the places and resources of interest and concern (Wilmsen et al., 2008). For example, in Figure 9.3, photographs show how one researcher used visual participatory methods, specifically photovoice, to explore worldviews and experiences of Indigenous small-scale fishers in Indonesia. See Swanson and Ardoin (2021) and Swanson (2022) for details on this work and its implications for marine conservation.

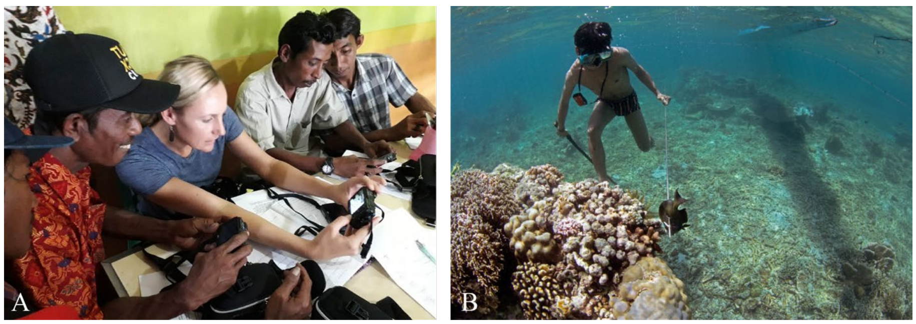


Fig. 9.3 (a) Dr. Shannon Switzer Swanson works with a local NGO, the Indonesian Nature Foundation (LINI), to train fishers to operate cameras they will use for a photovoice project. (b) The son of a fisherman accompanies his father to spearfish for the evening's dinner in Central Sulawesi, Indonesia. He carries the photovoice camera to document the event. (Photos courtesy of Shannon Switzer Swanson.)

Place-based education, which integrates place and learning to increase understanding, engagement, and community involvement (Ark et al., 2020) is another tool that yields positive outcomes including strengthened place connections. Place-based education has been used in a variety of marine settings, from islands (e.g., Howley et al., 2011; Streelasky, 2020) to coastal communities (e.g., Silbernagel et al., 2015). From a pedagogical perspective, place-based education has been shown to support learning outcomes, but can also enhance the very place connections that give place-based education its power (Sedawi et al., 2021; Semken & Brandt, 2010). In Figure 9.4A, tourists participate in a whale-watching program offered by the Oceanic Society in the San Francisco Bay Area, USA. In Figure 9.4B, children explore a coastal area in California, USA, as part of an environmental education field visit. Education programs such as these that foreground place-based experiences through field visits and guided tours, among other activities, can create new place connections and strengthen existing ones. Finally, community science, which combines principles of place-based education and participatory research methods, is another approach documented to effectively support engagement in marine conservation and build place connections (Cigliano & Ballard, 2017; Haywood et al., 2016; Kelly et al., 2020).

Fig. 9.4 (a) Participants on a whale-watching tour hosted by the Oceanic Society in San Francisco, California, USA, listen to a naturalist's pre-trip presentation. (b) Two children explore a coastal environment in California, USA, as part of a field visit. (Photos courtesy of Nicole M. Ardoin.)

Conclusion

As our global relationship with the ocean expands and evolves in concert with a changing climate, rising seas, and acidifying waters, it becomes increasingly critical to improve the sustainability of the connections between society and the whole ocean system (Kelly et al., 2022). For generations across societies, the ocean has been a teacher and a cultural hub for social and ecological knowledge. Yet, today the ocean is changing at an alarming rate across all scales and, with it, the structure of the socio-ecological system that it underpins (Halpern et al., 2019).

To address these and related challenges, marine conservation activities must fully engage with the social and ecological dimensions of coastal and oceanic problems and solutions. To that end, in this chapter, we offer a conceptual model to encourage marine conservation researchers and practitioners to leverage the power of place connections. Doing so initiates an additive process wherein local community engagement and the sharing of tacit knowledge can lead to protected and improved marine socio-ecological systems.

A call to focus time and resources on people's connections to marine places raises inevitable questions such as: In what ways might foregrounding the local ignore the global? How might we foster pro-environmental and pro-ocean decision-making about complex issues such as deep-sea mining when people can never visit, and thus form a personal connection with, an ecosystem under threat? How might we, as local and global ocean communities, address challenges to places, like low-lying Pacific islands, at imminent risk of ceasing to exist? How might, or might not, this work be scalable?

Although additional research, including comparative work across diverse places, is needed to address such questions, community engagement and education continue to be part of traditional marine conservation, representing one tool among a suite of marine conservation practices. We join other researchers and practitioners in promoting a novel and emerging approach to engagement, building on the SES framework by focusing on place connections. By using the place-based tools of participatory research, place-based education, and community science, marine conservationists can support a place-based stewardship approach that enables recognition of people's potential to be stewards of the global ocean. The ultimate power of place lies in the everyday people who live and work in threatened places. In their book on expertise and tacit knowledge, Collins and Evans (2007, p. 15) write, "Ordinary people are talented and skillful almost beyond comprehension." Thus, strengthening people's existing place-based knowledge, skills, and connections, and providing support for forming new ones, can enrich our collective path toward ocean sustainability.

References

Altman, I., & Low, S. M. (Eds.). (1992). Place attachment. Springer. https://doi.org/10.1007/978-1-4684-8753-4

Anderies, J. M., Janssen, M. A., & Ostrom, E. (2004). A framework to analyze the robustness of social-ecological systems from an institutional perspective. Ecology and Society, 9(1).

Arbo, P., Knol, M., Linke, S., & St. Martin, K. (2018). The transformation of the oceans and the future of marine social science. Maritime Studies, 17(3), 295–304. https://doi.org/10.1007/s40152-018-0117-5

Ardoin, N. M. (2014). Exploring sense of place and environmental behavior at an ecoregional scale in three sites. Human Ecology, 42(3), 425–441. https://doi.org/10.1007/s10745-014-9652-x

Ardoin, N. M., Schuh, J. S., & Gould, R. K. (2012). Exploring the dimensions of place: A confirmatory factor analysis of data from three ecoregional sites. Environmental Education Research, 18(5), 583–607. https://doi.org/10.1080/13504622.2011.640930

Ark, T. V., Liebtag, E., & McClennen, N. (2020). The power of place: Authentic learning through place-based education. ASCD.

Bennett, N. J. (2019). Marine social science for the peopled seas. Coastal Management, 47(2), 244–252. https://doi.org/10.1080/08920753.2019.1564958

Berkes, F., & Folke, C. (1998). Linking social and ecological systems: Management practices and social mechanisms for building resilience. Cambridge University Press.

Box, G. E. P. (1979). Robustness in the strategy of scientific model building. In R. L. Launer & G. N. Wilkinson (Eds.), Robustness in statistics (pp. 201–236). Academic Press. https://doi.org/10.1016/B978-0-12-438150-6.50018-2

Brook, R. K., & McLachlan, S. M. (2008). Trends and prospects for local knowledge in ecological and conservation research and monitoring. Biodiversity and Conservation, 17(14), 3501–3512. https://doi.org/10.1007/s10531-008-9445-x

Buchan, P. M., Evans, L. S., Barr, S., & Pieraccini, M. (2024). Thalassophilia and marine identity: Drivers of 'thick' marine citizenship. Journal of Environmental Management, 352, 120111. https://doi.org/10.1016/j.jenvman.2024.120111

Bukvic, A., Whittemore, A., Gonzales, J., & Wilhelmi, O. (2022). Understanding relocation in flood-prone coastal communities through the lens of place attachment. Applied Geography, 146, 102758. https://doi.org/10.1016/j.apgeog.2022.102758

Carr, M. H., Robinson, S. P., Wahle, C., Davis, G., Kroll, S., Murray, S., Schumacker, E. J., & Williams, M. (2017). The central importance of ecological spatial connectivity to effective coastal marine protected areas and to meeting the challenges of climate change in the marine environment. Aquatic Conservation: Marine and Freshwater Ecosystems, 27(S1), 6–29. https://doi.org/10.1002/aqc.2800

Carrasquilla-Henao, M., Ban, N., Rueda, M., & Juanes, F. (2019). The mangrove-fishery relationship: A local ecological knowledge perspective. Marine Policy, 108, 103656. https://doi.org/10.1016/j.marpol.2019.103656

Cheng, T.-M., & Wu, H. C. (2015). How do environmental knowledge, environmental sensitivity, and place attachment affect environmentally responsible behavior? An integrated approach for sustainable island tourism. Journal of Sustainable Tourism, 23(4), 557–576. https://doi.org/10.1080/09669582.2014.965177

Cheung, K., & O'Connor, R. (2023). Ocean and human health interconnections in California's Marine Protected Areas: Takeaways for future planning, assessment, and education [Manuscript in preparation]. Emmett Interdisciplinary Program in Environment and Resources, Stanford University.

Cigliano, J. A., & Ballard, H. L. (2017). Citizen science for coastal and marine conservation. Routledge.

Colding, J., & Barthel, S. (2019). Exploring the social-ecological systems discourse 20 years later. Ecology and Society, 24(1), 2. https://doi.org/10.5751/ES-10598-240102

Collins, H., & Evans, R. (2007). Rethinking expertise. University of Chicago Press.

Conley, E. D., & Diamond, E. P. (2024). Angler's sense of place as an indicator for perceived vulnerability to shifting stock distributions. Marine Policy, 161, 106007. https://doi.org/10.1016/j.marpol.2024.106007

Cresswell, T. (2015). Place: An introduction. John Wiley & Sons.

Dang, L., & Weiss, J. (2021). Evidence on the relationship between place attachment and behavioral intentions between 2010 and 2021: A systematic literature review. Sustainability, 13(23), Article 23. https://doi.org/10.3390/su132313138

Daryanto, A., & Song, Z. (2021). A meta-analysis of the relationship between place attachment and pro-environmental behaviour. Journal of Business Research, 123, 208–219. https://doi.org/10.1016/j.jbusres.2020.09.045

di Sciara, G. N., Hoyt, E., Reeves, R., Ardron, J., Marsh, H., Vongraven, D., & Barr, B. (2016). Place-based approaches to marine mammal conservation. Aquatic Conservation: Marine and Freshwater Ecosystems, 26(S2), 85–100. https://doi.org/10.1002/aqc.2642

Diz, D., Johnson, D., Riddell, M., Rees, S., Battle, J., Gjerde, K., Hennige, S., & Roberts, J. M. (2018). Mainstreaming marine biodiversity into the SDGs: The role of other effective area-based conservation measures (SDG 14.5). Marine Policy, 93, 251–261. https://doi.org/10.1016/j.marpol.2017.08.019

Drakou, E. G., Kermagoret, C., Comte, A., Trapman, B., & Rice, J. C. (2017). Shaping the future of marine socio-ecological systems research: When early-career researchers meet the seniors. ICES Journal of Marine Science, 74(7), 1957–1964. https://doi.org/10.1093/icesjms/fsx009

Duggan, J., Cvitanovic, C., & van Putten, I. (2024). An evolving understanding of sense of place in social-ecological systems research and the barriers and enablers to its measurement. Environmental Management, 73(1), 19–33. https://doi.org/10.1007/s00267-023-01882-1

Frazão Santos et al., Marine spatial planning in the age of climate change, in this volume

Friedrich, L. A., Glegg, G., Fletcher, S., Dodds, W., Philippe, M., & Bailly, D. (2020). Using ecosystem service assessments to support participatory marine spatial planning. Ocean & Coastal Management, 188, 105121. https://doi.org/10.1016/j.ocecoaman.2020.105121

Fudge, M., Ogier, E., & Alexander, K. A. (2023). Marine and coastal places: Wellbeing in a blue economy. Environmental Science & Policy, 144, 64–73. https://doi.org/10.1016/j.envsci.2023.03.002

Garavito-Bermúdez, D., & Lundholm, C. (2017). Exploring interconnections between local ecological knowledge, professional identity and sense of place among Swedish fishers. Environmental Education Research, 23(5), 627–655. https://doi.org/10.1080/13504622.2016.1146662

Halpern, B. S., Boettiger, C., Dietze, M. C., Gephart, J. A., Gonzalez, P., Grimm, N. B., Groffman, P. M., Gurevitch, J., Hobbie, S. E., Komatsu, K. J., Kroeker, K. J., Lahr, H. J., Lodge, D. M., Lortie, C. J., Lowndes, J. S. S., Micheli, F., Possingham, H. P., Ruckelshaus, M. H., Scarborough, C., … Youngflesh, C. (2023). Priorities for synthesis research in ecology and environmental science. Ecosphere, 14(1), e4342. https://doi.org/10.1002/ecs2.4342

Halpern, B. S., Frazier, M., Afflerbach, J., Lowndes, J. S., Micheli, F., O'Hara, C., Scarborough, C., & Selkoe, K. A. (2019). Recent pace of change in human impact on the world's ocean. Scientific Reports, 9(1), Article 1. https://doi.org/10.1038/s41598-019-47201-9

Haywood, B. K., Parrish, J. K., & Dolliver, J. (2016). Place-based and data-rich citizen science as a precursor for conservation action. Conservation Biology, 30(3), 476–486. https://doi.org/10.1111/cobi.12702

Herrero-Jáuregui, C., Arnaiz-Schmitz, C., Reyes, M. F., Telesnicki, M., Agramonte, I., Easdale, M. H., Schmitz, M. F., Aguiar, M., Gómez-Sal, A., & Montes, C. (2018). What do we talk about when we talk about social-ecological systems? A literature review. Sustainability, 10(8), Article 8. https://doi.org/10.3390/su10082950

Howley, A., Howley, M., Camper, C., & Perko, H. (2011). Place-based education at Island Community School. The Journal of Environmental Education, 42(4), 216–236. https://doi.org/10.1080/00958964.2011.556682

Kelly, R., Evans, K., Alexander, K., Bettiol, S., Corney, S., Cullen-Knox, C., Cvitanovic, C., de Salas, K., Emad, G. R., Fullbrook, L., Garcia, C., Ison, S., Ling, S., Macleod, C., Meyer, A., Murray, L., Murunga, M., Nash, K. L., Norris, K., … Pecl, G. T. (2022). Connecting to the oceans: Supporting ocean literacy and public engagement. Reviews in Fish Biology and Fisheries, 32(1), 123–143. https://doi.org/10.1007/s11160-020-09625-9

Kelly, R., Fleming, A., Pecl, G. T., von Gönner, J., & Bonn, A. (2020). Citizen science and marine conservation: A global review. Philosophical Transactions of the Royal Society B: Biological Sciences, 375(1814), 20190461. https://doi.org/10.1098/rstb.2019.0461

Leviston, Z., Dandy, J., Horwitz, P., & Drake, D. (2023). Anticipating environmental losses: Effects on place attachment and intentions to move. Journal of Migration and Health, 7, 100152. https://doi.org/10.1016/j.jmh.2023.100152

Lewicka, M. (2011). Place attachment: How far have we come in the last 40 years? Journal of Environmental Psychology, 31(3), 207–230. https://doi.org/10.1016/j.jenvp.2010.10.001

Lima, A. R. A., Ferreira, G. V. B., Barrows, A. P. W., Christiansen, K. S., Treinish, G., & Toshack, M. C. (2021). Global patterns for the spatial distribution of floating microfibers: Arctic Ocean as a potential accumulation zone. Journal of Hazardous Materials, 403, 123796. https://doi.org/10.1016/j.jhazmat.2020.123796

Lukacs, H. A., & Ardoin, N. M. (2014). The relationship of place re-making and watershed group participation in Appalachia. Society & Natural Resources, 27(1), 55–69. https://doi.org/10.1080/08941920.2013.840876

Masterson, V. A., Stedman, R. C., Enqvist, J., Tengö, M., Giusti, M., Wahl, D., & Svedin, U. (2017). The contribution of sense of place to social-ecological systems research: A review and research agenda. Ecology and Society, 22(1).

McKean, E. (Ed.). (2005). Place. In New Oxford American Dictionary. Oxford.

Meehl, G. A., Stocker, T. F., Collins, W. D., Friedlingstein, P., Gaye, A. T., Gregory, J. M., Kitoh, A., Knutti, R., Murphy, J. M., Noda, A., Raper, S. C. B., Watterson, I. G., Weaver, A. J., Zhao, Z.-C. (2007). Global climate projections. In S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, M. Tignor, & H. L. Miller (Eds.), Climate change 2007: The physical science basis: Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (pp. 747–845). Cambridge University Press. https://www.ipcc.ch/site/assets/uploads/2018/02/ar4-wg1-chapter10-1.pdf

O'Connor, R., Spalding, A., Bowers, A., & Ardoin, A. (2024). Power and Participation: A Systematic Review of Marine Protected Area Engagement Through Participatory Science Methods. Marine Policy, 163, 106133, https://doi.org/10.1016/j.marpol.2024.106133

O'Leary, B. C., & Roberts, C. M. (2018). Ecological connectivity across ocean depths: Implications for protected area design. Global Ecology and Conservation, 15, e00431. https://doi.org/10.1016/j.gecco.2018.e00431

O'Neill, S. J., & Graham, S. (2016). (En)visioning place-based adaptation to sea-level rise. Geo: Geography and Environment, 3(2), e00028. https://doi.org/10.1002/geo2.28

Ostrom, E. (2009). A general framework for analyzing sustainability of social-ecological systems. Science, 325(5939), 419–422. https://doi.org/10.1126/science.1172133

Raymond, C. M., Kyttä, M., & Stedman, R. (2017). Sense of place, fast and slow: The potential contributions of affordance theory to sense of place. Frontiers in Psychology, 8. https://www.frontiersin.org/articles/10.3389/fpsyg.2017.01674

Refulio-Coronado, S., Lacasse, K., Dalton, T., Humphries, A., Basu, S., Uchida, H., & Uchida, E. (2021). Coastal and marine socio-ecological systems: A systematic review of the literature. Frontiers in Marine Science, 8. https://www.frontiersin.org/articles/10.3389/fmars.2021.648006

Reineman, D. R., & Ardoin, N. M. (2018). Sustainable tourism and the management of nearshore coastal places: place attachment and disruption to surf-spots. Journal of Sustainable Tourism, 26(2), 325–340. https://doi.org/10.1080/09669582.2017.1352590

Rock, J., Sima, E., & Knapen, M. (2020). What is the ocean: A sea-change in our perceptions and values? Aquatic Conservation: Marine and Freshwater Ecosystems, 30(3), 532–539. https://doi.org/10.1002/aqc.3257

Sandifer, P. A., & Sutton-Grier, A. E. (2014). Connecting stressors, ocean ecosystem services, and human health. Natural Resources Forum, 38(3), 157–167. https://doi.org/10.1111/1477-8947.12047

Sedawi, W., Assaraf, O. B. Z., & Reiss, M. J. (2021). Regenerating our place: Fostering a sense of place through rehabilitation and place-based education. Research in Science Education, 51(1), 461–498. https://doi.org/10.1007/s11165-019-09903-y

Semken, S., & Brandt, E. (2010). Implications of sense of place and place-based education for ecological integrity and cultural sustainability in diverse places. In D. J. Tippins, M. P. Mueller, M. van Eijck, & J. D. Adams (Eds.), Cultural studies and environmentalism: The confluence of ecojustice, place-based (science) education, and indigenous knowledge systems (pp. 287–302). Springer Netherlands. https://doi.org/10.1007/978-90-481-3929-3_24

Silbernagel, J., Host, G., Hagley, C., Hart, D., Axler, R., Fortner, R., Axler, M., Smith, V., Drewes, A., Bartsch, W., Danz, N., Mathews, J., & Wagler, M. (2015). Linking place-based science to people through spatial narratives of coastal stewardship. Journal of Coastal Conservation, 19(2), 181–198. https://doi.org/10.1007/s11852-015-0380-1

Stedman, R. C. (2002). Toward a social psychology of place: Predicting behavior from place-based cognitions, attitude, and identity. Environment and Behavior, 34(5), 561–581. https://doi.org/10.1177/0013916502034005001

Stedman, R. C. (2003). Is it really just a social construction?: The contribution of the physical environment to sense of place. Society & Natural Resources, 16(8), 671–685. https://doi.org/10.1080/08941920309189

Streelasky, J. (2020). Weaving place-based education and coast Salish knowledge: Stories from Salt Spring Island. In A. Sriskandarajah & L. E. Bass (Eds.), Rethinking Young People's Lives Through Space and Place (Vol. 26, pp. 121–137). Emerald. https://doi.org/10.1108/S1537-466120200000026008

Swanson, S. S. (2022). Learning with fishing families: How worldviews and lived experience shape fisher livelihoods and marine conservation [Unpublished doctoral dissertation]. Stanford University.

Swanson, S. S., & Ardoin, N. M. (2021). Communities behind the lens: A review and critical analysis of visual participatory methods in biodiversity conservation. Biological Conservation, 262, 109293. https://doi.org/10.1016/j.biocon.2021.109293

Tuan, Y. F. (1977). Space and place: The perspective of experience. University of Minnesota Press.

UNEP-WCMC & IUCN. (February 2024). Protected planet: The world database on protected areas (WDPA) and world database on other effective area-based conservation measures (WD-OECM). [Online database]. http://www.protectedplanet.net

UN Environment Programme. (2022, December 20). COP15 ends with landmark biodiversity agreement. http://www.unep.org/news-and-stories/story/cop15-ends-landmark-biodiversity-agreement

Urquhart, J., & Acott, T. (2013). Constructing 'The Stade': Fishers' and non-fishers' identity and place attachment in Hastings, South-East England. Marine Policy, 37, 45–54. https://doi.org/10.1016/j.marpol.2012.04.004

van Putten, I. E., Plagányi, É. E., Booth, K., Cvitanovic, C., Kelly, R., Punt, A. E., & Richards, S. A. (2018). A framework for incorporating sense of place into the management of marine systems. Ecology and Society, 23(4).

Visbeck, M. (2018). Ocean science research is key for a sustainable future. Nature Communications, 9(1), Article 1. https://doi.org/10.1038/s41467-018-03158-3

Waiti, J. T. A., & Awatere, S. (2019). Kaihekengaru: Māori surfers' and a sense of place. Journal of Coastal Research, 87(SI), 35–43. https://doi.org/10.2112/SI87-004.1

Williams, D. R. (2008). Pluralities of place: A user's guide to place concepts, theories, and philosophies in natural resource management. In L. E. Kruger, T. E. Hall, & M. C. Stifel (Eds.), Understanding concepts of place in recreation research and management (Gen. Tech. Rep. PNW-GTR-744), (pp. 7–30). U.S. Department of Agriculture. https://www.fs.usda.gov/rm/pubs_journals/2008/rmrs_2008_williams_d002.pdf

Wilmsen, C., Elmendorf, W. F., Fisher, L., Ross, J., Sarathy, B., & Wells, G. (Eds.). (2008). Partnerships for empowerment: Participatory research for community-based natural resource management. Earthscan.

Wynveen, C. J., Kyle, G. T., & Sutton, S. G. (2012). Natural area visitors' place meaning and place attachment ascribed to a marine setting. Journal of Environmental Psychology, 32(4), 287–296. https://doi.org/10.1016/j.jenvp.2012.05.001

Young, O. R., Osherenko, G., Ekstrom, J., Crowder, L. B., Ogden, J., Wilson, J. A., Day, J. C., Douvere, F., Ehler, C. N., & McLeod, K. L. (2007). Solving the crisis in ocean governance: Place-based management of marine ecosystems. Environment: Science and Policy for Sustainable Development, 49(4), 20–32. https://doi.org/10.3200/ENVT.49.4.20-33

10. A brief conservationist's guide to self-governance with illustrations from small-scale fisheries

Xavier Basurto[1]

At the basis of addressing the challenge of how humans can develop and sustain ways to interact with our marine environment without damaging or destroying it in the process, there is the implicit need to understand how humans organize societal interactions with our coasts and oceans because marine conservation initiatives are built on top of, and their outcomes determined by, these societal interactions. In broad strokes, humans organize society and its governance in three interrelated ways, governance through markets, governance through central government approaches, and citizen participation in decision-making, or self-governance. Of the three, the latter has received the least attention of all in the literature and in policymaking. This chapter is situated within the Innovative Pathways to Solutions section of this book, to highlight that self-governance speaks to each of our individual and collective creativity. The outcome of marine conservation interventions in self-governed regimes can be the well-known tragedy of the commons (discouraging and negative). But it also can be the source of novel solutions to marine conservation problems emerging from individuals or communities themselves. Self-governance can be a form of direct or indirect democracy that yields citizen empowerment and learning about marine conservation and sustainability that often neither markets or central governments can offer. Novel pathways and solutions to complex conservation challenges often require the constant trial and error of many different groups of people, in many similar and different contexts. This type of self-governed daily experimentation with what works, and what does not, increases the likelihood that creative responses to complex challenges for marine conservation will be found. In the following sections I provide a brief overview of a general theory on self-governance highlighting key concepts of relevance to conservation science and practice. Then I offer some key takeaway lessons for conservation emerging from the self-governance literature based on examples from around the world, and from the Coasts and Commons Co-Laboratory's 20-year empirical research program on self-governance.

What is—and is not—self-governance

Self-governance was an enduring concern in political scientists Vincent and Elinor Ostrom's extensive study of human order, organization, and democracy. They worried that while a theory of the firm or a theory of the state were available,[2] no theory explained how individuals self-organized without an "external" leader who captured most of the benefits. As a default, the theory of the state was used to explain democratic self-governance, yet as Vincent Ostrom pointed out in various writings (Ostrom, 1986a; Ostrom 1986b), this was fundamentally

1 Nicholas School of the Environment, Duke University, https://orcid.org/0000-0002-5321-3654
2 In general, theories of the firm and of bureaucracies aim to explain why firms form in the first place, why they create different internal governance structures and how these structures affect their performance, whether it is their ability to survive, innovate, etc., For examples of exponents of these theories see the work of Gary J. Miller and Terry Moe respectively (Miller 1992; Moe 1990).

 https://doi.org/10.11647/OBP.0395.10

contradictory, because when one single center has the monopoly on the use of coercion, which refers to the use of expressed or implied threats of violence or reprisal or other intimidating behavior that compels someone to act against his or her will, it makes it impossible for the emergence of a self-governed society: the basis, in his view, of any functional democratic system.

Self-governance is defined as the involvement of individuals that depend on a given common-pool resource (CPR) for the maintenance of their livelihoods, in decision-making processes about the governance of such resources where the central authority does not have a monopoly on the use of coercion. A general theory of self-governance does not pre-determine what outcome is most desired, how power should be distributed, or whether the results of self-governance will be equitable or not. Yet, it is implied that stakeholders outside of a central authority have enough power through their influence in the decision-making processes to limit the coercive power of the state. Understanding self-governance is of interest to conservation because successful conservation of common-pool resources requires the engagement and collective action[3] of all stakeholders, not only governmental authorities. Also, because sites of high conservation value often correlate with the absence or weak presence of a central governmental authority, highlights the importance of well-developed locally based self-governed regimes for the emergence and maintenance of meaningful conservation interventions (Andersson et al., 2020).

A general theory of self-governance does not assume that the outcome of self-governance will be sustainability or conservation. To the contrary, self-governed arrangements often but not always lead to tragedies of the commons, and for that reason, understanding which conditions do not has received particular attention (Ostrom, 1990). Self-governance allows for citizens to have the right to organize and does not signify an absence of government. For instance, co-management constitutes a form of self-governance in cases where users most directly affected by conservation outcomes have a significant say in decision-making related to the use and access of the CPR in question (e.g., fishing grounds, beach, or coastline). Yet, some forms of co-management, such as instructive or consultative co-management as defined by Sen and Nielsen (1996),[4] where users have little or no decision-making power, are less likely to be considered as self-governed arrangements.

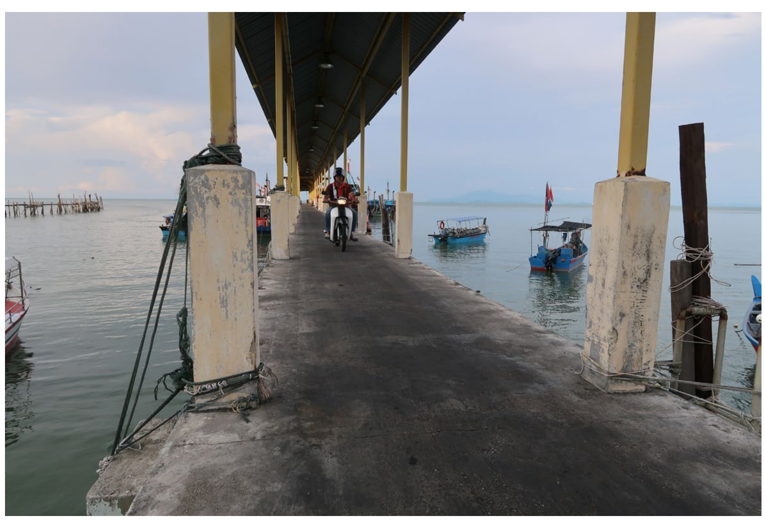


Fig. 10.1 Photo: Xavier Basurto 2018.[5]

3 Collective action is a central concept that refers to the capability of all interested individuals or parties to find a way to align their individual interests with those of the group as a whole. When the interests of the group are put ahead of the individual's, it is said that successful collective action is achieved or that it is possible to avoid Garrett Hardin's so-called tragedy of the commons.

4 According to Sen and Nielsen (1996), instructive co-management is "where there is only minimal exchange of information between government and users. This type of co-management regime is only different from centralized management in the sense that the mechanisms exist for dialogue with users, but the process itself tends to be government informing users on the decisions they plan to make." Consultative co-management is where "Mechanisms exist for governments to consult with users but all decisions are taken by government."

Emergence, robustness, and the configurational nature of self-governance

Emergence and robustness constitute two broad processes of institutional change of interest to self-governance scholars. Differentiating between these two processes of self-governance is of interest to marine conservationists because they influence the short and long-term effectiveness of local or global conservation efforts (Ostrom, 2005; Persha et al., 2011; Rockström et al., 2009). Institutional emergence constitutes the change from the null condition of no organization to some form of self-governance structure—in other words, a shift from no shared understandings by actors about enforced prescriptions concerning what actions or outcomes are required, prohibited, or permitted, to a rule structure that assigns different roles and responsibilities concerning what is required, prohibited, or permitted. In the context of property rights, institutional emergence would be the change from open access—the null condition of no property claims (McCay, 1996)—to a property rights regime that has assigned and enforced roles and responsibilities (e.g., private property or common property, or other types of property rights). In this context, institutional change involves some form of collective action (Ostrom, 2000). Hardin's (1968) tragedy of the commons narrative aimed to illustrate that without central control, users of common-pool resources would always fail to change from open access to some form of property-right structure.

Fig. 10.2 Photo: Xavier Basurto 2019, The Bardo Museum, Tunisia.[6]

Institutional robustness assumes that institutional emergence had previously taken place, and refers to the maintenance, adaptation, or reform of the ongoing governing system. In institutionally robust settings, resource users have developed or can rely on several enabling factors facilitating the constant iterations and adjustments to rule structures over time in order to adapt to changing conditions (Anderies et al., 2004; Janssen et al., 2007; Wilson 2006). Yet, there is no expectation that resource users will 'arrive' at or identify a set of optimal rules that remain unchanged over time (Ostrom, 1999).

Authors have devoted significant interest to identifying conditions that can increase the likelihood of the emergence and long-term robustness of institutions (Axelrod, 1984; Baland and Platteau, 1996; Berkes, 1989; McCay and Acheson, 1987; Olson, 1965; Ostrom, 1990; Wade, 1994). Different scholars have identified different

5 Keeping a fishing pier, like this one near Penang Malaysia, clean and in working conditions so fishers can conduct their daily activities requires organizing who will be responsible of its maintenance and developing rules on how loading, unloading, mooring, unmooring, repairing, or building an extension can take place. Fishers might have the autonomy to self-govern some or all of those activities, and the presence of port or fisheries authorities might only be felt through the need to follow certain general mandates about how, when or how fish can be landed, or how repairs to the port can take place

6 Humans have a deep history with the ocean and fishing has been a prominent activity shaping that history as illustrated by this Roman mosaic found in Tunisia dated 300 years BC. Even back then, fishers faced the need to organize who was allowed to fish, where, when, and what species. The emergence of rule structures and the traditions that maintain or reshaped them over time are part of the invisible structure that governs how people may interact with the ocean.

sets of facilitating conditions (Agrawal, 2001). For example, see the analysis of 69 cases of successful forest management (Pagdee et al., 2006), a 91-case assessment of the use of Ostrom's design principles (Cox et al., 2010), and the 130-case meta-analysis of successful fisheries co-management (Gutiérrez et al., 2011), or the extensive global study of 42 co-managed coral reefs (Cinner et al., 2012), to name a few. All examine conditions leading to successful local organization. Despite increased interest in facilitating conditions for institutional emergence and robustness, there is still significant confusion about what conditions are necessary or sufficient, and in which particular contexts (Agrawal, 2002)—notwithstanding explicit warnings that policy solutions derived from particular contexts do not constitute panaceas (Heikkila et al., 2011; Ostrom et al., 2007; Rudd et al., 2003; Rudel, 2005; Schlager, 2002; Young et al., 2008) for the emergence and robustness of self-governance. These are often interpreted as necessary conditions or "blueprints" (i.e., they all need to be present or absent for the outcome to occur). Increasingly however, scholars are developing techniques for the study of configurations of conditions leading to emergence or robustness (e.g., Baggio et al., 2016; Basurto, 2013).

Incorporating multi-level governance concerns

Of relevance to conservation is the shifting emphasis from local self-governed arrangements to multi-level self-governance. Multi-level self-governance refers to the processes and arrangements or rules (formal or informal) that govern interactions across different scales. Scales are often conceptualized as vertical (e.g., rules linking a local marine protected area with state and national authorities), or horizontal (e.g., rules linking the interaction of neighboring fishing cooperatives or other local users of the same marine area through a local management plan). Yet, scale is not often obvious, and it is necessary to engage in empirical and reflexive scale questions to uncover it (Smith et al., 2020).

As the world has become more interconnected, so have local and national or global processes of conservation, and the need to better understand how multi-level institutional arrangements affect processes of local institutional change, such as emergence or robustness (Adger, et al. 2005; Berkes, 2002; McGinnis and Ostrom, 2008; Young, 2002).

One approach to study how local conservation was affected by multi-level governance issues proposed focusing on understanding how changes in local autonomy take place (Basurto, 2013). Local autonomy, defined as local users' rights to design their own institutions (Ostrom, 1990), is a useful concept to anchor the study of the effect of multi-level institutions on self-governance. It is one of the conditions that scholars have often cited as increasing the likelihood of the emergence and robustness of self-governed regimes (Hayes and Persha, 2010; Ostrom, 2005). Autonomy is essential to counterbalance strong coercive power from higher level authorities. Without the possibility of designing rules without being immediately overruled by a higher-level authority, it is unlikely that CPR users will find incentives to self-organize to change their current rule structure or be able to adapt that rule structure over time to changing conditions. Examples of previous work on the relationship between multi-level linkages and local autonomy for protected area management and governance include: examining the importance of external, independent non-governmental organizations to help mediate demands on local forest governance systems (Hayes and Persha, 2010); the influence of stakeholders' participation on their autonomy for self-determination (Trench, 2008), or protected area effectiveness (Chowdhury and Koike, 2010), to name only a few. Other related approaches, such as polycentricity, have focused on paying attention to the distribution of centers of power and autonomy among multi-level institutional arrangements (Morrison, 2017; Ostrom, 2000). In the context of marine governance of a network of protected areas in Palau, prioritization of ecologically relevant scales in institutional reform resulted in more nested but less polycentric institutional arrangements governing the network that could threaten the sustainability and resilience of coral reefs in the long-term by constraining local rule-making, innovation and diversity (Gruby and Basurto, 2014).

Fig. 10.3 Photo: Xavier Basurto 2017.[7]

In fisheries, the study of co-management seeks to implicitly explore the role of local autonomy by explicitly highlighting the distribution of power (e.g., responsibilities) between resource users and authorities (e.g., Jentoft and McCay, 1995), and their adaptive capacity (Armitage, et al., 2007). Autonomy has also been explored and conceptualized as institutional interplay (Berkes, 2002; Gunderson and Holling, 2002; McKean, 2000; Young et al., 2008) which broadly refers to situations in which the emergence, development, and performance of a particular institution is affected by its interactions with another one (Oberthür and Stokke, 2011). Defining the authorized use of marine space, e.g., through marine spatial planning processes, requires complex institutional interplay among local, state, and federal authorities and other stakeholders. For instance, defining whether a given coastal area should be formally allocated for oil and gas extraction, fishing, or both, will require negotiation between agencies with different mandates e.g., energy or fisheries management. To reach agreements about how the area will be managed and agreements enforced, among other considerations, might require the involved agencies to give up some autonomy in favor of achieving coordination with another agency. The governance of the marine space and the design of new institutions that can govern it appropriately will require the input of a broad set of perspectives beyond narrow management considerations (Flannery et al., 2020).

The Social Ecological Systems (SES) Framework (Ostrom, 2009) has also received significant attention for its ability to highlight the role that multi-level linkages play in generating CPR dilemmas, and the processes of collective action that can address those dilemmas (Heikkila et al., 2011), as well as a structured approach to conduct comparative studies. For instance, we have used the framework as a knowledge classification system for benthic fisheries in Mexico and Chile and showcased how different case studies can be structured and organized (Basurto et al., 2013). The SES framework is loosely based on another framework known as the Institutional Analysis and Development Framework (IAD) (Ostrom, 2007). For decades the IAD Framework has been useful to structure thinking around self-governance research questions. The SES Framework constitutes an explicit effort to encourage natural scientists to seriously consider the role of institutional arrangements in their work. For diverse marine conservation applications see Basurto and Ostrom (2009), Cinner et al. (2012), Leslie et al. (2015), Morrison (2017), Partelow (2018), among others.

7 Small-scale fishers are usually deeply embedded in localities and rely on detailed knowledge about the biophysical conditions in order to fish successfully. Yet, they have identified challenges and needs that go beyond their local jurisdictions where they operate. To address these challenges, they have constituted into local organizations, federations, confederations, and supra-confederations like the World Forum of Fish Harvesters and Fish Workers. The general assembly of the World Forum of Fish Harvesters and Fish Workers in Salinas Ecuador in 2017 brought fisher representatives of countries in five continents. The meeting conducted in three different languages, constituted an example of the practice of multi-level governance by small-scale fishers.

There are other valuable perspectives that explicitly treat scale as a relational, power-laden process. These critiques have not received enough attention in the self-governance literature, but Smith et al. (2020) provide a roadmap to examine what scale is, instead of assuming it to be there. Students and practitioners of marine conservation can ask key questions during the design phase of conservation interventions to determine what is 'scale' in their context of interest. These questions include: (1) what assumptions am I making about scale? (2) What dimensions of scale can I identify? (3) Can I identify the moment(s) where different dimensions of scale are enacted to produce scale or rescale? (4) What are the limits and tradeoffs inherent in my chosen approach to scale and what are alternatives? See Smith et al. (2020) for examples applied to small-scale fisheries.

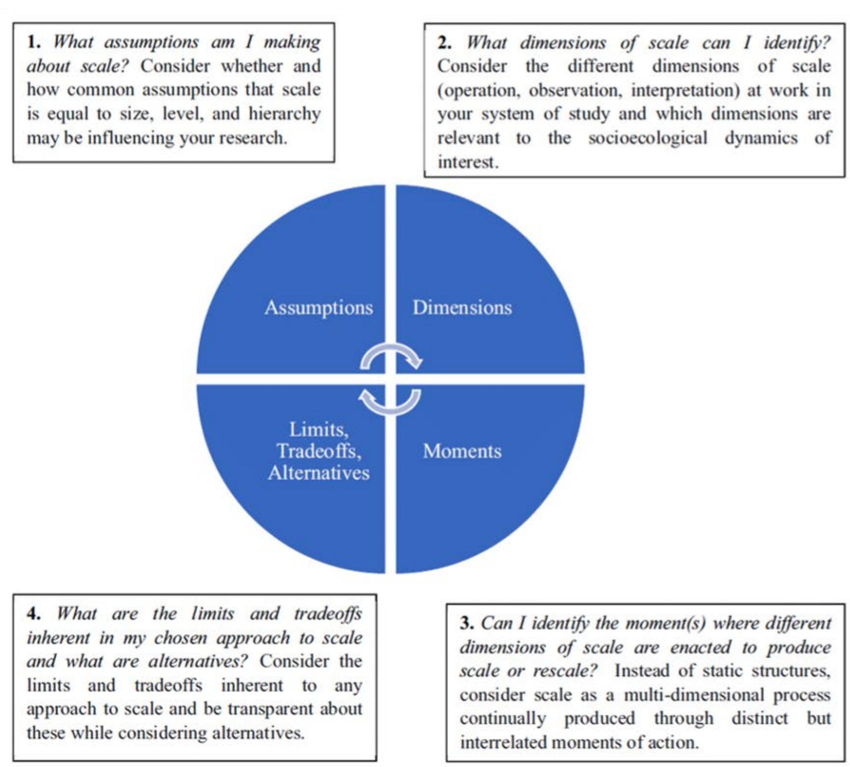


Fig. 10.4 Smith et al. (2020) proposed four steps to critically rethink scale in research and praxis. For more details refer to http://doi.org/10.5334/ijc.1041 Reprinted with permission.

In sum, knowing how to incorporate multi-level governance concerns to conservation interventions is critical in an increasingly interconnected world. First it is key to be reflective and empirically ask what is scale (and/or what is 'local') and how it is socially constructed in the context of its influence on the conservation intervention. Second, this understanding needs to be considered and reconciled with understanding about the level of local autonomy that local users have within the social-ecological system, and how their autonomy will be affected by the intervention in all its multi-level governance contexts.

The motivations to self-govern

Identifying the motivations to self-govern has been one of the central questions of concern among self-governance scholars. When referring specifically to the governance of CPRs, scholars have long used as point of departure the need to address the collective action challenges that emerge from the two defining characteristics of a CPR: costly excludability and subtractability. Costly excludability is a characteristic shared with public goods, which are goods that can be enjoyed by all whether those individuals contributed to creating and maintaining them or not (e.g., streets, parks, public radio, peace), given the high costs of excluding other potential users. In marine environments, designing effective methods to monitor and enforce mutual agreements regarding what, where, when, and how much to fish will often constitute an enduring challenge. Subtractability is a characteristic shared with private goods. When a unit of the common pool is subtracted, that unit is not available to anyone else except for the owner. When one buys a bicycle at the store, that unit is no longer available to other potential buyers. In a marine fisheries context, this characteristic generates incentives to appropriate the resource, to engage in 'a race to fish,' before others do the same. When there are no rules creating credible assurance to fishers that the common-pool resource will be available in the future for their individual or collective benefit, it is rational for that individual to decide not to give up the present for future exploitation. These considerations affect resource conservation and sustainability and have been a central concern in fisheries management as illustrated by Gordon's (1954) most cited article in fisheries "The Economic Theory of a Common-Pool Resource: The Fishery".

A challenge to the study of the motivation to self-govern is that it often has been taken as monolithic or static in time. But in community-based settings, common-pool resource users often face motivations to govern the access and use of their resources that wax and wane based on other competing interests and larger community and livelihood issues. Based on my own experience in Mexico, I have often found that local fishers faced conflicting motivations to control access and allow outsiders inside their fishing areas, even in cases where they had secure tenure or legal property-rights over their fishing grounds. Allowing an outsider to fish in your fishing grounds might represent short-term income that could allow you to solve an immediate need. As a result, often controlling the access of fishers to local fishing commons is an exercise in managing (not excluding) the presence of outsiders. Consider the case of the Comcáac or Seri of Northwest Mexico, the holders of tenure to fishing grounds through formal exclusion rights. The threat of their enforcement capability allowed them to monitor the actions of others to deter them, rather than having to continually enforce. Yet during the late 1990s and early 2000s the Comcáac fishing community found that it was in their interest to develop different paths by which outsiders could gain access to Seri fishing grounds (Basurto, 2005). The existence of multiple paths should not be interpreted as failure to control access but as an expression of the multiple ways Seri fishers benefited from the presence of outsiders. Only under exceptional circumstances, would local fishers find enough collective incentives to close access completely and expel outsiders from their fishing grounds. After the immediate crisis had subsumed, a fluid access regime would remerge. We have observed this in other settings, such as when high-value species attract a high number of outside fishers, as in the case of the sea cucumber fishery in the Yucatán peninsula. In this particular case, members of fishing cooperatives engaged in temporary closures of roads and waterways in an effort to prevent an overwhelming influx of outsiders (Bennett and Basurto, 2018). Not only fishers were concerned about protecting their future income, but also about the social issues and health risks that a rush to fish would bring to their communities.[8]

8 The portrait about this issue in the New York Times, 2018: https://www.nytimes.com/2018/10/05/science/sea-cucumbers-mexico.html?searchResultPosition=3).

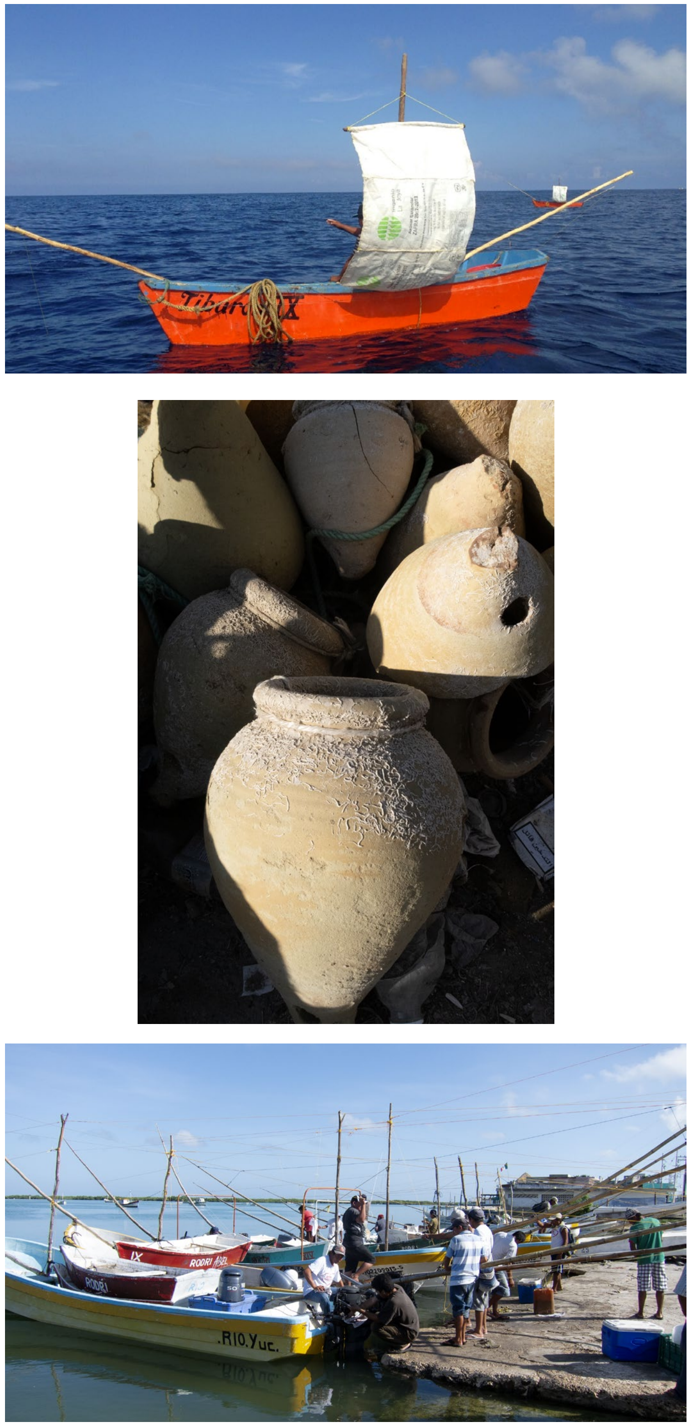


Fig. 10.5 Much of the theory on self-governance and common-pool resources has focused on understanding the diverse formal and informal rules and norms that shape harvesting activities and what might explain differences across geographies. For instance, in some places like in the Yucatán peninsula octopus is caught with 'alijos,' small boats where fishers drift with the wind using lines and bait to attract the octopus (Photo: by Abigail Bennett 2017). While in the North African countries of the Magreb region bordering the Mediterranean Sea, fishers employ strings of amphorae made of clay to catch octopus (Photo: Xavier Basurto 2019). Notably, other aspects of fishing, such as provisioning activities, e.g., fixing boats, motors, securing property-rights, bait, etc., have received less attention in the literature (Basurto et al. 2020). Yet understanding how these activities are self-governed is also important because they shape how harvesting is conducted and how benefits from fishing are distributed. The picture shows fishers getting ready for the octopus season in Rio Lagartos Mexico. Whether they will land their catch to a fishing cooperative or sell to a higher bidder might be determined by who supported their provisioning before the season started. These decisions have implications for conservation and equity. Photo: Xavier Basurto 2014).

Conservation and small-scale fisheries

As some of the above examples already suggest, in the context of the conservation of coastal and marine environments, small-scale fishing plays a prominent role in the application of self-governance ideas and theory. As one of the largest employers in the ocean, surpassing oil and gas, tourism, and shipping (Virdin et al., 2023), small-scale fisheries activities cannot be ignored for the substantial impact and contributions they make to the conservation of these environments (Basurto et al., 2017). Moreover, small-scale fishing constitutes quintessential examples of self-governed regimes because they have historically developed at the margins of central authorities. In many geographies around the world, fishers were using and governing coastal environments before the development of state-based authorities. This shapes their worldviews about tenure and ownership, among other issues that influence their relationship with external authorities.

As self-governed entities, small-scale fishers are confronted daily with collective-action dilemmas regarding where, when, and how to fish. For instance, from learning and understanding the dynamics and material complexity of coastal-marine environments, to managing the competition for access and use of the marine space, or the simultaneous need for cooperation and collaboration with fellow fishers to land fish, process it for household consumption, and/or get it to local or far-and-away markets. In sum, developing long-lasting conservation of coastal marine environments requires paying attention to the self-governing arrangements small-scale fishers develop in their quest to access and use marine environments, including their motivations to self-govern, how their different decision-making processes address collective action dilemmas, and the resulting activities relate to different outcomes. Take the study of tenure rights described in the previous section. Without understanding the motivations behind controlling access and use of marine resources, advocates of tenure rights will struggle to understand why and when local communities of small-scale fishers will decide to constrain access and use of valuable resources and when they will not.

What are the most dominant forms of self-governance in small-scale fisheries?

Managing fishing around a fishing organization or an entrepreneur that provides the means of production to fishers that work for him or her (i.e., a patron/client relationship) seem to be two of the most common ways fishing activities are structured around the world. In Mexico, officials estimate the existence of more than 3200 cooperatives (Juárez-Torres et al., 2007). In Turkey, one in every four fishers belongs to a cooperative (Unal et al., 2009) and more than 620 fishers' syndicates are reported in Chile (Marin et al., 2012). Patron-client informal arrangements can underpin the global seafood trade of certain species. For instance, the mahi mahi fishery of Peru and Ecuador, two of the most important producers in the world, is mostly small-scale and based on informal, unwritten, trust-based contracts between fishers and fish buyers. With nearly 60% of their catch exported to the US, its estimated worth was 232 million U.S. dollars in 2012 (NOAA 2013). Patron-client relationships are also prevalent in more localized fisheries and associated markets (Nurdin and Grydehøj, 2014; Ruddle, 2011). Patron-client forms of organization seem to be more common nowadays, likely because they do not require fishers to engage in often costly collective action efforts, and readily provide fishers with access to capital, physical means of production, and fishing property rights. When fishers are organized as a fishing organization like a cooperative, property rights and capital are usually owned collectively and are accessible only to members. If, however, fishers are working on their own through verbal short-term contracts with a fish buyer (i.e., a patron-client relationship), fishers often need to access capital to pay for short-term expenses (i.e., gas and food for the fishing trip) or to pay rent for the use of the boat and fishing gear (Basurto et al., 2020). Different forms of organizing fishing pose different challenges for conservation (Basurto et al., 2013; Frawley et al., 2024), as will be illustrated in the next section.

Takeaways for conservation science and practice

In this section I address three empirical lessons of particular relevance for conservation emerging from the self-governance literature. The first illustrates the importance of the involvement of resource users in governance for the effectiveness of conservation interventions. Simply put, resource users are in a much better position to develop rules, agreements, and procedures that are more likely to be complied with by fellow common-pool resource users and that might be better adapted to social and biophysical characteristics. The second highlights the delicate nature of success. Local successful collective action, the kind needed for conservation, is hard to achieve and it can be short-lived without the support of multi-level institutional arrangements, facilitated by civil society organizations and ultimately the state. Building long-term effective initiatives is essential to generate the trans-generational benefits needed for high-impact conservation. The final lesson calls attention to different kinds of self-governance. Self-governance is not a panacea. Some types of self-governed regimes will more easily find incentives to engage in long-term resource stewardship while others will not. Knowing how to distinguish them, particularly in the case of small-scale fisheries, is important for the effectiveness of conservation interventions.

i. Local users have an unparalleled vantage point to engage in rule-making and management practices well-adapted to the biophysical and cultural setting

Coastal marine environments are complex and dynamic, and fishers often have limited control over them. Learning which rules and norms might be most efficient for a particular time and space can be achieved only through repeated interactions and processes of trial and error (Lansing, 2006; Lansing, 2003; Wilson et al., 2007). Comparative studies show that resource users are most often in the best position to design rules and procedures that will remain effective for longer periods of time than those external authorities can design (Agrawal et al., 2008; Coleman, 2009). Processes of trial and error are based on the presence of biological characteristics of the resource system facilitating learning and experimentation. Take, for instance, the case of the sessile pen shell fishery of the Comcáac or Seri in Mexico, who for more than 20 years effectively self-governed access to their fishing grounds. In this setting, several biological characteristics outside of fishers' control helped shape their ability to address collective action challenges and avoid the tragedy of the commons (Basurto, 2008). Fishing pressure was modulated not only by the presence of communal rules banning the use of air compressors for commercial diving in some areas reserved for freediving (Basurto, 2005), but also by the seasonal presence of extensive eelgrass meadows precluding access due to the cumbersome nature of diving in these areas and risk of entanglement. Other biological characteristics of pen shells such as continuous reproduction and fast sexual maturity contributed resilience to the overall social-ecological system of pen shell harvesting in Comcáac territory. Institutional and ecological factors together provided the system with several redundancies to prevent overexploitation. This is particularly important in community-based settings where it can be expected that monitoring and enforcement waxes and wanes over time.

Significant scholarship has referred to the above issues as 'institutional and ecological fit' (e.g., Gelcich et al., 2010). And while to a certain degree, 'fit' is relative to one's point of view, assessing how much of the outcome is due to self-governing institutions matching well with ecological conditions has important implications for conservation. For instance, the same set of rules and norms that the Comcáac developed to self-govern and successfully conserve their pen shell fishery in the 80s and 90s did not emerge for the self-governance of other valuable target species like the seabass (*Totoaba macdonaldii*) or large species of sharks in earlier decades. Despite being the same community of fishers or having legally secured tenure rights over their fishing grounds, the Comcáac could not develop access controls and continued to treat their fisheries as open access. Overexploitation of marine resources included some sessile species of mollusks such as rock scallops. Sessile mollusks are often associated with the development of conservation measures (Castilla and Defeo, 2001), yet the fact that the same community was able to develop institutions to self-govern access for some species (sessile or mobile), but not for others, suggests that no one biological characteristic or political or cultural trait is sufficient for the development of successful conservation behavior. Instead, in the case of the Comcáac, it was the joint interrelation of political, cultural, and biological factors in the specific context of pen shell fishing that allowed them to develop rules and norms to control access and organize use at that particular moment in time. Oral history suggests that rules and norms that allowed the development of access controls for the Comcáac pen shell fishery were motivated by a sense of self-determination, more than a preoccupation with biological overexploitation (Basurto et al., 2012). The presence of outsider fishers in Comcáac fishing grounds at that moment in time was seen as a new form of invasion to their territory, and a threat to their self-determination. Their presence was not articulated as a resource conservation or fisheries management issue, but as part of a broader political effort to dominate and control the Comcáac since the time of the Spanish settlers. This framing was mainly mobilized by the Comcáac political leader at the time, threading the needle of the historical events of colonization and domination that the community had endured over hundreds of years. This successfully incentivized the rest of the fishing community to establish institutional arrangements to keep outsiders' presence in check in relation to their pen shells (Basurto and Garcia Lozano, 2021).

Fig. 10.6 Photo: Xavier Basurto 2022.[9]

9 For years, pen shell fishers in the Infiernillo Channel of Mexico, like the one in this picture, were able to engage in successful collective action to collectively control access to their fishing areas, showing robustness to seasonal or unexpected changing economic or environmental conditions, and adapting their rules related to who was allowed to fish, when, and how much, in order to maintain their livelihoods. In recent years, cultural and technological changes and economic incentives introduced by state authorities have decreased the ability of the fishing community to achieve collective agreements, and open access to the fishery has resulted in an unprecedented depletion of the local pen shell population.

ii. Self-organized systems are vulnerable to success and collapse without multi-level institutional support

Solving tragedies of the commons is costly and uncommon. However, it can be done and successful conservation examples from all over the world have been documented. Yet, in informally self-governed regimes, when users of a common-pool resource succeed in engaging in collective action to control access to outsiders or maintain their resource, they become vulnerable to the benefits they create. They tend to attract the attention of those who did not contribute to such success. For instance, local members of the community who were not part of the collective action process of developing access or fishing effort controls, might not feel the same commitment to abide by the same locally developed agreements to use the same harvesting technology or abide by temporary or permanent closures. Take the example of the lobster fishing communities of Cuba and the Mexican Caribbean, for whom it is important to effectively restrict the technology of harvesting, as a way to reduce fishing effort.

Fig. 10.7 Photo: Luis Bourillón 2014.[10]

In these communities, fishers harvest lobsters through freediving and have collectively agreed to continue to do so, despite the availability of more advanced diving technologies, as a way to slow down catch per unit of effort and allow the lobster population to repopulate harvested areas (Orensanz et al., 2013). Fishers harvest lobsters from *casitas*—habitat-enhancing artificial shelters where lobsters hide during their ontogenetic migration out of the bay. Originally from Cuba, *casitas* were first made out of wood but now are made of ferrocement, and lobsters are caught using a hand net known as *jamo*. These cooperatives contribute about 30% of the catch in the state (Orensanz et al., 2013) and have effectively developed internal rules and penalties to discourage fishers' undesirable behavior (Sosa-Cordero et al., 2008—cited in Orenzanz et al., 2013). As well as innovative collaborative partnerships with the state, civil society organizations and academia assist them in the production of biological knowledge, and monitoring and enforcement of their fishing areas (Mendez-Medina et al., 2020).

Other self-governed regimes, in contrast, become vulnerable to collapse after successful collective action. Following the rapid rise of communal self-governance in a network of marine reserves in northwest Mexico collapse occurred because the governance plan lacked collaboration agreements with higher levels of governance to help support their organizational efforts. In this case, fishers established a marine reserve

10 Spiny lobster is a high value target species and the main source of income for many fishers in the Mexican Caribbean. The fisher in the picture, who is from the community of Maria Elena, belongs to one of several fishing cooperatives in the region. These fishers long ago collectively agreed to only harvest spiny lobster through free diving as a way to control their own fishing efforts.

network and locally enforced harvesting rules, leading to a substantial and documented increase in local resource abundance (Cudney-Bueno et al., 2009). Reserves were created by a cooperative of 22 commercial divers to protect and enhance mollusk stocks, particularly rock scallops (*Spondylus calcifer*) and black murex snails (*Hexaplex nigritus*), two staple resources of commercial divers in the region (Cudney-Bueno et al., 2008; Cudney-Bueno and Rowell, 2008a; Cudney-Bueno and Rowell, 2008b). Local divers created and enforced the reserves while working closely with a local non-governmental conservation organization and an academic institution to design and implement a monitoring program for their fisheries. However, when news of these community-based management efforts and the abundance of resources at the reserves spread, at a regional scale, "roving bandits" from more than 300km away (along the coastline, eight hours' travel by boat) began fishing in the reserves. Since reserves and territorial use rights were not formally recognized by the government, local fishers did not have the right to expel others from their reserves and *de facto* fishing grounds. The marine reserves quickly became a free for all and in one month, mollusk populations were reduced by half. There were no incentives to continue protecting coastal reserves (Cudney-Bueno and Basurto, 2009).

iii. The form self-governance takes matters for conservation

As mentioned earlier, fishing organizations and patron-client structures are the two most common forms of self-governance in small-scale fishing (Basurto et al., 2020; Lindkvist et al., 2017; Schlüter et al., 2021; Frawley et al., 2024). As such, they offer different possibilities for the development of resource stewardship (Lejano and Ocampo-Salvador, 2006). Patron-client structures are usually thought to be less conducive to the development of resource stewardship for conservation (Johnson, 2010) than fishing cooperatives (Ovando et al., 2012), but exceptions can be found. Under a patron-client structure, incentives for governing fish production and understanding ecosystem dynamics can be easily decoupled (Crona et al., 2016). Middlemen face strong incentives to supply demand for fish and do not need to internalize the costs of ecosystem degradation when they can move unrestricted to other areas, acting as roving bandits (Berkes, et al., 2006). The capacity to adapt for environmental variability builds from the knowledge and understanding that fishers develop through experimentation in daily fishing activities (Berkes, 2008). Patron-client structures offer few incentives for building resource stewardship through the exchange of rich and valuable knowledge for adaptive capacity when fishers holding knowledge about resource dynamics have less decision-making power in relation to fish buyers, particularly if these patrons provide fishers with fishing permits, credit, loans, or fishing equipment. Thus, discussions of long-term concerns about resource depletion will be secondary to fishers' short-term concerns about building a relationship with a fish buyer to secure adequate buying terms for their catch. In contrast, cooperative governance structures offer the possibility that fishers might find it in their interest to integrate different aspects of the fishing activity, like processing, transportation, and even commercialization. When this happens, there is an increase in the likelihood of incorporating relevant knowledge for the maintenance of ecosystem functions into decision-making. Well-established fishing organizations in Mexico make regular investments in the maintenance of ecosystem functions by closing some fishing areas and taking the lead in monitoring and enforcement of these areas inside of their fishing concessions (McCay et al., 2014). A diverse range of conservation benefits has also been documented in the Chilean context (Gelcich et al., 2008), and by Ovando et al. (2012) more generally.

In summary, while the usual caveat applies that more research is needed to better understand what kinds of self-governing arrangements lead to a diversity of collective benefits beyond conservation—such as food security or equitable distribution of material assets—some scholars and practitioners have started to provide clear ways forward in the context of coastal marine environments (e.g., Bennett et al., 2021; Cohen et al., 2019). Below are the main takeaways from this section:

1. Involvement of resource users in well-thought-out, inclusive processes from the beginning of the planning of the initiative does not guarantee success and will slow down progress, but it will increase the likelihood of overall success over the long term.
2. Success is a subjective, contested issue that cannot be taken for granted. Rarely will success have the same meaning for all stakeholders and it should be thought of as dynamic and ever shifting. What was successful for some stakeholders today may not be successful for them tomorrow.
3. Self-governance can take many different forms. Some forms of self-governance will be more closely associated with resource stewardship than others, and determining which form of self-governance leads to the desired conservation outcomes will most often be an empirical question.

In closing, self-governance is one of the three main ways by which humans govern their interactions with their environment. As such, it can have a strong influence on why some conservation interventions will succeed while others will fail. Understanding basic tenets of this concept is essential: what self-governance is and what it is not; how it may emerge and be sustained over time; what incentives individuals or communities might have to self-govern for the common good and not only for their own self-gain; and how to think about self-governance in the increasingly interconnected, multi-level governance world in which we live; these are a few of the topics I have discussed here. The intention is to provide students and practitioners with some theoretical tools and empirical lessons that might increase their likelihood to think, design, and implement better conservation interventions. Note that this chapter and the rest of the contributions in this volume are exercises in self-governance, where lessons are shared to inform new trial-and-error approaches around the world and in specific contexts. In some instances, some creative conservation solutions will emerge and succeed, while others will fail. This is, in effect, the process of navigating our way to solutions in marine conservation, the very title of this book.

References

Adger, W. N., Brown, K., & Tompkins, E. L. (2005). The political economy of cross-scale networks in resource co-management. Ecology and Society, 10.

Agrawal, A. (2001). Common Property Institutions and Sustainable Governance of Resources. World Development, 29(10), 1649-1672.

Agrawal, A., Chhatre, A., & Hardin, R. (2008). Changing Governance of the World's Forests. Science, 320(5882), 1460-1462.

Anderies, J. M., Janssen, M. A., & Ostrom, E. (2004). A framework to analyze the robustness of social-ecological systems from an institutional perspective. Ecology and Society, 9.

Andersson, K. P., Chang, K., & Molina-Garzón, A. (2020). Voluntary leadership and the emergence of institutions for self-governance. Proceedings of the National Academy of Sciences, 117(44), 27292-27299.

Armitage, D., Berkes, F., & Doubleday, N. (2007). Adaptive Co-Management: Collaboration, Learning and Multi-Level Governance. Vancouver: UBC Press.

Axelrod, R. (1984). The Evolution of Cooperation. New York: Basic Books.

Baggio, J. A., Barnett, A. J., Perez-Ibarra, I., Brady, U., Ratajczyk, E., Rollins, N., Rubiños, C., Shin, H. C., Yu, D. J., Aggarwal, R., Anderies, J. M., & Janssen, M. A. (2016). Explaining success and failure in the commons: the configural nature of Ostrom's institutional design principles. International Journal of the Commons, 10(2), 417-439.

Baland, J., & Platteau, J. (1996). Halting Degradation of Natural Resources: Is There a Role for Rural Communities? Oxford, England: Oxford University Press.

Basurto, X., Cinti, A., Bourillón, L., Rojo, M., Torre, J., & Weaver, H. (2012). The Emergence of Access Controls in Small-Scale Fisheries: A Comparative Analysis of Individual Licenses and Common Property-rights from Mexico. In Forthcoming in Human Ecology.

Basurto, X., & Lozano, A. G. (2021). Commoning and the commons as more-than-resources: A historical perspective on Comcáac or Seri Fishing. In P.K. Nayak (Ed.), Making Commons Dynamic: Understanding Change Through Commonisation and Decommonisation. UK: Routledge.

Basurto, X., Virdin, J., Smith, H., & Juskus, R. (2017). Strengthening Governance of Small-Scale Fisheries: An Initial Assessment of Theory and Practice. Duke University.

Basurto, X. (2005). How Locally Designed Access and Use Controls Can Prevent the Tragedy of the Commons in a Mexican Small-Scale Fishing Community. Society & Natural Resources, 18(7), 643-659.

Basurto, X. (2008). Biological and Ecological Mechanisms Supporting Marine Self-Governance: The Seri Callo de Hacha Fishery in Mexico. Ecology and Society, 13(2).

Basurto, X. (2013). Linking multi-level governance to local common-pool resource theory using fuzzy-set qualitative comparative analysis: insights from twenty years of biodiversity conservation in Costa Rica. Global Environmental Change, 23(3), 573-587.

Basurto, X., Bennett, A., Lindkvist, E., & Schlüter, M. (2020). Governing the commons beyond harvesting: An empirical illustration from fishing. PLOS ONE, 15(4), e0231575.

Basurto, X., Gelcich, S., & Ostrom, E. (2013). The social–ecological system framework as a knowledge classificatory system for benthic small-scale fisheries. Global Environmental Change, 23(6), 1366-1380.

Basurto, X., & Ostrom, E. (2009). Beyond the Tragedy of the Commons. Economia delle fonti di energia e dell'ambiente. (Italian Journal), 52(1), 35-60.

Bennett, A., & Basurto, X. (2018). Local Institutional Responses to Global Market Pressures: The Sea Cucumber Trade in Yucatán, Mexico. World Development, 102, 57-70.

Bennett, A., Basurto, X., Virdin, J., Lin, X., Betances, S. J., Smith, M. D., Allison, E. H., Best, B. A., Brownell, K. D., Campbell, L. M., Golden, C. D., Havice, E., Hicks, C. C., Jacques, P. J., Kleisner, K., Lindquist, N., Lobo, R., Murray, G. D., Nowlin, M., Patil, P. G., Rader, D. N., Roady, S. E., Thilsted, S. H., & Zoubek, S. (2021). Recognize fish as food in policy discourse and development funding. https://doi.org/10.1007/s13280-020-01451-4

Berkes, F. (Ed.). (1989). Common Property Resources: Ecology and Community-Based Sustainable Development. London, UK: Belhaven Press.

Berkes, F. (2002). Cross-scale institutional linkages: Perspectives from the bottom up. In E. Ostrom, T. Dietz, N. Dolšak, S. P.C., S. Stonich, & E. Weber (Eds.), The Drama of the Commons (pp. 293-321). Washington, D.C.: National Academy Press.

Berkes, F. (2008). Sacred Ecology. PA: Taylor and Francis.

Berkes, F., Hughes, T. P., Steneck, R. S., Wilson, J. A., Bellwood, D. R., Crona, B., Folke, C., Gunderson, L. H., Leslie, H. M., Norberg, J., Nystrom, M., Olsson, P., Osterblom, H., Scheffer, M., & Worm, B. (2006). Globalization, Roving Bandits, and Marine Resources. Science, 311(5767), 1557-1558.

Castilla, J. C., & Defeo, O. (2001). Latin American benthic shellfisheries: emphasis on co-management and experimental practices. Reviews in Fish Biology and Fisheries, 11, 1-30.

Chowdhury, M. S. Hossain, & Koike, M. (2010). An overview of the protected area system for forest conservation in Bangladesh. Journal of Forestry Research, 21(1), 111-118.

Cinner, J. E., McClanahan, T. R., MacNeil, M. A., Graham, N. A. J., Daw, T. M., Mukminin, A., Feary, D. A., Rabearisoa, A. L., Wamukota, A., Jiddawi, N., Campbell, S. J., Baird, A. H., Januchowski-Hartley, F. A., Hamed, S., Lahari, R., Morove, T., & Kuange, J. (2012). Comanagement of coral reef social-ecological systems. Proceedings of the National Academy of Sciences, 109(14), 5219-5222.

Cohen, P. J., Allison, E. H., Andrew, N. L., Cinner, J., Evans, L. S., Fabinyi, M., Garces, L. R., Hall, S. J., Hicks, C. C., Hughes, T. P., Jentoft, S., Mills, D. J., Masu, R., Mbaru, E. K., & Ratner, B. D. (2019). Securing a Just Space for Small-Scale Fisheries in the Blue Economy. Frontiers in Marine Science, 6(171).

Coleman, E. A. (2009). Institutional factors affecting biophysical outcomes in forest management. Journal of Policy Analysis and Management, 28(1), 122-146.

Cox, M., Arnold, G., & Villamayor, S. (2010). A review of design principles for community-based natural resource management. Ecology and Society, 15.

Crona, B. I., Basurto, X., Squires, D., Gelcich, S., Daw, T. M., Khan, A., Havice, E., Chomo, V., Troell, M., Buchary, E. A., & Allison, E. H. (2016). Towards a typology of interactions between small-scale fisheries and global seafood trade. Marine Policy, 65, 1-10.

Cudney-Bueno, R., & Basurto, X. (2009). Lack of Cross-Scale Linkages Reduces Robustness of Community-Based Fisheries Management. PLoS ONE, 4(7), e6253.

Cudney-Bueno, R., Lavin, M., Marinone, S., Raimondi, P., & Shaw, W. (2009). Rapid Effects of Marine Reserves via Larval Dispersal. PLOS ONE, 4(e4140). https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0004140

Cudney-Bueno, Richard., Prescott, R., & Hinojosa-Huerta, O. (2008). The black murex snail, Hexaplex nigritus (Mollusca, Muricidae), in the Gulf of California, Mexico: I. Reproductive ecology and breeding aggregations. Bulletin of Marine Science, 83, 285-298.

Cudney-Bueno, R., & Rowell, K. (2008a). The Black Murex Snail, Hexaplex nigritus (Mollusca, Muricidae), in the Gulf of California, Mexico: II. Growth, longevity, and morphological variations with implications for management of a rapidly declining fishery. Bulletin of Marine Science, 83, 299-313.

Cudney-Bueno, R., & Rowell, K. (2008b). Establishing a baseline for management of the rock scallop, Sondylus calcifer (Carpenter 1857): Growth and reproduction in the upper Gulf of California, Mexico. Journal of Shellfish Research, 27, 625-632. https://bioone.org/journals/journal-of-shellfish-research/volume-27/issue-4/0730-8000(2008)27[625:EABFMO]2.0.CO;2/Establishing-a-Baseline-for-Management-of-the-Rock-Scallop-Spondylus/10.2983/0730-8000(2008)27[625:EABFMO]2.0.CO;2.short

Flannery, W., Toonen, H., Jay, S., & Vince, J. (2020). A critical turn in marine spatial planning. Maritime Studies, 19(3), 223-228.

Frawley, T. H., González-Mon, B., Nenadovic, M., Gladstone, F., Nomura, K., Zepeda-Dominguez, J.A., Leslie, H., Rodriguez-Van Dyck, S. Ferrer, E., Micheli, F., Basurto X. (2024). Self-Governance Mediante Small-Scale Fishery Operations, Vulnerability and Adaptive Response. Global Environmental Change. 84.102805. https://doi.org/10.1016/j.gloenvcha.2024.102805

Gelcich, S., Hughes, T. P., Olsson, P., Folke, C., Defeo, O., Fernandez, M., Foale, S., Gunderson, L. H., Rodriguez-Sickert, C., Scheffer, M., Steneck, R. S., & Castilla, J. C. (2010). Navigating transformations in governance of Chilean marine coastal resources. Proceedings of the National Academy of Sciences, 107(39), 16794-16799.

Gelcich, S., Kaiser, M. J., Castilla, J. C., & Edwards-Jones, G. (2008). Engagement in Co-management of Marine Benthic Resources Influences Environmental Perceptions of Artisanal Fisheries. Environmental Conservation, 35, 36-45.

Gordon, H. S. (1954). The Economic Theory of a Common-Property Resource: The Fishery. Journal of Political Economy, 62(2), 124.

Gruby, R., & Basurto, X. (2014). Multi-level governance for large marine commons: Politics and polycentricity in Palau's protected area network. Environmental Science & Policy, 36, 48-60.

Gunderson, L. H., & Holling, C. S. (2002). Panarchy: Understanding Transformations in Human and Natural Systems. Covelo, CA: Island Press.

Gutiérrez, N. L., Hilborn, R., & Defeo, O. (2011). Leadership, social capital and incentives promote successful fisheries. Nature, 470(7334), 386-389.

Hardin, G. (1968). The Tragedy of the Commons. Science, 162(859), 1243-12248.

Hayes, T., & Persha, L. (2010). Nesting local forestry initiatives: Revisiting community forest management in a REDD plus world. Forest Policy and Economics, 12, 545-553.

Heikkila, T., Schlager, E., & Davis, M. W. (2011). The role of cross-scale institutional linkages in common-pool resource management: Assessing interstate river compacts. Policy Studies Journal, 39, 121-145.

Janssen, M. A., Anderies, J. M., & Ostrom, E. (2007). Robustness of social-ecological systems to spatial and temporal variability. Society and Natural Resources, 20, 307-322.

Jentoft, S., & McCay, B. (1995). User participation in fisheries management: lessons drawn from international experiences. Marine Policy, 19(3), 227-246.

Johnson, D. S. (2010). Institutional Adaptation as a Governability Problem in Fisheries: Patron-Client Relations in the Junagadh Fishery, India. Fish & Fisheries, 11, 264-277.

Juárez-Torres, M., Flores-Escobar, M. de la L., & Martiínez, J. L. (2007). El sector pesquero en México. Documento Interno de Trabajo de Financiera Rural.

Lansing, J. S. (2006). Perfect Order: Recognizing Complexity in Bali. Princeton, MA: Princeton University Press.

Lansing, J. S., & Miller, J. H. (2003). Cooperation in Balinese Rice Farming. In Santa Fe Institute (Ed.), Pp. 1-14. Santa Fe.

Lejano, R. P., & Ocampo-Salvador, A. (2006). Context and differentiation: Comparative analysis of two community-based fishers' organizations. Marine Policy, 30(6), 726-736.

Leslie, H. M., Basurto, X., Nenadovic, M., Sievanen, L., Cavanaugh, K. C., Cota-Nieto, J. J., Erisman, B. E., Finkbeiner, E., Hinojosa-Arango, G., Moreno-Báez, M., Nagavarapu, S., Reddy, S. M. W., Sánchez-Rodríguez, A., Siegel, K., Ulibarria-Valenzuela, J. J., Weaver, A. H., & Aburto-Oropeza, O. (2015). Operationalizing the social-ecological systems framework to assess sustainability. Proceedings of the National Academy of Sciences.

Lindkvist, E., Basurto, X., & Schlüter, M. (2017). Micro-level explanations for emergent patterns of self-governance arrangements in small-scale fisheries—A modeling approach. PLOS ONE, 12(4), e0175532.

Marin, A., Gelcich, S., Castilla, J. C., & Berkes, F. (2012). Exploring Social Capital in Chile's Coastal Benthic Comanagement System Using a Network Approach. Retrieved from http://www.ecologyandsociety.org/vol17/iss1/art13/.

McCay, B. J. (1996). Common and Private Concerns. In S. S. Hanna, Folke, C., & K. G. Mäler (Eds.), Rights to Nature. Ecological, Economic, Cultural, and Political Principles of Institutions for the Environment (pp. 249-266). Covelo, CA: Island Press.

McCay, B. J., Micheli, F., Ponce-Díaz, G., Murray, G., Shester, G., Ramirez-Sanchez, S., & Weisman, W. (2014). Cooperatives, concessions, and co-management on the Pacific coast of Mexico. Marine Policy, 44, 49-59.

McCay, B. J., & Acheson, J. M. (Eds.). (1987). The Question of the Commons. The Culture and Ecology of Communal Resources. Tucson, Arizona: The University of Arizona Press.

McGinnis, M., & Ostrom, E. (2008). Will lessons from small-scale social dilemmas scale up? In A. E. Biel, T. Gärling, & G. M. (Eds.), New Issues and Paradigms in Research on Social Dilemmas (pp. 189-211). Berlin: Springer.

McKean, M. A. (2000). Common Property: What Is It, What Is It Good for, and What Makes It Work? Cambridge, Massachusetts, USA: Massachusetts Institute of Technology.

Miller, G. (1992). Managerial Dilemmas: The Political Economy of Hierarchy. Cambridge: Cambridge University Press. https://doi.org/10.1017/CBO9781139173742

Moe, T. (1990). The Politics of Structural Choice: Toward a Theory of Public Bureaucracy. In O. E. Williamson (Ed.), Organization Theory. From Chester Barnard to the Present and Beyond (pp. 116-153). Oxford, Oxford University Press.

Morrison, T. H. (2017). Evolving polycentric governance of the Great Barrier Reef. Proceedings of the National Academy of Sciences, 114(15), E3013-E3021.

NOAA. (2013). Cumulative trade data by product.

Nurdin, N., & Grydehøj, A. (2014). Informal governance through patron–client relationships and destructive fishing in Spermonde Archipelago, Indonesia. Journal of Marine and Island Cultures, 3(2), 54-59.

Oberthür, S., & Stokke, O. S. (Eds.). (2011). Managing Institutional Complexity. Regime Interplay and Global Environmental Change. The MIT Press. Cambridge USA.

Olson, M. (1965). The Logic of Collective Action: Public Goods and the Theory of Groups. Cambridge, Mass: Harvard University Press.

Orensanz, J. M., Cinti, A., Parma, A., Burotto, L., Espinosa-Guerrero, S., Sosa-Cordero, E., Sepúlveda, C., & Toral-Granda, V. (2013). Latin-American rights-based fisheries targeting sedentary resources. In J. M. Orensanz & J. C. Seijo (Eds.), Rights-based management in Latin American fisheries (pp. 72–134). Vol. FAO Fisheries and Aquaculture Technical Paper N. 582. Rome: Food and Agriculture Organization of the United Nations.

Ostrom, E. (1990). Governing the commons: The evolution of institutions for collective action. Cambridge, UK: Cambridge University Press.

Ostrom, E. (1999). Coping with Tragedies of the Commons. Annual Review of Political Science, 2, 493-535.

Ostrom, E. (2000). Collective Action and the Evolution of Social Norms. Journal of Economic Perspectives, 14(3), 137-158.

Ostrom, E. (2005). Understanding Institutional Diversity. Princeton, NJ: Princeton University Press.

Ostrom, E. (2007). Institutional Rational Choice. An Assessment of the Institutional Analysis and Development Framework. In P. A. Sabatier (Ed.), Theories of the Policy Process (pp. 21-64). Boulder, CO., Westview.

Ostrom, E. (2009). A General Framework for Analyzing Sustainability of Social-Ecological Systems. Science, 325(5939), 419-422.

Ostrom, E., Janssen, M. A., & Anderies, J. M. (2007). Going beyond panaceas. Proceedings of the National Academy of Sciences, 104(39), 15176-15178.

Ostrom, V. (1986a). Constitutional Considerations with Particular Reference to Federal Systems. In F. X. Kaufmann, G. Maione, & V. Ostrom (Eds.), Guidance, Control, and Evaluation in the Public Sector (pp. 111-125). New York: Walter de Gruyter.

Ostrom, V. (1986b). A Fallabvilist's Approach to Norms and Criteria of Choice. In F. X. Kaufmann, G. Majone, & V. Ostrom (Eds.), Guidance, Control, and Evaluation in the Public Sector (pp. 229-249). New York: Walter de Gruyter.

Ovando, D. A., Deacon, R. T., Lester, S. E., Costello, C., Van Leuvan, T., McIlwain, K., Strauss, K., Arbuckle, M., Fujita, R., Gelcich, S., & Uchida, H. (2012). Conservation incentives and collective choices in cooperative fisheries. Marine Policy, 37, 132-140.

Pagdee, A., Kim, Y., & Daugherty, P. J. (2006). What Makes Community Forest Management Successful: A Meta-Study From Community Forests Throughout the World. Society & Natural Resources, 19(1), 33-52.

Partelow, S. (2018). A review of the social-ecological systems framework: Applications, methods, modifications, and challenges. Ecology and Society, 23(4).

Persha, L., Agrawal, A., & Chhatre, A. (2011). Social and Ecological Synergy: Local Rulemaking, Forest Livelihoods, and Biodiversity Conservation. Science, 331(6024), 1606-1608.

Rockström, J., Steffen, W., Noone, K., Persson, Å., Chapin, F. S., Lambin, E. F., ... Foley, J. A. (2009). A safe operating space for humanity. Nature, 461(7263), 472-475.

Rudd, M. A., Tupper, M. H., Folmer, H., & Van Kooten, G. C. (2003). Policy analysis for tropical marine reserves: challenges and directions. Fish and Fisheries, 4(1), 65-85.

Ruddle, K. (2011). "Informal" Credit Systems in Fishing Communities: Issues and Examples from Vietnam. Human Organization, 224-232.

Rudel, T. K. (2005). Tropical Forests. Regional Paths of Destruction and Regeneration in the Late Twentieth Century. NY, NY: Columbia University Press.

Schlager, E. (2002). Rationality, cooperation, and common-pool resources. American Behavioral Scientist, 45, 801-819.

Schlüter, M., Lindkvist, E., & Basurto, X. (2021). The interplay between top-down interventions and bottom-up self-organization shapes opportunities for transforming self-governance in small-scale fisheries. Marine Policy, 104485.

Sen, S., & Nielsen, J. R. (1996). Fisheries co-management: A comparative analysis. Marine Policy, 20(5), 405-418.

Trench, T. (2008). From "Orphans of the State" to the Comunidad Conservacionista Institucional: The case of the Lacandon Community, Chiapas. Identities - Global Studies in Culture and Power, 15, 607-634.

Ünal, V., Güçlüsoy, H., & Franquesa, R. (2009). A better understanding of fishery cooperatives in the Aegean, Turkey. Journal of Animal and Veterinary Advances, 8(7), 1361-1366.

Virdin, J., Basurto, X., Nico, G., Harper, S., Mancha Cisneros, M. M., Vannuccini, S., Franz, N. (2023). Fishing for Subsistence Constitutes a Livelihood Safety Net for Populations Dependent Upon Aquatic Foods Around the World. Nature Foods. 4:874-885.

Wade, R. (1994). Village Republics: Economic Conditions for Collective Action in South India. San Francisco, CA: ICS Press.

Wilson, J. (2006). Matching social and ecological systems in complex ocean fisheries. Ecology and Society, 11(1).

Wilson, J., Yan, L., & Wilson, C. (2007). The precursors of governance in the Maine lobster fishery. Proceedings of the National Academy of Sciences, 104(39), 15212-15217.

Young, O. R. (2002). The institutional dimensions of environmental change: fit, interplay, and scale. Cambridge: MIT Press.

Young, O. R., King, L. A., & Schroeder, H. (2008). Building regimes for socioecological systems: Institutional diagnostics. In O. R. Young, L. A. King, & H. Schroeder (Eds.), Institutions and environmental change: principal findings, applications, and research frontiers. Cambridge: MIT Press.

11. Trait-based tools aid conservation planning for predator range shifts

Stephanie J. Green[1]

Causes and consequences of predator range shifts

Predators play vital ecological roles in marine systems ranging from controlling trophic cascades (Pinnegar et al., 2000; Baum and Myers, 2004), to enhancing carbon sequestration (Spiers et al., 2016), to stabilizing biodiversity (Ellingsen et al., 2015). Harvesting ocean predators also provides billions of dollars in revenue and affects the food security of millions of people globally (Christensen, 1996; Sumaila et al., 2012). The value of predators in our oceans has become more apparent amidst profound changes in their populations: targeted by fisheries and caught incidentally as bycatch, traded in the global aquarium industry, susceptible to contaminants, and facing dwindling prey resources and unprecedented extremes in ocean temperature and chemistry, the pace and scale at which predator distribution and abundance has shifted over the past two centuries continues to accelerate today.

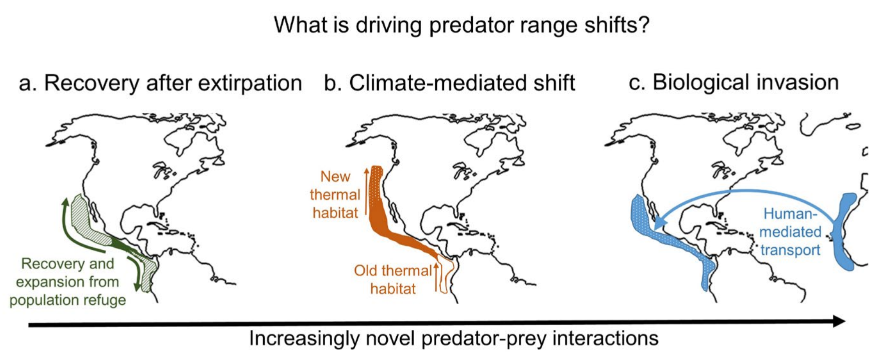


Fig. 11.1 The impacts of predator redistribution on ocean ecosystems depends on the extent to which novel predator-prey interactions form between range shifted species. (a) Following centuries of overharvesting, conservation measures have allowed many predator populations to recover some or all of their previous geographic range, re-establishing interactions with former prey species. (b) Intensifying climate change also has ocean predators moving into new ranges were previously beyond thermal limits, with range shift extent depending on a number of traits including foraging mode, body size, and mobility. (c) Global trade has resulted in the exchange of predators across ocean basins, adding a novel source of predation mortality for hosts of native species.

Predators are being added to and removed from ocean systems at unprecedented rates, generally as a result of three main processes (Figure 11.1). First, intensifying climate change has ocean predators on the move (Molinos et al., 2016). Geographic ranges and centers of abundance are being differentially affected by changing abiotic

1 Faculty of Science–Biological Sciences, University of Alberta, https://orcid.org/0000-0003-4705-7859

 https://doi.org/10.11647/OBP.0395.11

ocean conditions, with displacement under future climate scenarios predicted to be related to species' life history and trophic roles. Over the past several decades, fisheries data reveal that marine predator ranges have already shifted in some coastal marine ecosystems (Sorte et al., 2010; Pinsky et al., 2020). Climate-driven changes in ocean predator distribution will not only uncouple predator-prey interactions, allowing novel interactions, but will likely shift centers of distribution across federal, state, and international boundaries, challenging management approaches.

Second, a growing number of cases demonstrate the potential for previously depleted or extirpated ocean predator populations to recover and begin range re-expansion (Stier et al., 2016). In many cases, populations are expanding into areas that have been fundamentally reshaped by other human-mediated forces such as climate warming, habitat alteration, or the over-exploitation of key prey species (Cammen et al., 2019). Finally, biological invasions involving ocean predators, while relatively rarer than invasions by lower-trophic-level species, often have disproportionately negative consequences for native biodiversity in the recipient system (Carlton, 1989; Bax et al., 2001). The pace and scale of predator invasions in ocean systems is not slowing (Ricciardi, 2007).

What will marine ecosystems look like in the face of predator redistribution, and what are the consequences for goods and services we derive from ocean systems? There are myriad consequences of predator redistribution for ocean conservation and policy (Figure 11.2). Fisheries globally, and the management agencies that regulate them, must now adapt to the co-occurring effects of climate change, exploitation, and other stressors on ecosystem composition and productivity. Marine protected area design must also account for the changing distribution, abundance, and composition of ocean predators they often aim to protect. Habitat restoration programs must assess the implications of predator loss or gain in mediating trophic cascades that could help or hinder efforts to restore foundational species that form biogenic habitats like kelp forests, eelgrass beds, or oyster and coral reefs. Agencies must allocate sufficient resources to control exotic predators so as to alleviate the worst impacts on valued species and resources in priority locations.

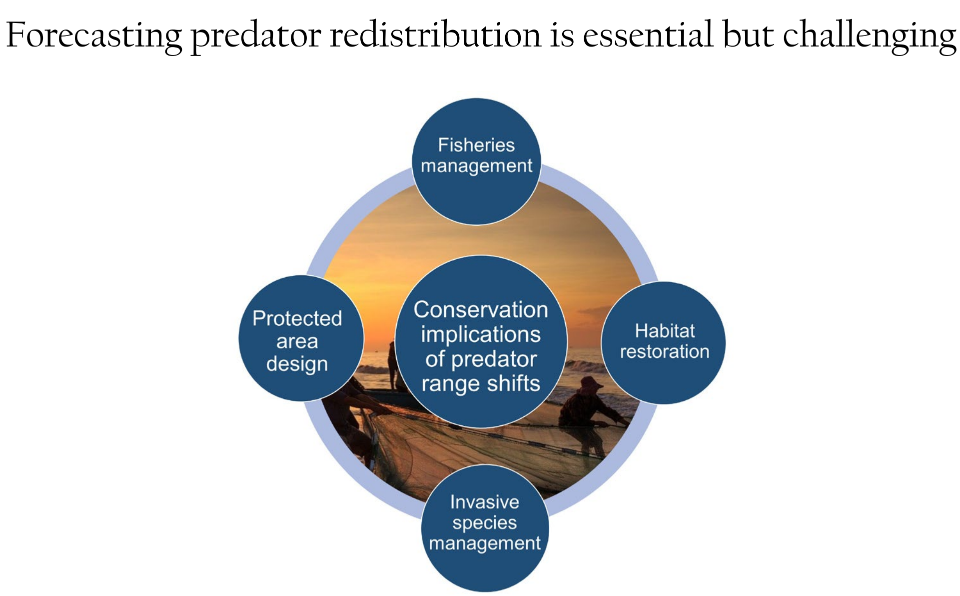


Fig. 11.2 Numerous conservation and management activities affected by the outcome of predator redistribution and resulting novel predator-prey relationships.[2]

2 Fisheries management must account for predator redistribution and accompanying abundance shifts, particularly for species harvested across jurisdictional boundaries. Marine protected area design must account for the future distribution of predators they seek to protect as global change intensifies. Habitat restoration programs must anticipate trophic cascades triggered by the loss or

Where will predators end up, and how many will there be in our future oceans? How will their changing populations interact with recipient ecosystems, and what will the consequences be for resources we derive from ocean spaces? Forecasting when, where, and how predator redistribution occurs is essential for managing the impacts of invasive predators as they spread, adjusting harvest strategies as targeted predators shift across jurisdictional boundaries, and anticipating the consequences of historically depleted predators re-establishing populations in extirpated territories.

Predator distribution is influenced by a range of abiotic and biotic factors influencing habitat selection and use. Of these factors, feeding relationships and prey requirements are often some of the most complex to disentangle. As a result, the bulk of existing tools for forecasting abundance and distribution focus on relationships between animal presence and abiotic drivers of ecological change (e.g., temperature, pH, hypoxia) which can be measured at high resolutions and over vast areas through remote sensing. Species distribution models rely on historical statistical links between ocean conditions and animal space use. Animal locations over space and time are gathered through methods such as satellite tracking studies, presence/catch records from fisheries-dependent sampling, or presence/absence or abundance metrics from systematic fisheries-independent research surveys. Typically, abiotic data are linked to observed variation in the distribution and abundance of the focal species in the recent past, and these relationships are then used to predict future distribution and/or abundance under forecasted environmental conditions (e.g., Hazen et al., 2013; Howell et al., 2013; Lehodey et al., 2015; Woodworth-Jefcoats et al., 2016). Species distribution models for top predators often omit information on trophic linkages, as accurate and precise information about prey distribution and abundance is challenging to collect. However, prey availability is a major driver of predator distribution and abundance in many systems (e.g., Ryan et al., 2022). Moreover, the greater the number of trophic linkages between predators and the base of the food web, the less tightly coupled their dynamics are likely to be to changes in the physical environment. Reciprocal feedbacks also exist wherein changes in predator abundance and distribution naturally influence the abundance, distribution and diversity of potential prey items.

Forecasting the consequences of predator redistribution for ecosystem structure and dynamics can also be achieved through 'end-to-end' ecosystem modeling, which seeks to model biomass flows throughout the ecosystem by way of integrated food web models (i.e., network models; e.g., Ecopath with Ecosim/Ecospace (EwE) or Atlantis; Kaplan et al., 2004). Spatially explicit versions of food web models offer a means to link changes in abiotic conditions to the relative abundance of food web constituents across space and over time, and explicitly to incorporate reciprocal feedback between predators and their prey. While these approaches offer the advantage of incorporating dynamic predator-prey relationships into forecasts, key feeding relationships are typically characterized by sparse and dated diet data. Moreover, both the diet and observational data needed to characterize predator-prey interactions are prohibitively expensive to collect in real time, and so are temporally and spatially disconnected from the time and location of the populations being modeled.

In all methods currently applied to this problem, a fundamental omission is the ability to account for diet selection in a changing landscape of available prey types. Diet often reflects a combination of what the predator encounters and can subsequently capture and consume (Figure 11.3), so that prey selection and interaction strength vary across space and time. Estimating resource selection functions for predator diets is fraught with logistical challenges and often suffers from major gaps spatially and temporally.

Trait-based approaches to predator-prey interactions

A range of morphological, behavioral, nutritional, and physiological traits have been theoretically proposed and empirically demonstrated to affect the predation process (Figure 11.3), with predators selectively

gain of predators. Agencies must allocate sufficient resources to the controlling exotic predators so as to alleviate the worst impacts to valued species and resources in priority locations.

consuming profitable prey that possess traits that confer high vulnerability to their predation strategy. An alternative approach to quantifying species interactions within ecosystem models centers on conceptualizing predators and prey as behavioral and morphological typologies—generated from foraging theory and supported by field and experimental data—rather than taxonomic identities. Shifting away from species' identities and towards their traits facilitates the creation of mechanistic predictions about interaction strengths among (1) species that do not currently co-occur, but likely will in the future, and (2) species that co-occur, but for which data used to generate interaction strength (i.e., diet or tissue isotope data) are limited or absent.

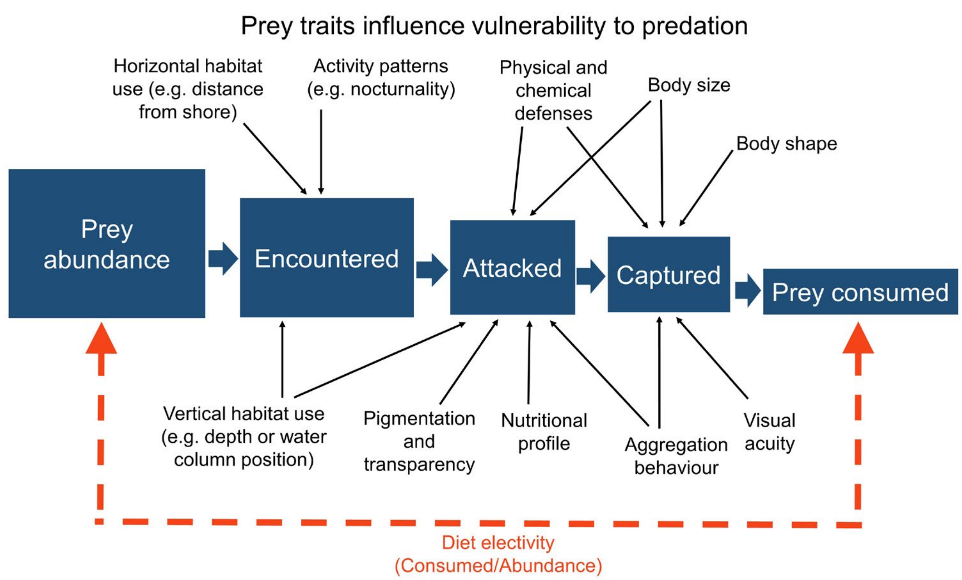


Fig. 11.3 Prey traits such as habitat use, morphology, behavior, and nutrient content affect vulnerability to predation. The extent to which predators will consume novel species they encounter following range shifts depends on their traits.

The phenomenon of selective predation (i.e., consumption of prey types in quantities disproportionate to their relative environmental abundance) is common among consumers (Abrams, 1996; Kondoh, 2003), and likely to have a substantial effect on the strength of interactions among species (Sundell and YlöNen, 2008). This is because predators seek to maximize energetic gain while minimizing energetic cost in locating, capturing, handling, and digesting prey (e.g., Pyke et al., 1977), and prey vary in ways that affect this foraging process (Rice et al., 1997). To date, predictions from foraging theory have not been widely integrated into food web models, because insights gained from most foraging ecology studies are specific to the set of species involved, and their relative abundances.

Differences in morphology and behavior for both predators and prey are at the heart of predictions for variable susceptibility to predation. In particular, characteristics associated with foraging mode (e.g., stalking versus ambush predation, particulate vs. filter feeding) and anti-predator responses (e.g., aggregation behavior or the presence of a chemical defense) are predicted to alter the probability of success during progressive steps in the foraging process (Sih and Christensen, 2001; Table 11.1; Figure 11.3). These traits typically recur across unrelated species found in distant habitats, offering a means to disentangle the influence of traits from taxonomy in forecasting which species will be most strongly affected by interactions with a novel predator (Table 11.1, Figure 11.3).

Table 11.1 Example traits of ocean species likely to affect the likelihood of consumption by a predator.

Type	Trait
Habitat	Minimum depth limit recorded
	Maximum depth limit recorded
	Minimum temperature limit recorded
	Maximum temperature limit recorded
	Vertical habitat association (benthic, demersal, epipelagic, mesopelagic, bathypelagic)
	Horizontal habitat association (intertidal, reef-associated, coastal, continental shelf, continental slope, oceanic, freshwater)
Behavior	Diel/diurnal vertical migration behavior
	Use of physical refuge
	Aggregation behaviour (solitary, shoaling, schooling)
	Minimum length (cm) for the specific life stage
	Maximum length (cm) for the specific life stage
	Presence or number of defensive spines
	Presence of exoskeleton, carapace, or armouring
	Presence of transparency
	Presence of disruptive coloration
	Presence of silvering
	Presence of countershading
	Presence or number of photophores
	Body shape (categorical [eel-like, elongated, fusiform, globiform, compressiform, depressiform] or continuous [total length: body height ratio])
	Visual acuity (eye diameter: total length ratio)
Nutritional quality	Lipid content in wet weight (%)
	Protein content in wet weight (%)
	Energy density in wet weight (kJ/g)

Applying trait analyses to predator conservation and management

Trait-based insights are increasingly being harnessed to predict the ecosystem effects of global change, including the consequences of predator redistribution (Green et al., 2022). Using insights into the trait forms of potential prey species that are most vulnerable to a given predator provides a means to estimate the strength of interactions with taxa for which the predator species has only recently become associated, or with which it is likely to become associated, given projected range change. Emerging examples include identifying hotspots of likely impact from invasive Indo-Pacific lionfish in the Western Atlantic and Caribbean basin to inform local control plans (Case Study 1, below) and improving forecasts of cross-jurisdictional range shifts by commercially valuable albacore tuna under climate change in the Eastern Pacific (Case Study 2, below).

In all cases, three types of information are needed to predict the strength of predation impact on newly encountered prey fields: 1) information on historic predator diet composition and use relative to environmental abundance; 2) information on the set of species the predator is likely to encounter in their new/recovered range; 3) classifications of these species sets by traits likely to affect the predation process for the given predator (Table 11.1). When possible, it may be important to assess the extent to which traits of focal prey for the given predator shift with key environmental conditions such as environmental state (Figure 11.4). Trait data are increasingly available in open-access regional and global repositories (e.g., Gleiber et al. 2022; Pauly and Frose 2000).

Case study 1: Anticipating impacts from invasive Indo-Pacific lionfish to inform early detection and population control

The global invasion of Indo-Pacific lionfish (*Pterois volitans* and *P. miles*) into multiple ocean basins perfectly illustrates the challenge range that expanding predators pose to marine conservation (Figure 11.4). Since their introduction into the Atlantic Ocean via the aquarium trade more than three decades ago, high populations of predatory lionfish have generated significant declines in native fish fauna across invaded coastal habitats in the Western Atlantic, Gulf of Mexico, and Caribbean Sea (Albins, 2012; Green et al., 2012; Côté et al., 2013).

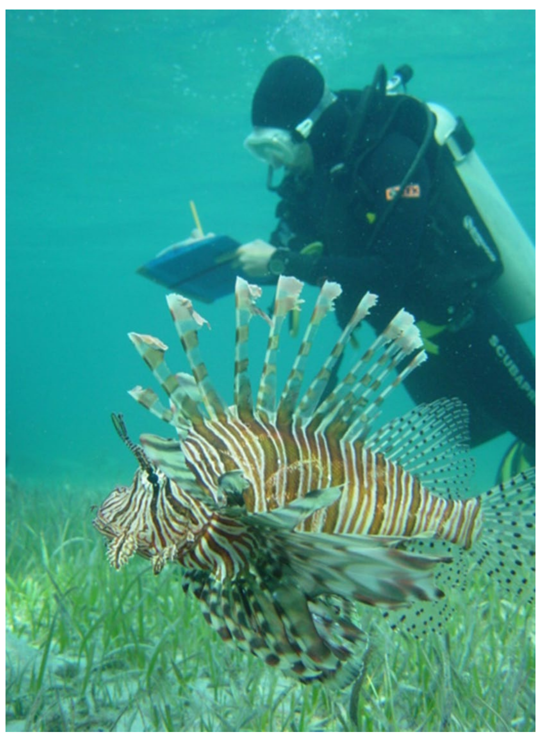
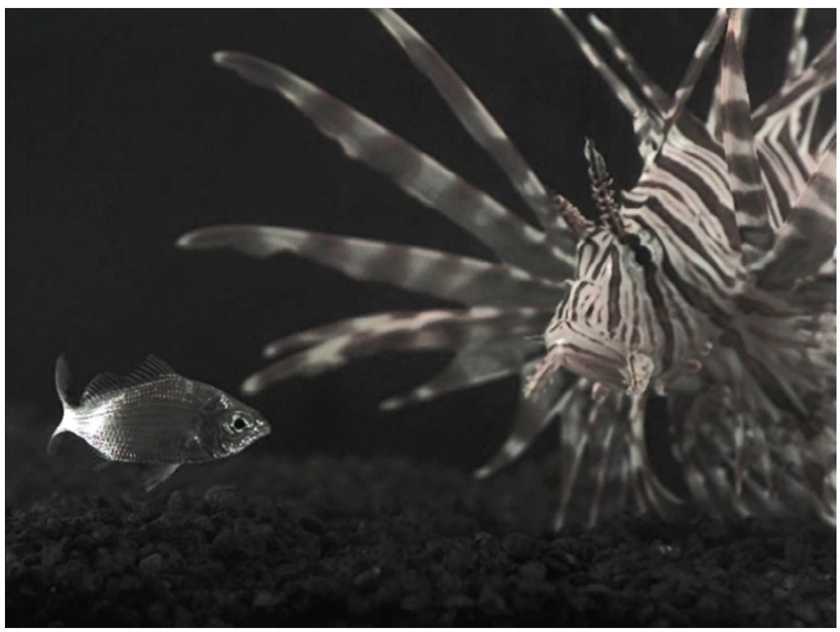


Fig. 11.4 An invasive Indo-Pacific red lionfish (*Pterois volitans*) hovers in the seagrass next to a coral reef off the coast of The Bahamas in the Western Atlantic Ocean. Photo courtesy of Lad Akins.

The invasion is now spreading along the east coast of South America and a second invasion of the same species is intensifying in the Mediterranean Sea. To date over 200 fishes and invertebrate species have been identified from the stomach contents of invasive lionfish (Peake et al. 2018). The composition of native species inhabiting coastal areas varies greatly from location to location. Thus, despite significant resources devoted to stomach contents assessment, diet studies are of limited use for identifying species that are most vulnerable to lionfish predation before impacts have occurred. As a result, patterns of predation by lionfish, and thus impacts, in one place are not generalizable to other sites. Lionfish population management is conducted through the removal of fish by natural resource agency staff, dive operators, volunteers, and fishers using hand-held pole spears (Ulman et al. 2022). With lionfish now spread over >2,000,000km^2 of ocean habitat ranging from shorelines to >305m deep, complete eradication of the species is not feasible. However, local removal programs can be successful in suppressing lionfish densities below levels that cause harm to the environment (Green et al., 2017). Information on the species and places most likely to be impacted by lionfish are urgently needed to help guide efforts by local removal programs (Ulman et al., 2022).

Examining the morphological and behavioral traits of fishes consumed by invasive lionfish in relation to the traits the fish community at large has revealed that lionfish exhibit strong patterns of diet selection for species with characteristics that make them susceptible to the predator's unique stalking method of hunting.



Video 11.1 Lionfish capturing a prey in slow motion (Credit: Dr. James Morris, National Oceanic and Atmospheric Administration). https://hdl.handle.net/20.500.12434/811191a3

Small, slender, schooling fishes that swim near the bottom and are active at night are more than 200 times more likely to be consumed by lionfish than species without these traits (Green and Côté, 2014; Green et al., 2019). Because these physical characteristics and behaviors are shared by unrelated taxa, it is possible to identify other species that will be most impacted by the arrival of lionfish to habitats that are currently ahead of the invasion front (Linardich et al., 2021). These trait-based insights are now being used to identify high-priority areas for management intervention, based on the presence of endemic and range-restricted species that possess this suite of vulnerable characteristics (Rocha, 2015; Chapman et al., 2019; Bogdanoff et al., 2021; Linardich et al., 2021; Figure 11.5).

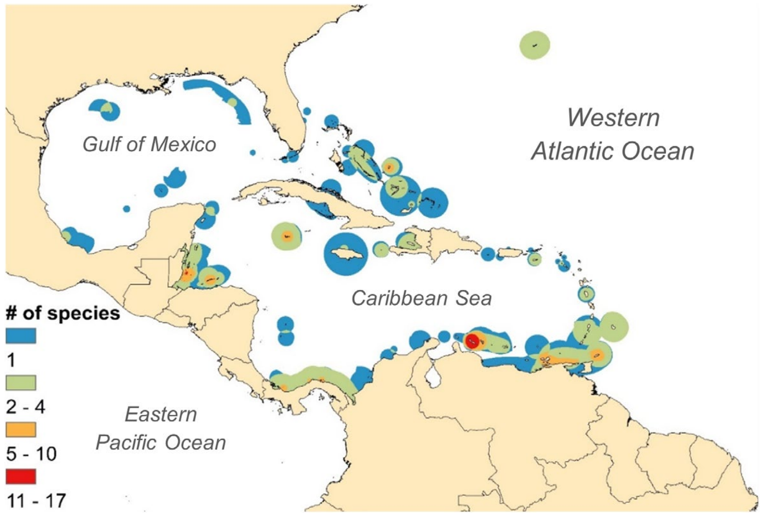


Fig. 11.5 The location of 'hot spots' of predation impact by invasive lionfish in the Western Atlantic basin. Hot spot locations are based on the number of endemic fish species with traits that are highly vulnerable to lionfish predation (i.e., small, slender, schooling fishes that swim near the bottom and are active at night).

Case Study 2: Estimating climate-driven shifts in albacore tuna to inform cross-jurisdictional fisheries management

Case study analysis created with Dr. Miram Gleiber

Albacore tuna (*Thunnus alalunga*), a highly migratory species targeted by pelagic fisheries globally, highlight the socio-economic implications of predator re-distribution in a changing ocean and the need for forecasting (Figure 11.6). At least three attributes make albacore an excellent test case with which to evaluate the utility of a trait-based approach for guiding cross-jurisdictional fisheries management under climate change. First, populations of albacore have historically varied in biomass and distribution as a result of long-term climate oscillations (Nieto et al., 2017), and there is evidence that both the edges of their geographic range and centers of population abundance will be sensitive to future climate conditions. Second, a suite of opportunistic diet studies over the past 40 years indicate that the buffet of marine taxa albacore consume varies greatly both spatially and temporally, reflecting variation in the assemblage of species available for albacore to forage upon (n= 308 species; Glaser, 2010; Hardy et al., 2023). This diet variation presents an opportunity to identify common morphological and behavioral traits shared among a broad range of prey species that confer vulnerability to albacore's foraging strategy. Finally, under climate change, albacore is likely to shift across multiple regional and international jurisdictions that share responsibility for ensuring albacore's sustainable harvest (Childers et al., 2011). For example, coastal fishing fleets off the Pacific coasts of Mexico, the United States, and Canada harvest albacore from the NE Pacific population as they migrate into the California Current Large Marine Ecosystem (CCLME) as sub-adults. Historically, the size and location of the population in this region has shifted with long-term climate oscillations in the region (i.e., El Niño/La Niña climate cycles). Climate changes in the CCLME are forecast to generally shift species centers of abundance north and change the timing of historical climate oscillations (Ruzicka et al., 2012), with implications for the multiple regional and international jurisdictions that currently share access to, and responsibility for, albacore within the EEZ of countries bordering the CCLME (Mexico, US, and Canada, and multiple territorial jurisdictions within these nations). Shifts in centers of albacore population abundance across jurisdictional boundaries that differ in management approach (e.g., harvest strategy, limits, and gear types) will have consequences for mortality rates at the population level.

Fig. 11.6 Albacore tuna (*Thunnus alalunga*) school at the surface of the ocean. Photo courtesy of the Canadian Highly Migratory Species Foundation.[3]

Information on foraging and anti-predator morphologies and behaviors expressed by albacore, and the suite of fish and invertebrate species they may consume within the CCLME, have been compiled from published foraging experiments, field studies, and functional morphology analyses. The data are available in an open-access database of pelagic species trait information[4] (Gleiber et al., 2024a). Clustering analyses drawing on these data reveal that the hundreds of prey species consumed by albacore globally can be distilled to a much smaller number of prey typologies with, for example, similar habitat use characteristics (Hardy et al., 2023).

Examining historical variation in albacore feeding linkages (from diet data) and community composition of potential prey (from scientific trawl surveys) driven by dramatic fluctuations in ocean conditions—for example due to El Niño-La Niña climate oscillations over relatively short time periods (Chavez et al., 2002; Wolter and Timlin, 2011)—provides key insights into traits that are likely to mediate albacore distribution shifts under future climate scenarios. Trait-based analyses reveal that at least seven trait forms, which recur across hundreds of distantly related prey taxa, are consistently consumed by albacore in far greater proportion than expected based on their environmental abundance. In particular, lipid- and energy-rich, silvered, counter-shaded, and undefended organisms that school in mid-water coastal habitats appear to be the tastiest (Gleiber et al., 2024b). Combining information on these traits into an aggregate 'yumminess index', which ranges from 0 to 7 depending on the number of preferred traits a taxon possesses, allows scientists to visualize spatial variation in the quality of prey communities that albacore forage on across the CCLME in relation to a changing climate (Figure 11.7). Estimates from trait-based analyses can be used to inform relative interaction strengths for predator-prey interaction equations within ecosystem models being used to forecast the ecosystem-scale consequences of predator range shifts across the system (Smith et al., 2023).

3 Migratory Albacore hunt in coastal ecosystems in the Eastern Pacific Ocean that are rapidly changing due to increasing extreme climate events that are disrupting historical cycles of ecosystem productivity. As a result of changing ocean conditions and shifts in prey species, Albacore centers of abundance are shifting inshore and northward to an extent not previously recorded, with implications for the fisheries that share harvest across international boundaries in the region.

4 https://borealisdata.ca/dataverse/pelagic_species_traits

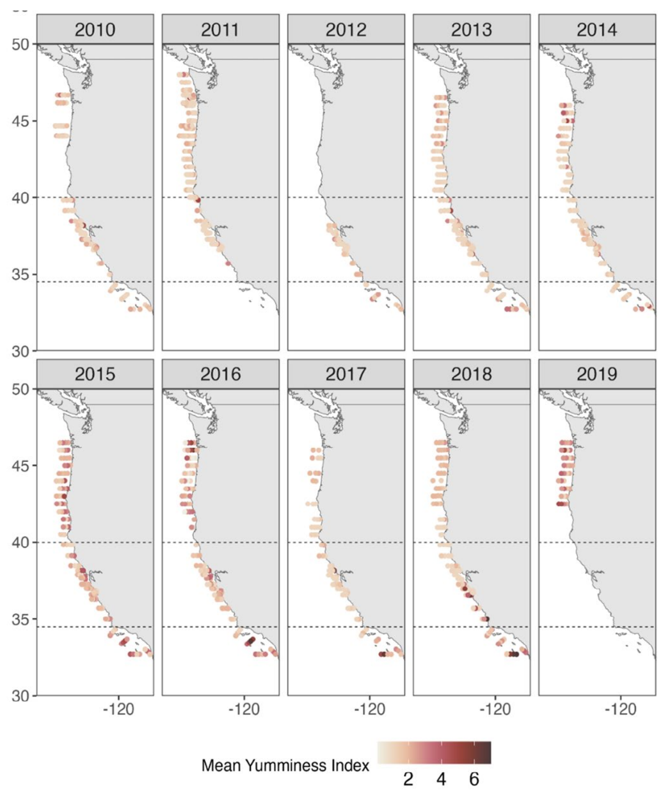


Fig. 11.7 Hotspots of highly suitable prey for Albacore tuna in the California Current Large Marine Ecosystem (CCLME) in the Northeast Pacific Ocean across a decade.[5]

Challenges and opportunities for trait-informed conservation

Most of the obstacles to using traits in forecasting the consequences of predator range change are logistical, and could be overcome with sufficient planning and resource allocation to initial trait data collection and processing. While by no means trivial, such efforts may help generate more efficient interventions in the long run by targeting ecosystem components that are most likely to change as a result of the presence of a new predator. Logistical challenges include mismatch in the timeline required for initial trait-data collection compared with the timeline on which range expansion is expected and conservation decisions are needed. In addition, when is the available diet data and trait data sufficient for predicting who will eat whom? Insights into the extent to which trait-based trends are robust, especially across major environmental regime shifts or gradients (Figure 11.8), reduces data needs.

Over time, it is necessary to generate trait-based forecasts and compare them against observations of real systems change, to reveal the extent to which 'the right traits' are captured for changing predator-prey regimes. As a result, initial efforts will involve trial and error, based on mechanistic hypotheses and empirical observations when possible. While the quantitative skills required to integrate trait-based biotic interaction data

5 Hotspots are approximated by the 'yumminess index' of pelagic organisms captured within mid-water trawl surveys (circles) conducted across the system each year. Yumminess index is calculated by first scoring each taxa identified within a trawl by the number of preferred traits they possess (0–7) and then computing the average index across all taxa, weighted by the proportional abundance of a given taxa in the trawl. Indices are displayed as averages across all trawls conducted within each 0.5° x 0.5° grid cell per year. The location of prey hotspots appears to shift across the region and time, perhaps in relation to major variation in ocean climate and environmental state. For example, prey hotspots appeared to form in the northern CCLME during 2014–16 and 2019 marine heatwave events.

into forecasting frameworks are substantial, open-source software applications (e.g., Ecospace; Atlantis) and community support for their training and use are increasingly available in the ocean science and management community. Finally, trait-based insights must be linked to taxonomy in order to estimate the consequences for novel predator-prey interactions on the population dynamics of the species involved. This is particularly important in cases where the focal predator and/or potential prey experience harvest mortality.

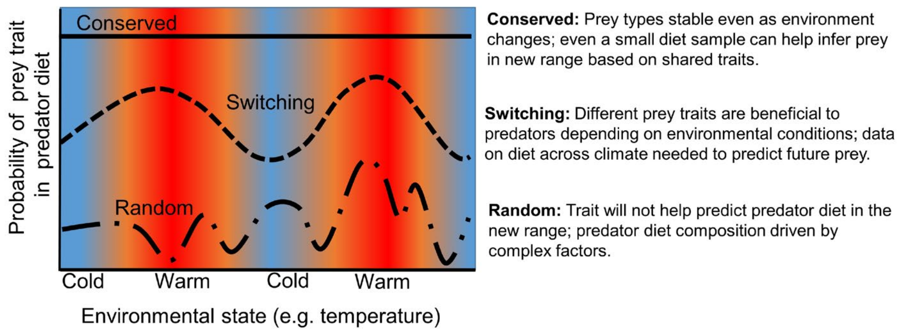


Fig. 11.8 The extent to which predators utilize similar prey (in terms of traits) across environmental conditions (e.g., climate states) affects the utility of a trait-based analytical approach to generating insights that can forecast the effect of predator redistribution on ocean ecosystem assembly.

Compared with even a few years ago, the availability of high quality, open-access data sources and reductions in the cost of computing infrastructure open the door much wider to trait-based analyses globally. In addition, predator-prey traits may add value to analyses of functional trait diversity as indicators of ecosystem vulnerability (as low or declining predator-prey trait diversity may signal impending system change). When considered against the status quo, trait-based approaches offer an exciting opportunity to reduce our reliance on time- and resource-intensive empirical observations of communities and provide a way to predict beyond the bounds of current species distribution and community assemblages. As more and more case studies evaluate the utility of trait-based projections over taxonomy-based analyses, these insights could be used to redesign coastal monitoring programs, reducing the burden on data collection, and monitoring after the initial trait data collection is complete to identify optimal conservation and management solutions that are ready to deal with the consequences of a radically different world for ocean predators.

Conclusion

A number of ocean predators make excellent candidates for using a trait-based lens to understand distribution and abundance change, and in turn to anticipate how these changes will reverberate through marine ecosystems. Candidate species could be identified based on two criteria:

1. The extent to which the species is likely to be affected by global change. Predators involved in biological invasion and harvest, and affected by habitat degradation, are likely to posit the greatest changes in distribution and abundance soon.
2. The number of connections to the species within its current food web. The greater number of potential connections, the more challenging predicting the effects of changes in distribution and abundance will be, and thus the greater the benefit of trait-based approaches.

Numerous predator species meet these criteria (Table 11.1). For example, the implications of climate-mediated expansion of salmonid predators into coastal communities in the Arctic Ocean, the global invasion of European green crab, the recovery of previously extirpated sea otters in the Eastern Pacific Ocean, and outbreaks of crown-of-thorns starfish on Indian Ocean coral reefs are cases of predators for whom distribution and abundance shifts are already evident, and for which a substantive amount of ecological information on feeding habits in occupied habitats is available (Figure 11.9). As species redistribution intensifies across all oceans, trait-based forecasting could provide a means to anticipate otherwise ‘surprising’ ecosystem shifts caused by predators foraging in novel environments—leading to more robust conservation decision-making in the face of ongoing global change. Re-analyzing historical range shifts through a trait-based lens may accelerate the pace at which we understand the utility of the approach.

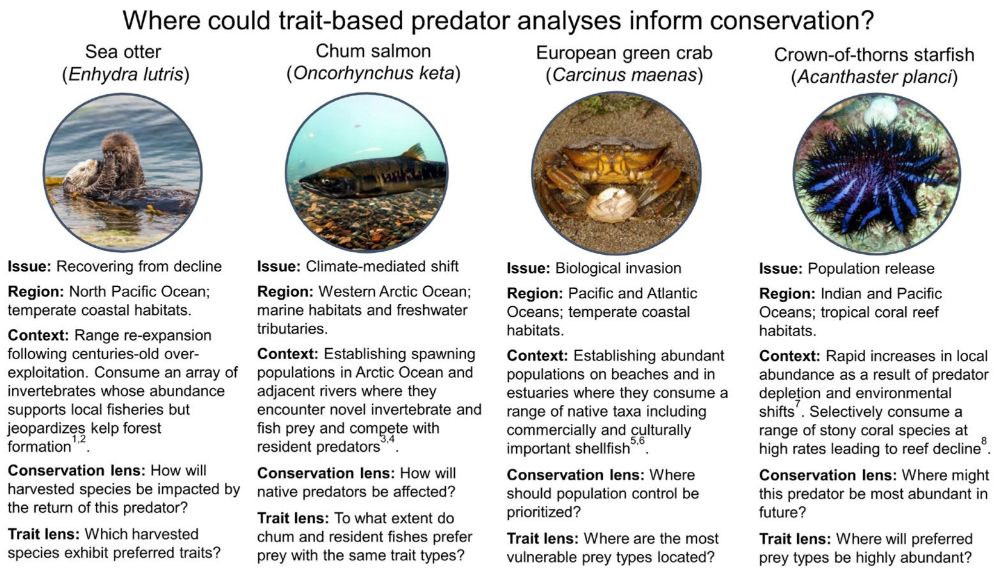


Fig. 11.9 Example predators for whom trait-based diet analyses could inform ecosystem responses to future population change. All are undergoing substantial geographic range and/or abundance shifts and are likely to encounter novel prey fields into the future. Each consumes a wide range of prey items, making them prime candidates for trait-based analyses. Below each case is a sample conservation question and paired trait-based analysis that could inform it. Numbers refer to the following citations: [1]Nicholson et al. (2024), [2]Boustany et al. (2021), [3]Bilous and Dunmall (2020), [4]Chila et al. (2022), [5]Ens et al. (2022), [6]Grosholz et al. (2021), [7]Uthicke et al. (2015), [8]Kayal et al. (2012).

References

Abrams, P. 1996. Dynamics and Interactions in Food Webs with Adaptive Foragers. Pages 113-121 in G. Polis and K. Winemiller, editors. Food Webs. Springer US.

Albins, M. 2012. Effects of invasive Pacific red lionfish Pterois volitans versus a native predator on Bahamian coral-reef fish communities. Biological Invasions:1-15.

Barrett, N. S., C. D. Buxton, and G. J. Edgar. 2009. Changes in invertebrate and macroalgal populations in Tasmanian marine reserves in the decade following protection. Journal of Experimental Marine Biology and Ecology 370:104-119.

Baum, J. K., and R. A. Myers. 2004. Shifting baselines and the decline of pelagic sharks in the Gulf of Mexico. Ecology Letters 7:135-145.

Bax, N., J. T. Carlton, A. Mathews-Amos, R. L. Haedrich, F. G. Howarth, J. E. Purcell, A. Rieser, and A. Gray. 2001. The control of biological invasions in the world’s oceans. Conservation Biology 15:1234-1246.

Bilous, M., & Dunmall, K. (2020). Atlantic salmon in the Canadian Arctic: potential dispersal, establishment, and interaction with Arctic char. Reviews in Fish Biology and Fisheries, 30(3), 463-483. Canadian Arctic.” Canadian Journal of Fisheries and Aquatic Sciences 79, no. 7 (2022): 1042-1055.

Bogdanoff, A. K., K. W. Shertzer, C. A. Layman, J. K. Chapman, M. L. Fruitema, J. Solomon, J. Sabattis, S. Green, and J. A. Morris. 2021. Optimum lionfish yield: a non-traditional management concept for invasive lionfish (Pterois spp.) fisheries. Biological Invasions 23:795-810.

Boustany, A. M., Hernandez, D. A., Miller, E. A., Fujii, J. A., Nicholson, T. E., Tomoleoni, J. A., & Van Houtan, K. S. (2021). Examining the potential conflict between sea otter recovery and Dungeness crab fisheries in California. Biological Conservation, 253, 108830. https://www.sciencedirect.com/science/article/pii/S0006320720308880?casa_token=LqjDej_arGsAAAAA:k8YRPxKZsCxxK_AvimSLfMbZa_YtBqCJcYtuu6W-FKkne9kDdBPau6z1KFtjNBoYmhy8aRjBUw

Byrne, M., N. Soars, P. Selvakumaraswamy, S. A. Dworjanyn, and A. R. Davis. 2010. Sea urchin fertilization in a warm, acidified and high pCO2 ocean across a range of sperm densities. Marine environmental research 69:234-239. https://www.sciencedirect.com/science/article/pii/S0141113609001408casa_token=c566l_hYNb0AAAAA:QeDLq3tVHJ7DcDGNIGJdIHA3DMdHsSzTKjW0mhHJ8v8nLg2sl2kiSsX8XjOliN-myfTuGYWjA

Cammen, K. M., D. B. Rasher, and R. S. Steneck. 2019. Predator recovery, shifting baselines, and the adaptive management challenges they create. Ecosphere 10:e02579.

Carlton, J. T. 1989. Man's Role in Changing the Face of the Ocean: Biological Invasions and Implications for Conservation of Near-Shore Environments. Conservation Biology 3:265-273.

Chapman, J., S. Green, J. Solomon, A. Bogdanoff, and M. Fruitman. 2019. Belize National Lionfish Management Strategy 2019-2023. Blue Ventures Conservation and Belize Fisheries Department.

Chavez, F., J. Pennington, C. Castro, J. Ryan, R. Michisaki, B. Schlining, P. Walz, K. Buck, A. McFadyen, and C. Collins. 2002. Biological and chemical consequences of the 1997–1998 El Niño in central California waters. Progress in Oceanography 54:205-232.

Chila, Zander, Karen M. Dunmall, Tracey A. Proverbs, Trevor C. Lantz, Aklavik Hunters and Trappers Committee, Inuvik Hunters and Trappers Committee, Sachs Harbour Hunters and Trappers Committee, Olokhaktomiut Hunters and Trappers Committee, and Paulatuk Hunters and Trappers Committee. Inuvialuit knowledge of Pacific salmon range expansion in the western Canadian Arctic. Canadian Journal of Fisheries and Aquatic Sciences 79, no. 7 (2022): 1042-1055.Childers, J., S. Snyder, and S. Kohin. 2011. Migration and behavior of juvenile North Pacific albacore (Thunnus alalunga). Fisheries Oceanography 20:157-173.

Christensen, V. 1996. Managing fisheries involving predator and prey species. Reviews in Fish Biology and Fisheries 6:417-442.

Côté, I. M., S. J. Green, and M. A. Hixon. 2013. Predatory fish invaders: Insights from Indo-Pacific lionfish in the western Atlantic and Caribbean. Biological Conservation 164:50-61. https://doi.org/10.1016/j.biocon.2013.04.014

Ellingsen, K. E., M. J. Anderson, N. L. Shackell, T. Tveraa, N. G. Yoccoz, and K. T. Frank. 2015. The role of a dominant predator in shaping biodiversity over space and time in a marine ecosystem. Journal of Animal Ecology 84:1242-1252.

Emlet, R. 2002. Sea urchin larval ecology: food rations, development, and size at metamorphosis. The sea urchin: from basic biology to aquaculture. Swets & Zeitlinger, Lisse:105-111.

Ens, Nicholas J., Bronwyn Harvey, Morgan M. Davies, Hanna M. Thomson, Keegan J. Meyers, Jennifer Yakimishyn, Lynn C. Lee, Meaghen E. McCord, and Travis G. Gerwing. The Green Wave: reviewing the environmental impacts of the invasive European green crab (Carcinus maenas) and potential management approaches. Environmental Reviews 30, no. 2 (2022): 306-322.

Figueira, W. F., and D. J. Booth. 2010. Increasing ocean temperatures allow tropical fishes to survive overwinter in temperate waters. Global Change Biology 16:506-516.

Glaser, S. M. 2010. Interdecadal variability in predator–prey interactions of juvenile North Pacific albacore in the California Current System. Marine Ecology Progress Series 414:209-221. https://www.int-res.com/abstracts/meps/v414/p209-221/

Gleiber, M.R., N.A. Hardy, Z. Roote, C.J. Morganson, A.M. Krug-Macleod, I. George, C. Matuch, C.B. Brookson, L.B. Crowder, and S.J. Green. 2024a. The pelagic species trait database, an open data resource to promote trait-based fisheries research. Scientific Data (in press).

Gleiber, M.R., N.A. Hardy, C.J. Morganson, C.F. Nickels, B.A. Muhling, E.J. Portner, R.D. Brodeur, B.K. Wells, T.D. Auth, J.A. Santora, D.J. Madigan, S.M. Glaser, E.L. Hazen, L.B. Crowder, and S.J. Green. 2024b. Trait-based drivers of diet selection in albacore tuna in the California Current system. Ecological Indicators 158 (2024) 111473.

Grosholz, Edwin, Gail Ashton, Marko Bradley, Chris Brown, Lina Ceballos-Osuna, Andrew Chang, Catherine de Rivera et al. Stage-specific overcompensation, the hydra effect, and the failure to eradicate an invasive predator. Proceedings of the National Academy of Sciences 118, no. 12 (2021): e2003955118.

Green, S. J., J. L. Akins, A. Maljković, and I. M. Côté. 2012. Invasive Lionfish Drive Atlantic Coral Reef Fish Declines. PLoS ONE 7: e32596.

Green, S. J., C. B. Brookson, N. A. Hardy, and L. B. Crowder. 2022. Trait-based approaches to global change ecology: moving from description to prediction. Proceedings of the Royal Society B 289:20220071.

Green, Stephanie J., and Isabelle M. Côté. Trait-based diet selection: prey behaviour and morphology predict vulnerability to predation in reef fish communities. Journal of Animal Ecology 83, no. 6 (2014): 1451-1460.

Green, S. J., E. R. Dilley, C. E. Benkwitt, A. C. Davis, K. E. Ingeman, T. L. Kindinger, L. J. Tuttle, and M. A. Hixon. 2019. Trait-mediated foraging drives patterns of selective predation by native and invasive coral-reef fishes. Ecosphere 10:e02752.

Hardy, N.A., C. Matuch, Z. Roote, I. George, B. Muhling, M. Jacox, E. Hazen, S.J. Bograd, L.B. Crowder, and S.J. Green. 2023. Trait-based analyses reveal global patterns in diverse albacore tuna diets. Fish and Fisheries, http://doi.org/10.1111/faf.12807

Hazen, E. L., S. Jorgensen, R. R. Rykaczewski, S. J. Bograd, D. G. Foley, I. D. Jonsen, S. A. Shaffer, J. P. Dunne, D. P. Costa, L. B. Crowder, and B. A. Block. 2013. Predicted habitat shifts of Pacific top predators in a changing climate. Nature Clim. Change 3:234-238.

Howell, E. A., C. C. C. Wabnitz, J. P. Dunne, and J. J. Polovina. 2013. Climate-induced primary productivity change and fishing impacts on the Central North Pacific ecosystem and Hawaii-based pelagic longline fishery. Climatic Change 119:79-93.

Johnson, C. R., S. Ling, D. Ross, S. Shepherd, and K. Miller. 2005. Establishment of the long-spined sea urchin (Centrostephanus rodgersii) in Tasmania: first assessment of potential threats to fisheries.

Kayal, Mohsen, Julie Vercelloni, Thierry Lison de Loma, Pauline Bosserelle, Yannick Chancerelle, Sylvie Geoffroy, Céline Stievenart et al. "Predator crown-of-thorns starfish (Acanthaster planci) outbreak, mass mortality of corals, and cascading effects on reef fish and benthic communities." (2012): e47363.

Kondoh, M. 2003. Foraging Adaptation and the Relationship Between Food-Web Complexity and Stability. Science 299:1388-1391.

Lawrence, J. M. 2001. Edible sea urchins: biology and ecology. Elsevier.

Lehodey, P., I. Senina, S. Nicol, and J. Hampton. 2015. Modelling the impact of climate change on South Pacific albacore tuna. Deep Sea Research Part II: Topical Studies in Oceanography 113:246-259.

Linardich, C., C. B. Brookson, and S. J. Green. 2021. Trait-based vulnerability reveals hotspots of potential impact for a global marine invader. Global Change Biology 27:4322-4338.

Linnane, Adrian, Anthony DM Smith, Richard McGarvey, John E. Feenstra, Janet M. Matthews, Klaas Hartmann, and Caleb Gardner. "Trends in productivity of Southern Rock Lobster Jasus edwardsii, across south-eastern Australia: Evidence of a regime shift?." Fisheries Research 219 (2019): 105308. Ling, S., C. Johnson, S. Frusher, and K. Ridgway. 2009a. Overfishing reduces resilience of kelp beds to climate-driven catastrophic phase shift. Proceedings of the National Academy of Sciences 106:22341-22345.

Ling, S., C. Johnson, K. Ridgway, A. Hobday, and M. Haddon. 2009b. Climate-driven range extension of a sea urchin: inferring future trends by analysis of recent population dynamics. Global Change Biology 15:719-731.

McLeay, L., Linnane, A., McGarvey, R., Bryars, S., & Hawthorne, P. (2021). Response of a southern rock lobster (Jasus edwardsii) population to three years of Marine Protected Area implementation within South Australia. Journal of the Marine Biological Association of the United Kingdom, 101(1), 141-149.

Molinos, J. G., B. S. Halpern, D. S. Schoeman, C. J. Brown, W. Kiessling, P. J. Moore, J. M. Pandolfi, E. S. Poloczanska, A. J. Richardson, and M. T. Burrows. 2016. Climate velocity and the future global redistribution of marine biodiversity. Nature Climate Change 6:83-88.

Nicholson, T. E., McClenachan, L., Tanaka, K. R., & Van Houtan, K. S. (2024). Sea otter recovery buffers century-scale declines in California kelp forests. PLOS Climate, 3(1), e0000290.

Nieto, K., Y. Xu, S. L. H. Teo, S. McClatchie, and J. Holmes. 2017. How important are coastal fronts to albacore tuna (Thunnus alalunga) habitat in the Northeast Pacific Ocean? Progress in Oceanography 150:62-71.

Peake, J., A. K. Bogdanoff, C. A. Layman, B. Castillo, K. Reale-Munroe, J. Chapman, K. Dahl, W. F. Patterson III, C. Eddy, and R. D. Ellis. 2018. Feeding ecology of invasive lionfish (Pterois volitans and Pterois miles) in the temperate and tropical western Atlantic. Biological Invasions 20:2567-2597.

Pinnegar, J., N. Polunin, P. Francour, F. Badalamenti, R. Chemello, M.-L. Harmelin-Vivien, B. Hereu, M. Milazzo, M. Zabala, and G. D'anna. 2000. Trophic cascades in benthic marine ecosystems: lessons for fisheries and protected-area management. Environmental Conservation 27:179-200.

Pinsky, Malin L., Rebecca L. Selden, and Zoë J. Kitchel. Climate-driven shifts in marine species ranges: Scaling from organisms to communities. Annual review of marine science 12 (2020): 153-179.

Poloczanska, E., R. Babcock, A. Butler, A. Hobday, O. Hoegh-Guldberg, T. Kunz, R. Matear, D. Milton, T. Okey, and A. Richardson. 2007. Climate change and Australian marine life. Oceanography and Marine Biology 45:407.

Pyke, G. H., H. R. Pulliam, and E. L. Charnov. 1977. Optimal Foraging: A Selective Review of Theory and Tests. The quarterly review of biology 52:137.

Ricciardi, A. 2007. Are modern biological invasions an unprecedented form of global change? Conservation Biology 21:329-336.

Rice, J., L. Crowder, and E. Marschall. 1997. Predation on juvenile fishes: dynamic interactions between size-structured predators and prey. Pages 333-356 in R. C. Chambers and E. Trippel, editors. Early Life History and Recruitment in Fish Populations. Springer Netherlands.

Rocha, L. A., C. R. Rocha, C. C. Baldwin, L. A. Weigt, and M. McField. 2015. Invasive lionfish preying on critically endangered reef fish. Coral Reefs 34:803-806.

Ruzicka, J. J., R. D. Brodeur, R. L. Emmett, J. H. Steele, J. E. Zamon, C. A. Morgan, A. C. Thomas, and T. C. Wainwright. 2012. Interannual variability in the Northern California Current food web structure: Changes in energy flow pathways and the role of forage fish, euphausiids, and jellyfish. Progress in Oceanography 102:19-41.

Sih, A., and B. Christensen. 2001. Optimal diet theory: when does it work, and when and why does it fail? Animal Behaviour 61:379-390.

Soars, N. A., T. A. A. Prowse, and M. Byrne. 2009. Overview of phenotypic plasticity in echinoid larvae,'Echinopluteus transversus' type vs. typical echinoplutei. Marine Ecology Progress Series 383:113-125.

Sorte, Cascade JB, Susan L. Williams, and James T. Carlton. "Marine range shifts and species introductions: comparative spread rates and community impacts." Global Ecology and Biogeography 19, no. 3 (2010): 303-316.

Smith, J.A., Buil, M.P., Muhling, B., Tommasi, D., Brodie, S., Frawley, T.H., Fiechter, J., Koenigstein, S., Himes-Cornell, A., Alexander, M.A. and Bograd, S.J., 2023. Projecting climate change impacts from physics to fisheries: a view from three California Current fisheries. Progress in Oceanography, p.102973.

Spiers, E. K., R. Stafford, M. Ramirez, D. F. V. Izurieta, M. Cornejo, and J. Chavarria. 2016. Potential role of predators on carbon dynamics of marine ecosystems as assessed by a Bayesian belief network. Ecological informatics 36:77-83.

Stier, A. C., J. F. Samhouri, M. Novak, K. N. Marshall, E. J. Ward, R. D. Holt, and P. S. Levin. 2016. Ecosystem context and historical contingency in apex predator recoveries. Science Advances 2:e1501769.

Sumaila, U. R., W. Cheung, A. Dyck, K. Gueye, L. Huang, V. Lam, D. Pauly, T. Srinivasan, W. Swartz, and R. Watson. 2012. Benefits of rebuilding global marine fisheries outweigh costs. PLoS ONE 7:e40542.

Sundell, J., and H. YlÖNen. 2008. Specialist predator in a multi-species prey community: boreal voles and weasels. Integrative Zoology 3:51-63.

Uthicke, S., M. Logan, M. Liddy, David Francis, N. Hardy, and M. Lamare. "Climate change as an unexpected co-factor promoting coral eating seastar (Acanthaster planci) outbreaks." Scientific Reports 5, no. 1 (2015): 8402.

Vergés, A., P. D. Steinberg, M. E. Hay, A. G. Poore, A. H. Campbell, E. Ballesteros, K. L. Heck Jr, D. J. Booth, M. A. Coleman, and D. A. Feary. 2014. The tropicalization of temperate marine ecosystems: climate-mediated changes in herbivory and community phase shifts. Proceedings of the Royal Society B: Biological Sciences 281:20140846.

Wolter, K., and M. S. Timlin. 2011. El Niño/Southern Oscillation behaviour since 1871 as diagnosed in an extended multivariate ENSO index (MEI. ext). International Journal of Climatology 31:1074-1087.

Woodworth-Jefcoats, P. A., J. J. Polovina, and J. C. Drazen. 2016. Climate change is projected to reduce carrying capacity and redistribute species richness in North Pacific pelagic marine ecosystems. Global Change Biology:n/a-n/a.

12. Modern marine conservation using environmental nucleic acids (eDNA and eRNA)

Collin J. Closek,[1] *Louw Claassens, and Helen J. Killeen*

The majority of marine ecosystems are vast, deep, and far from human populations, which ultimately makes accessing these ecosystems for the surveillance and monitoring of resident organisms challenging, and until recently accessing some of the deepest depths was impossible.

The health of marine ecosystems continues to decline in much of the world, and there is an increasing need to understand the impacts this trend has on the organisms and the marine resources humanity depends on. While it is possible to gain some insights about the ocean's conditions from satellite and buoy data, information about biodiversity in the ocean is largely manually collected. Much ecological research and conservation efforts rely on our ability to accurately estimate the occurrence of organisms through space and time. Traditional methods for estimating species occurrence often require physically removing organisms from their environment (e.g., trapping or net trawling), visual observation (e.g., microscopy for smaller organisms, visual surveys for larger organisms), or acoustic surveys to confirm presence or absence, or to quantify abundance. For larger species of interest, telemetry is used to track movement as well. These approaches can be time-intensive, costly, require significant taxonomic and sampling expertise, are ineffective for sampling rare or cryptic species, and are biased against certain life stages or sizes (Beng & Corlett, 2020; Eble et al., 2020). Methods that require the removal of an organism from its environment can be additionally invasive and potentially damaging to threatened or highly sensitive species. The methodology for molecular sequencing, where nucleic acids are identified and translated (Sanger et al., 1977), became popularized in the 1980s. Since then, we have been identifying and describing microorganisms by collecting them from water and sediments to sequence their unique genomic regions. More recently these same techniques have been employed to describe larger marine organisms by identifying two classes of nucleic acids associated with the environment—deoxyribonucleic acid (i.e., DNA) and ribonucleic acid (i.e., RNA)—macromolecules that carry information, which compose the genetic material comprising an organism's genome.

Environmental DNA (eDNA)—noun—is a DNA molecule that is associated with the environment, which can be associated with organic matter and occurs in the form of tissue, cells, cellular components or disassociated as extracellular DNA. eDNA is typically considered shed by the organism into the environment (air, water, sediment), allowing for a trace of the organism to be detected. Whole microorganisms, however, are also included as sources of eDNA as it is impossible to exclude microorganisms in environmental samples with current conventional methods. In fact, the first use of the term "environmental DNA" was in reference to microorganisms associated with marine sediment (Ogram et al., 1987).

Environmental RNA (eRNA)—noun—is the RNA molecule that is associated with the environment, released from its host in the form of tissue, cells, or extracellular RNA. Like eDNA, eRNA may indicate the presence or absence of a species, but it may also suggest something about the condition of an organism (e.g.,

1 Stanford Center for Ocean Solutions, Stanford University, https://orcid.org/0000-0003-4431-221X

 https://doi.org/10.11647/OBP.0395.12

stress response, reproductive state (Yates et al., 2021)). Due to the instability of RNA molecules compared to the more stable double-stranded structure of DNA molecules, eRNA is considered to be a more recent trace of an organism's presence or condition.

To date, more studies have focused on eDNA. As a result, in this chapter we will also focus mostly on eDNA, while eRNA studies will be highlighted when applicable. eDNA and eRNA have received significant attention over the past decade or more as they address many of the drawbacks of traditional approaches. The collection of eDNA/eRNA requires only the collection of air, sediment, water, or other environmental materials, which may be done quickly and easily, can reduce the per-sample cost, increase the feasibility of replication, and eliminate the need for disruption or destruction of target species. Furthermore, eDNA/eRNA samples are typically processed further in a laboratory setting and taxonomic classifications are conducted using computational methods against collective databases, replicable steps that allow for consistency and reproducibility. In addition to these logistical considerations, eDNA/eRNA possesses an advantage over other sampling methods by being able to detect a variety of life/size stages and rare or cryptic species with greater sensitivity (Jerde, 2021; Nevers et al., 2018).

The growing field of marine environmental nucleic acids has been reviewed by Ruppert et al., 2019; Eble et al., 2020; Miya, 2021; and Takahashi et al., 2023, providing a comprehensive overview of the state of the science. This chapter aims to provide a broad, introductory overview of the field and underscore potential uses of eDNA and eRNA in the marine environment for the larger goal of conservation. For more details on the following topics, please read the reviews, reports, and primary literature cited in this chapter.

Methods and state of the science

RNA, DNA, and whole-genome sequencing has been used to identify viruses, Archaea, Bacteria, micro- and macro-Eukaryotes. However, most molecular-based biological monitoring and long-term monitoring stations (i.e., observatories) in the marine realm have focused on microorganisms. These efforts have both identified and described microbial diversity and distributions that, for the most part, are otherwise invisible to the naked eye. The methods used have been the foundation for many of the methods now employed to collect and identify eDNA/eRNA from macroorganisms (described below). Since the first study was published (Thomsen et al., 2012) characterizing fish eDNA in seawater from Denmark, marine eDNA research targeting macroorganisms has grown exponentially (Figure 12.1).

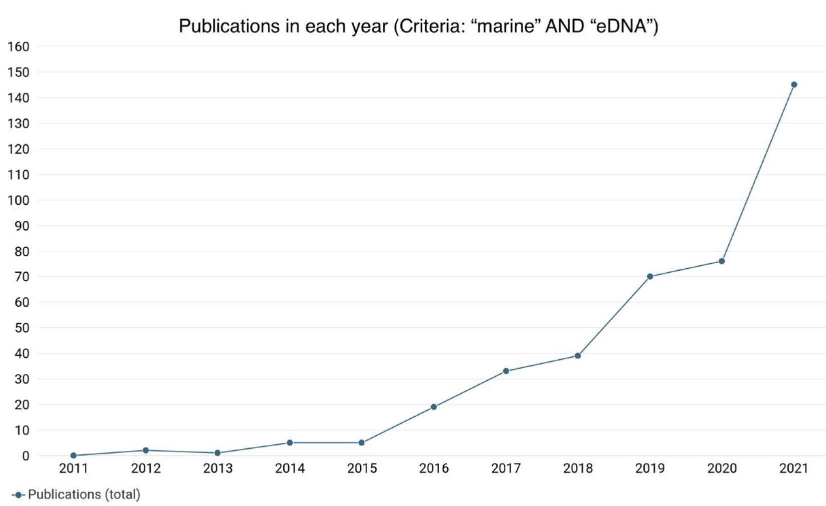


Fig. 12.1 Marine eDNA publications from 2011 to 2021. The current trend can be viewed at: https://app.dimensions.ai/analytics/publication/overview/timeline?search_mode=content&search_text=marine%20AND%20eDNA&search_type=kws&search_field=text_search

Collection, Extraction, and Amplification

eDNA/eRNA is collected by directly sampling environmental materials, such as water, sediment, or air, and then passing samples through a micropore filter to select and retain the particles down to a desired size. A filter pore size of 0.2 μm retains DNA fragments that range from 1 to 10 μm (Turner et al., 2014) and microorganisms larger than 0.2 μm (Azam & Hodson, 1977; Rappé et al., 2002). The DNA/RNA molecules retained on the filter are then isolated using standard methods for the extraction of nucleic acids from organic materials. Commercially available extraction kits are the most commonly used extraction methods and appear to provide the most consistent output (Djurhuus et al., 2017).

Once extracted, concentrations of targeted fragments of DNA/RNA are increased so they can be detected above the rest of the sample molecular contents. This process, called amplification, uses polymerase chain reaction (PCR) to selectively copy (or "amplify") the targeted DNA/RNA sequence. The targeted fragment is isolated for amplification by a synthetically generated, fragment-specific primer set (short strands of single stranded DNA/RNA) that binds to either end of the target fragment. The fragment is then copied by a polymerase enzyme through repeated heating and cooling cycles of PCR, exponentially increasing the concentration of target fragments until they are visually detectable by either gel electrophoresis or using a quantitative PCR (qPCR) or digital droplet PCR (ddPCR) machine.

Targeting single species or groups

Quantitative polymerase chain reaction (qPCR) technology allows one to quantify the amplification of DNA *in vitro* by measuring the fluorescence signal of resulting DNA after each cycle of PCR. A specific region of DNA is targeted using a qPCR assay. The same principles apply to digital droplet PCR (ddPCR), though the measurements are in discrete droplets, which allows for a more discrete, and thus accurate, measurement of the amplified targeted DNA molecules. Multiple studies have used both qPCR and ddPCR to quantify DNA of targeted species or groups. Best practices for qPCR are outlined in the Minimum Information for Publication of Quantitative Real-Time PCR Experiments (MIQE) guidelines (Bustin et al., 2009; dMIQE Group & Huggett, 2020).

The discovery of Clustered Regularly Interspaced Short Palindromic Repeats (CRISPR), a genomic editing mechanism discovered to naturally occur in bacteriophages, has opened new possibilities in scientific research and is being incorporated into a variety of biotechnologies. CRISPR and CRISPR-associated (Cas) systems are being used with eDNA as an alternative to targeted amplification without the need to extract DNA/RNA. Technologies like FLASH and SHERLOCK have been used to amplify DNA regions from targeted species, opening the possibility of using these technologies in the field and reducing both the steps and costs associated with methods currently used. SHERLOCK is able to distinguish between three closely related fish species without the use of instruments for detection in the field (Baerwald et al., 2020). FLASH allows for multiple known pathogens to be detected with a single sample (Quan et al., 2019). Other alternative amplification approaches such as loop-mediated isothermal amplification (LAMP) and reverse-transcription LAMP (RT-LAMP), and lateral flow assay (LFA) are being used because they are rapid and do not require a thermocycler, as the isothermal amplification is carried out at a constant temperature. While more optimization is needed to apply broadly to biomonitoring and management, amplification alternative technologies will be part of marine conservation practices in the future.

Next-generation sequencing of assemblages, communities, and populations

Metabarcoding (sequencing multiple samples with a common genomic region of interest where each sample has a unique identifier) enables the targeting of organismal groups that have a common evolutionarily conserved gene region (Figure 12.2). Metabarcoding results in sequences from organisms that have a common gene region, such as 16S ribosomal RNA (rRNA) gene—a highly conserved gene in species of bacteria and archaea.

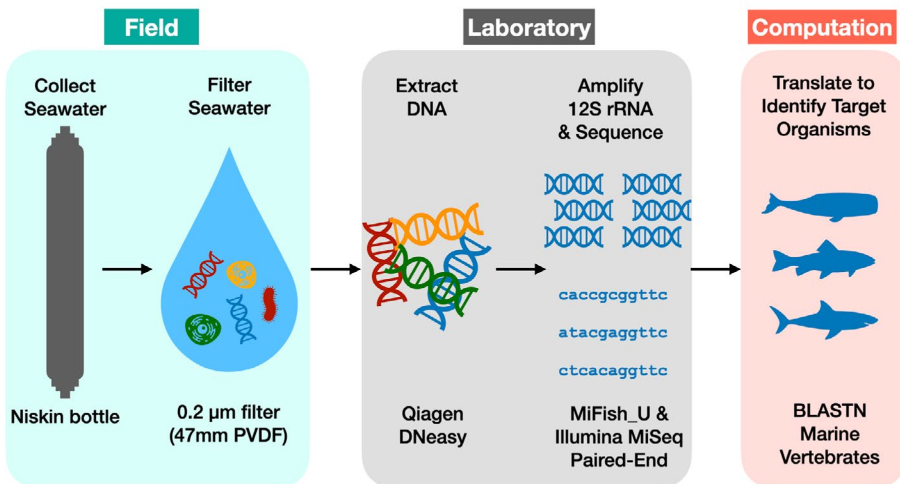


Fig. 12.2 Overview of typical processing steps currently conducted for eDNA metabarcoding from collection in the field to identification of organisms. These steps are indicated along the top and categorized by where they typically take place: in the Field, Laboratory, or via Computation. A set of select methods to complete these steps are indicated in text below the illustrations.

Metagenomics is the description of multiple genes and genomes. Although metagenomics has historically been used to describe microbial genomes, it can also be used to describe other cells associated with the environment, including those of marine macrofauna. As the characterization of biodiversity associated with environments continues with eDNA/eRNA, environmental metagenomics is beginning to be used as a method beyond the microbial communities to also describe macroorganisms associated with an environment (Cowart et al., 2018; Roesma et al., 2021). Since microbial organisms dominate environments, environmental samples will contain sequences; largely from microbial organisms and sequences from eukaryotic organisms, particularly animal sequences that comprise a small minority percentage of sequences.

Differentiation in haplotypes (a group of genes inherited from a parent) allows for eDNA to be used to track individuals and monitor populations of species of interest. Termed "eDNA haplotyping", with this method researchers are able to detect the genetic signature of individuals and distinguish populations. This approach has, for example, been used successfully to monitor whale shark populations in multiple bodies of water (Dugal et al., 2021; Jensen et al., 2021; Sigsgaard et al., 2016).

Limitations and best practices

eDNA/eRNA collection is relatively simple, non-invasive, and less expensive when compared to traditional methods of measuring biodiversity, such as net-based surveys. However, eDNA/eRNA presents its own set of challenges for when and how it may be used in conservation research. For example, sampling methodology and storage may influence eDNA/eRNA detection, impacting species observations. Collecting replicate samples *in situ* helps to avoid false negatives (not being detected, though it is present) as eDNA/eRNA concentrations can be unevenly dispersed in marine settings (Furlan et al., 2016). However, the total volume of water sampled must be balanced against the time required to filter each sample and the ability to store large volumes of water prior to filtration. Filter choice for eDNA/eRNA extraction from water samples can also influence the concentration of nucleic acids in extracts (Zaiko et al., 2022). Pore size in cellulose filters generally ranges from 0.2-6 µm with larger pore sizes being particularly useful for *in situ* collection in turbid environments (Tillotson et al., 2018). Choosing the right pore size for a particular application can help select for a targeted fragment size or to maximize detection given local water conditions.

eDNA molecule production and dynamics, sometimes referred to as the "ecology of eDNA" (Barnes & Turner, 2016), depend on the source of the molecules and ambient environmental conditions and the influence of biodiversity on their estimates or species detection. For instance, different species have been shown to produce eDNA at variable rates based on inherent taxonomic life-history differences and activity levels (Souza et al., 2016), impacting their likelihood of detection. Seasonal or discrete events such as spawning can also dramatically increase the concentration of eDNA within an area, increasing detection probability (Furlan et al., 2016). Once generated, eDNA molecules have variable longevity in seawater depending on abiotic and biotic factors, and are generally detectable on time scales from hours to days (Nielsen et al., 2007). Warm, acidic, high-UV environments cause eDNA molecules to break down more quickly into smaller and smaller fragments (Strickler et al., 2015). As fragments become smaller, the likelihood of collecting and successfully amplifying a sequence that can be associated with a known species or taxa declines. eDNA can further degrade after collection and before extraction, increasing the likelihood of false negatives for single-species detection and incomplete estimation of biodiversity. To limit post-collection degradation, water, sediment, and tissue samples are best frozen until filtration (Hinlo et al., 2017). Finally, as marine eDNA exists in a fluid medium, molecules can move away from the location of production (organism) within three dimensions, reducing the ability of a given sample to be a reliable indicator of local species presence. eDNA signal spillover must be considered when determining where to collect samples and deciding the spatial scale each sample represents (Jeunen et al., 2019; Jeunen et al., 2020; Lafferty et al., 2021). While less research has been conducted on the "ecology of eRNA", the same considerations are likely to impact collection and extraction of RNA molecules from environmental samples.

To reduce the likelihood of false positives or negatives, sample processing, including extraction and PCR, should be optimized for each research objective, taxonomic focus, and study location. There are a wide variety of extraction methods available for use in eDNA/eRNA applications. Extraction kits tend to outperform traditional methods of DNA/RNA extraction, such as phenol-chloroform extraction, for marine applications, though they are more costly (Djurhuus et al., 2017). Non-nucleic inorganic and organic compounds retained during extraction (e.g., humic acids from soil, glycogen, debris, etc.) can inhibit PCR, resulting in a failed amplification of target sequences (Schrader et al., 2012). Removal of PCR inhibitors is possible by diluting extracts (though this also dilutes eDNA/eRNA concentrations), use of nucleic acid purification kits, and other methods (Schrader et al., 2012).

Primer choice is another key consideration for optimization of eDNA/eRNA sample processing. Primers should be chosen that bind selectively to the DNA/RNA of target species during PCR so only the diagnostic sequences are amplified in PCR products. Amplification of eDNA/eRNA extracts generally requires that primers target relatively small fragments of the genome because eDNA/eRNA can be highly degraded (Eble et al., 2020). For multi-species detection, primers must amplify segments of the nucleic or mitochondrial genome that are variable enough across species to enable differentiation among amplified sequences (Eble et al., 2020). However, nucleic material of some species can amplify more quickly than others and through the exponential PCR amplification process may swamp out detection of other species (Kelly et al., 2019). The same is true of certain primers that may, in multi-marker approaches, swamp the amplified products of other primers (Kelly et al., 2019). Therefore, any form of amplification bias must be taken into account when selecting primers and when interpreting results.

After amplification, target fragments are sequenced using high-throughput next-generation sequencing. Resulting sequences must then be assigned to a particular species or taxon using a reference database of known sequences corresponding to the amplified gene. Public reference databases, such as GenBank, contain sequence information for many species, particularly for commonly sequenced portions of genomes including the cytochrome c oxidase subunit I (COI) gene. However, reference sequences may not be available for all species of interest or may be incorrect in public databases. In some cases, development of custom reference libraries and sequencing of organism genotypes to fill in missing or incorrect entries may be required. This can be a challenge for remote, understudied ecosystems where information on the scope of biodiversity is lacking.

Application in marine systems

Despite the various limitations that exist with current methods and the challenges inherent in studying marine environments, much progress has been made in detecting marine eDNA and using eDNA to observe trends in marine systems. Marine eDNA has been used to answer ecological and management questions for diverse taxonomic groups across a wide variety of habitats using both seawater and sediment sampling. For instance, eDNA from estuarine water has been used to detect a range of diversity in the Puget Sound (Kelly et al., 2017) and vulnerable manatee populations in Florida, Cuba, and Cameroon (Hunter et al., 2018). In coastal waters, eDNA has been used to detect elasmobranch presence in turbid urban waters (Ip et al., 2021) and map their biogeography in nearshore areas of the Caribbean and Coral Sea (Bakker et al., 2017). And across habitats, eDNA has increased our ability to detect cryptic and rare or endangered species, such as the estuarine pipefish in South Africa (Nester et al., 2020) and sawfishes in Australia and Mexico (Simpfendorfer et al., 2016; Bonfil et al., 2021; Cooper et al., 2021).

Biodiversity estimation can be challenging in very large regions and in habitats that are difficult to access. Further offshore, eDNA has helped to map eukaryotic biodiversity over broad spatial scales in the Caribbean and central California Current (Bakker et al., 2019; Closek et al., 2019) and in the vicinity of remote islands (West et al., 2020; Budd et al., 2021). Traditional methods, such as net sampling, can be challenging to use in open ocean contexts and can be costly to employ over very broad spatial scales, requiring many replicates. eDNA has been used as an alternative to plankton collection for detection of larval fish presence in the open ocean (Garcia-Vazquez et al., 2021). Similarly, eDNA has been used to estimate biodiversity below the surface at deeper depths using stratified water sampling (Jeunen et al., 2020; McClenaghan et al., 2020), allowing access to habitats where hands-on sampling is challenging. While these examples illustrate the breadth and value of eDNA sampling in comparison to more traditional methods, some of the most impactful eDNA studies have involved the collection of eDNA alongside traditional methods of biodiversity sampling. Many of these studies have demonstrated increased biodiversity detection when eDNA sampling is conducted with traditional methods or other relatively new biodiversity survey methods. For example, Stat and colleagues (Stat et al., 2019) found that when used in tandem, eDNA and a baited remote underwater video station (BRUVS) surveys estimated higher diversity than either method used alone.

In addition to mapping taxonomic biogeography and estimating biodiversity, eDNA has also been used to detect marine species of concern. For example, eDNA has been suggested as a way to facilitate detection by customs officials of illicit trade in ornamental fishes (Collins et al., 2012), which is both a threat to the persistence of these species in the wild and a vector for invasive species. A more common use of eDNA however has been to detect invasive species in the field. For instance, eDNA has been used to monitor invasive species in the ballast waters of ships (Ardura et al., 2021) as they move among remote Pacific islands, and to monitor the spread of European green crabs in coastal/estuarine environments of Australia and North America (Roux et al., 2020; Crane et al., 2021; Keller et al., 2022). eDNA/eRNA have been used to detect the presence of pathogens and have been proposed as a way to simultaneously detect the presence of potential animal hosts (Amarasiri et al., 2021; Farrell et al., 2021). Pathogens and invasive species tend to occur at low densities as they expand into new habitats. Consequently, detection of these species requires high sampling effort using traditional methods. eDNA is particularly useful in these cases because, while detection of species at low density still requires high levels of replication (Furlan et al., 2016; Andruszkiewicz et al., 2017), the marginal cost per sample tends to be lower for eDNA than for traditional methods.

Potential eDNA/eRNA applications and technology crossover to serve marine conservation science

To conserve, you have to know what is there to conserve. eDNA/eRNA can detect what is present and applying new technologies that use eDNA/eRNA has the potential to provide data at greater resolution to provide more insight beyond the "what". eDNA/eRNA will continue to reveal novel biodiversity and genetic insights as well as advance our understanding of ecosystems and how our planet is changing. These insights require a baseline (a starting point one can compare to), which is why collecting environmental samples now, not later, is worth pursuing, as these initial baselines will provide a better understanding of the state of biodiversity. Tara Oceans was one of the first explorations to traverse the globe, documenting biodiversity associated with the marine water column including microeukaryotes (de Vargas et al., 2015) and has assessed plankton globally across taxonomic, organismal, and environmental scales (Sunagawa et al., 2020). Other efforts like the Marine Biodiversity Observation Network[2] (MBON) within the Group on Earth Observation Biodiversity Observation Network[3] (GEO BON) have collected eDNA samples from set stations and conducted time-series sampling (repeated collections over time). In theory, every buoy, oil rig, surfboard, vessel, and human visiting the coast could collect eDNA/eRNA. In practice, however, there are many logistic challenges that make this approach currently impractical. A global marine census is possible with eDNA/eRNA, if standardized methods and materials are accessible to all. While optimization is inevitable as the methods and technology used will change over time, the more effort that is put into considering the variables of interest and priorities, the more informative the initial collections and baseline will be for future comparisons.

Most current monitoring and conservation efforts in marine spaces use traditional methods (e.g., trapping, trawling, and visual observations). Both existing and new monitoring programs could be enhanced by including eDNA/eRNA, as eDNA/eRNA data can broaden the number of species identified and reduce overall effort required for monitoring. Most studies that include eDNA with traditional monitoring methods have shown an increase in the total number of organisms identified. These early successes in eDNA-based monitoring could be scaled up to provide regional and global insights into species distributions. With a network of scientists, community scientists, and autonomous technologies more locations, time points, and organisms could be observed. A clearer understanding of diurnal, seasonal, or annual patterns could emerge with an increase in area, time intervals, or effort. Programs in California (CaleDNA[4] & SeMMAP[5]), the European Union (DNAqua-Net)[6], and New Zealand (Wai Tuwhera o te Taiao)[7] are making these combined efforts, which will improve our understanding of the distribution of species and allow for collections during periods that would otherwise not be monitored, due to a myriad of limiting factors making it difficult or unsafe for humans to sample, including physical effort, access to locations, and inclement weather conditions. These programs have used different approaches, such as including community science to help collect samples and incorporating both university and government institutions to optimize standardized methods and improve access to resources.

The eDNA/eRNA monitoring programs that exist are heavily biased towards terrestrial and freshwater ecosystems. Additional eDNA/eRNA monitoring programs have been slow to become established and officially adopted into government surveillance programs. However, marine eDNA monitoring programs have started in places where there is strong interest in monitoring marine resources and where access to traditional surveillance methods is relatively limited, like the Palmyra Atoll and the Republic of Palau. Marine eDNA assessments so

2 https://marinebon.org/
3 https://geobon.org/
4 https://ucedna.com/
5 https://experience.arcgis.com/experience/db3a30220d0d4bdea684781cdaef5230/
6 https://dnaqua.net/
7 https://www.epa.govt.nz/community-involvement/open-waters-aotearoa/

far have mostly taken the form of short-funded baseline collections. Longer time series are needed to monitor changes that are beyond seasonal fluctuations. Information about the organisms associated with a given space and how they change over time is vital for more accurate decision making and management of environments below the sea surface. In many cases, eDNA/eRNA monitoring may not reflect a pristine or healthy ecosystem. Baseline and subsequent collections through long-term monitoring are needed to detect changes over time and better understand the impact of these changes.

To expand eDNA/eRNA studies, logistical factors limiting the collection and use of eDNA/eRNA should be addressed. Collecting marine samples, particularly offshore, can be resource intensive, due to the time and equipment required to access the environment. Additionally, the number of samples that can be collected is often a limiting factor due to material and downstream processing costs. The development of novel technologies that reduce costs and limiting factors will offer new avenues to expand the use of eDNA/eRNA. Current technologies, and those on the horizon, allow for autonomous collections and more rapid sample processing. Water samples can be collected via a remotely operated vehicle (ROV) that is cabled to a ship, which enables sample collection to be paired with other biological samples or environmental data. An autonomous underwater vehicle (AUV) can collect samples independent of a ship, enabling sample collection to occur at any point in time. Stationary automated processing devices, like the second-generation Environmental Sample Processor (ESP), enable water samples to be collected and processed autonomously over time in a single location to detect or quantify eDNA/eRNA of targeted organisms. The newer third-generation ESP is housed within an AUV and can collect samples in multiple locations within the top 300m of the water column (Yamahara et al., 2019). These technologies are making autonomous eDNA monitoring possible. If scaled up and distributed globally, more autonomous samples and observations can be collected from marine environments around the world (Figure 12.3). To enable broader accessibility and application, eDNA technologies need to be low-cost and easy to deploy. In addition to high-tech advancements, low-tech solutions such as passive collection devices are also proving useful. Multiple filters (Bessey et al., 2021) or layers of gauze attached to a frame, as well as filter feeding animals like sponges (Jeunen et al., 2023), have served as passive eDNA collection devices.

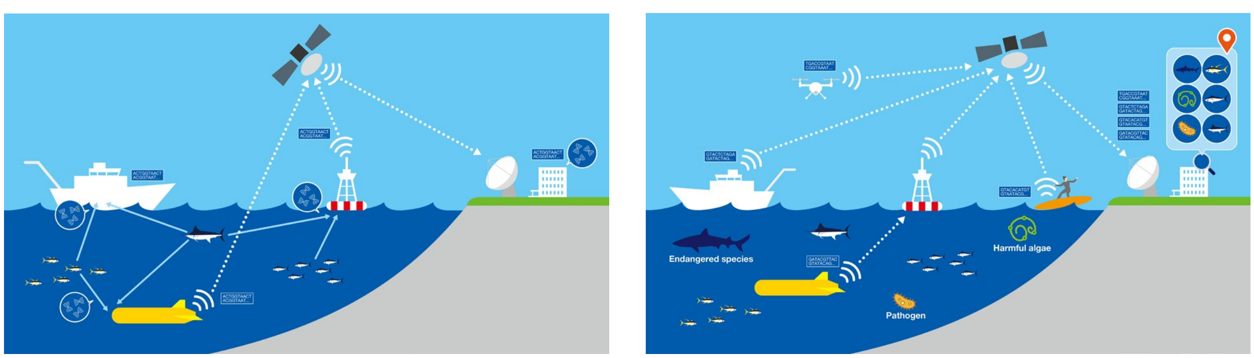


Fig. 12.3 Graphical representation of current (A) and future (B) scenarios with marine infrastructure monitoring eDNA/eRNA. Illustrations by Hiromi Ito.[8]

8 A) Beyond shoreline collections, current collections occur manually on vessels or via unmanned AUVs. Increased shipboard and AUV collections using standardized collection and downstream sample processing methods will enable data centers to collate and interpret baseline information about ocean conditions and marine biodiversity more readily. B) In the future, as technologies are developed to be more easily adapted to existing ocean infrastructure and transmit data, instant translation of eDNA/eRNA detection to organisms as well as lower costs will allow observing technologies to monitor ocean conditions and marine biodiversity continuously in real-time. Low-cost observing in real-time will enable these technologies to be more globally distributed. Increased observing through passive citizen participation during recreation (e.g., observing tech attached to surfboard) and ocean-related activities (e.g., observing tech attached to seafaring vessels), would ultimately lead to broader regional and global monitoring that could better inform decision making.

Downstream sample processing is often bottlenecked by the manual steps of extraction and amplification protocols. These steps can be automated through robotics to increase the number of samples processed in a given amount of time. Extraction and amplification steps may also be reduced or eliminated with improved technologies like the aforementioned LAMP. Sequencing of samples can occur through sequencing facilities that have the infrastructure and high throughput sequencing machines to process and sequence many samples. However, if sample counts are low, desktop sequencers, like Oxford Nanopore's MinIon, can expedite the time it takes to return sequence data. Options like the MinIon are decreasing costs and improving turnaround time for collections in remote locations—such as at sea (Truelove et al., 2019). Current methods are reliant on amplification to increase the gene region of interest and reduce non-targeted sequences. A metagenomics approach, where the genomes of associated microorganisms are sequenced simultaneously, may become a reality for all organisms associated with environmental samples as a result of the reduction in sequencing costs, increasing computational power, and increasing data storage capabilities.

With nanotechnology, it may one day be possible to simply scan the water to determine the organisms that are associated. This "pH stick'' or probe-like approach already exists for certain microbial species of interest. Additionally, streamlined data processing pipelines, machine learning approaches, and regional databases would allow for observations to be linked and trends over time can be more quickly determined. Similar to weather and human health, making data accessible allows for regional and global trends to be more quickly realized. These technological advancements will alleviate some of the hurdles that current monitoring efforts face and would allow long-term, global biodiversity monitoring of the ocean to become a reality. Including eDNA/eRNA in marine conservation surveillance requires accepting that the technology, approaches, and our knowledge will continue to change. As such, we must build transferability and flexibility into our practices, so we can expand upon our efforts and improve our knowledge of marine environments as our abilities increase.

Uptake and implementation of new technologies or approaches are difficult to achieve when a systematic approach has not yet been committed to, because every group has to figure out a method that works with their constraints. While a global marine biodiversity monitoring program is not yet a reality, companies have started to offer services that process collected eDNA/eRNA samples and post results to online databases that can be viewed on a map. These services allow lay individuals to submit environmental samples and gain more knowledge about the organisms associated with their sampled environment—effectively reducing the barrier for uptake and application for both citizens and environmental managers. Not every environmental manager needs to become a molecular biologist to conduct eDNA monitoring. Many, if not all, of the molecular steps required can be conducted by an external company. The expertise that cannot be easily outsourced is the knowledge of the local organisms and environment—the "boots on the ground" for a given location. With results from outsourced eDNA processing, decision makers can work with environmental managers to better understand and adaptively manage local marine environments.

If marine organisms and environments are monitored at all, they are typically monitored based on territorial jurisdictions. Marine organisms and environments often are not influenced by geopolitical delineations, therefore monitoring across these boundaries is critical for marine conservation. Connecting a network of monitoring databases (e.g., observatories) will enable greater insights into marine organismal distributions and changes in the marine environment. Essentially, in the not-so-distant future we could see a community science database (e.g., iNaturalist) where anyone can contribute eDNA/eRNA data they collected with a geotag, effectively crowdsourcing organismal data. Collectively knowing the state of the marine environment in almost real time can improve decision making, contribute to adaptive management methods, and lead to more accurate biodiversity forecasting. Whatever advancements technologies provide, it is clear that eDNA and eRNA can contribute insights into the biodiversity and health of the environment. It is up to us to determine how we are going to use this information to improve life on our planet.

Bibliography

Amarasiri, M., Furukawa, T., Nakajima, F., & Sei, K. (2021). Pathogens and disease vectors/hosts monitoring in aquatic environments: Potential of using eDNA/eRNA based approach. The Science of the Total Environment, 796(148810), 148810. https://doi.org/10.1016/j.scitotenv.2021.148810

Ardura, A., Fernandez, S., Haguenauer, A., Planes, S., & Garcia-Vazquez, E. (2021). Ship-driven biopollution: How aliens transform the local ecosystem diversity in Pacific islands. Marine Pollution Bulletin, 166, 112251. https://doi.org/10.1016/j.marpolbul.2021.112251

Azam, F., & Hodson, R. E. (1977). Size distribution and activity of marine microheterotrophs1. Limnology and Oceanography, 22(3), 492–501. https://doi.org/10.4319/lo.1977.22.3.0492

Baerwald, M. R., Goodbla, A. M., Nagarajan, R. P., Gootenberg, J. S., Abudayyeh, O. O., Zhang, F., & Schreier, A. D. (2020). Rapid and accurate species identification for ecological studies and monitoring using CRISPR-based SHERLOCK. Molecular Ecology Resources, 20(4), 961–970. https://doi.org/10.1111/1755-0998.13186

Bakker, J., Wangensteen, O. S., Baillie, C., Buddo, D., Chapman, D. D., Gallagher, A. J., Guttridge, T. L., Hertler, H., & Mariani, S. (2019). Biodiversity assessment of tropical shelf eukaryotic communities via pelagic eDNA metabarcoding. Ecology and Evolution, 9(24), 14341–14355. https://doi.org/10.1002/ece3.5871

Bakker, J., Wangensteen, O. S., Chapman, D. D., Boussarie, G., Buddo, D., Guttridge, T. L., Hertler, H., Mouillot, D., Vigliola, L., & Mariani, S. (2017). Environmental DNA reveals tropical shark diversity in contrasting levels of anthropogenic impact. Scientific Reports, 7(1), 16886. https://doi.org/10.1038/s41598-017-17150-2

Barbara McClenaghan, Nicole Fahner, David Cote, Julek Chawarski, Avery McCarthy, Hoda Rajabi, Greg Singer, & Mehrdad Hajibabei. (2020). Harnessing the power of eDNA metabarcoding for the detection of deep-sea fishes. PloS One, 15(11).

Barnes, M. A., & Turner, C. R. (2016). The ecology of environmental DNA and implications for conservation genetics. Conservation Genetics , 17(1).

Beng, K. C., & Corlett, R. T. (2020). Applications of environmental DNA (eDNA) in ecology and conservation: opportunities, challenges and prospects. Biodiversity and Conservation, 29(7), 2089–2121. https://doi.org/10.1007/s10531-020-01980-0

Bessey, C., Neil Jarman, S., Simpson, T., Miller, H., Stewart, T., Kenneth Keesing, J., & Berry, O. (2021). Passive eDNA collection enhances aquatic biodiversity analysis. Communications Biology, 4(1), 236. https://doi.org/10.1038/s42003-021-01760-8

Bonfil, R., Palacios-Barreto, P., Vargas, O. U. M., Ricaño-Soriano, M., & Díaz-Jaimes, P. (2021). Detection of critically endangered marine species with dwindling populations in the wild using eDNA gives hope for sawfishes. Marine Biology, 168(5), 60. https://doi.org/10.1007/s00227-021-03862-7

Budd, A. M., Cooper, M. K., Port, A. L., Schils, T., Mills, M. S., Deinhart, M. E., Huerlimann, R., & Strugnell, J. M. (2021). First detection of critically endangered scalloped hammerhead sharks (Sphyrna lewini) in Guam, Micronesia, in five decades using environmental DNA. Ecological Indicators, 127, 107649. https://doi.org/10.1016/j.ecolind.2021.107649

Bustin, S. A., Benes, V., Garson, J. A., Hellemans, J., Huggett, J., Kubista, M., Mueller, R., Nolan, T., Pfaffl, M. W., Shipley, G. L., Vandesompele, J., & Wittwer, C. T. (2009). The MIQE guidelines: minimum information for publication of quantitative real-time PCR experiments. Clinical Chemistry, 55(4), 611–622. https://doi.org/10.1373/clinchem.2008.112797

Closek, C. J., Santora, J. A., Starks, H. A., Schroeder, I. D., Andruszkiewicz, E. A., Sakuma, K. M., Bograd, S. J., Hazen, E. L., Field, J. C., & Boehm, A. B. (2019). Marine Vertebrate Biodiversity and Distribution Within the Central California Current Using Environmental DNA (eDNA) Metabarcoding and Ecosystem Surveys. Frontiers in Marine Science, 6.

Collins, R. A., Armstrong, K. F., Meier, R., Yi, Y., Brown, S. D. J., Cruickshank, R. H., Keeling, S., & Johnston, C. (2012). Barcoding and Border Biosecurity: Identifying Cyprinid Fishes in the Aquarium Trade. PloS One, 7(1), e28381. https://doi.org/10.1371/journal.pone.0028381

Cooper, M. K., Huerlimann, R., Edmunds, R. C., Budd, A. M., Le Port, A., Kyne, P. M., Jerry, D. R., & Simpfendorfer, C. A. (2021). Improved detection sensitivity using an optimal eDNA preservation and extraction workflow and its application to threatened sawfishes. Aquatic Conservation: Marine and Freshwater Ecosystems, 31(8), 2131–2148. https://doi.org/10.1002/aqc.3591

Cowart, D. A., Murphy, K. R., & Cheng, C.-H. C. (2018). Metagenomic sequencing of environmental DNA reveals marine faunal assemblages from the West Antarctic Peninsula. Marine Genomics, 37, 148–160. https://doi.org/10.1016/j.margen.2017.11.003

Crane, L. C., Goldstein, J. S., Thomas, D. W., Rexroth, K. S., & Watts, A. W. (2021). Effects of life stage on eDNA detection of the invasive European green crab (Carcinus maenas) in estuarine systems. Ecological Indicators, 124, 107412. https://doi.org/10.1016/j.ecolind.2021.107412

de Vargas, C., Audic, S., Henry, N., Decelle, J., Mahé, F., Logares, R., Lara, E., Berney, C., Bescot, N. L., Probert, I., Carmichael, M., Poulain, J., Romac, S., Colin, S., Aury, J.-M., Bittner, L., Chaffron, S., Dunthorn, M., Engelen, S., … Velayoudon, D. (2015). Eukaryotic plankton diversity in the sunlit ocean. Science, 348(6237), 1261605. https://doi.org/10.1126/science.1261605

Djurhuus, A., Port, J., Closek, C. J., Yamahara, K. M., Romero-Maraccini, O., Walz, K. R., Goldsmith, D. B., Michisaki, R., Breitbart, M., Boehm, A. B., & Chavez, F. P. (2017). Evaluation of Filtration and DNA Extraction Methods for Environmental DNA Biodiversity Assessments across Multiple Trophic Levels. Frontiers in Marine Science, 4. https://doi.org/10.3389/fmars.2017.00314

dMIQE Group, & Huggett, J. F. (2020). The Digital MIQE Guidelines Update: Minimum Information for Publication of Quantitative Digital PCR Experiments for 2020. Clinical Chemistry, 66(8), 1012–1029. https://doi.org/10.1093/clinchem/hvaa125

Dugal, L., Thomas, L., Reinholdt Jensen, M., Sigsgaard, E. E., Simpson, T., Jarman, S., Thomsen, P. F., & Meekan, M. (2021). Individual haplotyping of whale sharks from seawater environmental DNA. Molecular Ecology Resources. https://doi.org/10.1111/1755-0998.13451

Eble, J. A., Daly-Engel, T. S., DiBattista, J. D., Koziol, A., & Gaither, M. R. (2020). Marine environmental DNA: Approaches, applications, and opportunities. In C. Sheppard (Ed.), Advances in Marine Biology (Vol. 86, pp. 141–169).

Elizabeth Andruszkiewicz, Hillary Starks, Francisco Chavez, Lauren Sassoubre, Barbara Block, & Alexandra Boehm. (2017). Biomonitoring of marine vertebrates in Monterey Bay using eDNA metabarcoding. PloS One, 12(4).

Farrell, J. A., Whitmore, L., & Duffy, D. J. (2021). The promise and pitfalls of environmental DNA and RNA approaches for the monitoring of human and animal pathogens from aquatic sources. Bioscience, 71(6), 609–625. https://doi.org/10.1093/biosci/biab027

Furlan, E. M., Gleeson, D., Hardy, C. M., & Duncan, R. P. (2016). A framework for estimating the sensitivity of eDNA surveys. Molecular Ecology Resources, 16(3).

Garcia-Vazquez, E., Georges, O., Fernandez, S., & Ardura, A. (2021). eDNA metabarcoding of small plankton samples to detect fish larvae and their preys from Atlantic and Pacific waters. Scientific Reports, 11(1), 7224. https://doi.org/10.1038/s41598-021-86731-z

Hinlo, R., Gleeson, D., Lintermans, M., & Furlan, E. (2017). Methods to maximise recovery of environmental DNA from water samples. PloS One, 12(6).

Hunter, M., Meigs-Friend, G., Ferrante, J. A., Takoukam Kamla, A., Dorazio, R., Keith Diagne, L., Luna, F., Lanyon, J. M., & Reid, J. P. (2018). Surveys of environmental DNA (eDNA): a new approach to estimate occurrence in Vulnerable manatee populations. Endangered Species Research, 35, 101–111. https://doi.org/10.3354/esr00880

Ip, Y. C. A., Chang, J. J. M., Lim, K. K. P., Jaafar, Z., Wainwright, B. J., & Huang, D. (2021). Seeing through sedimented waters: environmental DNA reduces the phantom diversity of sharks and rays in turbid marine habitats. BMC Ecology and Evolution, 21(1), 166. https://doi.org/10.1186/s12862-021-01895-6

Jensen, M. R., Sigsgaard, E. E., Liu, S., Manica, A., Bach, S. S., Hansen, M. M., Møller, P. R., & Thomsen, P. F. (2021). Genome-scale target capture of mitochondrial and nuclear environmental DNA from water samples. Molecular Ecology Resources, 21(3), 690–702. https://doi.org/10.1111/1755-0998.13293

Jerde, C. L. (2021). Can we manage fisheries with the inherent uncertainty from eDNA? Journal of Fish Biology, 98(2), 341–353. https://doi.org/10.1111/jfb.14218

Jeunen, G.-J., Cane, J. S., Ferreira, S., Strano, F., von Ammon, U., Cross, H., Day, R., Hesseltine, S., Ellis, K., Urban, L., Pearson, N., Olmedo-Rojas, P., Kardailsky, A., Gemmell, N. J., & Lamare, M. (2023). Assessing the utility of marine filter feeders for environmental DNA (eDNA) biodiversity monitoring. Molecular Ecology Resources, 23(4), 771–786. https://doi.org/10.1111/1755-0998.13754

Jeunen, G.-J., Knapp, M., Spencer, H. G., Lamare, M. D., Taylor, H. R., Stat, M., Bunce, M., & Gemmell, N. J. (2019). Environmental DNA (eDNA) metabarcoding reveals strong discrimination among diverse marine habitats connected by water movement. Molecular Ecology Resources, 19(2), 426–438. https://doi.org/10.1111/1755-0998.12982

Jeunen, G.-J., Lamare, M. D., Knapp, M., Spencer, H. G., Taylor, H. R., Stat, M., Bunce, M., & Gemmell, N. J. (2020). Water stratification in the marine biome restricts vertical environmental DNA (eDNA) signal dispersal. Environmental DNA, 2(1), 99–111. https://doi.org/10.1002/edn3.49

Keller, A. G., Grason, E. W., McDonald, P. S., Ramón-Laca, A., & Kelly, R. P. (2022). Tracking an invasion front with environmental DNA. Ecological Applications: A Publication of the Ecological Society of America, 32(4), e2561. https://doi.org/10.1002/eap.2561

Kelly, R. P., Closek, C. J., O'Donnell, J. L., Kralj, J. E., Shelton, A. O., & Samhouri, J. F. (2017). Genetic and Manual Survey Methods Yield Different and Complementary Views of an Ecosystem. Frontiers in Marine Science, 3. https://doi.org/10.3389/fmars.2016.00283

Kelly, R. P., Shelton, A. O., & Gallego, R. (2019). Understanding PCR Processes to Draw Meaningful Conclusions from Environmental DNA Studies. Scienific Reports, 9(1).

Lafferty, K. D., Garcia-Vedrenne, A. E., McLaughlin, J. P., Childress, J. N., Morse, M. F., & Jerde, C. L. (2021). At Palmyra Atoll, the fish-community environmental DNA signal changes across habitats but not with tides. Journal of Fish Biology, 98(2), 415–425. https://doi.org/10.1111/jfb.14403

Meredith B. Nevers, Murulee N. Byappanahalli, Charles C. Morris, Dawn Shively, Kasia Przybyla-Kelly, Ashley M. Spoljaric, Joshua Dickey, & Edward F. Roseman. (2018). Environmental DNA (eDNA): A tool for quantifying the abundant but elusive round goby (Neogobius melanostomus). PloS One, 13(1).

Miya, M. (2021). Environmental DNA metabarcoding: A novel method for biodiversity monitoring of marine fish communities. Annual Review of Marine Science, 14(1). https://doi.org/10.1146/annurev-marine-041421-082251

Nester, G. M., De Brauwer, M., Koziol, A., West, K. M., DiBattista, J., White, N. E., Power, M., Heydenrych, M. J., Harvey, E., & Bunce, M. (2020). Development and evaluation of fish eDNA metabarcoding assays facilitate the detection of cryptic seahorse taxa (family: Syngnathidae). Environmental DNA, 2(4).

Nielsen, K. M., Johnsen, P. J., Bensasson, D., & Daffonchio, D. (2007). Release and persistence of extracellular DNA in the environment. Environmental Biosafety Research, 6(1-2).

Ogram, A., Sayler, G. S., & Barkay, T. (1987). The extraction and purification of microbial DNA from sediments. Journal of Microbiological Methods, 7(2), 57–66. https://doi.org/10.1016/0167-7012(87)90025-X

Quan, J., Langelier, C., Kuchta, A., Batson, J., Teyssier, N., Lyden, A., Caldera, S., McGeever, A., Dimitrov, B., King, R., Wilheim, J., Murphy, M., Ares, L. P., Travisano, K. A., Sit, R., Amato, R., Mumbengegwi, D. R., Smith, J. L., Bennett, A., … Crawford, E. D. (2019). FLASH: a next-generation CRISPR diagnostic for multiplexed detection of antimicrobial resistance sequences. Nucleic Acids Research, 47(14), e83. https://doi.org/10.1093/nar/gkz418

Rappé, M. S., Connon, S. A., Vergin, K. L., & Giovannoni, S. J. (2002). Cultivation of the ubiquitous SAR11 marine bacterioplankton clade. Nature, 418(6898), 630–633. https://doi.org/10.1038/nature00917

Roesma, D. I., Djong, H. T., Janra, M. N., & Aidil, D. R. (2021). Freshwater vertebrates monitoring in Maninjau Lake, West Sumatra, Indonesia using environmental DNA. Biodiversitas Journal of Biological Diversity, 22(5). https://doi.org/10.13057/biodiv/d220543

Roux, L.-M. D., Giblot-Ducray, D., Bott, N. J., Wiltshire, K. H., Deveney, M. R., Westfall, K. M., & Abbott, C. L. (2020). Analytical validation and field testing of a specific qPCR assay for environmental DNA detection of invasive European green crab (Carcinus maenas). Environmental DNA, 2(3), 309–320. https://doi.org/10.1002/edn3.65

Ruppert, K. M., Kline, R. J., & Rahman, M. S. (2019). Past, present, and future perspectives of environmental DNA (eDNA) metabarcoding: A systematic review in methods, monitoring, and applications of global eDNA. Global Ecology and Conservation, 17, 29. https://doi.org/10.1016/j.gecco.2019.e00547

Sanger, F., Air, G. M., Barrell, B. G., Brown, N. L., Coulson, A. R., Fiddes, J. C., Hutchison, C. A., Slocombe, P. M., & Smith, M. (1977). Nucleotide sequence of bacteriophage φX174 DNA. Nature, 265(5596), 687–695. https://doi.org/10.1038/265687a0

Schrader, C., Schielke, A., Ellerbroek, L., & Johne, R. (2012). PCR inhibitors – occurrence, properties and removal. Journal of Applied Microbiology, 113(5), 1014–1026. https://doi.org/10.1111/j.1365-2672.2012.05384.x

Sigsgaard, E. E., Nielsen, I. B., Bach, S. S., Lorenzen, E. D., Robinson, D. P., Knudsen, S. W., Pedersen, M. W., Jaidah, M. A., Orlando, L., Willerslev, E., Møller, P. R., & Thomsen, P. F. (2016). Population characteristics of a large whale shark aggregation inferred from seawater environmental DNA. Nature Ecology & Evolution, 1(1), 4. https://doi.org/10.1038/s41559-016-0004

Simpfendorfer, C. A., Kyne, P. M., Noble, T. H., Goldsbury, J., Basiita, R. K., Lindsay, R., Shields, A., Perry, C., & Jerry, D. R. (2016). Environmental DNA detects Critically Endangered largetooth sawfish in the wild. Endangered Species Research, 30, 109–116. https://doi.org/10.3354/esr00731

Souza, L. S., Godwin, J. C., Renshaw, M. A., & Larson, E. (2016). Environmental DNA (eDNA) Detection Probability Is Influenced by Seasonal Activity of Organisms. PloS One, 11(10).

Stat, M., John, J., DiBattista, J., Newman, S. J., Bunce, M., & Harvey, E. S. (2019). Combined use of eDNA metabarcoding and video surveillance for the assessment of fish biodiversity. Conservation Biology: The Journal of the Society for Conservation Biology, 33(1), 196–205. https://doi.org/10.1111/cobi.13183

Strickler, K. M., Fremier, A. K., & Goldberg, C. S. (2015). Quantifying effects of UV-B, temperature, and pH on eDNA degradation in aquatic microcosms. Biological Conservation, 183, 85–92. https://doi.org/10.1016/j.biocon.2014.11.038

Sunagawa, S., Acinas, S. G., Bork, P., Bowler, C., Tara Oceans Coordinators, Eveillard, D., Gorsky, G., Guidi, L., Iudicone, D., Karsenti, E., Lombard, F., Ogata, H., Pesant, S., Sullivan, M. B., Wincker, P., & de Vargas, C. (2020). Tara Oceans: towards global ocean ecosystems biology. Nature Reviews. Microbiology, 18(8), 428–445. https://doi.org/10.1038/s41579-020-0364-5

Takahashi, M., Saccò, M., Kestel, J. H., Nester, G., Campbell, M. A., van der Heyde, M., Heydenrych, M. J., Juszkiewicz, D. J., Nevill, P., Dawkins, K. L., Bessey, C., Fernandes, K., Miller, H., Power, M., Mousavi-Derazmahalleh, M., Newton, J. P., White, N. E., Richards, Z. T., & Allentoft, M. E. (2023). Aquatic environmental DNA: A review of the macro-organismal biomonitoring revolution. The Science of the Total Environment, 873, 162322. https://doi.org/10.1016/j.scitotenv.2023.162322

Thomsen, P. F., Kielgast, J., Iversen, L. L., Møller, P. R., Rasmussen, M., & Willerslev, E. (2012). Detection of a diverse marine fish fauna using environmental DNA from seawater samples. PloS One, 7(8), e41732. https://doi.org/10.1371/journal.pone.0041732

Tillotson, M. D., Kelly, R. P., Duda, J. J., Hoy, M., Kralj, J., & Quinn, T. P. (2018). Concentrations of environmental DNA (eDNA) reflect spawning salmon abundance at fine spatial and temporal scales. Biological Conservation, 220.

Truelove, N. K., Andruszkiewicz, E. A., & Block, B. A. (2019). A rapid environmental DNA method for detecting white sharks in the open ocean. Methods in Ecology and Evolution / British Ecological Society. https://besjournals.onlinelibrary.wiley.com/doi/abs/10.1111/2041-210X.13201

Turner, C. R., Barnes, M. A., & Xu, C. C. Y. (n.d.). Particle size distribution and optimal capture of aqueous macrobial eDNA. Methods in Ecology and Evolution / British Ecological Society. https://doi.org/10.1111/2041-210X.12206

West, K. M., Stat, M., Harvey, E. S., Skepper, C. L., DiBattista, J., Richards, Z. T., Travers, M. J., Newman, S. J., & Bunce, M. (2020). eDNA metabarcoding survey reveals fine-scale coral reef community variation across a remote, tropical island ecosystem. Molecular Ecology, 29(6), 1069–1086. https://doi.org/10.1111/mec.15382

Yamahara, K. M., Preston, C. M., Birch, J., Walz, K., Marin, R., Jensen, S., Pargett, D., Roman, B., Ussler, W., Zhang, Y., Ryan, J., Hobson, B., Kieft, B., Raanan, B., Goodwin, K. D., Chavez, F. P., & Scholin, C. (2019). In situ Autonomous Acquisition and Preservation of Marine Environmental DNA Using an Autonomous Underwater Vehicle. Frontiers in Marine Science, 6. https://doi.org/10.3389/fmars.2019.00373

Yates, M. C., Derry, A. M., & Cristescu, M. E. (2021). Environmental RNA: A Revolution in Ecological Resolution? - Trends Ecol Evol. 2021 Jul;36(7):601-609. https://doi.org/10.1016/j.tree.2021.03.001. Epub, 36(7), 601–609.

13. Building the scientific and analytical framework for Dynamic Ocean Management

Elliott L. Hazen,[1] *Briana Abrahms, Hannah Blondin, Kylie Scales and Heather Welch*

The combined impacts of climate change, coastal development, and intensifying use of the ocean are leading to rapid and widespread changes in the structure and function of marine ecosystems (Halpern et al., 2019). As species respond to new environmental regimes and anthropogenic threats redistribute and intensify (Figure 13.1), species management plans based on static approximations of biodiversity distribution may become rapidly outdated and therefore ineffective (Hazen et al., 2018; Oliver et al., 2018; Oestreich et al., 2020). Adaptive management approaches use repeated expert assessment to adapt management approaches during a management cycle to allow for timely intervention in the processes that link population status and anthropogenic threats, so they are particularly useful for threat mitigation under changing conditions (Maxwell et al., 2015). A drawback of such approaches, however, is that they require expert elicitation to update any information that goes into making management decisions, which can slow the process (Wilson Jono et al., 2018; Lomonico et al., 2021). Dynamic ocean management automates the process of updating management decisions as new information and data become available, and so can offer greater opportunity for climate-ready management by allowing more rapid responses to changing ocean conditions (Maxwell et al., 2015. Welch et al., 2019a; Maxwell et al., 2020).

Fig. 13.1 Interactions between protected species and human uses of the ocean are leading to new risks and unwanted mortality. a) Leatherback turtles (ELH) and b) loggerhead turtle in shrimp trawls in the Gulf of Mexico (ELH), c) Harbor Porpoise entangled in a gillnet (CC), d) blue whale struck by a ship (CC).

1 NOAA Fisheries, Southwest Fisheries Science Center, https://orcid.org/0000-0002-0412-7178

https://doi.org/10.11647/OBP.0395.13

Dynamic ocean management (DOM) is an approach to managing marine resources that 'changes rapidly in space and time in response to the shifting nature of the ocean and its users based on the integration of new biological, oceanographic, social and/or economic data in near real-time' (Maxwell et al., 2015). The key difference to more conventional adaptive management is that, in DOM, an initial set of 'control rules' for management decisions are chosen, and then management decisions are made based on incoming data in accordance with the control rules, as opposed to requiring expert elicitation at each step. An example of a control rule would be: "If spatial models predict fisheries bycatch risk—the incidental capture of non-target species—above a specific threshold in a given area, that area can be closed to fishing" (Howell et al., 2008; Hobday et al., 2011; O'Keefe and DeCelles, 2013; Hazen et al., 2018; Breece et al., 2021). In this scenario, expert opinion is not needed to adjust the management decision. This approach enables more fluid management strategies that can be frequently and automatically adjusted, allowing management decisions to reflect biological, environmental, economic, and social conditions in real time and with the goal of continuous separation between species of conservation concern and anthropogenic threats (Lewison et al., 2015; Dunn et al., 2018; Hazen et al., 2018). But initial efforts to operationalize DOM tools can be more onerous than other adaptive management approaches, since there are inherent requirements that a) data are regularly collected, b) clear decision rules are implemented and remain effective across changing conditions, and c) results are regularly delivered to managers or resource users (Hobday and Hartog, 2014; Welch et al., 2019a).

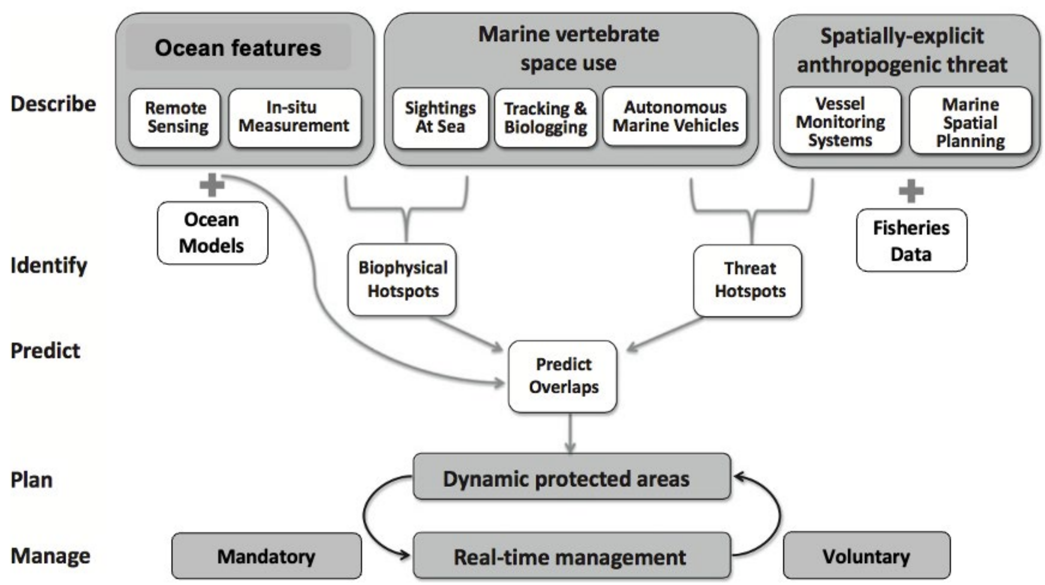


Fig. 13.2 Dynamic Ocean Management flowchart (adapted from Scales et al., 2014). Data on ocean features, biological space use, and threats can be combined to predict overlaps in time and space. Real time DOM implementation can be mandatory (e.g., tuna in eastern Australia; Hobday and Hartog, 2011) or voluntary (e.g., TurtleWatch).

While dynamic management is increasingly explored for use in marine resource management, it is not unique to marine systems (Oestreich et al., 2020). For example, automated predictions are used by air traffic control to assign runways, arrivals, and departure times based on weather conditions; for travel duration estimates in maps that update continuously based on real-time traffic data; and in weather prediction where nowcasts and forecasts inform multiple scales of planning for a wide range of applications from agriculture to tourism (Welch et al., 2018; Oestreich et al., 2020). In marine systems, DOM tools have been developed to predict harmful algal blooms (Anderson et al., 2015); reduce whale ship strikes and entanglements (Hazen et al., 2017; Meyer-Gutbrod et al., 2018; Abrahms et al., 2019); reduce fisheries bycatch (Howell et al., 2008; Hobday et al., 2011; O'Keefe and DeCelles, 2013; Howell et al., 2015; Hazen et al., 2018; Breece et al., 2021); and improve the efficiency of fisheries by predicting the dynamic distributions of target species (Spillman and Hobday, 2014; Hobday et al., 2018). These approaches integrate new data into the decision-making process, for example from the previous day's bycatch numbers (O'Keefe and DeCelles, 2013) or oceanography-based models that use species-environment relationships to predict species distributions (Hobday et al., 2011; Hazen et al., 2018; Abrahms et al., 2019) which can automatically provide advice, or, with control rules, can automatically provide management actions without the need for user input or manual adjustments (Figure 13.2). DOM can rely on sophisticated, data-driven analytical approaches that incorporate a range of datasets and cross disciplinary boundaries, and it is therefore a progressive and rapidly developing field with emerging applications that support the resilience of marine resource extraction industries against the impacts of climate change. In this chapter we discuss the different approaches to DOM, from data, to analytics, to decision-making, to guide DOM implementation in new regions. We end with future directions of DOM in supporting climate-ready fisheries and navigating the novel human-wildlife conflicts our ecosystems are facing.

DOM analytical approaches

Dynamic ocean management tools rely on biological, environmental, economic, and/or societal data (Lewison et al., 2015; Oestreich et al., 2020), frequently in combination, to describe features of management relevance (Figure 13.2). Of these, biological and environmental data are most commonly used. Biological data can be collected by fisheries observer programs (Hazen et al., 2018), logbooks (O'Keefe and DeCelles, 2013; Merrifield et al., 2019), satellite telemetry data (Hazen et al., 2018), acoustic receivers (Clark et al., 2005; Breece et al., 2021), eDNA (Gallego et al., 2020), citizen science data (Wiley et al., 2013), and aerial or shipboard surveys (Becker et al., 2020). Environmental data are frequently sourced from Earth Observation satellites (Hobday et al., 2010; Hartog et al., 2011; Dierssen et al., 2015; Anderson et al., 2016), or ocean model products (Abrahms et al., 2019; Welch et al., 2020) (Figure 13.2). A range of simple to complex DOM tools exist based on the species being managed, the data available, and the technological capacity of the end users (Figure 13.3, Box 13.1). Below we describe four different ways DOM tools utilize biological and environmental information to inform real-time management (daily to monthly): aggregation and summation, heuristic algorithms, predictive models, and synthetic tools that combine two or more methods.

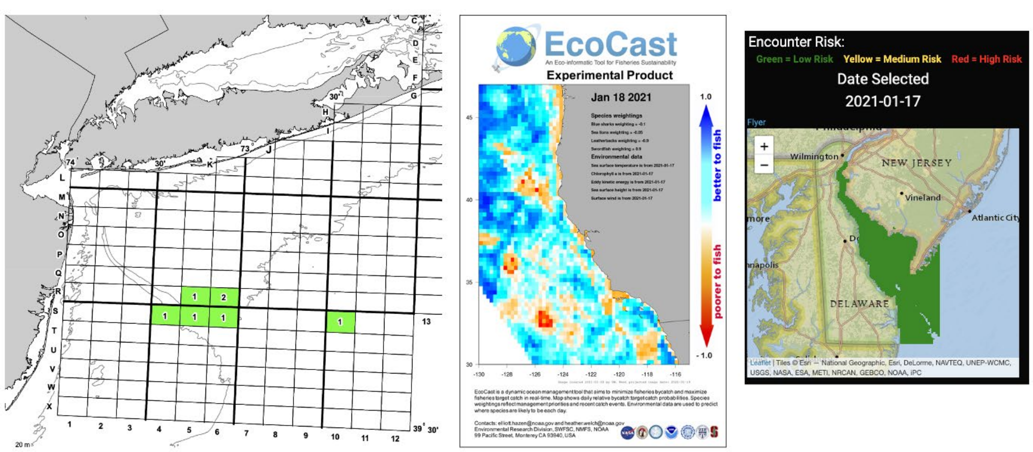


Fig. 13.3 Examples of North American products for dynamic ocean management. a) SMAST product for Atlantic scallop fisheries on the east coast of the US avoid bycatch of yellowtail and window pane flounder (also delivered as text-based zones), b) EcoCast product for swordfish to avoid bycatch of leatherback turtles, sea lions, and blue sharks, and c) ASMR product to avoid fishery interactions with Atlantic Sturgeon. These products can be delivered as a map (shown here) but a) & c) via text message as well for fishers with only limited cell access.

Box 13.1

DOM approaches can be simple to complex. These examples show how the various approaches have been implemented throughout north America.[2]

	Aggregation/ Summarization	Correlative (univariate)	Single species (multivariate)		Multi-species (multivariate)	
Name	SMAST Bycatch Avoidance	TurtleWatch	Sturgeon Text Alerts	WhaleWatch	EcoCast	PriSM
Protected species	Yellowtail flounder	Loggerhead sea turtle	Atlantic sturgeon	Blue whale	Blue shark, sea lion, leatherback	Multiple shark species
Target species/ activity	Scallops	Swordfish	Striped bass, skates, and other gillnet targets	Shipping	Swordfish	
Predictors	Location of bycatch events	Sea surface temperature	Multiple environmental variables	Multiple environmental variables	Multiple environmental variables	
Timescale	Near-real-time	Near-real-time	Real-time	Near-real-time	Real-time	
Sources		Howell et al. 2008 https://origin-apps-pifsc.fisheries.noaa.gov/eod/turtlewatch.php	Breece et al. 2018	Hazen et al. 2016 https://oceanview.pfeg.noaa.gov/WhaleWatch/; Abrahms et al. 2019 https://coastwatch.pfeg.noaa.gov/projects/whalewatch2/	Hazen et al. 2018 https://coastwatch.pfeg.noaa.gov/ecocast/	

Aggregation and summation

The simplest and most reliably tested form of dynamic ocean management is based on the aggregation and summation of pooled biological data such as fisheries logbooks or observer data (O'Keefe and DeCelles, 2013; Hobday and Hartog, 2014; O'Keefe et al., 2014; Lewison et al., 2015; Dunn et al., 2016; Keith et al., 2020; Oestreich et al., 2020). For example, in applications that seek to minimize bycatch in commercial fisheries, logbook or observer data on bycatch events can be shared in real time via mobile devices (Merrifield et al., 2019) or aggregated and shared a day later (Gilman et al., 2006; O'Keefe and DeCelles, 2013). Similar approaches are implemented to reduce ship-strike risk to North Atlantic right whales (*Eubalaena glacialis*) when three or more right whales are sighted within a discrete area, termed Dynamic Management Areas (Meyer-Gutbrod et al., 2018). These are put in place alongside existing seasonal and static ship speed restrictions to provide extra layers of confidence to management strategies that seek to protect threatened species in heavily trafficked or rapidly changing ecosystems.

2 Increasing complexity of dynamic ocean management can be a function of modeling approach, multi-species or multi-sector integrations, or predictor variables. Tools can be a) aggregation and summarization where reporting occurs on data from a previous timestep, b) correlative univariate where a single predictor variable such as SST is used, c) single species multivariate where there are multiple predictor variables (SST, Chl-a, etc.) and a single species being managed, d) multispecies multivariate with multiple species and multiple predictor variables, or e) forecasting models that use future ocean state to provide leading information to fishers or managers. Simpler models require less data and can be implemented in fisheries with lesser technical capacity while complex models can be more valuable to assess tradeoffs and can be implemented for data rich systems. Other important components of a fishery, e.g., quality of meat (Bolin et al., 2021) can also be predicted in a dynamic framework.

As with all DOM applications, there are benefits and drawbacks of reliance on real-time biological data for informing management decisions. Aggregation and summation-based DOM approaches rely on timely delivery of biological data rather than environmental data. As such, regular surveys, observer programs (O'Keefe and DeCelles, 2013), or acoustic data (Meyer-Gutbrod et al., 2018; Baumgartner et al., 2019) must be maintained to ensure that dynamic management approaches are updated as conditions change. Observational data can be used to close an area to fishing in the case of bycatch, reduce ship speeds in the case of ship-strike risk, or to dictate move-on rules where fishing is displaced based on real-time observations of bycatch events (Dunn et al., 2016). Real-time observational biological data are a "gold standard" for DOM since the data are direct measures of species occurrence rather than model-based inferences. These data can provide greater confidence in the DOM process, particularly when species' movement rates are low (Dunn et al., 2016). However, aggregation and summation approaches will be biased towards where the observers or surveys are, in contrast to model-based inference than can extrapolate in space and time. Additionally, gaps in data collection due to unpredictable events such as inclement weather, phenomena such as COVID-19, or movement of species beyond their historical ranges (Davies and Brillant, 2019; Rutz et al., 2020), can render aggregation and summation approaches less effective (Meyer-Gutbrod et al., 2018; Rutz et al., 2020). Furthermore, for fisheries-dependent data, such data-pooling approaches require high trust in the fishery as they call for accurate and transparent reporting. Some of the most successful aggregation and summation approaches have used either bycatch pooling, where participants receive a greater bycatch quota for reporting incidents (O'Keefe and DeCelles, 2013), or an industry-run approach towards data pooling and sharing (Gilman et al., 2006; Merrifield et al., 2019).

Heuristic algorithms

A second type of dynamic ocean management approach relies on heuristic algorithms, i.e., rule-based rather than model-based approaches, to describe the relationships between target features or species of management interest and the physical environment, with the ultimate aim of identifying and predicting the presence of target features or species in near real time. For example, TurtleWatch (Howell et al., 2008) uses an algorithm that describes the relationship between endangered loggerhead turtles (*Caretta caretta*) near Hawaii and sea surface temperature (SST) in order to identify areas to avoid fishing to reduce loggerhead bycatch each day.[3] Similarly, the Temperature Observations To Avoid Loggerhead (TOTAL) tool (Welch et al., 2019b) uses an algorithm that captures the relationship between loggerhead turtles and SST anomalies to guide the timing of the Loggerhead Conservation Area in the Southern California Bight.[4] Coral Reef Watch (Liu et al., 2006) uses an algorithm that describes the relationship between coral bleaching events and temperature in order to predict bleaching hotspots each day. Similar algorithms have been developed to identify Harmful Algal Blooms (Kavanaugh et al., 2013; Anderson et al., 2016), and to identify Sargassum blooms (Dierssen et al., 2015) for the benefit of faster management responses.

Algorithm-based tools have the advantage of being relatively simple to develop and operationalize compared to tools that rely on predictive models or synthetic tools. They also alleviate challenges associated with the real-time data collection that aggregation and summation-based tools rely on, since algorithm-based tools often use remotely sensed data or data-assimilative ocean models (Figure 13.2). However, this simplicity comes at the cost of flexibility: algorithm-based tools assume stationary relationships between target features and environmental information. As climate change continues to accelerate and produce anomalous environmental conditions, these relationships can break down (Muhling et al., 2020) as species are forced to form new habitat associations or novel threats emerge. Additionally, algorithm-based tools frequently rely on

3 https://oceanwatch.pifsc.noaa.gov/turtlewatch.html
4 https://coastwatch.pfeg.noaa.gov/loggerheads/

relationships between target features and a single environmental variable, such as temperature, while in reality, species distributions can be driven by multiple environmental factors. These complex species-environment relationships can be more accurately captured by species distribution models (SDMs), which are able to describe multivariate relationships. However, SDMs are data-hungry, requiring a significant amount of biological data in order to build robust and high-performing models. When there is a paucity of biological data, the relatively parsimonious algorithm-based tools may be necessary.

Predictive models

A third type of dynamic ocean management approach relies on data from predictive models, which can fall into the category of species distribution, or habitat, models (SDMs) or less commonly mechanistic models (Fiechter et al., 2016). SDMs relate species occurrence to environmental variation in order to predict species distributions in novel locations and times, and they are increasingly used in spatial planning (Elith and Leathwick, 2009). When applied to dynamic ocean management, SDMs use dynamic environmental variables that can provide predictions of species occurrence at temporal scales relevant to the timescales needed to make management decisions (Gallego et al., 2020). For example, oceanography-based species distribution models can be automated to update species distributions as new physical variables come in (Hazen et al., 2018; Abrahms et al., 2019; Becker et al., 2019). With the advancement of statistical modeling approaches and the availability of high-resolution environmental data, examples of SDMs developed for DOM are rapidly growing. For example, the Atlantic Sturgeon Risk Model provides daily predictions of endangered Atlantic sturgeon (*Acipenser oxyrhynchus oxyrhynchus*) in the mid-Atlantic based on an SDM with the goal of minimizing interaction with human activities (Breece et al., 2018; Breece et al., 2021). In contrast, the Tuna Seasonal Forecast System uses an SDM to forecast southern bluefin tuna (*Thunnus maccoyii*) distributions in the Great Australian Bight in order to maximize catch (Eveson et al., 2015). EcoCast [5]offers a novel combination of these goals by providing daily SDM predictions for target species (swordfish *Xiphias gladius;* Scales et al., 2017) and non-target bycatch species along the U.S. West Coast to help fishers and managers better allocate fishing effort to optimize catch while minimizing accidental bycatch (Hazen et al., 2018).

Predictive models alleviate many of the challenges associated with relying on aggregation and summation or heuristic rules. The predictive nature of such tools allows for a regular stream of near-real-time, and in some cases forecasted, data. In the widely adopted case of species distribution models, the ability to predict species occurrence spatially has demonstrated value for informing management decisions that are spatial in nature, such as time-area closures, protected area designation, zoning development decisions, and more. Because predictive models in a DOM context incorporate recent or forecasted physical variables, they can ensure that DOM approaches are climate-ready (Hazen et al., 2018; Holsman et al., 2019), with the caveat that predictive skill of management information remains high under anomalous environmental conditions (Muhling et al., 2020). These approaches require data on both species occurrences and underlying environmental or habitat conditions, and, given their complexity, take significant effort to build and validate. As such, a wide literature exists regarding best practices for developing (Araújo and New, 2007; Elith and Leathwick, 2009; Barbet-Massin et al., 2012; Robinson et al., 2017; Derville et al., 2018) and evaluating (Allouche et al., 2006; Fourcade et al., 2018) SDMs. In addition, the spatial or temporal resolution of predictive models are only as good as the underlying environmental data upon which they rely. For instance, WhaleWatch (fisheries.noaa.gov/west-coast/marine-mammal-protection/whalewatch), an SDM product for blue whales (*Balaenoptera musculus*) developed to reduce whale-ship collisions, relied on satellite-derived oceanographic variables provided at a monthly resolution (Hazen et al., 2017); however, an updated version of the tool, WhaleWatch 2.0 (https://coastwatch.pfeg.noaa.gov/projects/whalewatch2/), uses oceanography derived from a data-assimilative ocean model which allows for predictions at a daily timescale (Abrahms et al., 2019).

5 https://coastwatch.pfeg.noaa.gov/ecocast/

Synthetic tools

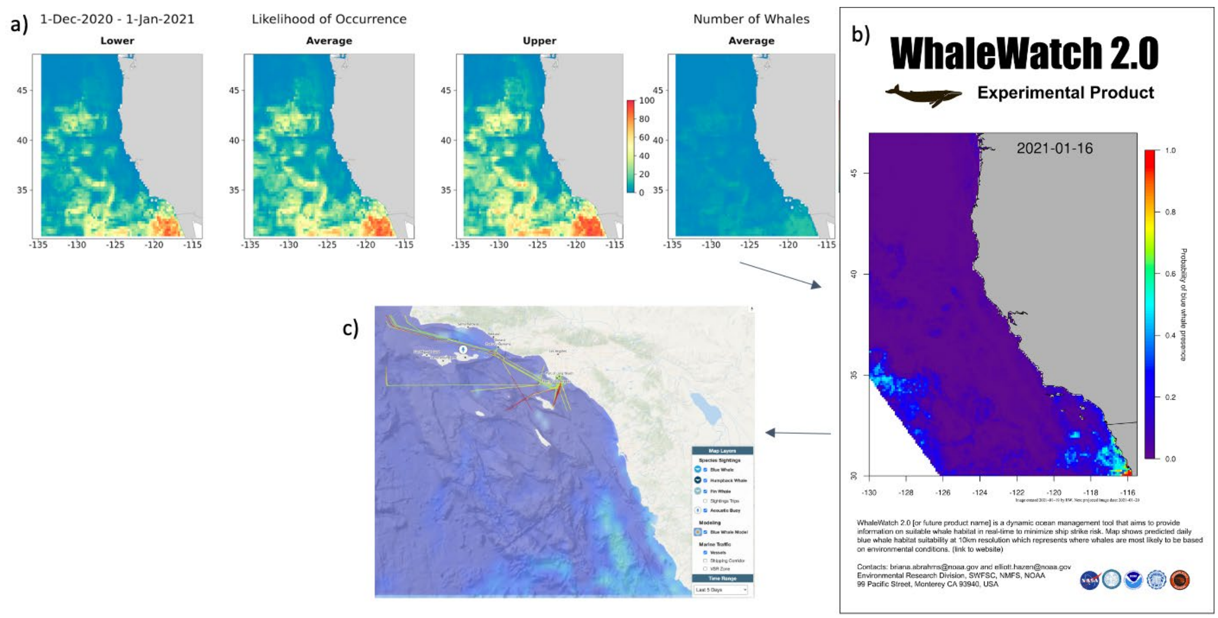


Fig. 13.4 Evolution of dynamic ocean management approaches to reduce ship strike risk for blue whales (WhaleWatch) and implementation alongside multiple data types. a) WhaleWatch built on satellite data at monthly resolution, https://www.fisheries.noaa.gov/west-coast/marine-mammal-protection/whalewatch (Hazen et al., 2017), b) WhaleWatch 2.0 built on ocean model output at daily resolution, https://coastwatch.pfeg.noaa.gov/projects/whalewatch2/whalewatch2_map.html, Abrahms et al., 2019, and c) WhaleSafe.com which ingests WhaleWatch 2.0 model output alongside acoustic, and visual sightings-based tool for reducing whale ship strike risk.

Synthetic tools bring together multiple datasets or multiple DOM approaches to allow users to leverage the strengths of multiple informational data streams within the decision-making framework. Two examples of the implementation of synthetic tools for dynamic ocean management occur along the U.S. West Coast and focus on mitigating the take of large whales. WhaleSafe[6] integrates a predictive whale distribution model (WhaleWatch 2.0; Abrahms et al., 2019; Figure 13.4), acoustic detections (Baumgartner et al., 2019), and visual observations of whales to alert transiting ships of the risk of whale-ship collisions in the waters surrounding two of the West Coast's busiest shipping ports. Similarly, the California Department of Fish and Wildlife and partners have developed a seasonal Risk Assessment and Mitigation Program[7] that evaluates ocean and forage conditions and multiple data sources on whale concentrations to inform dynamic closures to the Dungeness Crab fishery, which has seen a significant rise in large whale entanglements in recent years (Santora et al., 2020). Both of these synthetic tools combine aggregation and summation with predictive models.

By integrating multiple types of DOM tools, and often multiple data sources, synthetic tools are arguably the most robust for use in management because they inherently reduce reliance on any one given data stream. In the event of a data gap from one source, for instance, the alternative data streams enable the tool to still be used to inform management. Additionally, multiple data sources reduce uncertainty or noise associated with any single type of data source. However, operationalizing synthetic tools can present a technical challenge, particularly if data streams must be integrated in near real-time. Furthermore, researchers or managers developing synthetic tools must devise decision trees for how different data sources will be considered and

6 www.whalesafe.com
7 https://www.opc.ca.gov/risk-assessment-and-mitigation-program-ramp/

weighted in the final product. For example, WhaleSafe takes a conservative approach in which the integrated "whale presence rating" (ranging from low to very high) is determined based on the highest individual rating any of its three constituent data streams reaches. However, because the rating associated with the predictive whale distribution model has greater uncertainty than that derived from visual or acoustic detections, the distribution model can only lead to a "low" or "medium" rating. How different data types are weighted in a combination tool will depend on a range of factors, such as the uncertainty or the likelihood of false positives or negatives associated with a data type, the consistency of data access (for example in the case of intermittent survey data), or how different data sources are valued.

While predictions of species distributions are valuable outputs of operational DOM, predictions of other ecological parameters would prove useful in identifying management strategies and interventions. Other useful population parameter forecasts could include infectious disease outbreaks in a population, body condition, and quality of seafood product (Pirotta et al., 2018; Bolin et al. 2021)—this is already done on land to dynamically manage the transmission of brucellosis from bison to cattle near Yellowstone National Park (Hobbs et al., 2015). Similarly, population parameter forecasts could inform adaptive survival strategies (Pirotta et al., 2018), such as how jumbo squid shorten their lifespans and reproduce earlier in response to warming conditions within the Gulf of California (Frawley et al., 2019). There are also ample opportunities to apply DOM outside of fisheries applications (Anderson et al., 2016; Hazen et al., 2017). Beyond the ship strike examples mentioned earlier (e.g., whalesafe.com), other sectors and maritime activities to consider include offshore wind production, waste discharge from cruise ships, seismic exploration, tourism, naval SONAR testing, and addressing marine ecosystem protection targets (Butchart et al., 2016).

Nuts and bolts of Dynamic Ocean Management

Operationalizing dynamic ocean management tools follows a four-stage framework consisting of Acquisition, Prediction, Dissemination, and Automation (Welch et al., 2019a). In the Acquisition stage, near real-time or forecasted biological, environmental, ecological, and/or societal data are collected (Lewison et al., 2015). These data are used to identify the locations of target features or species, and/or to predict them under novel conditions. For example, in this stage, tools that rely on aggregation and summation will acquire new data on recent bycatch events (Gilman et al., 2006; O'Keefe and DeCelles, 2013) or recent species sightings (Meyer-Gutbrod et al., 2018). Tools that rely on heuristic algorithms and predictive models will acquire new environmental data from satellites (Howell et al., 2008; Hazen et al., 2017; Hazen et al., 2018; Breece et al., 2021) or regional ocean models (Hobday et al., 2011; Brodie et al., 2018; Abrahms et al., 2019; Welch et al., 2020).

In the Prediction stage, newly acquired data are post-processed into the final product that communicates management recommendations. For tools that rely on aggregation and summation, this stage involves summarizing newly acquired species data into actionable products. For tools that rely on heuristic algorithms or predictive models, the predetermined algorithm or model is applied to newly acquired environmental data to identify or predict where target species or features are likely to be.

In the Dissemination stage, these final products are distributed to end users, who may be resource managers, resource users, or the general public. Final products may be disseminated as mapped images (Hazen et al., 2017; Hazen et al., 2018; Abrahms et al., 2019; Figure 13.3), indicators (Welch et al., 2019b), written georeferenced descriptions (O'Keefe and DeCelles, 2013; Breece et al., 2018), or spatially-explicit georeferenced files such as comma-separated values (CSVs) with latitude/longitude coordinates, Google Earth KMZ files, network Common Data Forms (netCDFs), or shapefiles (Liu et al., 2006; Hazen et al., 2018). These final products are disseminated across a variety of pathways, including persistent URLs (Hazen et al., 2018; Abrahms et al. 2019), websites (Howell et al., 2008; Howell et al., 2015; Welch et al., 2018), text messages (Breece et al., 2021), or smartphone apps (Wiley et al., 2013). Dissemination formats and pathways are not mutually exclusive, and often several methods are used within the same tool to meet the various needs and technical capacities of multiple end users.

In the Automation stage, the Acquisition, Prediction, and Dissemination stages are integrated together to produce streamlined workflows that operate over the prescribed temporal scale of the tools, for example, daily (Hazen et al., 2018), weekly (Kavanaugh et al., 2013), or monthly (Hazen et al., 2017). This stage knits together the disparate code libraries of the previous stages into one unified workflow and may involve integration across multiple coding platforms. See a detailed discussion of temporal scale in the section below titled "Multi-species, multi-stressor, multi-scale." Below we discuss the next generation of DOM tools, and specifically, ways that human uses of the ocean and new data types can be merged to provide management advice such as 1) automated management approaches, 2) bringing in traditional knowledge to the quantitative DOM approach, and 3) incorporating more species, more stressors, and more management needs into single tools to better evaluate tradeoffs in a changing world.

Future of Dynamic Ocean Management

Models as a part of the management toolbox

While most dynamic management modeling approaches rely on correlative species distribution models (Lewison et al., 2015), there is a growing effort to include mechanistic models including individual-based movement models (Dodson et al., 2020), mechanistic movement, bioenergetic and population models (Fiechter et al., 2016), or more broad ecosystem models (Fulton et al., 2014). Analogous to general climate models (GCMs), which simulate the physical and chemical interactions within the earth's land, ocean and atmosphere that drive climate, general ecosystem models, which simulate ecological mechanisms and ecosystem behavior, could dramatically improve our understanding of the global ecosystem and change the way management and policy decisions are made (Purves et al., 2013). For example, the ability to understand how ecosystems work as a whole, as well as the broad-scale structure and function of the biosphere, would enhance our abilities to predict population distributions and abundance. While regional ocean models simulate how a particular region of the ocean responds to various physical forcings, the additional simulation of key ecological processes such as foraging, reproduction and mortality could inform how these processes change on a global scale in response to multiple stressors such as diseases, invasive species, and climate change (Purves et al., 2013). These models would provide valuable information on the vulnerability of species to multiple stressors and guide decisions of conservationists from local to international levels (Crespo et al., 2020; Visalli et al., 2020). Forecasts of future ocean conditions become even more important in the context of a quickly changing climate, reinforcing the need for holistic and dynamic approaches to both predictive models and management (Hobday et al., 2017; Purves et al., 2013).

Validation from non-traditional sources

Using additional data sources to validate predictions and forecasts is an important step towards building and maintaining dynamic management tools. Models can be validated internally by separating the data into a training and testing data set, or they can be validated on out-of-bag data to ensure the broad applicability of models (Abrahms et al., 2019; Woodman et al., 2019; Figure 13.5). Recently environmental DNA (eDNA) has proven to be an efficient, low-cost method in the assessment of species abundance (Shaw et al., 2016, Tillotson et al., 2018). One recent study found that eDNA closely tracked the rise and fall of salmon numbers in a creek after accounting for local environmental and biological conditions, providing an essential advancement in understanding the relationship between animal abundance and detectable genetic material (Tillotson et al., 2018). Further research in this arena could scale up the capacity for using genetic technologies for model validation. Other techniques for validation include unmanned vehicles and aircraft systems, which, in tandem with accompanying detection algorithms, provide options for cost-effective high-resolution data (Johnston, 2019). Alternatively, traditional ecological knowledge and local ecological knowledge have proven valuable in filling data gaps or validating biophysical models, particularly in data-poor regions of the world (Mason et al., 2019; Skroblin et al., 2021). In the case of the Peruvian shark fishery (Mason et al., 2019), the authors found strong agreement among expert-based variable mapping of temperature and chlorophyll isopleths, participatory mapping approaches, and quantitative species distribution models. This is a great example of how a variety of these approaches could be used to implement dynamic ocean management measures while also showing how integrating across data types could increase robustness.

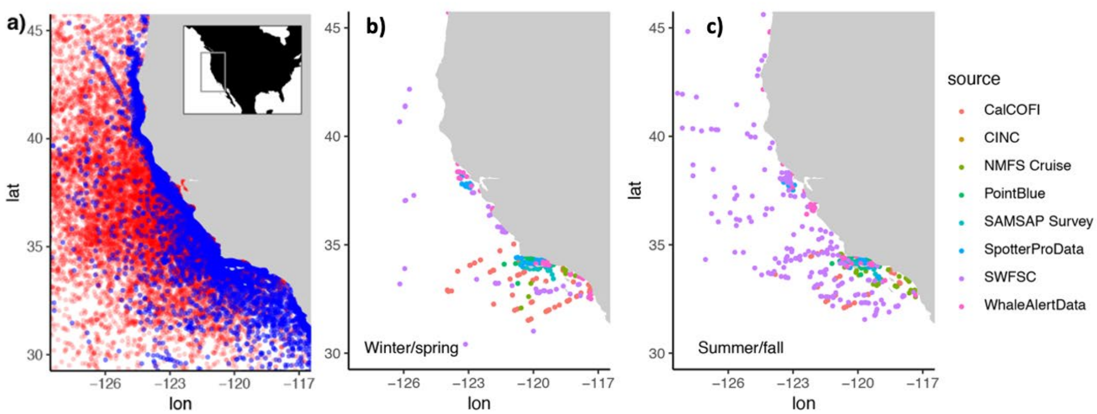


Fig. 13.5 Examples of the pieces of dynamic ocean management for WhaleWatch 2.0. A) Presence data from ARGOS tags and generated absences from the CCS used in WhaleWatch modeling. B) Winter/spring (left) and C) summer/fall (right) distributions of N=3,413 independent blue whale sightings data in the California Current. Modified from Abrahms et al., 2019–supplement.[8]

Multi-species, multi-stressor, and multi-scale

The recent push to adopt dynamic approaches for more traditional area-based management techniques (ABMTs) like Marine Protected Areas (Hyrenbach et al., 2000; Maxwell et al., 2020) represents an opportunity to scale up DOM to accommodate multiple species, multiple stressors, and multiple scales. To date, DOM approaches have generally been designed to mitigate one stressor to one species at one spatial or temporal scale. There are only a few examples of DOM approaches that address either multiple species—for example the EcoCast tool accommodates four species—or multiple scales, with WhaleWatch 2.0 offering coarse and high-resolution predictions across the California Current and Southern California Bight, respectively; these examples are the exception to the rule. For DOM to be amenable to use in traditional area-based management scenarios, the field must expand beyond these single-target scenarios. Multi-use approaches allow decision makers to attenuate impacts of cross-sectoral stressors on marine resources by regulating the distribution, timing, and intensity of industry activities (Ban et al., 2014; Wright et al., 2019). While dynamic management has mainly focused on direct threats to organisms (e.g., ship strikes, bycatch), indirect and diffuse threats such as seismic surveys and ocean noise are also significant (Pirotta et al., 2019; Maxwell et al., 2020) and should be incorporated in multi-use analyses. However, there is a point of diminishing returns, where the performance

8 Independent sightings data were collated from NOAA/Southwest Fisheries Science Center Surveys (SWFSC), California Cooperative Oceanic Fisheries Investigations Surveys (CalCOFI), NOAA/National Marine Fisheries Service (NMFS) Cruise, Spotter Pro, Whale Alert, Channel Islands National Marine Sanctuary (CINMS) SAMSAP Survey, Channel Islands Naturalist Corps (CINC) Sightings, and Point Blue Marine Mammal Survey.

of DOM tools becomes compromised as additional species, stressors and scales are added (Welch et al., 2020; Smith et al., 2021). Further work is needed to identify tipping points in the trade-off between inclusion and efficiency, which will often be system specific.

As described by Crespo et al. (2020), the application of dynamic approaches depends on timescale, including both the lead time needed to apply projects to a management decision and the application of the management decision itself (Tommasi et al., 2017):

a) Real-time or near-real-time predictions can be used to mitigate adverse impacts of sectoral uses, while also increasing their efficiency (e.g., catch of a target species; Crespo et al., 2020). Frequent and accurate measurements resulting in high-quality input data are key in producing models in which the predictions are trustworthy enough for decision makers (Purves et al., 2013; Petchey et al., 2015).

b) Intra-annual/seasonal applications depend on the forecasts of physical and biological variables (Jacox et al., 2020) which drive distributions of higher trophic levels and can help to predict species' migrations. Dynamic management at this temporal scale can allow for the isolation of areas of highest risk before negative interactions are likely to occur (Crespo et al., 2020).

c) At the decadal scale, predictions can be made with a goal of developing multi-year forecasts (Hobday et al., 2018) to predict anomalous conditions that may cause regime shifts. Managing for this scale will ensure irreversible damage does not occur to populations who shift outside of typical ranges, as management has been historically slow to adapt in response to shifting species distributions (Crespo et al., 2020). These forecasts can also inform rebuilding plans and long-term industry capitalization (Tommasi et al., 2017).

d) DOM tools can be used to explore the multi-decadal scale to predict major shifts in the distribution of populations as well as changes in the size of core habitats (Hazen et al., 2013). Within this management framework, we can forecast the effectiveness of area-based closures, and changes in negative interactions between populations and multi-sector uses of the marine environment, to ensure the resilience and sustainability of our oceans (Tommasi et al., 2017; Crespo et al., 2020).

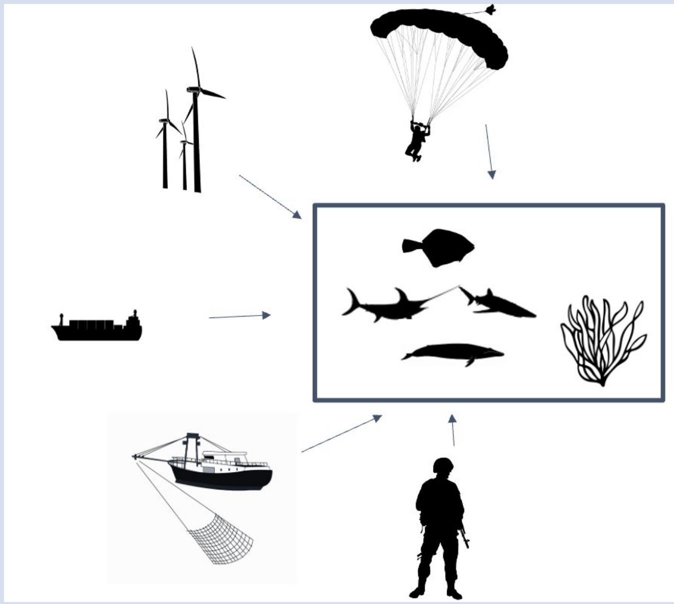
Particularly relevant to multi-year and multi-decadal temporal scales, dynamic approaches to ABMTs would allow managers to "futureproof" the protection of species before they move and their distributions change (Maxwell et al., 2020). By mitigating interactions between multi-sectoral uses and at-risk populations before they occur, managers can respond to threats that occur dynamically in the present and build climate responsiveness for the future.

For management to be most effective and adaptive to a changing climate, dynamic approaches will also need to be considered in areas beyond national jurisdiction (Maxwell et al., 2020). Building from examples of domestic DOM, measures in the high seas could provide less restrictive measures for anthropogenic uses and may be more practical to protect many wide-ranging and migratory species (Crespo et al., 2020; Maxwell et al., 2020).

Box 13.2

Multiple uses of the ocean include energy, shipping, tourism, fishing, military that can impact a single parcel of water. The future of DOM requires a multi-sectoral, ecosystem based approach to adjust management at relevant time scales.[9]

9 Increasing complexity of dynamic ocean management can be a function of modeling approach, multi-species or multi-sector integrations, or predictor variables. Tools can be a) aggregation and summarization where reporting occurs on data from a previous timestep, b) correlative univariate where a single predictor variable such as SST is used, c) single species multivariate where there are multiple predictor variables (SST, Chl-a, etc.) and a single species being managed, d) multispecies multivariate with multiple species and multiple predictor variables, or e) forecasting models that use future ocean state to provide leading information to fishers or managers. Simpler models require less data and can be implemented in fisheries with lesser technical



The future of dynamic ocean management also points towards building ensembles of multiple frameworks, ingestion of open-source (e.g., citizen science) data, and code to allow for rapid development and testing of such models (Box 13.2). Both anthropogenic uses of the ocean and the multitude of species within an area the goals of increasing the catch of a sustainably managed and under-exploited fish species. DOM requires a suite of tools that allow for redundancy, trade-offs among the various management approaches (e.g., Welch et al., 2020) and includes multiple sectors that would allow for more sustainable uses of the ocean, in addition to a greater capacity to respond to changing conditions in a rapid time frame. Currently, technological capacity and data richness are highly variable across nations, enabling more developed countries to have stronger dynamic management approaches in place. Thus, it is necessary to ensure that marine conservation technology and ecological information are more widely available than they currently are in order to balance power among political entities and multiple cultural needs (Jenkins, Chapter 14).

References

Abrahms, B., Welch, H., Brodie, S., Jacox, M.G., Becker, E.A., Bograd, S.J., Irvine, L.M., Palacios, D.M., Mate, B.R. & Hazen, E.L. (2019). Dynamic ensemble models to predict distributions and anthropogenic risk exposure for highly mobile species. Diversity and Distributions, 25(8), 1182-1193.

Allouche, O., Tsoar, A., & Kadmon, R. (2006). Assessing the accuracy of species distribution models: prevalence, kappa and the true skill statistic (TSS). Journal of applied ecology, 43(6), 1223-1232.

Anderson, C. R., Moore, S. K., Tomlinson, M. C., Silke, J., & Cusack, C. K. (2015). Living with harmful algal blooms in a changing world: strategies for modeling and mitigating their effects in coastal marine ecosystems. In Coastal and marine hazards, risks, and disasters (pp. 495-561). Elsevier.

Araújo, M. B., & New, M. (2007). Ensemble forecasting of species distributions. Trends in ecology & evolution, 22(1), 42-47.

Ban, N.C., Maxwell, S.M., Dunn, D.C., Hobday, A.J., Bax, N.J., Ardron, J., Gjerde, K.M., Game, E.T., Devillers, R., Kaplan, D.M. & Dunstan, P.K. (2014). Better integration of sectoral planning and management approaches for the interlinked

capacity while complex models can be more valuable to assess tradeoffs and can be implemented for data rich systems. Other important components of a fishery, e.g., quality of meat (Bolin et al., 2021) can also be predicted in a dynamic framework.

ecology of the open oceans. Marine Policy, 49, 127-136.

Barbet-Massin, M., Jiguet, F., Albert, C. H., & Thuiller, W. (2012). Selecting pseudo-absences for species distribution models: how, where and how many?. Methods in ecology and evolution, 3(2), 327-338.

Baumgartner, M.F., Bonnell, J., Van Parijs, S.M., Corkeron, P.J., Hotchkin, C., Ball, K., Pelletier, L.P., Partan, J., Peters, D., Kemp, J. & Pietro, J., (2019). Persistent near real-time passive acoustic monitoring for baleen whales from a moored buoy: System description and evaluation. Methods in Ecology and Evolution, 10(9), 1476-1489.

Becker, E. A., Carretta, J. V., Forney, K. A., Barlow, J., Brodie, S., Hoopes, R., ... & Hazen, E. L. (2020). Performance evaluation of cetacean species distribution models developed using generalized additive models and boosted regression trees. Ecology and evolution, 10(12), 5759-5784.

Becker, E. A., Forney, K. A., Redfern, J. V., Barlow, J., Jacox, M. G., Roberts, J. J., & Palacios, D. M. (2019). Predicting cetacean abundance and distribution in a changing climate. Diversity and Distributions, 25(4), 626-643.

Bolin, J. A., Schoeman, D. S., Evans, K. J., Cummins, S. F., & Scales, K. L. (2021). Achieving sustainable and climate-resilient fisheries requires marine ecosystem forecasts to include fish condition. Fish and Fisheries, 22(5), 1067-1084..

Breece, M. W., Fox, D. A., Haulsee, D. E., Wirgin, I. I., & Oliver, M. J. (2018). Satellite driven distribution models of endangered Atlantic sturgeon occurrence in the mid-Atlantic Bight. ICES Journal of Marine Science, 75(2), 562-571.

Breece, M.W., Oliver, M.J., Fox, D.A., Hale, E.A., Haulsee, D.E., Shatley, M., Bograd, S.J., Hazen, E.L. & Welch, H. (2021). A satellite-based mobile warning system to reduce interactions with an endangered species. Ecological Applications, 31(6), e02358.

Brodie, S., Jacox, M.G., Bograd, S.J., Welch, H., Dewar, H., Scales, K.L., Maxwell, S.M., Briscoe, D.M., Edwards, C.A., Crowder, L.B. & Hazen, E. L. (2018). Integrating dynamic subsurface habitat metrics into species distribution models. Frontiers in Marine Science, 5, 219.

Butchart, S. H., Di Marco, M., & Watson, J. E. (2016). Formulating smart commitments on biodiversity: lessons from the Aichi Targets. Conservation Letters, 9(6), 457-468.

Clark, C. W., Calupca, T., Gillespie, D., Von der Heydt, K., & Kemp, J. (2005). A near-real-time acoustic detection and reporting system for endangered species in critical habitats. The Journal of the Acoustical Society of America, 117(4), 2525-2525.

Crespo, G.O., Mossop, J., Dunn, D., Gjerde, K., Hazen, E., Reygondeau, G., Warner, R., Tittensor, D. & Halpin, P. (2020). Beyond static spatial management: Scientific and legal considerations for dynamic management in the high seas. Marine Policy, 122, 104102.

Davies, K. T., & Brillant, S. W. (2019). Mass human-caused mortality spurs federal action to protect endangered North Atlantic right whales in Canada. Marine Policy, 104, 157-162.

Derville, S., Torres, L. G., Iovan, C., & Garrigue, C. (2018). Finding the right fit: Comparative cetacean distribution models using multiple data sources and statistical approaches. Diversity and Distributions, 24(11), 1657-1673..

Dierssen, H. M., Chlus, A., & Russell, B. (2015). Hyperspectral discrimination of floating mats of seagrass wrack and the macroalgae Sargassum in coastal waters of Greater Florida Bay using airborne remote sensing. Remote sensing of environment, 167, 247-258.

Dodson, S., Abrahms, B., Bograd, S. J., Fiechter, J., & Hazen, E. L. (2020). Disentangling the biotic and abiotic drivers of emergent migratory behavior using individual-based models. Ecological Modelling, 432, 109225.

Dunn, D.C., Jablonicky, C., Crespo, G.O., McCauley, D.J., Kroodsma, D.A., Boerder, K., Gjerde, K.M. & Halpin, P. N. (2018). Empowering high seas governance with satellite vessel tracking data. Fish and Fisheries, 19(4), 729-739.

Dunn, D. C., Maxwell, S. M., Boustany, A. M., & Halpin, P. N. (2016). Dynamic ocean management increases the efficiency and efficacy of fisheries management. Proceedings of the National Academy of Sciences, 113(3), 668-673.

Elith, J., & Leathwick, J. R. (2009). Species distribution models: ecological explanation and prediction across space and time. Annual Review of Ecology, Evolution and Systematics, 40(1), 677-697.

Eveson, J. P., Hobday, A. J., Hartog, J. R., Spillman, C. M., & Rough, K. M. (2015). Seasonal forecasting of tuna habitat in the Great Australian Bight. Fisheries Research, 170, 39-49.

Fiechter, J., Huckstadt, L. A., Rose, K. A., & Costa, D. P. (2016). A fully coupled ecosystem model to predict the foraging ecology of apex predators in the California Current. Marine Ecology Progress Series, 556, 273-285.

Fourcade, Y., Besnard, A. G., & Secondi, J. (2018). Paintings predict the distribution of species, or the challenge of selecting environmental predictors and evaluation statistics. Global Ecology and Biogeography, 27(2), 245-256.

Frawley, T. H., Crowder, L. B., & Broad, K. (2019). Heterogeneous perceptions of social-ecological change among small-scale fishermen in the central Gulf of California: implications for adaptive response. Frontiers in Marine Science, 6, 78.

Fulton, E. A., Smith, A. D., Smith, D. C., & Johnson, P. (2014). An integrated approach is needed for ecosystem based fisheries management: insights from ecosystem-level management strategy evaluation. PloS one, 9(1), e84242.

Gallego, R., Jacobs-Palmer, E., Cribari, K., & Kelly, R. P. (2020). Environmental DNA metabarcoding reveals winners and losers of global change in coastal waters. Proceedings of the Royal Society B, 287(1940), 20202424.

Gilman, E. L., Dalzell, P., & Martin, S. (2006). Fleet communication to abate fisheries bycatch. Marine Policy, 30(4), 360-366.

Halpern, B.S., Frazier, M., Afflerbach, J., Lowndes, J.S., Micheli, F., O'Hara, C., Scarborough, C. & Selkoe, K. A. (2019). Recent pace of change in human impact on the world's ocean. Scientific reports, 9(1), 1-8.

Hartog, J. R., Hobday, A. J., Matear, R., & Feng, M. (2011). Habitat overlap between southern bluefin tuna and yellowfin tuna in the east coast longline fishery–implications for present and future spatial management. Deep Sea Research Part II: Topical Studies in Oceanography, 58(5), 746-752.

Hazen, E.L., Jorgensen, S., Rykaczewski, R.R., Bograd, S.J., Foley, D.G., Jonsen, I.D., Shaffer, S.A., Dunne, J.P., Costa, D.P., Crowder, L.B. & Block, B. A. (2013). Predicted habitat shifts of Pacific top predators in a changing climate. Nature Climate Change, 3(3), 234-238.

Hazen, E.L., Palacios, D.M., Forney, K.A., Howell, E.A., Becker, E., Hoover, A.L., Irvine, L., DeAngelis, M., Bograd, S.J., Mate, B.R. & Bailey, H. (2017). WhaleWatch: a dynamic management tool for predicting blue whale density in the California Current. Journal of Applied Ecology, 54(5), 1415-1428.

Hazen, E.L., Scales, K.L., Maxwell, S.M., Briscoe, D.K., Welch, H., Bograd, S.J., Bailey, H., Benson, S.R., Eguchi, T., Dewar, H. & Lewison, R. L. (2018). A dynamic ocean management tool to reduce bycatch and support sustainable fisheries. Science advances, 4(5), eaar3001.

Hobbs, N. T., Geremia, C., Treanor, J., Wallen, R., White, P. J., Hooten, M. B., & Rhyan, J. C. (2015). State-space modeling to support management of brucellosis in the Yellowstone bison population. Ecological Monographs, 85(4), 525-556.

Hobday, A. J., & Hartog, J. R. (2014). Derived ocean features for dynamic ocean management. Oceanography, 27(4), 134-145.

Hobday, A. J., Hartog, J. R., Spillman, C. M., & Alves, O. (2011). Seasonal forecasting of tuna habitat for dynamic spatial management. Canadian Journal of Fisheries and Aquatic Sciences, 68(5), 898-911.

Hobday, A. J., Hartog, J. R., Timmiss, T., & Fielding, J. (2010). Dynamic spatial zoning to manage southern bluefin tuna (Thunnus maccoyii) capture in a multi-species longline fishery. Fisheries Oceanography, 19(3), 243-253.

Hobday, A. J., Spillman, C. M., Eveson, J. P., Hartog, J. R., Zhang, X., & Brodie, S. (2018). A framework for combining seasonal forecasts and climate projections to aid risk management for fisheries and aquaculture. Frontiers in Marine Science, 137.

Holsman, K.K., Hazen, E.L., Haynie, A., Gourguet, S., Hollowed, A., Bograd, S.J., Samhouri, J.F. & Aydin, K. (2019). Towards climate resiliency in fisheries management. ICES Journal of Marine Science, 76(5), 1368-1378.

Howell, E. A., Kobayashi, D. R., Parker, D. M., Balazs, G. H., & Polovina, J. J. (2008). TurtleWatch: a tool to aid in the bycatch reduction of loggerhead turtles Caretta caretta in the Hawaii-based pelagic longline fishery. Endangered Species Research, 5(2-3), 267-278.

Howell, E. A., Hoover, A., Benson, S. R., Bailey, H., Polovina, J. J., Seminoff, J. A., & Dutton, P. H. (2015). Enhancing the TurtleWatch product for leatherback sea turtles, a dynamic habitat model for ecosystem-based management. Fisheries Oceanography, 24(1), 57-68.

Hyrenbach, K. D., Forney, K. A., & Dayton, P. K. (2000). Marine protected areas and ocean basin management. Aquatic conservation: marine and freshwater ecosystems, 10(6), 437-458.

Jacox M.G., Alexander M.A., Siedlecki S., Chen K., Kwon Y.O., Brodie S., Ortiz I., Tommasi D., Widlansky M.J., Barrie D., Capotondi A., Cheng W., Di Lorenzo E., Edwards C., Fiechter J., Fratantoni P., Hazen E.L., Hermann A.J., Kumar A., Miller A.J., Pirhalla D., Pozo Buil M., Ray S., Sheridan S.C., Subramanian A., Thompson P., Thorne L., Annamalai H., Aydin K., Bograd S.J., Griffis R.B., Kearney K., Kim H., Mariotti A., Merrifield M., & Rykaczewski, R. (2020).

Seasonal-to-interannual prediction of North American coastal marine ecosystems: Forecast methods, mechanisms of predictability, and priority developments. Progress in Oceanography, 183, 102307.

Johnston, D. W. (2019). Unoccupied aircraft systems in marine science and conservation. Annual review of marine science, 11, 439-463.

Kavanaugh, K. E., Derner, K., Fisher, K. M., David, E. E. P., Urizar, C., & Merlini, R. (2013). Assessment of the eastern Gulf of Mexico Harmful Algal Bloom Operational Forecast System (GOMX HAB-OFS): A comparative analysis of forecast skill and utilization from October 1, 2004 to April 30, 2008.

Keith, D. M., Sameoto, J. A., Keyser, F. M., & Ward-Paige, C. A. (2020). Evaluating socio-economic and conservation impacts of management: A case study of time-area closures on Georges Bank. PloS one, 15(10), e0240322.

Lewison, R., Hobday, A. J., Maxwell, S., Hazen, E., Hartog, J. R., Dunn, D. C., Briscoe, D., Fossette, S., O'Keefe, C.E., Barnes, M., Abecassis, M., Bograd, S. David Bethoney, N., Bailey, H., Wiley, D., Andrews, S., Hazen, L. & Crowder, L. B. (2015). Dynamic ocean management: identifying the critical ingredients of dynamic approaches to ocean resource management. BioScience, 65(5), 486-498.

Liu, G., Strong, A. E., Skirving, W., & Arzayus, L. F. (2006, June). Overview of NOAA Cuba program's near-real time satellite global coral bleaching monitoring activities. In Proceedings of the 10th international coral reef symposium (Vol. 1793, pp. 1783-1793). Okinawa, Japan: Gurugram.

Lomonico, S., Gleason, M. G., Wilson, J. R., Bradley, D., Kauer, K., Bell, R. J., & Dempsey, T. (2021). Opportunities for fishery partnerships to advance climate-ready fisheries science and management. Marine Policy, 123, 104252.

Mason, J. G., Alfaro-Shigueto, J., Mangel, J. C., Brodie, S., Bograd, S. J., Crowder, L. B., & Hazen, E. L. (2019). Convergence of fishers' knowledge with a species distribution model in a Peruvian shark fishery. Conservation Science and Practice, 1(4), e13.

Maxwell, S. M., Gjerde, K. M., Conners, M. G., & Crowder, L. B. (2020). Mobile protected areas for biodiversity on the high seas. Science, 367(6475), 252-254.

Maxwell, S. M., Hazen, E. L., Lewison, R. L., Dunn, D. C., Bailey, H., Bograd, S. J., ... & Crowder, L. B. (2015). Dynamic ocean management: Defining and conceptualizing real-time management of the ocean. Marine Policy, 58, 42-50.

Merrifield, M., Gleason, M., Bellquist, L., Kauer, K., Oberhoff, D., Burt, C., Reinecke, S. & Bell, M. (2019). eCatch: Enabling collaborative fisheries management with technology. Ecological Informatics, 52, 82-93.

Meyer-Gutbrod, E. L., Greene, C. H., & Davies, K. T. (2018). Marine species range shifts necessitate advanced policy planning: the case of the North Atlantic right whale. Oceanography, 31(2), 19-23.

Muhling, B. A., Brodie, S., Smith, J. A., Tommasi, D., Gaitan, C. F., Hazen, E. L., Jacox, M. G., Auth, T. D. & Brodeur, R. D. (2020). Predictability of species distributions deteriorates under novel environmental conditions in the California Current System. Frontiers in Marine Science, 7, 589.

O'Keefe, C. E., Cadrin, S. X., & Stokesbury, K. D. (2014). Evaluating effectiveness of time/area closures, quotas/caps, and fleet communications to reduce fisheries bycatch. ICES Journal of Marine Science, 71(5), 1286-1297.

O'Keefe, C. E., & DeCelles, G. R. (2013). Forming a partnership to avoid bycatch. Fisheries, 38(10), 434-444.

Oestreich, W. K., Chapman, M. S., & Crowder, L. B. (2020). A comparative analysis of dynamic management in marine and terrestrial systems. Frontiers in Ecology and the Environment, 18(9), 496-504.

Oliver, E. C., Donat, M. G., Burrows, M. T., Moore, P. J., Smale, D. A., Alexander, L. V., ... & Wernberg, T. (2018). Longer and more frequent marine heatwaves over the past century. Nature communications, 9(1), 1-12.

Petchey, O. L., Pontarp, M., Massie, T. M., Kéfi, S., Ozgul, A., Weilenmann, M., ... & Pearse, I. S. (2015). The ecological forecast horizon, and examples of its uses and determinants. Ecology letters, 18(7), 597-611.

Pirotta, E., Mangel, M., Costa, D. P., Mate, B., Goldbogen, J. A., Palacios, D. M., ... & New, L. (2018). A dynamic state model of migratory behavior and physiology to assess the consequences of environmental variation and anthropogenic disturbance on marine vertebrates. The American Naturalist, 191(2), E40-E56.

Pirotta, V., Grech, A., Jonsen, I. D., Laurance, W. F., & Harcourt, R. G. (2019). Consequences of global shipping traffic for marine giants. Frontiers in Ecology and the Environment, 17(1), 39-47.

Purves, D., Scharlemann, J. P., Harfoot, M., Newbold, T., Tittensor, D. P., Hutton, J., & Emmott, S. (2013). Time to model all life on Earth. Nature, 493(7432), 295-297.

Robinson, N. M., Nelson, W. A., Costello, M. J., Sutherland, J. E., & Lundquist, C. J. (2017). A systematic review of marine-based species distribution models (SDMs) with recommendations for best practice. Frontiers in Marine Science, 4, 421.

Rutz, C., Loretto, M. C., Bates, A. E., Davidson, S. C., Duarte, C. M., Jetz, W., ... & Cagnacci, F. (2020). COVID-19 lockdown allows researchers to quantify the effects of human activity on wildlife. Nature Ecology & Evolution, 4(9), 1156-1159.

Santora, J. A., Mantua, N. J., Schroeder, I. D., Field, J. C., Hazen, E. L., Bograd, S. J., ... & Forney, K. A. (2020). Habitat compression and ecosystem shifts as potential links between marine heatwave and record whale entanglements. Nature communications, 11(1), 1-12.

Scales, K. L., Hazen, E. L., Maxwell, S. M., Dewar, H., Kohin, S., Jacox, M. G., ... & Bograd, S. J. (2017). Fit to predict? Eco-informatics for predicting the catchability of a pelagic fish in near real time. Ecological Applications, 27(8), 2313-2329.

Shaw, J. L., Clarke, L. J., Wedderburn, S. D., Barnes, T. C., Weyrich, L. S., & Cooper, A. (2016). Comparison of environmental DNA metabarcoding and conventional fish survey methods in a river system. Biological Conservation, 197, 131-138.

Skroblin, A., Carboon, T., Bidu, G., Chapman, N., Miller, M., Taylor, K., ... & Wintle, B. A. (2021). Including indigenous knowledge in species distribution modeling for increased ecological insights. Conservation Biology, 35(2), 587-597.

Smith, J. A., Tommasi, D., Welch, H., Hazen, E. L., Sweeney, J., Brodie, S., ... & Jacox, M. G. (2021). Comparing dynamic and static time-area closures for bycatch mitigation: A management strategy evaluation of a swordfish fishery. Frontiers in Marine Science, 8, 630607.

Spillman, C. M., & Hobday, A. J. (2014). Dynamical seasonal ocean forecasts to aid salmon farm management in a climate hotspot. Climate Risk Management, 1, 25-38.

Tillotson, M. D., Kelly, R. P., Duda, J. J., Hoy, M., Kralj, J., & Quinn, T. P. (2018). Concentrations of environmental DNA (eDNA) reflect spawning salmon abundance at fine spatial and temporal scales. Biological Conservation, 220, 1-11.

Tommasi, D., Stock, C. A., Hobday, A. J., Methot, R., Kaplan, I. C., Eveson, J. P., ... & Werner, F. E. (2017). Managing living marine resources in a dynamic environment: the role of seasonal to decadal climate forecasts. Progress in Oceanography, 152, 15-49.

Visalli, M. E., Best, B. D., Cabral, R. B., Cheung, W. W., Clark, N. A., Garilao, C., ... & McCauley, D. J. (2020). Data-driven approach for highlighting priority areas for protection in marine areas beyond national jurisdiction. Marine Policy, 122, 103927.

Welch, H., Brodie, S., Jacox, M. G., Bograd, S. J., & Hazen, E. L. (2020). Decision-support tools for dynamic management. Conservation Biology, 34(3), 589-599.

Welch, H., Hazen, E. L., Bograd, S. J., Jacox, M. G., Brodie, S., Robinson, D., ... & Lewison, R. (2019a). Practical considerations for operationalizing dynamic management tools. Journal of Applied Ecology, 56(2), 459-469.

Welch, H., Hazen, E. L., Briscoe, D. K., Bograd, S. J., Jacox, M. G., Eguchi, T., ... & Bailey, H. (2019). Environmental indicators to reduce loggerhead turtle bycatch offshore of Southern California. Ecological Indicators, 98, 657-664.

Welch, H., Pressey, R. L., & Reside, A. E. (2018). Using temporally explicit habitat suitability models to assess threats to mobile species and evaluate the effectiveness of marine protected areas. Journal for Nature Conservation, 41, 106-115.

Wiley, D., Hatch, L., Schwehr, K., Thompson, M., & MacDonald, C. (2013). Marine sanctuaries and marine planning. The Coast Guard Proceedings of the Marine Safety and Security Council, 70, 10-15.

Wilson, J. R., Lomonico, S., Bradley, D., Sievanen, L., Dempsey, T., Bell, M., ... & Gleason, M. (2018). Adaptive comanagement to achieve climate-ready fisheries. Conservation Letters, 11(6), e12452.

Woodman, S. M., Forney, K. A., Becker, E. A., DeAngelis, M. L., Hazen, E. L., Palacios, D. M., & Redfern, J. V. (2019). eSDM: a tool for creating and exploring ensembles of predictions from species distribution and abundance models. Methods in Ecology and Evolution, 10(11), 1923-1933.

Wright, G., Gjerde, K. M., Johnson, D. E., Finkelstein, A., Ferreira, M. A., Dunn, D. C., ... & Grehan, A. (2021). Marine spatial planning in areas beyond national jurisdiction. Marine Policy, 132, 103384.

Linking natural and social science to governance

As a natural scientist, it is hard to admit that the science we do is often ‘necessary but not sufficient’ to solve problems in the real world. Excellent science can certainly inform promising pathways to solutions, but of course, one must also fully engage with cutting-edge social science approaches to frame possible solutions according to human dimensions. Why? Because we don’t manage ecosystems or even species—we manage the behavior of people and their negative or positive interactions with our watery world. But if we suppose we have a deep understanding of both the natural and social sciences underlying a complex problem, is that understanding sufficient to proceed to a solution? The answer to that deep understanding is often, “so what?”. Using that deep understanding requires also understanding governance, not government per se, but the operation of formal and informal governance in the system for which you are designing pathways to solutions. The chapters in this section of the book explore these human dimensions from a variety of useful perspectives. One bottom line is that if you want to be a ‘navigator’ toward solutions in a particular setting, you will need to assemble a ‘crew’ that can address this range of daunting issues and help design paths forward.

Lekelia D. Jenkins is a scholar who has focused on these human dimension issues, primarily in small-scale fisheries and coastal communities. A major focus of her work has been Marine Conservation Technology, which often involves inventing a device, or technological approach, that can contribute to resolving a conflict, such as bycatch in fisheries. She has probed the importance of power, politics, and culture in the invention/diffusion process. Who leads the invention and modification of these solutions has a big influence on how willing the community is to adopt the new technology. Thus, successful pathways to solutions require sensitive engagement of individuals and communities to foster the uptake of a workable solution.

Andrea J. Reid and **Natalie C. Ban** provide invaluable guidance from the perspective of an indigenous scientist and a ‘colonialist-settler’ scientist who has long worked with tribal people in marine resource systems. Their experiences provide invaluable advice on how to engage in these systems. They focus on the necessity of collaborating with Indigenous leaders from developing the problem definition, to designing culturally appropriate pathways to solutions, to designing implementation approaches that suit the local culture and biophysical setting. Reid is an advocate of ‘Two-Eyed Seeing’ which recognizes the value of Western and Indigenous perspectives and proposes maintaining both views to operate effectively in these situations. They provide engaging examples from coastal British Columbia.

Elena M. Finkbeiner, **Juno Fitzpatrick**, **Lily Z. Zhao**, **Gabrielle Lout**, **Marissa Anne S. Miller**, **Juan Carlos Jeri**, and **John N. Kittinger**’s chapter focuses on small-scale fisheries and the intricacies of engaging local communities in effective conservation planning and interventions. The authors of this piece are practitioners in the communities with which they work and focus on the importance of considering the human rights of local resource users as a critical element in framing plans that are appropriate and ethical. Individuals who are treated with respect are much more likely to engage creatively in planning, but also much more likely to act on the plan they created.

Ratana Chuenpadgee and **Svein Jentoft** provide a thorough global review of governance in small-scale fisheries. They focus both on formal 'top-down' governance in a variety of different settings and countries, but they also review various forms in informal 'bottom-up' governance that have proven effective in many cases. There are many ways for governance to fail, but also many ways for combinations of formal and informal governance to promote sustainability for local social-ecological systems. The authors emphasize emerging approaches to 'Blue Justice' principles that seem to be spreading in small-scale fisheries, particularly those associated with marine protected areas.

14. Power, politics, and culture: The human dimensions of marine conservation technology

Lekelia D. Jenkins[1]

Increasingly, governments are turning to technology to protect marine life and habitats. For examples, governments have passed legislation and implemented regulations that require the use of technology to reduce bycatch (i.e., the incidental capture of non-target species in fisheries). Mandated marine conservation technology use is at the intersection of science and governance. Ecological knowledge and engineering expertise are needed to create these technologies but the regulatory process often shortens the developmental process, resulting in technologies that are not well refined, fail to consider socio-cultural factors, and are impractical for everyday use. This chapter discusses how to better integrate science, especially social science, into the innovation process for marine conservation technologies and presents definitions and a framework for better conceptualizing the full management system in which marine conservation technologies operate.

Specifically, this chapter will discuss how the term conservation technology is applied widely and loosely to any technology connected to conservation. This overly broad understanding can lead to confusion around the actual mechanisms of conservation within a technological system, which can result in neglect and underdevelopment of the human dimensions of conservation technology, impacting its effectiveness. To improve understanding, this chapter offers precise definitions of marine conservation technology and a technological marine conservation system. It summarizes some of the concerns about the use of marine conservation technologies and discusses in depth how technology and technological systems can possess power of influence in and of themselves, as well as politics, and culture. It concludes by proposing a socio-ecological-technological systems framework to incorporate this broader understanding, so that the values and concerns of people, groups, and society are more effectively addressed in the creation and implementation of marine conservation technologies and technological marine conservation systems.

What is marine conservation technology?

History

While the term conservation technology originated in agricultural literature around techniques for soil conservation, Chopin and Inoue (1996a, 1996b) first used it in reference to marine conservation in 1996, to refer to technological approaches for reducing overfishing. Although marine conservation technology is a relatively new concept, its roots go back hundreds of years. Selective fishing to maximize exploitation and profit was the forerunner of marine conservation technology. Records of selective fishing practices date back several centuries,

1 School for the Future of Innovation in Society, College of Global Futures, Arizona State University, https://orcid.org/0000-0002-2375-2032

 https://doi.org/10.11647/OBP.0395.14

but concerted efforts of selective fishing in commercial fisheries notably increased at the end of the 19th century. This increased effort was initially motivated by exploitation, not conservation. This work focused on selecting large sizes of commercial fish by adjusting the shape and size of meshes and placing grids into the codends of trawls (Chopin, 1996a; Prado, 1997). Later, research sought to address the issue of separating species in multi-species fisheries. During the 1960s, rising public interest in charismatic species led to an increase in selectivity efforts for the purpose of conservation, and resulted in the development of capture prevention and escape technology for marine mammals, sea turtles, and seabirds beginning in the 1970s. Subsequently, researchers began exploring technologies that would increase the survival of organisms after interactions with fishing gear (Prado, 1997; Coe, 1984). Now, the term conservation technology is often indiscriminately applied to any technology however loosely connected to marine conservation (Berger-Tal and Lahoz-Monfort, 2018) and is in need of a precise definition.

Definition

The field of Science and Technology Studies (STS) offers a nuanced and socially contextualized understanding of technology in general. Some STS scholars define technology as a physical component with a practice (Pacey, 1983; Rogers, 1995). The physical component can be hardware, liveware, or both. Hardware consists of the tool that embodies the technology as a material or physical object (Rogers, 1995). Liveware is when a living thing is used as a tool in a technical process, such as biotechnologies or bacteria in sewage treatment (Pacey, 1983). In a marine conservation context, other examples would be biological control of invasive species through predator introductions or gene editing (Owens, 2017; Berger-Tal and Lahoz-Monfort, 2018). The practice component of technology is the information base for the tool such as software, philosophy, or process (Rogers, 1995). But more expansively, practice includes the organizational aspects (e.g., economic, regulatory, and professional activities; and users and consumers) and cultural aspects (e.g., goals, values, ethics) that create the system in which the technology operates, is supported, and constrained (Figure 14.1) (Pacey, 1983). In this broader sense, especially at industrialized scales, the technological practice is largely synonymous with a technological system. In sum, all technologies have a social component to some degree (Bergman et al., 2010).

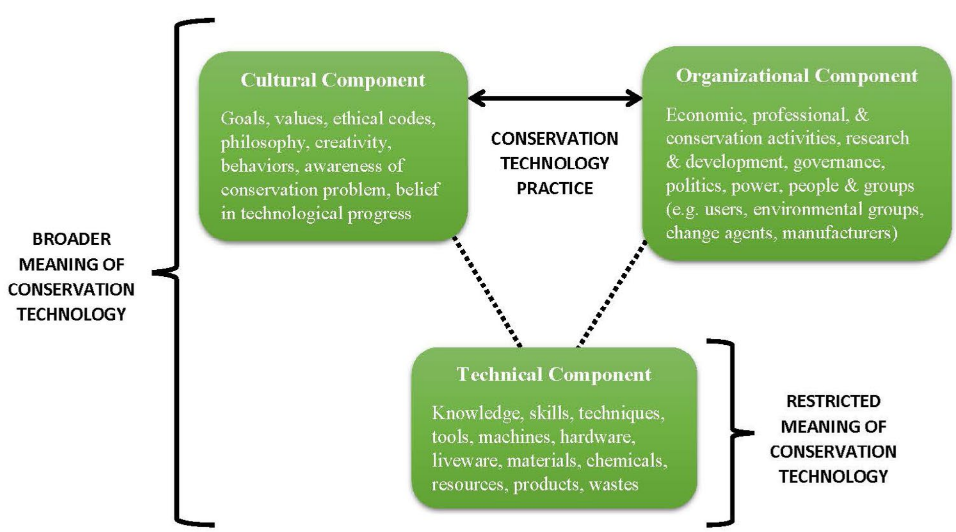


Fig. 14.1 Diagrammatic restricted and broader definition of conservation technology (adapted from Pacey, 1983).

Within the conservation community, the current understanding of conservation technology is both wide and narrow. It is wide in that it encompasses most any technology that can aid conservation, even indirectly. An example is remote sensing and telemetry technologies (e.g., GPS, sensor tags, satellites, drones), which simply yield information but do not have a direct conservation function (Nyman, 2019). The current understanding is also narrow, because it focuses on high-tech devices (Berger-Tal and Lahoz-Monfort, 2018) and often overlooks simple technologies, such as separator grids or tori lines, that are not electronic or digital.

To differentiate and clarify the use of technology within marine conservation, I offer four terms: conservation function, conservation benefit, marine conservation technology, and technological marine conservation system. I will discuss how these terms can sharpen our understanding of the use, power, and impact of technology on nature and society and how this improved understanding can lead to better practice around conservation technologies.

I define conservation function as a purposeful design feature that is intended to yield a certain conservation outcome. I define conservation benefit as a positive conservation outcome. For example, a turtle excluder device (TED) is purposefully designed to remove endangered sea turtles from fishing nets and prevent the turtles from drowning. This is the conservation function of TEDs. When TEDs are used properly and widely throughout a fishery, sea turtle deaths decrease and the sea turtle population size increases. This positive conservation outcome is a conservation benefit of TEDs.

With the definitions of conservation function and conservation benefit in mind, I propose that marine conservation technology (MCT) is best understood as a tool that directly protects marine organisms and/or marine habitats (e.g., bycatch reduction devices). For an MCT, the conservation function is inherent to the tool. Although, like all tools, there is an associated practice, and in the case of MCT, the organization component can have a conservation function as well (Figure 14.2A). For other marine conservation approaches that incorporate technology, I propose the term technological marine conservation system (TMCS). For a TMCS, technology is used to contribute to a process of conservation, but the technology on its own cannot yield a conservation benefit (e.g., drones). In a TMCS, the technology does not have an inherent conservation function, rather the conservation function is embedded in the organizational component of the technology practice (Figure 14.2B). By its nature a TMCS is a technological system. MCTs, however, are usually incorporated into a technological system when being widely applied as a conservation solution or technological fix.

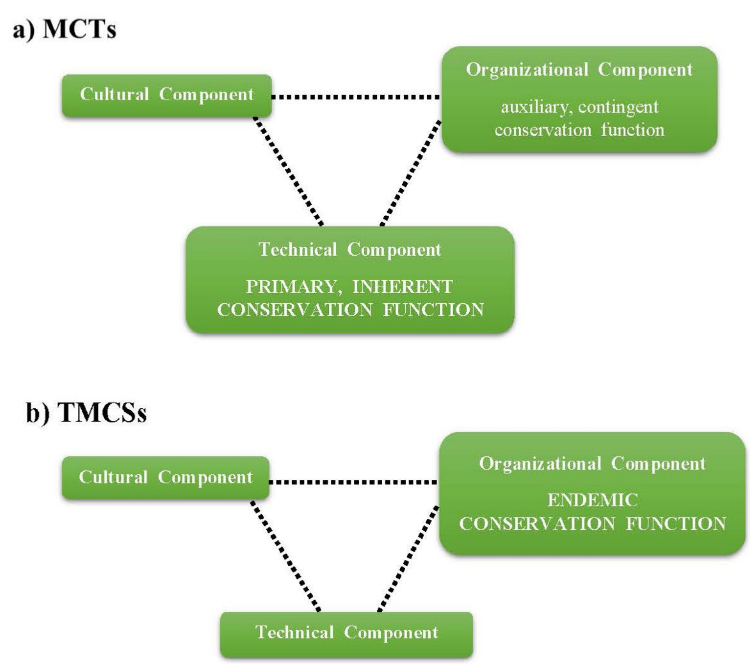


Fig. 14.2 Differences in location and nature of conservation function between A) marine conservation technologies and B) technological marine conservation systems.

The nature of MCTs versus TMCSs is important because it impacts their effectiveness as technological fixes for conservation problems. Sarewitz and Nelson (2008) offer three rules of technological fixes, which are: 1) the technology must largely embody the cause–effect relationship connecting a problem to its solution; 2) the effects of the technological fix must be assessable using relatively unambiguous or uncontroversial criteria (e.g., the conservation benefit must be easily observable); 3) research and development (R&D) is most likely to contribute decisively to solving a social problem when it focuses on improving a standardized technical core that already exists (Sarewitz and Nelson, 2008).

All three of these rules are more easily achieved with MCTs than with TMCSs. It is easier to obtain some level of conservation benefit from an MCT (i.e., rule 1), because the conservation function is inherent in the tool and the practice is more tightly bound to the technology. Also MCTs tend to evolve from existing technologies (i.e., rule 3) (Jenkins, 2006). In contrast, for a TMCS, the technology practice is more expansive and diffuse. In TMCSs, the practice and not the tool component of the technology embodies the cause-effect relationship (e.g., the conservation function). The conservation benefit is less easy to observe, and R&D must focus on the technology practice to develop conservation function and yield conservation benefit. However, we can move towards more effective TMCSs and also MCTs with increased awareness, broader understanding, and focused effort on developing the practice component. This could increase adoption of TMCSs and MCTs and also maximize conservation benefits (Bergman et al., 2010).

In the following sections, I will summarize some of the criticisms, concerns, and considerations for the use of MCTs, including halfway technology, techno-arrogance, and unintended consequences. I will briefly cover existing best practices for developing and promoting MCTs. Then, I will largely focus on how technology and technological systems possess power of influence in and of themselves, as well as politics, culture, and organization. Incorporating this broader understanding can help us develop and implement MCTs and TMCSs that are more effective by addressing a range of critical values and concerns. This can potentially be achieved through the better integration of social sciences into MCT and TMCS development and the application of the Social-Ecological-Technological Systems framework.

Pitfalls

In comparison to non-technological management options, such as time/area closures, conservation technology as a technological fix often requires fewer changes in the behavior of the resource users (Sarewitz and Nelson, 2008). An excellent example is the use of acoustic pingers to alert cetaceans and prevent their entanglement in gillnets; fishers, managers, and scientists supported this technology (Kraus, Read, et al., 1997). A difficulty with conservation technology is that consensus among typically factious groups might drive a management decision that does not adequately resolve the problem or may even create new problems.

Halfway technology

In the excitement of discovery, conservation technologies can be subject to unrealistic expectations and misapplications, and this has led to some criticism (Frazer, 1992; Meffe, 1992). Frazer (1992) points out that some technological fixes are “halfway technologies”, i.e., technologies that address the symptoms of a problem but not the cause of the problem. Frazer backs his argument with the example of a misguided TMCS involving sea turtle captive breeding, hatcheries, and head-starting programs. Sea turtle hatcheries are facilities that house and protect sea turtle eggs that have been removed from wild nesting beaches. Headstarting programs raise the resulting hatchlings until they are juveniles and have outgrown many of their natural predators. The misguided TMCS used these approaches attempted to address the symptom of the declining turtle populations, rather than the cause, bycatch and disorienting beach lighting. The better solutions were to use turtle excluder devices (TEDs) to reduce the deaths of large juvenile and adult sea turtles in shrimp trawl nets and to use low-pressure sodium lighting on beaches to prevent disorientation of nesting females and natural hatchings. TEDs consist of a hard grid or mesh panel that is placed in a trawl net to direct sea turtles and other large objects out of an escape hole in the net. Unlike captive breeding, hatcheries, and head-starting, TEDs and low-pressure sodium lighting would directly address the causes of sea turtle mortality.

Meffe (1992) illustrated the concept of halfway technologies with an overview of salmon conservation. For instance, dams blocking salmon rivers are a major cause of declining salmon populations; a symptom of this problem is that fewer salmon can return to their home streams to breed. In most cases, managers have chosen not to address the problem (i.e., the dam), but instead to address the symptom (i.e., low numbers of spawning fish) by artificially increasing salmon numbers through hatcheries.

Halfway technologies can be seductive, yet dangerous. Sometimes halfway technologies are the only options available, such as using cold medicine to treat symptoms because a vaccine against the cold virus does not exist. Or, with the complexities of conservation, sometimes a halfway technology is a compromise around the only socio-politically feasible resolution. The problem is that, like cold medicine, often people will not be aware that the resolution is a halfway technology and thus does not truly and permanently solve the issue. In tension-filled political and governance structures, halfway technologies can be a way to appear to be addressing a problem without requiring significant change in the behavior of stakeholders. The danger is that this can expend political will and public attention so that people move away from the issue before the problem is truly solved. Moreover, halfway technologies—and technological fixes in general—cannot offer moral absolution to problems that humans and society have caused. A technological fix, even an effective one, does not release us from the blame and ethical obligation to make amends (Sarewitz and Nelson, 2008; Frazer, 1992).

Techno-arrogance and related concepts

Meffe (1992) also argues that people have developed a “techno-arrogance”, which is the failure to recognize or accept limitations and ramifications of the attempted control through technology of our human environment and of nature. He states that:

> humankind has adopted a shortsighted and ultimately self-defeating philosophy toward nature and our modification of it. We seem to feel that we can solve any man-induced problem in the natural world, be it habitat destruction, the spread of exotic species [...] and even global climate change, through even further modifications using a concerted application of technology. The notion is that we can right virtually any wrong, given enough money, motivation, and innovation. And if any of those “solutions” cause unanticipated problems, simply apply more technology (Meffe, 1992, p. 351).

Meffe explains this idea with the example of the use of hatcheries to recover Pacific salmon populations without addressing the on-going overfishing and habitat destruction that originally caused the crisis. These hatcheries have also created other problems, such as negative effects on the genetics of natural salmon populations, water pollution, and habitat alteration (Meffe, 1992).

The concept of techno-arrogance is closely related to techno-optimism, techno-addiction, and the Human Exemptionalism Paradigm (HEP). Techno-optimism is “an exaggerated and unwarranted belief in human technological abilities to solve problems of unsustainability while minimizing or denying the need for large-scale social, economic and political transformation” (Barry, 2012). Techno-optimism has been raised as an issue for the use of drones, automated identification system (AIS), and satellite surveillance to combat piracy and illegal, unreported, and unregulated (IUU) fishing (Nyman, 2019). Techno-addiction is the societal obsession with technologies that are illusory solutions to problems that are fundamentally social, psychological, or spiritual in nature (Huesemann and Huesemann, 2011). HEP is a worldview that justifies human dominance over nature through the use of technology, based on the belief that humans are unique compared to other organisms, independent from nature, and can solve any problem with human ingenuity (Gardezi and Arbuckle, 2018; Williams, 2007). HEP, Techno-arrogance, techno-optimism, or techno-addiction can lead to recklessly embracing the benefits of MCTs and TMCSs without addressing environmental, societal and other associated risks. This then may lead to problems that further innovation cannot solve and society and nature may be left to suffer the consequences.

Unintended consequences

Often people label these consequences as unintended. There are several types of unintended consequences, including unexpected benefits (i.e., a positive unplanned result), unexpected drawbacks (i.e., a negative unplanned result), and perverse outcomes (i.e., a result contrary to what was intended). For instance, in Ecuador, an organization promoted the use of circle hooks to reduce sea turtle mortality in fisheries, a move that resulted in an unexpected drawback. The fishers perceived that the hooks also increased the capture of profitable sharks, which the fishers could not legally target but could land and sell if they were captured incidentally. So, some fishers started using circle hooks not to protect sea turtles but to capture imperiled sharks (Jenkins et al., 2012b, 2012a).

Some scholars argue that the term unintended consequences is a misnomer (Jasanoff, 2016; Winner, 1986). Jasanoff (2016) contends that consequences are foreseeable and that people, businesses, and society would rather not foresee them, so they place inadequate effort into considering consequences. Winner (1986) claims that the process of innovation is biased in favor of certain social interests, resulting in technologies that inequitably benefit and harm different segments of society. For the everyday person, our values and cultural norms greatly influence our thinking and thus the technologies we produce and use. It is unlikely that, without special training, adequate resources, and motivation, the average innovator or user would anticipate anything but the most obvious consequences. However, Jasanoff and Winner reason that with social and political will and a "moral and political language" for discussing and evaluating technologies, many consequences of the uses of technology could be anticipated and preemptively addressed.

Power, politics, culture, and organization

We often mistakenly believe that the same MCT can be used anywhere in the world and yield the same conservation benefit. We frequently restrict the list of things that can influence the function of an MCT to a small number of external factors, such as the need for similar fishing gear types, species assemblages, or benthic habitat types. However, inherent to MCTs is not only conservation function, but also power, politics and the culture of the inventor and the place where it was created and intended for use. Furthermore, while the same physical technology may be transported and applied around the world, the people who use or experience it differ in where and how they live, how they support their families, what they believe and value, their education and wealth, and their societal freedoms.

Power, politics, culture, and organization may be external components to the physical technology, but they are still an inherent component of the technology (Barry, 2012; Jasanoff, 2016; Pacey, 1983; Winner, 1986). A useful analogy would be the dependence of the human body on air, food, and water. Air, food, and water are external to the human body, but inherently necessary, because without them the body dies. If these things are poisoned the body is poisoned. With society's tendency to divide, categorize, and narrowly define much of the natural world, we view these things as separate from the body, as associated and important, but not a connected component of the body. Likewise, I suggest a narrow definition is a root cause of problems with the invention and adoption of conservation technologies. I propose that we need to radically change our understanding of technology. Power, politics, culture, and organization are not peripheral to technical matters. Rather power, politics, culture, organization and technical matters are interdependent systems that must all work together to form a successful conservation technology. Adopting a holistic definition of conservation technology is the first step to a holistic approach to inventing and promoting the use of MCTs and TMCSs. That process of invention and innovation is not only technological but must be social as well.

The transition from unsustainability is one in which innovation is absolutely vital, and that includes technological innovation. But it also requires and involves what might be called "full-spectrum innovation"; new ways of doing, collaborating, governing, and thinking at different scales and in different places. It requires, in short, social innovation, which is much more difficult, longer term and more uncertain than the easier and less uncertain path of technological innovation (though of course, this path is not without risks).

This interaction between technology, people and society is a critical consideration in obtaining conservation benefits from MCTs and especially TMCS. In creating them, the field of marine conservation must begin to attend to the human and societal aspects of technology as much as they attend to engineering aspects and ecological impacts. In the words of the STS scholar, Sheila Jasanoff, "new and emerging technologies redraw the boundaries between self and other and nature and artifice. Technological inventions penetrate our bodies, mind, and social interactions, altering how we relate to others both human and nonhuman."(Jasanoff 2016) The redrawing of boundaries and the alteration of nature and society will flow from the creation and use of MCTs and TMCS, so we must actively and consciously engage in shaping these boundaries and guiding these alterations.

Power

Technology has power. Technology has the power to shape nature, to shape society, and to shape us. Technology has the power and authority to rule and govern us (Jasanoff, 2016). Jasanoff uses the example of traffic lights, which have the authority to tell us when we can legally stop and go. In Baltimore City, an audit of speed cameras found that they had an average error rate over 10% (Broadwater and Calvert, 2014). The technology system metes out judgements and, regardless of whether that judgement is correct or incorrect, a bill for the fine comes in the mail. There is no immediate opportunity to plead your case with a police officer and perhaps avoid a ticket. Similarly, researchers touted that they had achieved proof of concept for how to use remote sensing and artificial intelligence (AI) to identify fishing boats that might be using forced labor (McDonald et al., 2021). However, other researchers quickly responded that the model and how it was tested was flawed, and could lead to the misidentification of vessels that are not engaged in forced labor abuses (Swartz et al., 2021). They argued that scientists should not be so quick to embrace technologies that could shape policy and practices that impact human lives.

MCTs and TMCSs also have power. With this power comes concerns for how MCTs and TMCSs, such as those that harness AI, are reshaping decision-making and enforcement processes, making these processes less transparent and participatory, and shifting the distribution of power among stakeholders to favor the developers of MCTs and TMCSs (Scoville et al., 2021). An example is the current development of autonomous vessels to police marine protected areas (MPAs). These vessels use AI to patrol MPAs, identify the presence of vessels, whether or not they are just transiting through or engaging in a prohibited practice like fishing, and documenting their presence and activity with video and GPS. Currently, government lawyers and conservation and enforcement experts are trying to determine if evidence gathered from autonomous vessels would be admissible in court (Minke-Martin 2020). While this TMCS has great potential to patrol large MPAs that are prohibitively expensive to police with typical crewed boats, there are also concerns around power that must be considered. What if a fisher was fishing just outside of park boundaries, suffered a power loss and drifted into park boundaries with their fishing gear in the water? In California, having gear in the water inside of an MPA is grounds for prosecution (Minke-Martin, 2020). As with the traffic cameras, there is no one to whom to explain your circumstances before being identified as a law-breaker.

Autonomous vessels also have the power to potentially increase the wealth and power divide and worsen disparities in access to resources and opportunities. MPAs often tout the creation of local jobs as guardians for the MPA as a direct benefit to the local community. Would autonomous vessels take these jobs? In many developing countries, basic human necessities like food, clean water, decent work, healthcare, and education outweigh fisheries enforcement as a priority. Considering these other issues, some developing countries cannot afford even basic skiffs for patrolling, so purchasing an autonomous vehicle would not be fiscally feasible. Even if they had the vessels, these same countries often lack the scientific resources and manpower to analyze all the data these vessels would produce (Nyman, 2019). Could this disparity lead to displacement of IUU fishing? Will the use of autonomous vessels in wealthy countries push industrial scale IUU fishing into the waters of developing countries and cost their people precious resources? These are valid questions given concerns that current trade-based measures to combat IUU fishing amplify inequities to the detriment of countries dependent on small-scale fisheries (Song et al., 2020).

As we develop MCTs and TMCSs we must grapple with these issues. We must ask ourselves: Who or what is at risk? Who is responsible for risk? How do we foresee risk? How can we prevent widening wealth, power, resource, and opportunity gaps (Jasanoff, 2016)? While designing the conservation function of MCTs and TMCSs, we must actively design the other aspects of the technological system to address these questions.

Politics

Technology has politics. According to the seminal work of Langdon Winner, "The issues that divide or unite people in society are settled not only in the institutions and practices of politics proper, but also, and less obviously, in tangible arrangements of steel and concrete, wires and semiconductors, nuts and bolts." Winner supports this declaration with multiple examples, including the classic case of Robert Moses (Winner, 1986). From the 1920s to the 1970s, Robert Moses was the master builder of roads, parks, bridges, and other public works in New York City. He was also racially prejudiced and biased along the lines of social class. He intentionally engineered 200 overpasses in Long Island with only nine feet of clearance to allow cars but not buses to pass. Thus, he gave access to recreational areas, such as Jones Beach, to car-owning, middle-class or better, primarily white people, while effectively excluding access to lower-class and minority people who rode buses. "His monumental structures of concrete and steel embody a systematic social inequality, a way of engineering relationships among people" that still persists long after his death (Winner, 1986).

While Moses intentionally embedded politics—and injustice—into his constructions to achieve political ends, purposeful intent is not needed for technologies to have politics. Until the passing of the Americans with Disabilities Act in 1990, people with disabilities were excluded from many aspects of public life, because of neglect. Architects, designers, and engineers neglected to consider the needs of people with disabilities when creating buildings, transportation systems, and communication systems (Winner, 1986). Subsequently, these were and are being redesigned and rebuilt, illustrating that, with political will, even major technologies and technological systems can be reworked to remove injustices embedded within them.

Winner shows that technologies can be political in two ways. First, they can be inherently political, such as with nuclear power that requires a complex system to manage the hazardous, weaponizable substances needed to create it and produced by it. These inherently political technologies tend to be part of large, sophisticated technological systems that typically depend on centralized, hierarchical structures for management and control (Winner, 1986). Notably, many in the environmental movement are skeptical of this type of technological system, because it could undermine efforts to democratize society and science (Barry, 2012). This could potentially reduce the ability and tendency of technological systems to incorporate considerations of power, politics, culture and organization. Second, technologies can be political in cases where the invention, design, or arrangement of a technology or technical system is used to resolve an issue within a community, such as curb cuts and other accommodations for people with disabilities.

Like the examples provided by Winner, MCTs and TMCSs also can have politics. An MCT is usually adopted at personal cost for the common good, especially in fisheries. Fishers bear a personal financial and time cost of purchasing, maintaining, and using MCTs to protect aspects of the marine environment, such as marine mammals, sea turtles, and seabirds, for the common good of the public that treasures these animals. The common good is expressed through laws, rules, and regulations, which by their nature are political. Ensuring compliance to these regulations requires a political system of monitoring and enforcement (Jenkins, 2006; Eayrs, Pol, and Kraan, 2019). Furthermore, the general study and practice of marine conservation is often political and this can result in MCTs and TMCSs that are political intentionally or from lack of attentiveness to broader implications.

One instance of an MCT system that was political through lack of attentiveness was the use of circle hooks to prevent the bycatch of sea turtles in Ecuador (Jenkins et al., 2012b, 2012a). The designers of the circle hooks made them out of stainless steel to prevent rust and corrosion. Neither the designers of circle hooks nor of the system for introducing and promoting the use of circle hooks in Ecuador considered the political implications of steel in that country. Ecuador does not manufacture steel, so to protect its domestic markets there is a tariff on the importation of steel products. The need to import hooks meant that fishing gear suppliers would need to buy circle hooks in large quantities. This coupled with the tariffs made the costs of circle hooks too high for the suppliers and their customers, the fishers. In retrospect, from its inception the MCT system should have included a mechanism to negotiate with the Ecuadorian government for a tariff exemption for circle hooks. To avoid future problems like this one, it is critical that the evaluation of MCTs and TMCS goes beyond the obvious uses of a tool to include a "moral and political language" for evaluation. We need to understand the broader implications of the design of MCTs and arrangement of TMCSs (Winner, 1986).

MTCs and TMCSs can be inherently political or a way of settling a political issue. For example, with the passing of the Marine Mammal Protection Act and Endangered Species Act, the bycatch of dolphins and sea turtles became a political concern. In response, scientists, engineers, and fishers created MCTs like the Medina Panel and the turtle excluder device (TED) to help dolphins and sea turtles escape from fishing nets (Jenkins, 2007; Jenkins, 2010). These technologies settled much of the concern around dolphin and sea turtle bycatch. Subsequently, the United States passed a law requiring the use of TEDs in fisheries around the world that exported seafood to the United States. The technological system for implementing this law was large, complex, and political, because it was necessary for engaging and negotiating with other governments to implement a U.S. law in sovereign waters of foreign nations (Senko, Jenkins, and Peckham, 2017; Benaka, Cimo, and Jenkins, 2012). The technological system for international use of TEDs is an example of an inherently political MCT system.

Whether intentionally or unintentionally, societies choose structures for technologies that influence how people work, communicate, travel, and consume. Over the course of these decisions, different people are positioned differently and possess unequal degrees of power and information. In cases of inherently political technologies, the need to keep the large, complex technological system functioning is often prioritized over other moral or political concerns (Winner, 1986). For example, in the case of international use of TEDs, the United States initially recognized that different countries had different capacities for implementing and enforcing the use of TEDs. So, the United States gave more flexibility to some nations, especially developing nations, in how quickly and fully they became compliant with the regulations on TED use. This prompted other nations to sue the United States through the World Trade Organization, forcing the United States to treat every country the same, regardless of wealth or capacity (Brotmann, 1999; DeSombre and Barkin, 2002). The result was a MCT system that was equal but not equitable, because the full cost of complying with the regulations was more burdensome for developing countries.

Culture and organization

Technology has culture and organization. The practice component of technology houses many of the cultural and organizational elements. In comparison, the physical component may be more culturally neutral but not perfectly so. To be useful, technology must be a part of life. It must fit into a certain pattern of activities, lifestyles and values, such as practical uses, status symbols, required supporting technology and infrastructure, and required skills and expertise (Pacey, 1983).

To illustrate the idea that technology has culture, Arnold Pacey uses the example of snowmobiles. Snowmobiles became a commercial success in the 1970s as a recreational vehicle marketed to wealthy white people. The design of the machine was intended for brief periods of use in relatively balmy winter conditions, reflecting the purpose of recreation and the values of the target customer. However, indigenous people in artic regions saw the potential of the snowmobile as a work vehicle. To achieve this potential, they had to reinvent (i.e., undertake a process of modification and reengineering) the snowmobile to carry extra fuel for long trips, hold tools for emergency repairs, and have capacity to haul cargo and tow sleds. They also had to provide shelters to keep snowmobiles warm so the machines would start in the extreme cold. The history of the snowmobile is an example of how "a machine designed in response to the values of one culture needed a great deal of effort to suit the purposes of another" (Pacey, 1983).

Further evidence that conservation technologies change in different settings can be found in the impact of cultural and organizational changes on the technical components of conservation technologies. There is great diversity within the U.S. shrimp trawl fishery. As TEDs were implemented in various segments of the shrimp fishery and in various other fisheries, the structure of the device changed; for instance, the dimensions of the grid or the width of bar spacing. These changes did not happen spontaneously, nor were they purely related to mechanical or biological problem solving. These changes in the structure of the device precipitated from the changes in cultural and organizational setting. For example, bycatch of juvenile red snapper was a concern for some stakeholders, especially for the Florida shrimp fishery. This concern about red snapper was a value, an element of the cultural component, and specific to only a portion of the shrimp fishery. To address this value, the federal government scientists and Sea Grant extension agents worked to create TEDs that maximized the reduction of finfish bycatch. In other segments of the U.S. shrimp trawl fishery, especially along the East Coast, shrimpers wanted to keep some of the flatfish bycatch, because they could sell certain species, such as flounder, and increase their fishing profit (Jenkins, 2012). Once again, this value impacted the types of TEDs that gear researchers tried to develop.

In essence, changing the practice associated with an established conservation technology makes it a new technology and creates a new technological system. When the Australian shrimp trawl industry began using a U.S.-designed TED, it was vastly more effective in protecting sea turtles in Australia, because of the high level of willing adoption. The technical components of the TED were unchanged from that used by the U.S. industry, but the cultural and organizational components were very different (Tucker, Robins, and McPhee, 1997). The shrimp trawl fleet in Australia was smaller, the boats larger, and the profit per boats greater than in the United States. TEDs were a relatively smaller expense for the Australian shrimp trawl industry, so the fishing organizations supported their use. The success of TEDs in Australia is intrinsically tied to the values of the shrimpers and the activities of the organizations involved in the use of TEDs. These things, in fact, defined the application of TEDs in Australia; it is not a definition that could be transplanted somewhere else, and so TEDs became a different technology when used in Australia.

If the cultural and organizational components change, the conservation technology and technological systems would be different—even if the technical components remain unchanged. This means that a conservation technology becomes a new thing simply by being applied in a new setting. If you attempt to separate the cultural and organization components from the technology, or simply neglect them, then the

MCT or TMCS will likely have less or no conservation function, resulting in fewer or no conservation benefits (Jenkins, 2006).

Marine Social-Ecological-Technological Systems

I have shown how essential aspects of MCTs and TMCSs have been neglected, namely power, politics, culture, and organization. These are just a few prominent examples of human and societal dimensions of technology that must be considered in the creation, implementation, and use of MCTs and TMCSs. Unfortunately, in comparison to technological innovation, social, cultural, and political innovations are often undervalued to the point of being discriminated against in receiving government funding and resources (Barry, 2012; Bergman et al., 2010). Further, more fully exploring and incorporating these dimensions requires the expertise of marine social scientists. However, marine social science is often underutilized, marginalized, and disempowered within the field of marine conservation, which often gives supremacy and privilege to natural science (Aswani et al., 2018). A more interdisciplinary approach to the innovation of environmental technologies that includes social scientists, historians, philosophers, and humanists is needed. Moreover, we need a transdisciplinary approach that empowers end users, citizens, and stakeholders in the innovation and evaluation of environmental technologies (Barry, 2012). This can lead to bottom-up innovation by civil society and user-led innovation, which can result in contextually appropriate technologies that integrate social, cultural, and organizational concerns (Bergman et al., 2010; Ornetzeder and Rohracher, 2006).

The Social-Ecological Systems (SES) framework has sought to bridge these divides, especially between natural and social sciences. But some social scientists find this framework lacking, because of disciplinary differences in understandings of core concepts such as system boundaries, self-organization, function, and a failure to take up other important concepts like agency, conflict, knowledge, and power (Aswani et al., 2018). SES also relegates technology to a sub-element of the social component in the framework and is frequently overlooked, even though technology has great agency (Markolf et al., 2018; Ahlborg et al., 2019). Arguably, in the Anthropocene, the technologies we create are powerful actors that are shaping nature and society (Jasanoff, 2016; Ahlborg et al., 2019; Markolf et al., 2018). As a solution, some scholars have proposed combining of the fields of STS and SES (Ahlborg et al., 2019). This led to the Social-Ecological-Technological Systems (SETS) framework.

The SETS framework recognizes the agency of each component: social, ecological, and technological (Figure 14.3). The framework is predicated on an understanding that the components interact, are dependent upon, and have influence over each other. While the ecological system could rationally exist without the others, this is rarely the case in the Anthropocene. Humans impact nearly every corner of the natural world and increasingly must manage it to sustain it. The social system (people, societies, governance, livelihoods values etc.) is dependent on the ecological system to provide the resources for sustenance, shelter, recreation, and ecosystem services. The social system also leverages the technological system to its advantage to the extent that the social system is dependent on the technological system.

Within the SETS framework, scholars recognize technology as the frequent intermediary between the social and ecological components of the SETS (Markolf et al., 2018; Ahlborg et al., 2019). Technology is the means for obtaining and enhancing resources from the ecological system for the benefit and protection of the social system, for example energy systems or flood mitigation. Technology is also the conduit through which the social system most impacts the ecological system in the form of pollution, habitat degradation, and overexploitation. Further, most human interactions with the marine environment depend on technology.

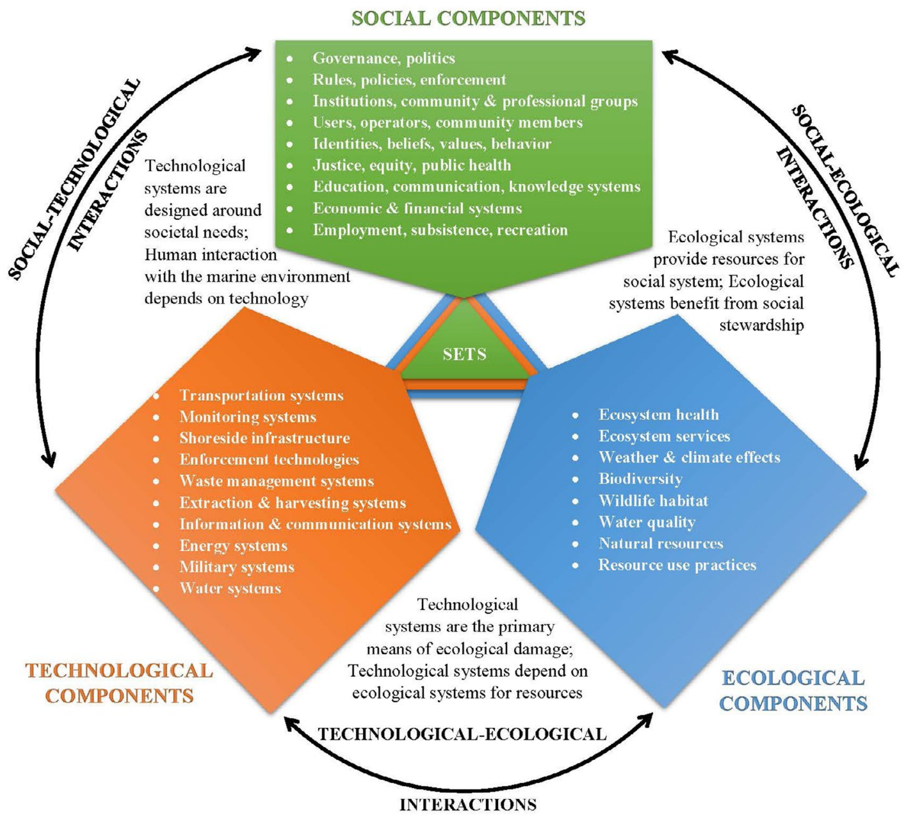


Fig. 14.3 Overview of social, ecological, and technological components and interactions of marine SETSs (adapted from Markolf et al., 2018).

The fields of urban ecology and infrastructure systems have begun to take up the SETS framework, but marine conservation has yet to do so (Grimm et al., 2017; Markolf et al., 2018; Ahlborg et al., 2019). The current approaches in marine conservation are inadequate for fully understanding the human and societal dimensions and implications of MCTs and TMCSs. If we are to advance in creating technologies and technological systems that help address conservation problems more holistically without creating additional problems, the SETS framework is a promising avenue to explore. It could serve as a boundary object around which researchers from various disciplines, including fields of social science, can contribute their necessary knowledge and expertise. It could also be used as a lens to more fully consider all relevant aspects of MCTs and TMCSs, such as politics, power, culture, and organization. This then could expand and democratize who creates MCTs and TMCSs. It could transform how we create them, through context-based approaches and re-envisioned goals (Ahlborg et al., 2019). As the Americans with Disabilities Act led to transportation and communication systems being redesigned and rebuilt to remove embedded injustices, we can begin to transform how we conceive of MCTs and TMCSs. Marine conservation can move towards technologies and technological systems that explicitly and inclusively engage with the social elements that are embedded with them and the social systems in which they are situated. And in so doing, we can design a conservation function that is better suited to the social context, and this in turn will allow us to reap more conservation benefits.

Conclusion

In this chapter, I presented a formal definition of marine conservation technology that ties the function of the technology to direct conservation outcomes. I also differentiated MCT from a technological marine conservation system. In a TMCS, the technology does not have an inherent conservation function, rather the conservation function is embedded in the organizational component of the technology practice. I discussed how inappropriate development and use of marine conservation technologies can lead to halfway technologies, techno-arrogance, and unintended consequences. I delved into how technology and technological systems can have power, politics, and culture. This awareness of the socio-cultural elements of technology is critical when governments are considering implementing MCTs that were developed elsewhere. Awareness of these elements are prerequisites for properly adapting technologies and technological systems to suite new contexts. I conclude by proposing the Social-Ecological-Technological Systems framework, so that the values and concerns of people, groups, and society are more effectively addressed in the creation and implementation of MCTs and TMCSs. The takeaway message is that MCTs and TMCSs are not just engineered mechanisms to address ecological problems, but they are also socio-cultural solutions. Any attempt to use technology to govern or manage a marine conservation issue must account for the social-cultural context, and a framework like SETS helps support the better integration of natural science, social science, engineering, and governance.

References

Ahlborg, Helene, Ilse Ruiz-Mercado, Sverker Molander, and Omar Masera. 2019. 'Bringing Technology into Social-Ecological Systems Research—Motivations for a Socio-Technical-Ecological Systems Approach', Sustainability, 11.

Aswani, S., X. Basurto, S. Ferse, M. Glaser, L. Campbell, J. E. Cinner, T. Dalton, L. D. Jenkins, M. L. Miller, R. Pollnac, I. Vaccaro, and P. Christie. 2018. 'Marine resource management and conservation in the Anthropocene', Environmental Conservation, 45: 192-202.

Barry, John. 2012. 'Bio-fuelling the Hummer? Transdisciplinary thoughts on techno-optimism and innovation in the transition from unsustainability.' in Edmond Byrne, Gerard Mullally and Colin Sage (eds.), Transdisciplinary Perspectives on Transitions to Sustainability (Routledge: Abingdon, UK).

Benaka, L.R., L. F. Cimo, and L.D.Jenkins. 2012. 'Bycatch Provisions in the Reauthorized Magnuson-Stevens Act. Marine Fisheries Review', 74: 1-12.

Berger-Tal, Oded, and José J. Lahoz-Monfort. 2018. 'Conservation technology: The next generation', Conservation Letters, 11: e12458.

Bergman, Noam, Nils Markusson, Peter Connor, Lucie Middlemiss, and Miriam Ricci. 2010. "Bottom-up, social innovation for addressing climate change." In Sussex Energy Group conference — ECEEE 2010. Brighton, UK.

Broadwater, Luke, and Scott Calvert. 2014. 'Secret audit found city speed cameras had high error rates', The Baltimore Sun, January 22, 2014.

Brotmann, M. 1999. 'The Clash between the WTO and the ESA: Drowning a Turtle to Eat a Shrimp', Pace Environmental Law Review, 16: 321-52.

Chopin, F., Inoue, Y., and He, P. 1996a. 'Future directions in conservation technology', Contrib. Res. Fish. Eng.: 59-67.

Chopin, F., Inoue, Y., and Matsushita, Y. 1996b. "Conservation harvesting technology: a perspective from Japan." In Proceedings of the solving bycatch workshop., 293-300.

Coe, J. M., Holts, D. B., Butler, R. W. . 1984. 'The tuna-porpoise problem: NMFS dolphin mortality reduction research, 1970-1981', Marine Fisheries Review, 46: 18-33.

DeSombre, Elizabeth R. , and J. Samuel Barkin. 2002. 'Turtles and Trade: The WTO's Acceptance of Environmental Trade Restrictions', Global Environmental Politics, 2: 12-18.

Eayrs, Stephen, Michael Pol, and Marloes Kraan. 2019. 'The myth of voluntary uptake of proven fishing gear: investigations into the challenges inspiring change in fisheries', ICES Journal of Marine Science, 76: 392-401.

Frazer, N. B. . 1992. 'Sea Turtle conservation and halfway technology', Conservation Biology, 6: 179-84.

Gardezi, Maaz, and J. Gordon Arbuckle. 2018. 'Techno-Optimism and Farmers' Attitudes Toward Climate Change Adaptation', Environment and Behavior, 52: 82-105.

Grimm, Nancy B., Steward T. A. Pickett, Rebecca L. Hale, and Mary L. Cadenasso. 2017. 'Does the ecological concept of disturbance have utility in urban social–ecological–technological systems?', Ecosystem Health and Sustainability, 3.

Huesemann, M. , and J.Huesemann. 2011. Techno-fix: Why Technology Won't Save Us or the Environment (New Society Publishers: Gabriola Island).

Jasanoff, Sheila. 2016. 'The Power of Technology.' in Sheila Jasanoff (ed.), The ethics of invention : technology and the human future (W.W. Norton & Company: New York).

Jenkins, L. D. 2007. 'Bycatch: interactional expertise, dolphins and the US tuna fishery', Stud. Hist. Phil. Sci., 38: 698-712.

Jenkins, L.D. . 2012. 'Reducing sea turtle bycatch in trawl nets: A history of NMFS turtle excluder device (TED) research', Marine Fisheries Review, 74: 26-44.

Jenkins, L.D., P. Christie, W.J. Nichols, N. Benitez, N. Gaibor, M. Mizrahi, and M.AViña. 2012a. "Improving International Adoption of Circle Hooks and TEDs: Lessons from Ecuador. ." In Thirty-first Annual Symposium on Sea Turtle Biology and Conservation, edited by T. Todd Jones and Bryan P. Wallace, 96.

———. 2012b. 'Understanding Factors Affecting International Adoption of Circle Hooks: A Progress Report. ', Bulletin of Marine Science, 88: 802.

Jenkins, Lekelia D. 2006. 'The invention and adoption of conservation technology to successfully reduce bycatch of protected marine species', Duke University.

———. 2010. 'The evolution of a trading zone: a case study of the turtle excluder device.', Studies in the History and Philosophy of Science, 41: 75-85.

Markolf, Samuel A., Mikhail V. Chester, Daniel A. Eisenberg, David M. Iwaniec, Cliff I. Davidson, Rae Zimmerman, Thaddeus R. Miller, Benjamin L. Ruddell, and Heejun Chang. 2018. 'Interdependent Infrastructure as Linked Social, Ecological, and Technological Systems (SETSs) to Address Lock-in and Enhance Resilience', Earth's Future, 6: 1638-59.

McDonald, G. G., C. Costello, J. Bone, R. B. Cabral, V. Farabee, T. Hochberg, D. Kroodsma, T. Mangin, K. C. Meng, and O. Zahn. 2021. 'Satellites can reveal global extent of forced labor in the world's fishing fleet', Proc Natl Acad Sci U S A, 118.

Minke-Martin, Vanessa. 2020. "RoboCop Sets Sail." In Hakai Magazine.

Nyman, Elizabeth. 2019. 'Techno-optimism and ocean governance: New trends in maritime monitoring', Marine Policy, 99: 30-33.

Ornetzeder, Michael, and Harald Rohracher. 2006. 'User-led innovations and participation processes: lessons from sustainable energy technologies', Energy Policy, 34: 138-50.

Owens, Brian. 2017. 'The big cull', Nature, 541: 148-50.

Pacey, Arnold. 1983. The Culture of Technology (The MIT Press: Cambridge).

Prado, J. . 1997. 'Technical measures for bycatch reduction', FAO Fisheries Report 547, suppl.: 25-44.

Rogers, E. M. 1995. Diffusion of Innovations (The Free Press: New York).

Sarewitz, Daniel, and Richard Nelson. 2008. 'Three Rules for Technological Fixes', Nature, 456: 871-72.

Scoville, Caleb, Melissa Chapman, Razvan Amironesei, and Carl Boettiger. 2021. 'Algorithmic conservation in a changing climate', Current Opinion in Environmental Sustainability, 51: 30-35.

Senko, J., L. D. Jenkins, and S. H. Peckham. 2017. 'At loggerheads over international bycatch: Initial effects of a unilaterally imposed bycatch reduction policy', Marine Policy, 76: 200-09.

Song, Andrew M., Joeri Scholtens, Kate Barclay, Simon R. Bush, Michael Fabinyi, Dedi S. Adhuri, and Milton Haughton. 2020. 'Collateral damage? Small-scale fisheries in the global fight against IUU fishing', Fish and Fisheries, 21: 831-43.

Swartz, W., A. M. Cisneros-Montemayor, G. G. Singh, P. Boutet, and Y. Ota. 2021. 'AIS-based profiling of fishing vessels falls short as a "proof of concept" for identifying forced labor at sea', Proc Natl Acad Sci U S A, 118.

Tucker, A. D., J. B. Robins, and D. P. McPhee. 1997. 'Adopting Turtle Excluder Devices in Australia and the United States: What Are the Differences in Technology Transfer, Promotion and Acceptance?', Coastal Management [Coast. Manage.], 12: 405-21.

Williams, J. 2007. 'Thinking as natural: Another look at human exemptionalism', Human Ecology Review, 14: 130-39.

Winner, Langdon. 1986. 'Do Artifacts Have Politics?' in Langdon Winner (ed.), The Whale and the Reactor: A Search for Limits in an Age of High Technology (University of Chicago Press: Chicago).

15. Indigenous leadership is essential to conservation: Examples from coastal British Columbia

Andrea J. Reid[1] *and Natalie C. Ban*

Positionality statement and preface

Dr. Andrea Reid is a Nisg̱a’a fisheries scientist and Dr. Natalie Ban is a Canadian settler marine conservation scientist. Dr. Andrea Reid carries a responsibility to hold place for Indigenous voices in the academe, especially within the natural sciences, where often no space is held, and she is supported and upheld in this work by colleague and ally, Dr. Natalie Ban. Together, we welcome readers to this space created to highlight the importance of Indigenous leadership in conservation for the benefit of all—people, place, and non-human relatives—today and in the future.

The topics covered throughout this chapter reflect the experiences gained by us through our respective research programs that are carried out in full and equal partnership with Indigenous Peoples in the place now known as British Columbia (BC), Canada. Given the uniqueness of Indigenous Nations in BC, Canada, and around the world, the commonalities and distinctions drawn here will not necessarily be relevant or reflective of the reality of all Indigenous Nations.

Territorial statement

This chapter was prepared from the territories of the Anishinaabeg [Ottawa], xʷməθkʷəy'əm (Musqueam), Sḵwx̱wú7mesh (Squamish) and səlil'ilw'ətaʔɬ (Tsleil-Waututh) [Vancouver], as well as the Lək'ʷəŋən (Lekwungen)-speaking Peoples, namely the Songhees, Esquimalt and W̱SÁNEĆ [Victoria]. We work to be respectful guests while visitors on these lands and waters and are committed to working in a good way with local Indigenous governments, communities, organizations, and individuals. Ultimately, it is our hope that we can work together towards building space for multiple ways of knowing in institutes of higher education that have long histories of Indigenous exclusion and injustice that fundamentally need to be recognized and redressed.

Indigenous-led conservation

The need for and value of Indigenous-led conservation is being increasingly recognized by the academic community and public alike. This is apparent across Canada and around the world where policymakers and various actors in dominant society have failed to control human activities driving climate change and habitat loss, while Indigenous lands and waters have been successfully stewarded and managed over millennia. In

1 The University of British Columbia, https://scholar.google.com/citations?user=WWdYxJgAAAAJ&hl=en&oi=sra

 https://doi.org/10.11647/OBP.0395.15

Canada, Brazil, and Australia, for instance, vertebrate biodiversity in Indigenous territories has been shown to equal or surpass that found within formally protected areas (Schuster et al., 2019). Far from the colonial idea of separating people from nature in order to preserve nature and the concept of the "pristine primitive" or "wilderness" free from human influence (Anderson et al., 2008), Indigenous approaches to conservation regularly place reciprocal people–place relationships (Figure 15.1) at the center of cultural and stewardship practices (Kimmerer, 2013). As such, Indigenous approaches to conservation ought to be centered in discussions around integrating science and governance.

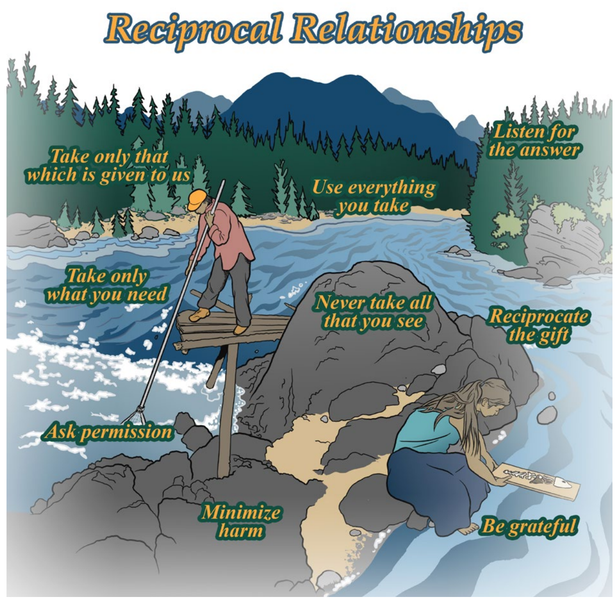


Fig. 15.1 Reciprocal relationships between Indigenous Peoples of the Pacific Northwest and Pacific salmon are linked to entire fishing ethics as depicted here that embody respect, reverence, responsibility and reciprocity. The practices highlighted here stem from Kimmerer's[33] conceptualizations of the "honorable harvest" in the realm of harvesting plants and medicines—all of which were found to exist in parallel in salmon-centered studies undertaken and described in Reid. These ideas were illustrated by Nicole Marie Burton.

Indigenous-led conservation supports and embraces Indigenous knowledge systems, sovereignty, and governance structures. The return to this mode of conserving flora and fauna can help countries meet their responsibilities to the United Nations Declaration on the Rights of Indigenous Peoples (UNDRIP, 2007) and respond to national calls to action such as those prescribed by the Truth and Reconciliation Commission of Canada (Government of Canada, 2015) or agreements reached to govern Crown-Indigenous relations (e.g., pre-Canadian Confederation: Peace and Friendship Treaties, 1725–1779; post-Canadian Confederation: Canada's Numbered Treaties, 1971–1921). In 2019, British Columbia (BC) became the first province in Canada to create legislation setting out a process to align provincial law with UNDRIP (SBC, 2019), creating the potential to transform what has historically been a relationship of tension and conflict to one possibly characterized by collaboration, respect, and real partnership. At this current time of political and racial awakening (e.g., Black Lives Matter, Land/Water/Fish Back), there is perhaps greater societal and institutional will to cultivate a more socially just reality for all people—ultimately creating space for Indigenous societies, values, and knowledge systems to govern (as they once did) lands and waters within their traditional territories.

A reckoning for conservation science

Over the last two decades, there has been a reckoning in conservation science that social sciences are vital to ensuring the uptake and efficacy of conservation measures (e.g., Bennett et al., 2017; Moon and Blackman, 2014; Pressey and Bottrill, 2009), and that conservation science needs to embrace socio-ecological systems thinking to meet the needs of both the environment and society at large (e.g., Ban et al., 2013; Miller et al., 2012). The interdisciplinary and transdisciplinary endeavor of conservation science started as a normative field seeking to protect biodiversity. Initially, conservation science focused on ecological and biological studies about species and their habitats to identify places and actions that recover and ensure persistence of biodiversity (Margules and Pressey, 2000; Soule, 1985). Since the formation of conservation science (initially termed 'conservation biology') in the 1980s, there has been an increasing realization that social science methodologies and insights are essential to achieving successful conservation (e.g., Jacobson and McDuff, 1998), and that the effects of conservation on people matter (e.g., Ban et al., 2019).

We believe conservation science is at the cusp of another reckoning: that socio-ecological approaches and methodologies are insufficient, and that embracing multiple ways of knowing—especially Indigenous ways of knowing—is essential if humanity is to protect biodiversity, and respect and uplift human rights. To date, conservation science has been guided by dominant approaches to academic (or "Western") science (Redford and Richter, 1999; Robinson, 2006; Soule, 1985). Recognizing the value of Indigenous knowledges[2] in conservation is not new (Gadgil et al., 1993). Indeed, there is a growing body of literature based on the importance of traditional ecological knowledge for conservation (e.g., Berkes, 2004; Drew, 2005; Moller et al., 2004). However, many conservation case studies to date have focused on utilitarian aspects of Indigenous knowledge systems by considering traditional ecological knowledge as a source of data to be incorporated into Western framings of conservation (Nadasdy, 2005), or by appropriating aspects of Indigenous cultures into conservation (e.g., taboos, Osterhoudt, 2018). Such approaches contribute to disempowering Indigenous Peoples by extracting their knowledge for external purposes (Thompson et al., 2020), and continue colonial legacies (Tran et al., 2020). Instead, we need conservation science that supports, uplifts, and respects Indigenous rights, stewardship, and knowledges, and thereby expands conservation beyond our current Western scientific approaches.

In this chapter, we draw upon our experiences in the place now known as BC, Canada, to showcase examples of Indigenous conservation and science. We emphasize historical and contemporary conservation leadership by Indigenous Peoples, highlight the history of active suppression of such practices by colonizers, and provide some guidance on how non-Indigenous scholars can be allies to Indigenous leadership in conservation.

Understanding Indigenous science and stewardship

Along with the reckoning of conservation science to recognize multiple ways of knowing comes the need to understand Indigenous science. While Indigenous science was only defined as a term in the literature in recent decades, coined by Colorado (1988), its existence is long-standing. It is generally accepted now as the scientific knowledge (see below) of "all peoples who, as participants in culture, are affected by the worldview and interests of their home community" (Snively and Corsiglia, 2016). According to the Worldwide Indigenous Science Network (wisn.org), Indigenous science "is a way of perceiving the world that is holistic, participatory, and in balance with the Earth's life support systems." While scientific knowledge is understood as deriving from a "systematic enterprise that gathers and condenses knowledge into testable laws and principles" (Wilson, 1999), the term 'science' is most often used only in reference to that which has roots in the philosophies of

2 'Peoples' and 'knowledges' are used in these pluralized forms here and throughout the chapter to reflect the plurality of knowledge systems (as well as cultures, identities, traditions, languages, and institutions) across distinct Indigenous Nations both in Canada and around the world.

Ancient Greece and the Renaissance, favouring reductionism and physical law (i.e., Western science). We believe conservation would improve by embracing systematic enterprises of gathering and condensing knowledge that stem from other worldviews and ways of knowing and being.

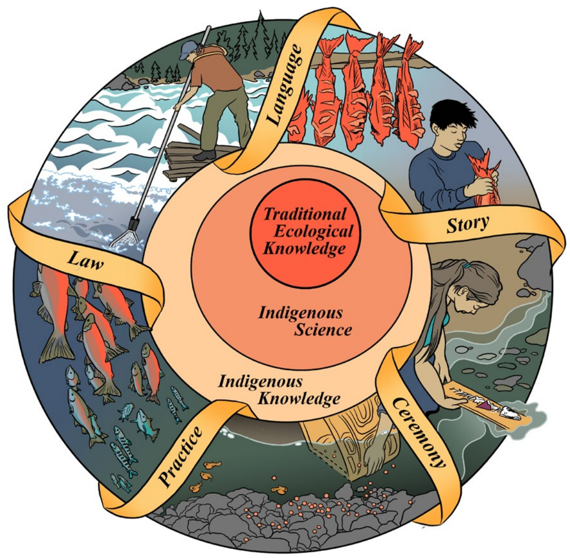


Fig. 15.2 Interrelationships between traditional ecological knowledge, Indigenous science, and Indigenous knowledge are depicted here using the symbology of the life cycle of Pacific salmon, starting with the salmon egg at the core of the image. The understandings and philosophies embedded in this center are carried through time—across generations—through language, story, ceremony, practice and law. Salmon and Salmon People not only co-exist in these settings but are interdependent with one another. These ideas were illustrated by Nicole Marie Burton.

In many cases across distinct Indigenous cultures, Indigenous science is holistic and inherently transdisciplinary (Berkes, 2017). It is contained within a much larger body of philosophies and understandings—Indigenous knowledge—and may pertain to, but is not limited to, human relationships with the environment (Figure 15.2). Languages and stories are the vessels that transmit these understandings through time and space, and they are carried across generations through ceremonies and practices that are guided and protected by laws. Another common feature is that so-called nature, which is not viewed in isolation or as separable from people, is understood as being alive, intelligent, and possessing inherent rights (Kimmerer, 2013) to which humans bear a great responsibility (pers. comm., Mi'kmaw Elder Dr. Albert Marshall). This is reflected, as one example, in the legal rights of personhood bestowed in 2017 on the Whanganui River in Aotearoa/New Zealand to align with Māori rights and cosmology (Magallanes, 2015). The non-human (or what many term the 'more-than-human') are positioned as relatives or gifts, depending on the context and culture, rather than as commodities or machinery subject to human control (Kimmerer, 2013). Indigenous science therefore stems from a vastly different foundation than Western science, which culminates in distinct approaches to understanding, interacting with and stewarding the natural world.

Indigenous stewardship practices are often steeped in highly reciprocal relationships, as noted above, in which, for example, it is not solely humans that need fish or land, but fish and land also need people—not only as harvesters or users, but as caretakers and stewards (e.g., Land Needs Guardians initiative; https://landneedsguardians.ca/). According to this view, humans are not strictly perceived as a destructive or consumptive force, but as beings with constructive or productive powers (Kimmerer, 2013). For Indigenous Peoples in coastal BC, determining who has access as well as responsibility to a specific place was—and remains so in certain areas—linked to the clan system and specific house groups. In these systems, chiefs and matriarchs provide(d) oversight over such matters, often in the context of house feasts or potlatches (gift-giving feasts, a crucial governance mechanism for coastal First Nations in the Pacific region) which were banned in Canada from 1885 to 1951 as part of national cultural assimilation processes (Cole and Chaikin, 1990). The potlatching system creates community accountability as well as serving as a "monitoring device" wherein the sustainability of harvest and stewardship practices are subject to repeated assessments by those who potlatch together (Weinstein, 1999).

Coastal Indigenous stewardship

Indigenous leadership has fostered successful marine stewardship and management in the past and at present through a multitude of strategies that play out differently across the world. Indeed, coastal Indigenous Peoples have been managing oceans and coastal regions for thousands of years (McKechnie, 2007; Turner and Berkes, 2006). Indigenous marine and coastal conservation, stewardship, and management practices (hereafter 'Indigenous marine conservation') vary globally to support local ecosystems, customs, and ongoing use (Ban and Frid, 2018; Berkes, 2017; Lepofsky and Caldwell, 2013). Some Indigenous marine conservation strategies are similar across diverse cultures, including customary tenure areas where rights of use, management, and access to the ocean belong to specific people or entities as discussed above; e.g., a village, chief, or family (Jupiter et al., 2014). Some Indigenous marine conservation approaches are increasingly well-recognized, whereas others are little known or misunderstood by Western science. Indeed, in some parts of the world—especially Oceania—Indigenous marine governance systems have been embraced, revitalized, and are forming the basis of contemporary ocean management (Johannes, 2002; Jupiter et al., 2014). In particular, customary marine tenure, often in the form of locally managed marine areas, are common forms of management of marine species and spaces (Cinner, 2005; Cinner et al., 2007; Lam, 1998; Winter et al., 2018). In other regions, especially where colonial forces actively undermine(d) Indigenous Peoples, Indigenous governance revitalization efforts are underway but recognition by colonial governments is slow (Ban and Frid, 2018; Bess, 2001; Eckert et al., 2018; Nursery-Bray and Jacobson, 2014; Nursery-Bray and Rist, 2009). Here we provide two examples of Indigenous marine and coastal stewardship by Indigenous Nations with whom we have partnered in our research: the Kitasoo Xai'xais Nation, and the Nisg̱a'a Nation (Figure 15.3).

Fig. 15.3 Map of the Great Bear Rainforest in British Columbia (BC), Canada, specifying the approximate contemporary location of villages of the Kitasoo/Xai'xais (Klemtu) and the Nisg̱a'a Nations (Gingolx, Laxgalts'ap, Gitwinksihlkw and Gitlaxt'aamiks). Map illustrated by Nicole Marie Burton.

Kitasoo Xai'xais Nation marine governance[3]

Kitasoo Xai'xais marine governance flows from the underlying principles of Kitasoo Xai'xais Law that guides all actions: respect, reciprocity, intergenerational knowledge, and interconnectedness. Everything—people, plants, animals, place—has the right to be respected in all forms, including physically and verbally. People have a responsibility to show gratitude and maintain reciprocity in relationships with the land, sea, natural environment, and other humans. This responsibility is commonly shown through territorial access and gift giving. Exchanges can be between people, animals, and supernatural beings. People should base decisions on learning from experience, including the experiences of past generations (Ban et al., 2019; Ban et al., 2020).

Exchanging intergenerational knowledge, especially through stories, is the main method to pass down past experiences, and thus language revitalization is very important. Storytelling often occurs on the land and water while harvesting and processing foods, allowing experiential learning to take place. Adaptive management is a scientific principle that ties in with the concept of 'listening to your elders'. Indeed, it is the responsibility of community members and especially elders to teach younger generations their knowledge. Furthermore, the natural environment and its species, including humans, are all connected. This oneness means that one small change can affect everything else. Thus, everyone has a responsibility to ensure intergenerational and interspecies equity by using species (non-human relatives, gifts) as food sustainably. Kitasoo Xai'xais marine governance implements these underlying principles through societal structures and practices. The ocean is a key place where knowledge is passed through generations and teaching takes place (Ban et al., 2019). However, because the oral tradition is not documented in the way that Western science acknowledges, it can be challenging to recognize or cite this knowledge within the Western scientific paradigm.

Historically as well as today, Kitasoo Xai'xais Hereditary Chiefs are stewards for the land and ocean territory held under their chief name to ensure their areas remain plentiful and healthy (Ban et al., 2020). Historically, families and lineages dispersed to seasonal spring, summer, and fall camps to use species as food—or what might be called 'resources' in Western science—to which their lineage have rights or to which individual families have rights. Everyone using more-than-human-beings as food has an obligation to steward areas. Historically, the responsibility rested on the Hereditary Chiefs to ensure conservation of species by making decisions around harvesting—for example by observing how many salmon are returning to a stream—including telling families when fish can be harvested without overfishing. Conservation was also practiced through the right to exclude people and regulate access to the territory, both in the short term to allow recovery of species, and in the long term through agreements with neighboring Nations. Although inevitably impacted by colonization, aspects of these practices and responsibilities continue today. Ongoing use of species as food through time was and continues to be a way of maintaining and displaying rights to resource claims. In other words, harvesting throughout the territory is a way to take care of places, and enables stewardship actions through ongoing observations carried out while fishing. Selective harvesting is paramount; examples include harvesting species that are abundant, selecting for specific characteristics and sizes (e.g., using fish traps and weirs; throwing back female crabs and small crabs) (Ban et al., 2020).

Kitasoo Xai'xais Hereditary Chiefs continue to use their longstanding authority to stand against non-Kitasoo Xai'xais decisions imposed upon them. For example, in the 2010s, the Kitasoo Xai'xais created their own herring management plan (2019), distinct from the federal government's plan, and Kitasoo Xai'xais members protested in an important bay in their territory (Kitasu Bay) against the commercial herring roe fishery, reacting to concerns about declines in herring populations and unsustainable contemporary fisheries management. After many years of protests, this has led to co-management of herring with Fisheries and

3 Ideas and some text for this section are taken or adapted from previously published sources of Ban et al., 2019 and Ban et al., 2020. All information in this chapter about the Kitasoo Xai'xais peoples comes from these two articles, co-authored with Doug Neasloss and Emma Wilson.

Oceans Canada in their territory. Similarly, when Fisheries and Oceans Canada (formerly the Department of Fisheries and Oceans; DFO)—the Canadian fisheries agency—disclosed new fishing regulations in Kitasu Bay for community members, the Chiefs told the fisheries officer that they did not accept them, and they went out to protest. Hereditary Chiefs have the right and obligation to stand up and provide a voice for people, plants, animals, and places. By this act of self-determination, Hereditary Chiefs and community members practiced their authority with regard to harvesting decisions, despite the Canadian government not fully recognizing their authority (Ban et al., 2020).

Nisga’a Nation salmon stewardship

Another example of historic and contemporary Indigenous coastal fisheries stewardship involves the Nisg̱a’a Nation and the Nass salmon fishery in northern BC. Here, the K̲’alii Aksim Lisims (Nisg̱a’a for Nass River; used hereafter) sits at the very base of the Alaska Panhandle, where it flows from its headwaters, Mag̱oonhl Lisims (Nass Lake), for approximately 380km into Saxwhl Lisims (the mouth of the Nass) and then out into the Portland Inlet and Pacific Ocean. With a drainage area of >20,000km^2 (Fissel et al., 2017), the Nass River is BC’s third largest salmon producer, supporting all five species of anadromous BC salmon—ya’a (Chinook; *O. tshawytscha*), k’a’it (chum; *O. keta*), eek (coho; *O. kisutch*), sdim̓oon (pink; *O. gorbuscha*), and miso’o (sockeye; *O. nerka*) (Connors et al., 2019; Nisga’a Fisheries and Wildlife 2019)—as well as milit (steelhead; *O. mykiss*) and saak (oolichan; *Thaleichthys pacificus*). Salmon are a key link between marine and coastal systems and epitomize how connected these systems are. Indeed, unlike the realities of Western governance, in many Indigenous worldviews—and indeed according to that of the Nisg̱a’a—the land, fresh water, and the sea are not seen as distinct, but rather as an interconnected and interdependent continuum. Conservation of coastal species such as salmon that provide a crucial link between systems is essential for healthy animals and people, plants, and places.

Through Ayuuk̲hl Nisg̱a’a (Nisg̱a’a Law) and Adaawak̲ (Nisg̱a’a oral histories, legends, and customs), the Nisg̱a’a way of life has been maintained for centuries, before European contact until today. Nisg̱a’a cosmology centers on harmony and balance between people and all of the other elements of the environment in which Nisg̱a’a live. Balance has been built into Nisg̱a’a life to provide for the wellbeing of whole families—the Nisg̱a’a way is said to be one of sharing within and among families, and of being closely related to the land (Dr. Joseph Arthur Gosnell, Sr. CC OBC, personal communication). As examples of this balance, and in line with the reciprocal salmon–people relationships described above (Figure 15.1), Nisg̱a’a fishing ethics often involve not playing with food (e.g., avoiding catch and release fishing), keeping what you catch (e.g., using selective fishing methods so there is no need for bycatch reduction strategies), only taking what you need and sharing what you have with family (Reid, 2020).

This system has provided for the ‘People of the Nass River’—the Nisg̱a’a—as well as neighboring Nations for millennia. The English name “Nass” likely derives from the neighboring Tlingit language, from their word “Naasí” meaning intestines or guts, in reference to the river’s large food capacity in its fish (Akrigg and Akrigg, 1997; Edwards, 2009). The Nass River served as a veritable food basket for many peoples and organisms pre-colonization (Scott, 2009), and it continues to do so today where it underpins a large commercial fishery (in Portland Inlet—Fisheries Management Area 3) and remains the lifeblood of Nisg̱a’a culture and commerce. In 2000, a landmark agreement between the governments of the Nisg̱a’a, BC, and Canada came into effect, creating BC’s first modern-day treaty (one of only four ratified treaties out of 200+ First Nations in the province), which involves a specific right to fish salmon. The Treaty sets out the Nisg̱a’a right to self-government (represented by the Nisg̱a’a Lisims Government) and the authority to manage lands and species (represented by the Nisg̱a’a Fisheries and Wildlife Department). Via the Joint Fisheries Management Committee, the Nisg̱a’a Lisims Government, BC, and Canada co-manage the Nass salmon fishery.

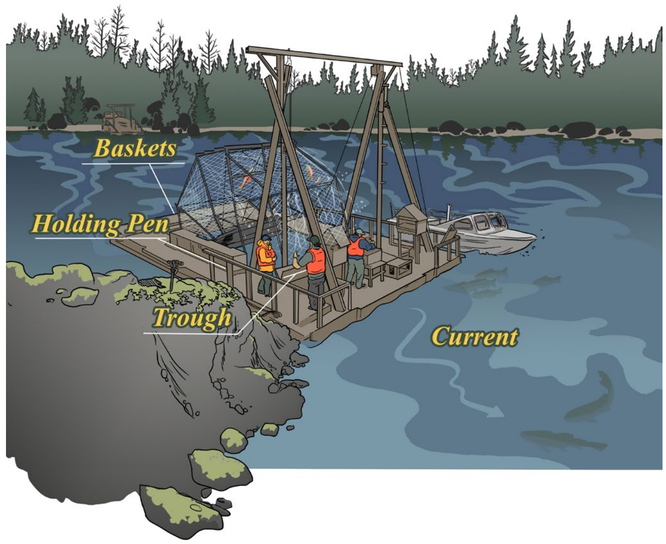


Fig. 15.4 A Nisg̱a’a fishwheel on the Nass River of BC. The current powers the rotational movement of baskets that gently catch and lift fish from the river and deposit them into submerged holding pens. Fish are held here until Nisg̱a’a Fisheries and Wildlife Department biologists and technicians transfer them by dipnet into a flow-through trough where they can be tagged, measured, and released unharmed or retained for food. These ideas were illustrated by Nicole Marie Burton.

Together, they now co-manage a renowned fisheries science program that has been used for Nass salmon assessment and management for over three decades (est. 1991). The Nisg̱a’a Fisheries Management Program uses fishwheels (Figure 15.4) and other technologies on the Nass River to monitor, mark, and collect data from fish swimming upstream, facilitating stock assessments on a variety of species throughout the Nass watershed. Between 1992 and 2018, an average of 1.5 million salmon have returned to the Nass River each year, with sockeye, pink, and coho salmon dominating returns (43%, 39%, and 13%, respectively) (Nisg̱a’a Fisheries and Wildlife, 2019). The goals of the program, according to the Nisg̱a’a Lisims Government, are to: “(1) determine the status of Nass stocks; (2) provide information required for better management; (3) determine run size, timing, and harvest rates; (4) determine factors limiting production; (5) provide training and employment for Nisg̱a’a people” and it does so by “(6) collaborating with researchers from around the world” (Nisg̱a’a Lisims Government, 2019). This management plan is guided by Nisg̱a’a knowledge systems and priorities, and hinges on deep respect for salmon and recognition that salmon and people are inter-reliant. Ayuuḵhl Nisga’a and Adaawaḵ detail Nisg̱a’a responsibilities to salmon, and describe what living in a good way in the Nass River Valley entails. The methods used to monitor salmon populations are thus positioned to minimize stress and harm to the fish, and endeavor to bring together the best tools available to improve collective understanding of salmon status and fate of the population (Reid, 2020). A lauded example is that of the fishwheel-based monitoring program, described as: “an ingenious fish-counting system in the Nass River that combines ancient Nisg̱a’a fishwheel technology with modern statistical methods of data analysis” (Corsiglia, and Snively, 1997). The Nisg̱a’a fishwheel program has enabled the continued monitoring of salmon escapement and harvest, the study of factors limiting salmon production, as well as the participation of Nisg̱a’a citizens in the active and continual stewardship of the Nass River (Nisg̱a’a Lisims Government, 2019).

Suppression of Indigenous conservation

That Indigenous conservation continues—as exemplified above with the Kitasoo Xai’xais and Nisg̱a’a cases—is evidence of the strength of Indigenous Peoples and worldviews in the face of historical colonial atrocities, including genocide (Truth and Reconciliation Commission of Canada, 2015). While these are examples that can and should be celebrated, it is undeniable that past and ongoing European colonization of coastal regions has resulted in rapid and drastic changes in Indigenous management practices (including within Kitasoo Xai'xais and Nisga'a Territories) because they were criminalized, dispossessed and/or restricted out of existence (Atlas et al., 2021). Indigenous Peoples were forcibly relocated, and the decline of many species due to commercialization contributed to reduced access to fish and a reduced ability to exercise self-determined management practices (Harris, 2002; Osterhoudt, 2018). In Canada, the Indian Act (enacted in 1876) and associated policies prohibited Indigenous cultural practices such as potlatches, banned Indigenous selective fishing methods such as fish traps and weirs (barriers across rivers that allowed for selective harvest of salmon) (Atlas et al., 2017), confined Indigenous Peoples inside reserves, and forcibly removed children from their families, cultures, and languages by sending them to residential schools (Harris, 2002; Truth and Reconciliation Commission, 2015). These past and ongoing policies severely diminished the wellbeing of entire Nations, disrupting Indigenous knowledges and management practices (Truth and Reconciliation Commission, 2015).

Indigenous Peoples created many strategies to continue their traditions and keep practicing their cultures despite these genocidal policies. For example, an important celebration for the Kitasoo Xai'xais—like many coastal First Nations—is the annual return of the salmon. When potlatches were banned, Kitasoo Xai'xais still celebrated this important event, but concealed it under the Salmon Queen and, later, the May Queen celebrations (i.e., ostensibly celebrating the Queen of England). A pole was erected in the 1950s next to the May Queen stand in the center of the community with a salmon on top. People risked arrest to continue this important celebration (Ban et al., 2019). Potlatches across many Nations were not extinguished but instead driven underground, and the languages and bodies of practice—while purposefully diminished in strength by the oppressors—have not altogether disappeared in all contexts, but in many cases, they are waiting to be reawakened through Indigenous resurgence and reassertion of Indigenous rights.

Supporting Indigenous conservation

To transform conservation science into a science and practice that embraces multiple ways of knowing, conservation scientists and practitioners must support the original caretakers of lands, fresh waters, and seas. This is not a question of 'allowing' Indigenous peoples to manage, steward, and govern their territories (a paternalistic attitude that has characterized much related policy and practice to date), but rather it is a matter of creating space and stepping aside so Indigenous leaders can indeed lead. Various guidance exists for scientists to support Indigenous Peoples in conservation and related fields in a good way (e.g., Adams et al., 2014; Ban et al., 2018), and here we highlight some of that pertinent guidance.

Supporting Indigenous Peoples in conservation entails that non-Indigenous conservationists should be allies. As examples, two Canadian-based organizations have provided guidance on what it means to be an effective ally. The Montreal Indigenous Community Network developed an online Indigenous Ally Toolkit[4] that includes three steps. First, be critical of any motivations, to ensure that engagement is not aimed simply at furthering one's own self-interest (e.g., publishing a paper), but rather genuinely supports Indigenous Peoples and voices (i.e., does the work at hand originate from Indigenous needs and interests?). Second, start learning. This is an ongoing process of education that then includes applying the lessons in meaningful ways, for example, to ask if one's privileged position can be used to listen, shift power dynamics, and further reconciliation. There must be efforts made to understand the impact of colonialism and to be willing to give up space and power so that it is available for others. Finally, act accordingly, including in communications with relevant Indigenous Peoples or organizations. We present these here, not as a panacea, but as an entry point for readers to begin to interrogate their own positionality and identify steps that lead to greater equitability in the research process

4 http://reseaumtlnetwork.com/wp-content/uploads/2019/04/Ally_March.pdf

and in the practice of conservation science.

Another ally toolkit, specifically aimed at supporting Indigenous-led conservation, was developed by the Indigenous Leadership Initiative[5]. It shares their hopes and expectations of how we—Indigenous and non-Indigenous people—can collaborate. Very briefly, the guidance includes: trust Indigenous leadership; create space for Indigenous voices; understand the connection between land and nationhood; recognize Indigenous science; participate with interest; focus on solutions; share stories with respect; continue to learn; and influence your peers. We cannot stress enough the importance of taking guidance from leaders in this space, and of advocating for transparent discussions with Indigenous partners in research and conservation science to learn what each of these specific recommendations look like in their individualized context (i.e., what is the connection to land here and what does it mean? What is the core problem and what would solutions look like?). A promising new toolkit was recently developed by the Kitasoo Xai'xais Nation and research partners to provide an 'open source' and generalizable research guide to inform equitable applied research practices (available for download here: https://klemtu.com/research-guide/).

Important ethical guidance around data ownership and intellectual property also exists for research with Indigenous Peoples, which is especially important for conservation scientists conducting research in Indigenous territories and in partnership with Indigenous Peoples. In particular, the principles of ownership, control, access, and possession (OCAP® principles[6]) are a set of standards for how First Nations data should be collected, used, or shared. Ownership means that First Nations own their cultural knowledge, data, and information; control emphasizes that First Nations can control all aspects of research and information; access means that the data themselves have to be shared with First Nations; and possession refers to First Nations having physical control of data. These are very similar to the CARE principles for Indigenous data governance: Collective benefit; Authority to Control; Responsibility; and Ethics[7] (GIDA, 2019), and fit within a broader and growing movement and literature base on the subject of Indigenous data sovereignty (Walter et al., 2021).

Furthermore, the concept of *Etuaptmumk* (meaning 'the gift of multiple perspectives' in Mi'kmaw) or 'Two-Eyed Seeing' might be helpful for non-Indigenous and Indigenous scientists alike in embracing knowledge pluralism in conservation. The relevance of *Etuaptmumk* was recently articulated for fisheries research and management (Reid et al., 2021), and similarly applies to conservation. As stated in that paper, this teaching "embraces 'learning to see from one eye with the strengths of Indigenous knowledges and ways of knowing, and from the other eye with the strengths of mainstream knowledges and ways of knowing, and to use both these eyes together, for the benefit of all,' as envisaged by Elder Dr. Albert Marshall" (Reid et al., 2021). *Etuaptmumk* provides a pathway whereby Indigenous knowledge systems can be paired with, not subsumed by, Western scientific insights.

We strongly encourage readers to engage with these references and guidelines as but a first step in the learning process of how to support Indigenous conservation and create space for multiple ways of knowing in both research and management. Working in this space in a good way requires, amongst other things, being open to learning and self-reflection, while building relationships and trust with Indigenous partners, and being able and willing to stand aside to let Indigenous leaders lead. Guidelines such as these are just that, guidelines, and they need to be adapted to the needs and interests of Indigenous communities and partners, which will surely differ across contexts.

5 https://www.ilinationhood.ca/publications/how-to-be-an-ally-of-indigenous-led-conservation
6 https://fnigc.ca/ocap
7 https://www.gida-global.org/care

Conclusion

We demonstrated in this chapter that, in order to transform conservation science, we—all conservation scientists—must recognize that to uplift Indigenous conservation means supporting Indigenous Peoples in their conservation leadership. The examples we highlight are just two of many Indigenous Peoples leading stewardship in their territories. They are illustrative of the many and diverse forms of conservation that exist, and that all conservation scientists should uphold, including as part of integrating science and governance. For example, the holistic, intergenerational approach of the Kitasoo Xai'xais people has enabled them to stand up for their beliefs when federal management has endangered their territory. The Nisg̱a'a Nation provides one example of how ancient knowledge can be paired with modern techniques in the maintenance of respectful relations with salmon. These positive examples exist because of the many skilled and tenacious Indigenous leaders who continue to fight for their holistic view of the land, fresh waters, and sea. These examples showcase some of the many reasons why Indigenous knowledges, but particularly Indigenous knowledge systems, are so essential for conservation. In our view, it is not possible to support Indigenous conservation without a fundamental shift in the purpose and process of mainstream conservation science.

References

Adams, M.S., Carpenter, J., Housty, J.A., Neasloss, D., Paquet, P.C., Service, C., Walkus, J. and Darimont, C.T. (2014). Toward increased engagement between academic and indigenous community partners in ecological research. *Ecology and Society*, *19*(3).

Akrigg, G.P.V. and Akrigg, H.B. (1997). *British Columbia place names*. 3rd edn. Vancouver, British Columbia. UBC Press.

Anderson, C.N., Hsieh, C.H., Sandin, S.A., Hewitt, R., Hollowed, A., Beddington, J., May, R.M. and Sugihara, G. (2008). Why fishing magnifies fluctuations in fish abundance. *Nature*, *452*(7189), pp.835-839.

Atlas, W.I., Ban, N.C., Moore, J.W., Tuohy, A.M., Greening, S., Reid, A.J., Morven, N., White, E., Housty, W.G., Housty, J.A. and Service, C.N. (2021). Indigenous systems of management for culturally and ecologically resilient Pacific salmon (Oncorhynchus spp.) fisheries. *BioScience*, *71*(2), pp.186-204.

Atlas, W.I., Housty, W.G., Béliveau, A., DeRoy, B., Callegari, G., Reid, M. and Moore, J.W. (2017). Ancient fish weir technology for modern stewardship: lessons from community-based salmon monitoring. *Ecosystem Health and Sustainability*, *3*(6), p.1341284.

Ban, N.C., Wilson, E. and Neasloss, D. (2019). Strong historical and ongoing indigenous marine governance in the northeast Pacific Ocean: a case study of the Kitasoo Xai'xais First Nation. *Ecology and Society*, *24*(4). https://pdfs.semanticscholar.org/7f66/a1755f27f9aee8babf54d30ce5d08544726b.pdf

Ban, N.C. and Frid, A. (2018). Indigenous peoples' rights and marine protected areas. *Marine Policy*, *87*, pp.180-185. https://www.sciencedirect.com/science/article/pii/S0308597X17305547?casa_token=5o6ivd2LHuEAAAAA:RzCkpxtThzhQU3d_tGxZPumxXYCbxKrSLgby0vrWbhrFAqgGyWa6ekHHstv2b5-9X3A1wIjKVw

Ban, N.C., Frid, A., Reid, M., Edgar, B., Shaw, D. and Siwallace, P. (2018). Incorporate Indigenous perspectives for impactful research and effective management. *Nature ecology & evolution*, *2*(11), pp.1680-1683.

Ban, N.C., Gurney, G.G., Marshall, N.A., Whitney, C.K., Mills, M., Gelcich, S., Bennett, N.J., Meehan, M.C., Butler, C., Ban, S. and Tran, T.C. (2019). Well-being outcomes of marine protected areas. *Nature Sustainability*, *2*(6), pp.524-532.

Ban, N.C., Mills, M., Tam, J., Hicks, C.C., Klain, S., Stoeckl, N., Bottrill, M.C., Levine, J., Pressey, R.L., Satterfield, T. and Chan, K.M. (2013). A social–ecological approach to conservation planning: embedding social considerations. *Frontiers in Ecology and the Environment*, *11*(4), pp.194-202.

Ban, N.C., Wilson, E. and Neasloss, D. (2020). Historical and contemporary indigenous marine conservation strategies in the North Pacific. *Conservation Biology*, *34*(1), pp.5-14.

Bennett, N.J., Roth, R., Klain, S.C., Chan, K., Christie, P., Clark, D.A., Cullman, G., Curran, D., Durbin, T.J., Epstein, G. and Greenberg, A. (2017). Conservation social science: Understanding and integrating human dimensions to improve conservation. *biological conservation*, *205*, pp.93-108.

Berkes, F. (2004). Rethinking community-based conservation. *Conservation biology*, *18*(3), pp.621-630.

Berkes, F. (2017). Sacred Ecology (4th ed.). Routledge. New York. https://doi.org/10.4324/9781315114644

Bess, R. (2001). New Zealand's indigenous people and their claims to fisheries resources. *Marine Policy*, *25*(1), pp.23-32.

British Columbia. (2019). Declaration on the Rights of Indigenous Peoples Act, Bill 41, (SBC 2019). Chapter 44. https://canlii.ca/t/544c3

Cinner, J.E. (2005). Socioeconomic factors influencing customary marine tenure in the Indo-Pacific. *Ecology and society*, *10*(1).

Cinner, J.E., Sutton, S.G. and Bond, T.G. (2007). Socioeconomic thresholds that affect use of customary fisheries management tools. *Conservation Biology*, *21*(6), pp.1603-1611.

Cole, D. and Chaikin, I. (1990). An iron hand upon the people: the law against the Potlatch on the Northwest Coast. Douglas & McIntyre: Vancouver.

Colorado, P. (1988). Bridging native and western science. *Convergence*, *21*(2), p.49.

Connors, K., Hertz, E., Jones, E., Honka, L., Kellock, K., and Alexander, R. (2019). The Nass Region: Snapshots of Salmon Population Status. The Pacific Salmon Foundation. Vancouver, British Columbia.

Corsiglia, J. and Snively, G. (1997). Knowing home: NisGa'a traditional knowledge and wisdom improve environmental decision making. *Alternatives Journal*, *23*(3), pp.22-25.

Drew, J.A. (2005). Use of traditional ecological knowledge in marine conservation. *Conservation biology*, *19*(4), pp.1286-1293.

Eckert, L.E., Ban, N.C., Tallio, S.C. and Turner, N. (2018). Linking marine conservation and Indigenous cultural revitalization. *Ecology and Society*, *23*(4). https://doi.org/10.5751/ES-10417-230423.

Edwards, K. (2009). *Dictionary of Tlingit*. Sealaska Heritage Institute.

Fissel, D.B., Lin, Y., Scoon, A., Lim, J., Brown, L. and Clouston, R. (2017). The variability of the sediment plume and ocean circulation features of the Nass River Estuary, British Columbia. *Satellite Oceanography and Meteorology*, *2*(2).

Gadgil, M., Berkes, F. and Folke, C. (1993). Indigenous knowledge for biodiversity conservation. *Ambio*, pp.151-156.

Global Indigenous Data Alliance (GIDA) (2019). Care Principles for Indigenous Data Governance. *Research Data Alliance International Indigenous Data Sovereignty Interest Group*, GIDA-global.org

Government of Canada. (2015). Honouring the Truth, Reconciling for the Future: Summary of the Final Report of the Truth and Reconciliation Commission of Canada.

Harris, C. (2002). Making native space: Colonialism, resistance, and reserves in British Columbia. University of British Columbia Press.

Jacobson, S.K. and McDuff, M.D. (1998). Training idiot savants: the lack of human dimensions in conservation biology. Conservation Biology, 12(2), pp.263-267.

Johannes, R.E. (2002). The renaissance of community-based marine resource management in Oceania. *Annual review of Ecology and Systematics*, pp.317-340.

Jupiter, S.D., Cohen, P.J., Weeks, R., Tawake, A. and Govan, H. (2014). Locally-managed marine areas: multiple objectives and diverse strategies. *Pacific Conservation Biology*, *20*(2), pp.165-179.

Kimmerer, R.W. (2013). Braiding sweetgrass: Indigenous wisdom, scientific knowledge and the teachings of plants. Milkweed editions.

Kitasoo Xai'xais First Nation. (2019). Kitasoo Xai'xais Management Plan for Pacific Herring. Kitasoo Xai'xais *Integrated Resource Authority*. Klemtu, British Columbia, Canada.

Lam, M. (1998). Consideration of customary marine tenure system in the establishment of marine protected areas in the South Pacific. *Ocean & Coastal Management*, *39*(1-2), pp.97-104.

Lepofsky, D. and Caldwell, M. (2013). Indigenous marine resource management on the Northwest Coast of North America. *Ecological Processes*, *2*(1), pp.1-12.

Magallanes, C.J.I. (2015). Maori cultural rights in Aotearoa New Zealand: Protecting the cosmology that protects the environment. *Widener L. Rev.*, *21*, p.273.

Margules, C.R., and Pressey, R.L. (2000). Systematic conservation planning. *Nature*, *405*(6783), pp.243-253.

McKechnie, I. (2007). Investigating the complexities of sustainable fishing at a prehistoric village on western Vancouver Island, British Columbia, Canada. *Journal for Nature Conservation*, *15*(3), pp.208-222.

Miller, B.W., Caplow, S.C. and Leslie, P.W. (2012). Feedbacks between conservation and social-ecological systems. *Conservation Biology*, *26*(2), pp.218-227.

Moller, H., Berkes, F., Lyver, P.O.B. and Kislalioglu, M. (2004). Combining science and traditional ecological knowledge: monitoring populations for co-management. *Ecology and society*, *9*(3).

Moon, K. and Blackman, D. (2014). A guide to understanding social science research for natural scientists. *Conservation biology*, *28*(5), pp.1167-1177.

Nadasdy, P. (2005). The anti-politics of TEK: the institutionalization of co-management discourse and practice. *Anthropologica*, pp.215-232.

Nisga'a Lisims Government (2019). Fisheries Management. https://www.nisgaanation.ca/fisheries-management

Nisga'a Fisheries and Wildlife. (2019). Nass River Salmon Stock Assessment Update. pp. 34.

Nursey-Bray, M. and Jacobson, C. (2014). 'Which way?': The contribution of Indigenous marine governance. *Australian Journal of Maritime & Ocean Affairs*, *6*(1), pp.27-40.

Nursey-Bray, M. and Rist, P. (2009). Co-management and protected area management: Achieving effective management of a contested site, lessons from the Great Barrier Reef World Heritage Area (GBRWHA). *Marine Policy*, *33*(1), pp.118-127.

Ommer, R.E. (2007). *Coasts under stress: restructuring and social-ecological health*. McGill-Queen's Press-MQUP.

Osterhoudt, S.R. (2018). Community Conservation and the (Mis) appropriation of Taboo. *Development and change*, *49*(5), pp.1248-1267.

Pressey, R.L. and Bottrill, M.C. (2009). Approaches to landscape-and seascape-scale conservation planning: convergence, contrasts and challenges. *Oryx*, *43*(4), pp.464-475.

Redford, K.H. and Richter, B.D. (1999). Conservation of biodiversity in a world of use. *Conservation biology*, *13*(6), pp.1246-1256.

Reid, A.J. (2020). *Fish–People–Place: interweaving knowledges to elucidate Pacific salmon fate* (Doctoral dissertation, Carleton University).

Reid, A.J., Eckert, L.E., Lane, J.F., Young, N., Hinch, S.G., Darimont, C.T., Cooke, S.J., Ban, N.C. and Marshall, A. (2021). "Two-Eyed Seeing": An Indigenous framework to transform fisheries research and management. *Fish and Fisheries*, *22*(2), pp.243-261.

Robinson, J.G. (2006). Conservation biology and real-world conservation. *Conservation Biology*, *20*(3), pp.658-669.

Schuster, R., Germain, R.R., Bennett, J.R., Reo, N.J. and Arcese, P. (2019). Vertebrate biodiversity on indigenous-managed lands in Australia, Brazil, and Canada equals that in protected areas. *Environmental Science & Policy*, *101*, pp.1-6.

Scott, A. (2009). *The Encyclopedia of Raincoast Place Names: A Complete Reference to Coastal British Columbia*. Harbour Publishing.

Snively, G. and Corsiglia, J. (2016). Indigenous science: Proven, practical and timeless. *Knowing Home: Braiding Indigenous Science with Western Science (Book 1); Snively, G., Williams, WL, Eds*, pp.89-104.

Soulé, M.E. (1985). What is conservation biology?. *BioScience*, *35*(11), pp.727-734.

Thompson, K.L., Lantz, T. and Ban, N. (2020). A review of Indigenous knowledge and participation in environmental monitoring. *Ecology and Society*, *25*(2).

Tran, T.C., Ban, N.C. and Bhattacharyya, J. (2020). A review of successes, challenges, and lessons from Indigenous protected and conserved areas. *Biological Conservation*, *241*, p.108271.

Truth and Reconciliation Commission of Canada. (2015). *Honouring the truth, reconciling for the future: Summary of the final report of the Truth and Reconciliation Commission of Canada*. Truth and Reconciliation Commission of Canada.

Turner, N.J. and Berkes, F. (2006). Coming to understanding: developing conservation through incremental learning in the Pacific Northwest. *Human ecology*, *34*(4), pp.495-513.

UN General Assembly. (2007). United Nations Declaration on the Rights of Indigenous Peoples: resolution/adopted by the General Assembly, 2 October 2007, A/RES/61/295. https://www.refworld.org/docid/471355a82.html.

Walter, M., Kukutai, T., Carroll, S.R. and Rodriguez-Lonebear, D. (2021). *Indigenous data sovereignty and policy* (p. 244). Taylor & Francis.

Weinstein, M.S. (1999). Pieces of the puzzle: solutions for community-based fisheries management from native Canadians, Japanese cooperatives, and common property researchers. *Georgetown International Environmental Law Review*, *12*, pp.375.

Wilson, E.O. (1999). *Consilience: The Unity of Knowledge* (Vol. 31). Vintage Books, pp.382.

Winter, K.B., Beamer, K., Vaughan, M.B., Friedlander, A.M., Kido, M.H., Whitehead, A.N., Akutagawa, M.K., Kurashima, N., Lucas, M.P. and Nyberg, B. (2018). The moku system: managing biocultural resources for abundance within social-ecological regions in Hawai'i. *Sustainability*, *10*(10), p.3554.

16. A conservation practitioner's guide to using a human-rights-based approach: applications in small-scale fisheries

Elena M. Finkbeiner,[1] *Juno Fitzpatrick, Lily Z. Zhao, Gabrielle Lout, Marissa Anne S. Miller, Juan Carlos Jeri, and John N. Kittinger*

"Realizing the rights of fishing communities is not an option. It is an obligation."
—Chandrika Sharma

Following major concerns about the environmental sustainability of seafood production, over the last several decades, governments, non-governmental organizations (NGOs), researchers, and industry have invested significant resources in trying to reduce overfishing, minimize the environmental impacts of fishing and aquaculture activity, and build supply-chain incentives and consumer awareness around seafood sustainability.

Yet, many of these science, management, and advocacy efforts have largely ignored the other side of the equation—the human story behind seafood production. Hundreds of millions of people worldwide depend on the seafood sector for their livelihood, half of whom are women, and billions of people rely on fish as their primary source of protein and micronutrients. For many, fishing is much more than food and livelihood security—it is an identity, a culture, and a way of life.

There is now mounting evidence and increasing recognition that environmental sustainability efforts have been stunted or undermined by a lack of attention to the underlying social dimension in the sector, and worse, human wellbeing is at stake; the people employed in fisheries face human rights and labor abuses, chronic poverty, and systemic inequality. While fishworkers, civil society organizations, and researchers have worked to elevate these issues for decades, recent investigative journalism has brought the pervasiveness and urgency of these issues to the public eye, with continually emerging instances of human rights violations in fisheries around the world (Levitt, 2016; Marschke and Vandergeest, 2016; Kittinger et al., 2017; Greenpeace, 2018).

We can no longer afford to ignore the human side behind seafood production. The need to use a 'human-rights-based approach' (HRBA) to fisheries management and conservation has never been more clear, yet coherent guidance for practitioners is still lacking. Recent scholarship has pointed to the important role of practitioners at international conservation NGOs working at the nexus of human rights and fisheries sustainability, given their geographic reach across countries and fishing communities and strong connections with governments and powerful market players (Singleton et al., 2017; Smallhorn-West et al., 2023). Furthermore, many of the international conservation NGOs have formally committed to respecting and protecting human rights, following decades of conservation malpractice that unintentionally worked to undermine community

1 Coastal Community Fisheries, Conservation International, https://scholar.google.com/citations?user=dE7_zzEAAAAJ&hl=en&oi=sra

 https://doi.org/10.11647/OBP.0395.16

wellbeing and human rights (CIHR, 2010). Well-intentioned fisheries management and conservation efforts that do not consider the social inequities and power differentials occurring in global seafood value chains can further exacerbate these issues, in contravention of a "do-no-harm" approach (Anderson, 1999). There is a strong need to clarify the roles and responsibilities of fisheries managers and practitioners in accordance with do-no-harm principles, and in the progressive realization of human rights established in internationally agreed-upon frameworks.

This chapter aims to provide definitions of and guidance on using an HRBA for conservation practitioners (who are, in some cases, *de facto* managers) working with fishing communities, on fisheries governance and policy, or in seafood value chains. We will begin by clarifying the roles and responsibilities of states, supply-chain actors, and international conservation NGOs, under primary and internationally agreed-upon human rights frameworks. Next, we will discuss the emergence of an HRBA in development practice and shortly thereafter in fisheries management and conservation, namely through the FAO Voluntary Guidelines for Securing Sustainable Small-Scale Fisheries in the Context of Food Security and Poverty Eradication (FAO, 2015). We will then describe an emerging movement to address human rights abuses in fisheries conservation through seafood value-chain interventions and discuss the gaps inherent in this approach with the latter. We will end by basing our recommendations on these perceived gaps on HRBAs in fisheries, targeted specifically for conservation practitioners either working with fishing communities, in governance and policy, with supply-chain actors, or in influencing funding/financing spheres.

Human rights obligations for actors in the fishing sector

According to international human rights treaties, customary law, and the primary instruments governing the protection of human rights,[2] nation states are designated as the primary duty-bearers in upholding human rights, and are tasked with three obligations: respect, protect, and fulfill. Its obligation to respect implies that the duty bearer itself must not infringe upon human rights. The obligation to protect characterizes the duty bearer's role in ensuring third parties (such as businesses) do not infringe upon human rights. Finally, the obligation to fulfill sets forth the task of a duty bearer to actively promote the positive realization of human rights. Whereas respect of and protection for human rights are regarded as immediate obligations of the duty bearer, the fulfillment of human rights can be achieved through progressive realization over time.

It is important to highlight the relevance and importance of all human rights in fisheries, noting that human rights are universal, inalienable, indivisible, and interdependent. Yet, there is a tendency in fisheries interventions to perpetuate a false dichotomy and prioritization between Civil and Political (CP) rights, and Economic, Social, and Cultural (ESC) rights (Allison et al., 2011; Teh et al., 2019; Finkbeiner et al., 2021). Example violations of CP rights in fisheries are when workers aboard a fishing vessel are discriminated against, treated inhumanely, held against their will, or do not have formal rights to organize. However, human trafficking and deplorable labor conditions are not the only violations of human rights and may be accompanied by other serious, but less elevated social issues. For example, when foreign fleets overfish in the Exclusive Economic Zone of developing countries, such that fishing as a livelihood or way of life is no longer economically viable, or communities' rights to food security are undermined, this is a violation of ESC rights. Where CP rights violations are more easily litigated by application of international conventions and national criminal, maritime, and labor laws, ESC rights violations are often perceived as systemic issues where it is much harder to determine who is accountable and how remediation occurs (Teh et al., 2019). Furthermore, countries such as the United States

2 Adopted in 1948, the Universal Declaration of Human Rights (UDHR) continues to be the authority of all international human rights law—establishing the building blocks for civil and political, economic, social, and cultural rights, freedoms, conventions, treaties, and legal instruments. The UDHR, together with the two covenants—the International Covenant for Civil and Political Rights (ICCPR, 1966), and the International Covenant for Economic, Social and Cultural Rights (ICESCR, 1966) are the foundations of the International Bill of Rights.

of America have yet to ratify the International Covenant for Economic Social and Cultural Rights (ICESCR, 1966) due to the perception that ESC rights are desirable social goals, but not human rights (Svadlenak-Gomez, 2007). In addition to CP and ESC rights, collective rights are critically important to uphold in fisheries, such as Indigenous Peoples' rights to lands, territories, and resources (UNDRIP, 2007).

Fig. 16.1 Human rights violations in fisheries.

States also have constitutional obligations to the International Labor Organization's (ILO) Core Conventions, which establish fundamental principles of rights at work through a tripartite process (i.e., involving states, workers' organizations, and employers' organizations) (ILO, 1978). These Core Conventions include freedom of association and the effective recognition of the right to collective bargaining, the elimination of all forms of forced or compulsory labor, the effective abolition of child labor, and the elimination of discrimination in respect of employment and occupation (ILO, 2022).

Obligations of businesses are further clarified with the adoption of the United Nations Guiding Principles on Businesses and Human Rights (UNGP, 2011). The UNGPs set expectations of states and businesses about how to prevent and address negative impacts on human rights, and provide guidance on operationalizing existing international human rights standards. Businesses are obliged to respect human rights and provide remedy in the event that they contribute to human rights violations. The UNGPs further outline steps for businesses to comply with this international standard: 1) make a public commitment to respect human rights; 2) identify, prevent, mitigate, and account for damage caused to human rights; and 3) disclose procedures for remedying negative consequences on human rights that they cause. Protecting human rights against business-related abuse is expected of all states, and, in most cases, is a legal obligation through their ratification of legally binding international human rights treaties. At the same time, the UNGPs state:

> The responsibility to respect human rights is a global standard of expected conduct for all business enterprises wherever they operate. It exists independently of States' abilities and/or willingness to fulfill their own human rights obligations and does not diminish those obligations. And it exists over and above compliance with national laws and regulations protecting human rights" (UNGP, 2011, p. 13).

In addition to the role of civil society and international organizations as a "moral duty bearer" (Boesen and Martin, 2007), some conservation NGOs have committed more formally to the obligations of duty bearer

(Singleton et al., 2017). Following years of concerning practice by conservation NGOs with respect to human rights (Chapin, 2004; Brockington and Igoe, 2006; Agrawal and Redford, 2009; Smallhorn-West et al., 2023), the Conservation and Human Rights Framework was created to set forth agreed-upon principles that seek to uphold human rights in conservation, including: respect human rights, promote human rights within conservation programs, protect the vulnerable, and encourage good governance. This framework was adopted in 2010 by the Conservation Initiative on Human Rights (CIHR, 2010), a consortium of international conservation organizations including the World Wildlife Fund, International Union for Conservation of Nature, Conservation International, The Nature Conservancy, and the Wildlife Conservation Society. In addition to respecting human rights in conservation practice through the adoption of this framework, these NGOs have also committed to protecting human rights from infringement by third parties and to fulfilling the progressive realization of human rights in rights holders (i.e., communities, workers, fishers) within the scope of conservation programs (Singleton et al., 2017).

The emergence of HRBA in fisheries development and conservation programs

Today, conservation organizations are increasingly attempting to address environmental problems, societal needs and the fair treatment of people in concert; however, this was not always the case. Below we describe the emergence of an HRBA in development practice and thereafter in fisheries management and conservation.

Fig. 16.2 A timeline summary of the emergence of HRBA in fisheries development and conservation programs.

Beginning in the late 1990s, development scholars and practitioners increasingly acknowledged that their field had both benefited from and contributed to global inequity and unsustainability—be it through historical ties to Western imperialism, racism, or contemporary resource extraction (Sen, 1999; Reidy and Rozwadowski, 2014; Bennet et al, 2021). By the early 2000s, numerous national and multilateral development agencies and NGOs committed to participatory, or human-rights-based approaches rather than solely an economic-growth-based approach. While an HRBA remained nebulously defined and operationalized differently across organizations, the United Nations adopted a common definition, which includes the following necessary, specific, and unique elements: 1) assessment and analysis to identify the human rights claims of rights-holders and the corresponding human rights obligations of duty-bearers, as well as the immediate, underlying, and structural causes of the non-realization of rights; 2) programs to assess the capacity of rights-holders to claim their rights, and of duty-bearers to fulfill their obligations. They then develop strategies to build these capacities; 3) programs to monitor and evaluate both outcomes and processes guided by human rights standards and principles; 4) programming informed by the recommendations of international human rights bodies and mechanisms (UN, 2003). Other core tenets of an HRBA include: people are recognized as key actors in their own development; participation is both a means and a goal; development strategies are empowering, not disempowering; stakeholder analyses are inclusive; development programs focus on marginalized, disadvantaged, and excluded groups; and the development process is locally owned (UN, 2003). By the 2010s, conservation organizations began exploring and committing to human-rights-based approaches to conservation (CIHR, 2010; Springer et al., 2011), in response to concerns about conservation malpractice in Indigenous and resource-dependent communities (Chapin, 2004) and as linkages between human rights, development, and conservation agendas were increasingly recognized (Svadlenak-Gomez, 2007).

Initially, the adoption of HRBA in fisheries lagged behind other sectors due to a prioritization and focus on limiting access and fishing rights to address ecological collapse and economic inefficiencies (Allison, 2011). At the turn of the 21st century, fisheries development initiatives focused on securing property rights and marine spatial tenure for fishers, while marine conservation initiatives were historically underpinned by spatial exclusion of fishers with the singular goal of ecosystem protection. Over the last 20 years, it has become increasingly apparent that insecure rights of access are not the only insecurity faced by fisherfolk—income and asset poverty, discrimination, marginalization, and vulnerability are also at stake (Allison et al., 2012). Additionally, there have been instances where the allocation of fishing rights under new legislation undermined human rights by excluding the small-scale sector (Jaffer and Sunde, 2006).

Meanwhile, marine protected areas without local participation or just allocation continued to produce social inequities (Christie, 2004) and are now under increasing scrutiny with respect to key issues including physical dispossession (Masifundise and Kontakt, 2014) and ocean grabbing (Bennett et al., 2015). Within this context, small-scale fisherfolk are reclaiming their rights and arguing for a new interpretation of a rights-based approach, and new basis for fisheries development strategies focused not only on securing spatial tenure but also on rights holders' claims to their basic entitlements: enough food, decent work, freedom from oppression, and the right to a dignified life (Allison et al., 2012). Thus, an HRBA approach to fisheries conservation and management encompasses an expanded definition of 'rights' to be secured beyond that of fishing rights or property rights; it emphasizes prioritization of meeting a communities' basic human rights and socio-economic needs as a precondition to engaging them in effective sustainable resource governance—which is, in turn, a pre-condition for integration into global seafood markets (Allison et al., 2012).

While many scholars and practitioners began to rally around HRBA in fisheries, others offered important critiques of the model. For example, Ruddle and Davis (2013) discuss the construct of human rights as a western neoliberal philosophy, with a focus on individual freedoms subsequently minimizing the importance of collective rights of and social roles within fishing communities. Based on this premise, the concept of human dignity in place of human rights may be a more nuanced, yet broadly applicable and culturally acceptable application within fisheries (Song, 2015). It remained unclear how HRBA would be operationalized in the context of the fishing sector.

However, momentum shifted in 2014, when the 31st Session of the FAO Committee on Fisheries (COFI) adopted the Voluntary Guidelines for Securing Sustainable Small-Scale Fisheries (SSF Guidelines), creating the legal scaffolding for sector-specific human rights protection and fulfillment (FAO, 2015). The SSF Guidelines were designed in consultation with more than 4,000 fisheries stakeholders and provide the first global voluntary agreement by which to consider international human rights-based standards in the context of fisheries management. The SSF Guidelines include guidance tailored to member states (but applicable more broadly) on realizing six focal areas in a manner that respects, protects, and fulfills human rights for fishers specifically. Those six focal areas include: 1) resource management; 2) governance of tenure; 3) value chains and trade; 4) social development and decent work; 5) disaster risks and climate change; and 6) gender equality. The SSF Guidelines articulate the full suite of human rights as necessary for the wellbeing of fishing communities, including fishers' rights to basic services, participatory governance, equality and non-discrimination, decent work and standards of living, access to avenues of justice, rights of women and youth, and additional fishing access rights for Indigenous Peoples. The next challenge became how the SSF Guidelines as a voluntary instrument would be adopted by governments and embedded into national policy. Relevant to this chapter, international conservation NGOs have been identified as well placed to aid in the implementation of the SSF Guidelines given their extensive geographic reach and relationships with government, industry, and communities, but they will need to fully lean into using an HRBA (Singleton et al., 2017).

The sustainable seafood movement takes on social responsibility and human rights

Subsequent to the emergence of HRBA in fisheries development and conservation programs, a parallel community of practice has begun to take on human rights via seafood value-chain interventions. The seafood sustainability movement, growing in popularity over the last several decades, is a community of practice dedicated to driving environmental sustainability in seafood production through the use of market-based interventions (i.e., certifications, ratings, and benchmarking schemes) (Roheim et al., 2018). Critical to this theory of change, some conservation NGOs have formed partnerships with businesses and seafood supply-chain actors to facilitate their engagement with and improvements in environmental sustainability efforts, under the umbrella of the Conservation Alliance for Seafood Solutions (Conservation Alliance). In North America, over 80% of the top 25 retailers have partnerships with NGOs from the Conservation Alliance, and increasingly, the Conservation Alliance is comprised of NGOs from across Europe, Asia, and the Americas.

While the movement has prioritized environmental sustainability in previous years, in response to recent media revelations about forced labor and human trafficking in fisheries (i.e., Levitt, 2014), human rights and social responsibility have emerged as new priorities. For example, a group of actors from within and outside the seafood sustainability movement led the development of the Monterey Framework, a consensus-driven definition of social responsibility in the seafood sector, inclusive of three principles: 1) protecting human rights, dignity, and access to resources; 2) ensuring equality and the equitable opportunity to benefit; and 3) improving food and livelihood security (Kittinger et al., 2017). Likewise, the Conservation Alliance for Seafood Solutions has recently revised their Vision for Seafood (CASS, 2023) and Guidelines for Supporting Fishery Improvement Projects (CASS, 2022) to include elements of human and labor rights. Beyond this, the seafood sustainability movement has seen a proliferation of both NGO- and industry-led certifications, vessel codes of conduct, and other forms of market-based interventions intended to drive social improvements. Many of these market-based interventions are focused on egregious forms of abuse in fisheries (human trafficking and forced labor) in the offshore and industrial sector, where the risk of these abuses occurring is particularly high (Tickler et al., 2018; McDonald et al., 2021).

These efforts are critically important for protecting fishers' and workers' rights at sea, something that is long overdue. However, their focus on protecting the rights of fishers and workers offshore has disregarded the rights of those working nearshore or onshore, namely women, who account for 40% of fishworkers globally, and small-scale fishers, who comprise 90% of the global fisheries labor force (FAO, 2015; Finkbeiner et al., 2021; FAO, Duke University & Worldfish, 2023). This has also inadvertently shifted priorities away from the suite of ESC rights that are of particular importance for small-scale fishing communities, such as the right to food, education, healthcare, and decent work (Allison et al., 2011; Finkbeiner et al., 2021). Furthermore, many of the market-based interventions that have emerged in recent years have been critiqued by labor experts due to their overreliance on voluntary commitments, lack of meaningful involvement by fishworker organizations, inappropriate application of environmental sustainability models in the context of human rights, and inadequate treatment of human rights and labor principles (Sparks et al., 2022; HRAS, 2023; William and Sparks, 2023).

The central challenge for conservation practitioners remains: how can we effectively implement a human rights-based approach in our fisheries work, drawing from previous and parallel experiences and lessons learned? Specifically, there is an imperative need to elevate the rights of women and small-scale fisheries in the seafood sustainability movement and draw from the experiences of integrating HRBA in fisheries development and conservation programs. The recommendations for conservation practitioners we outline below are intended to bridge the chasm across these parallel movements and consider all human rights as indivisible.

Best practices for conservation practitioners

In light of conservation NGOs' moral duty and commitment to respect, protect, and fulfill human rights under the CIHR, and their vital role as bridging organizations among communities, governments, supply chains, and funders (Singleton et al., 2017), we will end with a set of recommendations targeted towards conservation practitioners. These recommendations are specifically designed for their work with: 1) fishers, fishworkers, fishing communities, and their representative organizations; 2) governments and policymakers; 3) businesses and supply chain actors; and 4) funders. Given the many interpretations of an HRBA, we align our recommendations within the three dimensions of an HRBA articulated by the UN FAO: 1) embedding human rights within conservation and management processes; 2) using human rights as a guiding framework or objective of fisheries interventions; and 3) building capacity among actors, including rights holders and duty bearers (FAO, 2016). Our recommendations emphasize the importance of taking both a bottom-up and top-down HRBA in fisheries (while recognizing that some conservation practitioners have more leverage in certain areas), and that an HRBA to fisheries conservation and management involves a locally driven and locally owned process (UN, 2003).

First and foremost, it is important to have institutional support for applying human rights in the conservation or management of fisheries (i.e., the practitioner's organization has already committed to integrating an HRBA). In this way, practitioners can receive proper training, guidance, and financial resources for integrating human rights into their work. Even so, the organization may lack programmatic coherence in the application of human rights principles; certain programs may prioritize the integration of human rights relative to others, necessitating institution-wide dialogue on alignment. Increasingly, conservation NGOs are interested in integrating Diversity, Equity and Inclusion (DEI) into human resource management, programs, and projects. This may also provide a foundation for using an HRBA. For example, efforts to ensure greater diversity of staff members who are representative of the cultures and geographies where projects are implemented, and efforts to embed more equitable and inclusive engagement with communities is consistent with using a human-rights-based approach. In any case, conservation and management practitioners may consider partnering with experts from development, labor and human rights fields, and civil society organizations or other frontline groups representing fishworkers, who already possess the relevant expertise and experience and can serve as important guides in this work.

Unpacking a Human Rights-Based Approach (HRBA)

The table below summarizes actions that conservation NGOs can take when engaging these key actors to help implement, standardize, and institutionalize a human rights-based approach in all fisheries.

Actors	Action
Fishers, fish workers, fishing communities, and civil society organizations	• Pay attention to procedural equity and the prioritization of vulnerable and marginalized groups and individuals • Embed Participation, Accountability, Non-discrimination, Transparency, Human Dignity, Empowerment, and Rule of Law (PANTHER) principles within all stages of conservation and management processes • Implement fishworker-driven or community-driven human rights evaluations & monitoring (i.e., HRBA situational analysis, human rights risk assessments) • Use Free Prior and Informed Consent (FPIC) with Indigenous Peoples and Local Communities • Use grievance and conflict resolution mechanisms during conservation and management processes • Build capacity of rights holders by training fishers, workers, and communities on their rights and facilitating access to mechanisms for claiming their rights • Elevate voices of fishers, workers, and communities in international policy circles and within seafood supply chains, acting as interlocutors bridging power differentials • Use guiding human rights frameworks in conservation and management (i.e., SSF guidelines) that prioritize the realization of human rights as part of the process and as objectives/outcomes
Governments and policy-makers	• Encourage policy coherence between development and labour agencies with fisheries and environmental agencies • Advocacy-oriented NGOs can engage in watchdog and whistle-blowing activity to hold governments accountable • Lobby governments to ratify treaties and conventions; embed these standards in domestic law (i.e., ratify ILO Conventions), embed SSF Guidelines in national law, amend constitutions and legislation to include human rights standards
Businesses and supply chain actors	• Build awareness on the full suite of human rights as equally important to protect and provide specific guidance to businesses on the protection of economic, social, and cultural rights when sourcing from SSF or indirectly impacting SSF • Build capacity of businesses for full supply chain human rights due diligence, combining genuine worker representation, enforceable and legally binding agreements, and changes to brand purchasing practices • Advocacy-oriented NGOs can engage in watchdog and whistle-blowing activity to hold businesses accountable
Funders	• Leverage working relationships with funders to directly encourage the development of more HRBA funding opportunities, straightforward and uncomplicated re-granting requirements, and flexibility on grant objectives, activities, and outcomes. • Indirectly influence funder priorities by deliberately including HRBA in grant proposals, ensuring a substantial portion of grant funding reach fishing communities and fisher organizations, and committing to locally led projects and grant activities determined by the communities themselves

Fig. 16.3 Unpacking a human rights-based approach (HRBA)

Working with fishers, fishworkers, fishing communities, and representative organizations

Conservation NGOs stand to fill a unique and vital role as they often work simultaneously with fishing communities, governments, and businesses. These diverse partnerships increase their potential to initiate collaboration and protect and fulfill human rights from multiple angles. Yet, historically, conservation organizations have not respected human rights—which is an antecedent to protecting and fulfilling them. In order to remain legitimate and trusted, organizations must complete actions within the 'respect' realm as a bare minimum, prior to protecting and fulfilling human rights at a scale beyond their own institutional actions. This must include taking accountability for past harms and human rights violations and a commitment towards reconciliation.

Critical to the conservation practitioner's role in respecting the human rights of fishworkers and fishing communities, and ensuring that their activities and programs are not undermining human rights, is the embedding of principles of participation, accountability, non-discrimination, transparency, human dignity, empowerment, and the rule of law (PANTHER) within all stages of conservation or management processes, including during design, implementation, monitoring, and evaluation (FAO, 2016). Imperative to this is the recognition that participation is not inherently equitable, and vulnerable and marginalized groups face structural barriers to fully participate in or benefit from participatory processes. Thus, prioritization of vulnerable and marginalized groups and individuals is a principal tenet of an HRBA (Willmann et al., 2017). Achieving Free, Prior, and Informed Consent (FPIC) from Indigenous Peoples and Local Communities is also central to an HRBA, where "Free" refers to the absence of coercion, intimidation, or manipulation; "Prior" refers to when consent is sought sufficiently in advance of any authorization or commencement of conservation or management activities, with respect shown to the time requirements of Indigenous consultation or consensus processes; and "Informed" refers to the provision of information that covers a range of aspects (UNDRIP, 2007). Importantly, communities must be allowed to withhold consent. A characteristic of an HRBA is that it is locally-driven or -owned (UN, 2003), with fishers, workers and communities as primary decision-makers and centrally involved.

Additional practices to respect human rights in conservation and management include implementation of human rights evaluations (i.e., HRBA situational analysis or human rights impact assessment (HRIA)) (Harris-Curtis et al., 2005) to determine whether rights belonging to the individual or group are being violated, and if so, by whom. These analyses focus specifically on identifying: the immediate and underlying causes of rights violations and obstacles to rights fulfillment; the views of the concerned people on rights and rights violations; their awareness of their rights and any violations; their priorities for action; who the duty bearers are that are responsible for upholding rights and preventing violations; and whether the duty bearers are aware of their responsibilities and have capacity to uphold them. Conservation organizations must also, at a minimum, create grievance- and conflict-resolution mechanisms by which individuals or communities can report concerns as part of all conservation initiatives and management processes (Singleton et al., 2017).

In addition to respecting human rights in their own conservation and management activities when working with fishworkers and fishing communities, some conservation practitioners have also committed to protecting and fulfilling human rights under the CIHR. The application of guiding frameworks in conservation programs and projects (such as the SSF Guidelines) that prioritize the realization of human rights as critical objectives and outcomes—beyond ensuring 'do no harm'—is an important step towards achieving this goal (FAO, 2016). Furthermore, NGOs can help to build the capacity of rights holders for this work by training fishers, workers, and communities on their rights, and facilitating access to mechanisms for claiming their rights (Sharma, 2011; Ratner et al., 2014). Practitioners are also in a unique position to elevate the voices of fishers, workers, and communities in international policy circles and within seafood supply chains, by acting as interlocutors bridging power differentials (Singleton et al., 2017), and by supporting the independent actions of locally rooted civil society (Banks et al., 2015).

Working in governance and policy

Conservation NGOs can also play a pivotal role in actively promoting the realization of human rights, and in influencing third parties such as governments to provide greater protection of the rights of fishworkers and fishing communities.

To promote human rights protections in the seafood sector, conservation NGOs can advocate for the ratification and implementation of the ILO Work in Fishing Convention, or ILO C188 (2007, No. 188). If implemented, ILO C188 establishes minimum decent work standards to improve the safety, health, and medical care for workers on board fishing vessels and provides adequate protection (written work agreement, social security protections, etc.) for all of the people who work in this sector. Conservation NGOs can look to engage their respective ministries, industry representatives, labor and human rights groups, fishers and their representatives, and civic society organizations to ensure that the C188 ratification process and domestic legislation is effective and far-reaching (ILRF, 2018). Similarly, Conservation NGOs can urge governments to adopt other frameworks addressing decent work and safety at sea, such as the FAO Agreement on Port State Measures to Prevent, Deter, and Eliminate Illegal, Unreported, and Unregulated Fishing (PSMA, 2009), the IMO Cape Town Agreement (CTA, 2012) and IMO Convention on Standards of Training, Certification, and Watchkeeping for Fishing Vessel Personnel (STCW-F, 1995).

Conservation NGOs can advocate for and support government adoption of the SSF Guidelines to ensure an HRBA is embedded within national policies relevant to small-scale fisheries. Meaningful adoption of the SSF Guidelines will require integration into domestic legal frameworks and policy coherence across development, labor, fisheries, and environment agencies. Advising on legal reforms and tracking legislative efforts can therefore be a tangible way for conservation NGOs to create the enabling environment for the realization of fishworkers and communities' rights to equitable development (FAO, 2020). Numerous resources and guides exist to enable this support, such as: Legislating for Sustainable Small-Scale Fisheries—A guide and considerations for implementing aspects of the Voluntary Guidelines for Securing Sustainable Small-Scale Fisheries in the Context of Food Security and Poverty Eradication in National Legislation (FAO, 2020). Furthermore, conservation NGOs can encourage states to enshrine economic, social, and cultural rights in their constitution, statutory legislation, and customary practices to ensure compliance with International Human Rights Law—enforcing the rights to equality and equitable opportunity to benefit from food and livelihood security in coastal states (Graham and D'Andrea, 2021). Conservation NGOs can further encourage governments to prohibit discrimination against women in line with the Convention on the Elimination of All Forms of Discrimination against Women (CEDAW, 1979), supporting the intersecting agendas of bolstering human rights and conservation outcomes.

Practitioners can also proactively cultivate knowledge exchanges with governments to build their capacity as duty bearers to respect, protect, and fulfill human rights under existing and emerging legislation. Conservation NGOs can contribute to the development of reliable data, the documentation of best practices, and the promotion of responsibilities and accountability mechanisms for duty bearers to meet their obligations to rights holders. In many cases, fishworkers and their communities lack access to justice, the right to an effective remedy, and legal redress for infringement of their rights. As such, conservation practitioners can look at raising awareness among rights holders in small-scale fishing communities about claiming their rights, accessing associated legal services, and holding duty bearers accountable for legitimate tenure rights, rights against arbitrary forced eviction, the right to an adequate standard of living, labor and social security rights, and the rights of women, Indigenous Peoples, and other vulnerable and marginalized groups (FAO, 2016).

Working with businesses and supply-chain actors

Conservation practitioners can play a vital role in holding businesses and supply-chain actors accountable in their responsibility to respect human rights and can work alongside businesses to build capacity for meaningful worker-driven human rights due diligence in seafood value chains.

Advocacy-oriented practitioners play an important role in promoting compliance with national laws and international obligations concerning human and labor rights through whistleblowing and watchdog efforts. These efforts are critical for raising awareness about non-compliant private sector actors and emerging social responsibility issues and human rights threats. Thus, watchdog and sentinel roles can catalyze substantial private sector and government action and can further bring buyers and NGOs to the table to discuss potential solutions to critical challenges and reinforce accountability mechanisms (CEA, 2020).

To date, business commitments to human rights and the environment in the seafood sector have been voluntary and market-driven (e.g., certifications). While these commitments show progress, they are limited in their ability to reduce the adverse impacts of business operations (Kittinger et al., 2020; Business and Human Rights Resource Centre, 2021). As outlined in the UNGPs, businesses must move beyond public commitments and actively identify, prevent, mitigate, and account for how they will address adverse human rights impacts. This includes assessing actual and potential human rights impacts, integrating, and acting on the findings, tracking responses, and communicating about how impacts are addressed. However, given that seafood supply chains are often long and opaque, mapping supply chains, assessing risks, and acting on these findings to improve fishworker welfare can be intimidating for businesses. Conservation practitioners can help fulfill these capacity gaps through one-on-one relationships with businesses or by participating as key partners in pre-competitive platforms (i.e., NGO-coordinated industry groups).

Beyond its reference in the UNGPs, legal requirements for human rights due diligence are rapidly changing in Europe and across the globe. As a trading bloc, the EU has introduced foundational sustainable corporate governance legislation in 2021, which will impose human rights and environmental due diligence to all companies in all sectors (including seafood) operating in the EU market. Thus, there is a salient opportunity for conservation practitioners, particularly those with longstanding business relationships, to guide the business sector in this shift towards full supply-chain due diligence, combining genuine worker representation, enforceable and legally binding agreements, and changes to purchasing practices (ILRF, 2018). Practitioners can support supply-chain actors' pathway from addressing only the visible human rights violations and known risks towards mitigating potential risks and ultimately, towards mitigating their root causes in seafood-producing geographies.

While guidance for businesses on respecting labor rights in industrial fishing operations is relatively well-developed (RISE, 2021), there is an urgent need to bolster guidance for businesses to reduce adverse human rights impacts on small-scale fishworkers and their communities, particularly with respect to their rights to food, decent work, gender equity and freedom from gender-based violence, and Indigenous Peoples' rights. For example, conservation practitioners can help businesses to understand and support the rights of Indigenous Peoples and local communities, such that they identify and respect Indigenous Peoples' and local communities' formal and customary rights to lands, territories, and resources in the context of any company activity and ensure that their free, prior, and informed consent (FPIC) is secured before any activity that may affect Indigenous Peoples' and local communities' rights, land, resources, territories, livelihoods, or food security. In the development of this guidance, NGO partnerships with civil society organizations, frontline groups, and fishworker-led organizations are critical for understanding fishworker and community needs and priorities to ensure these are ultimately addressed.

Working in funding/financing spheres

Typically, the influence of donors on NGO agendas is unidirectional, with donors determining strategic priorities and programs, to which NGOs must demonstrate alignment to receive funding. Oftentimes, civil society organizations or local NGOs do not have the capacity to seek out funding opportunities, and international NGOs act as gatekeepers or *de facto* grantors. Thus, once funding reaches local NGOs, civil society organizations, or community groups, it may reflect the agendas and priorities of large international NGOs and their funders and be less rooted in local realities and priorities, running counter to an HRBA and providing dubious outcomes for communities and conservation (Chapin, 2004).

However, in some cases, there are direct or indirect opportunities for NGOs to influence funding priorities. For example, NGOs may utilize positive working relationships with funders to encourage: 1) the development of fisheries-specific HRBA-oriented funding opportunities; 2) straightforward and uncomplicated regranting requirements and processes; 3) flexibility on grant objectives, activities, and outcomes so that the ultimate application of funds is determined by local civil society organizations, frontline groups, and communities. NGOs can also influence funding streams by incorporating HRBA fisheries initiatives into their grant proposals to donor organizations, by ensuring a substantial proportion of their grants reach fishing communities and their representative organizations, and finally by committing to locally led projects and grant activities determined by fishwoker organizations and fishing communities.

Conclusion

In summary, conservation practitioners have a moral and legal obligation to respect the human rights of fishers, fishworkers, and coastal communities where they work (Smallhorn-West et al., 2023). Critically, international conservation NGOs are well-poised to support the adoption and implementation of HRBA instruments such as the SSF Guidelines given their geographic reach across countries and fishing communities, and strong connections with governments and market players (Singleton et al., 2017). Furthermore, many of the international conservation NGOs have formally committed to protecting and fulfilling human rights, following decades of conservation malpractice that unintentionally worked to undermine community wellbeing and human rights (CIHR, 2010).

Given the importance of putting an HRBA into practice as a conservation organization, in this chapter we sought to clarify for conservation practitioners what this means and how to do it by: 1) clarifying the roles and responsibilities of states, supply-chain actors, and international conservation NGOs, under primary internationally agreed-upon human rights frameworks; 2) discussing the emergence of an HRBA in development practice and shortly thereafter in fisheries management and conservation efforts; and 3) providing recommendations targeted specifically for conservation practitioners on using an HRBA while working with fishing communities, in governance and policy, with supply-chain actors, or in influencing funding/financing spheres. We hope this chapter has helped to demystify what a human-rights-based approach is: 1) embedding principles of human rights within conservation and management processes, to at a minimum, meet the legal obligation of respecting human rights; 2) looking to human rights frameworks and standards as objectives of programs and projects; and 3) building expertise or seeking partnerships with existing expertise to support the progressive realization of rights through capacity building with duty bearers and rightsholders. We also hope conservation practitioners will benefit from the tangible steps for implementing an HRBA when engaging different actors, as we have outlined in the Best Practices section. In conclusion, regardless of a conservation practitioner's particular role as a researcher, project implementer, convener, mediator, or advocator, we urge everyone to consider the guidance outlined in this chapter, to ultimately support enduring improvements for human wellbeing and environment sustainability.

References

Agrawal, A., & Redford, K. (2009). Conservation and displacement: An overview. Conservation & Society, 7, 1-10.

Allison, E. H. (2011). Should states and international organizations adopt a human rights approach to fisheries policy? https://digitalarchive.worldfishcenter.org/handle/20.500.12348/1125

Allison, E. H., Åsgård, B., & Willmann, R. (2011). Human rights approaches to governing fisheries. https://digitalarchive.worldfishcenter.org/handle/20.500.12348/1091

Allison, E. H., Ratner, B. D., Åsgård, B., Willmann, R., Pomeroy, R., & Kurien, J. (2012). Rights-based fisheries governance: From fishing rights to human rights. Fish and Fisheries, 13(1), 14-29.

Anderson, M. B. (1999). Do No Harm: How Aid Can Support Peace – Or War. Lynne Rienner Publishers.

Banks, N., Hulme, D., & Edwards, M. (2015). NGOs, states, and donors revisited: Still too close for comfort? World Development, 66, 707-718.

Bennett, N. J., Govan, H., & Satterfield, T. (2015). Ocean grabbing. Marine Policy, 57, 61-68.

Bennett, N. J., Katz, L., Yadao-Evans, W., Ahmadia, G. N., Atkinson, S., Ban, N. C., ... & Wilhelm, A. (2021). Advancing social equity in and through marine conservation. Frontiers in Marine Science, 8, 711538.

Boesen, J. K., & Martin, T. (2007). Applying a rights-based approach: An inspirational guide to civil society. The Danish Institute for Human Rights.

Brockington, D., & Igoe, J. (2006). Eviction for conservation: A global overview. Conservation & Society, 4, 424-470.

Business & Human Rights Resource Centre. (2021). All at sea: An evaluation of company efforts to address modern slavery in Pacific supply chains of canned tuna. Retrieved from https://www.business-humanrights.org/en/from-us/briefings/all-at-sea-an-evaluation-of-company-efforts-to-address-modern-slavery-in-pacific-supply-chains-of-canned-tuna/

CASS. (2022). Guidelines for supporting Fishery Improvement Projects. Conservation Alliance for Seafood Solutions. https://solutionsforseafood.org/wp-content/uploads/2023/04/FIP-Guidelines-Apr2023.pdf

CASS. (2023). A vision for seafood. Conservation Alliance for Seafood Solutions. https://solutionsforseafood.org/wp-content/uploads/2023/04/VISION-for-Seafood-Apr2023-FINAL.pdf

CEA. (2020). Global landscape review of fishery improvement projects (FIPs). CEA Consulting.

CEDAW. (1979). Committee on the Elimination of Discrimination Against Women.

Chapin, M. (2004). A challenge to conservationists. World Watch Magazine. World Watch Institute.

CIHR. (2010). Conservation Initiative on Human Rights. http://www.thecihr.org/

Christie, P. (2004, January). Marine protected areas as biological successes and social failures in Southeast Asia. In American Fisheries Society Symposium (Vol. 42, No. 155-164).

Conservation International. (2021). Actioning the Monterey Framework. https://riseseafood.org/topics/actioning-the-monterey-framework/

CTA. (2012). IMO Cape Town Agreement.

Finkbeiner, E. M., Fitzpatrick, J., & Yadao-Evans, W. (2021). A call for protection of women's rights and economic, social, cultural (ESC) rights in seafood value chains. Marine Policy, 128, 104482.

FAO. (2015). Voluntary Guidelines for Securing Sustainable Small-Scale Fisheries in the context of Food Security and Poverty Eradication. Rome, Italy.

FAO. (2016). Human rights based approach to the implementation and monitoring of the SSF Guidelines: Background paper. Rome, Italy.

FAO. (2020). Legislating for sustainable small-scale fisheries. A guide and considerations for implementing aspects of the Voluntary Guidelines for Securing Sustainable Small-Scale Fisheries in the Context of Food Security. Retrieved from: http://www.fao.org/3/cb0885en/CB0885EN.pdf

FAO, Duke University & WorldFish. (2023). Illuminating Hidden Harvests – The contributions of small-scale fisheries to sustainable development. Rome. https://doi.org/10.4060/cc4576en

Graham, A., & D'Andrea, A. (2021). Gender and human rights in coastal fisheries and aquaculture. A comparative analysis of legislation in Fiji, Kiribati, Samoa, Solomon Islands, Tonga and Vanuatu. Noumea, New Caledonia: Pacific Community.

Greenpeace. (2018). Misery at sea: human suffering in Taiwan's distant water fishing fleets.

Harris-Curtis, E., Marleyn, O., & Bakewell, O. (2005). The implications for northern NGOs of adopting rights-based approaches (Occasional papers series, 41). International NGO Training Centre.

International Labour Organization. (1978). Convention concerning Tripartite Consultations to Promote the Implementation of International Labour Standards (Entry into force: 16 May 1978). Retrieved from: https://www.ilo.org/dyn/normlex/en/f?p=NORMLEXPUB:12100:0::NO::P12100_ILO_CODE:C144

International Labour Organization. (2022). ILO Declaration on Fundamental Principles and Rights at Work and its Follow-up. Retrieved from: https://www.ilo.org/wcmsp5/groups/public/---ed_norm/---declaration/documents/normativeinstrument/wcms_716594.pdf

ILO Work in Fishing Convention, 2007 (No. 188)

ILRF. (2018). Taking stock: labor exploitation, illegal fishing, and brand responsibility in the seafood industry. International Labor Rights Forum. https://laborrights.org/sites/default/files/publications/Taking%20Stock%20final.pdf

International Covenant on Civil and Political Rights, 1966

International Covenant on Economic, Social and Cultural Rights, 1966

ITF. (2006). Out of Sight, Out of Mind: Seafarers, Fishers & Human Rights. International Transport Workers' Federation (ITF). https://issuu.com/sdm2007/docs/humanrights

Jaffer, N., & Sunde, J. (2006). Fishing rights vs. human rights. Samudra Report, 44, 83-86.

Jonas, H., Roe, D., & Makagon, J. E. (2014). Human rights standards for conservation: An analysis of responsibilities. Rights Redress Just Conserv.

Kittinger, J. N., Bernard, M., Finkbeiner, E. M., Murphy, E., Obregon, P., Klinger, D. H., Schoon, M. L., Dooley, K. J., & Gerber, L. R. (2020). Applying a jurisdictional approach to support sustainable seafood. Conservation Science and Practice, e386. http://doi.org/10.1111/csp2.386

Kittinger, J. N., Teh, L. C. L., Allison, E. H., Bennett, N. J., Crowder, L. B., Finkbeiner, E. M., Hicks, C., Scarton, C. G., Nakamura, K., Ota, Y., Young, J., Alifano, A., Apel, A., Arbib, A., Bishop, L., Boyle, M., Cisneros-Montemayor, A. M., Hunter, P., Cornu, E. L., … Wilhelm, T. 'Aulani. (2017). Committing to socially responsible seafood. Science, 356(6341), 912–913. https://doi.org/10.1126/science.aam9969

Levitt, T. (2016). Our love of seafood is tainted by slavery: how can it be fixed? The Guardian.

Marschke, M., & Vandergeest, P. (2016). Slavery scandals: Unpacking labour challenges and policy responses within the off-shore fisheries sector. Marine Policy, 68, 39-46.

McDonald, G. G., Costello, C., Bone, J., Cabral, R. B., Farabee, V., Hochberg, T., ... & Zahn, O. (2021). Satellites can reveal the global extent of forced labor in the world's fishing fleet. Proceedings of the National Academy of Sciences, 118(3).

PSMA. (2009). FAO Agreement on Port State Measures to Prevent, Deter, and Eliminate Illegal, Unreported, and Unregulated Fishing.

Ratner, B. D., Åsgård, B., & Allison, E. H. (2014). Fishing for justice: Human rights, development, and fisheries sector reform. Global Environmental Change, 27, 120-130.

Reidy, M. S., & Rozwadowski, H. M. (2014). The spaces in between: Science, ocean, empire. Isis, 105, 338–351.

RISE. (2021). Actioning the Monterey Framework. Retrieved from https://riseseafood.org/topics/actioning-the-monterey-framework/

Roheim, C. A., Bush, S. R., Asche, F., Sanchirico, J. N., & Uchida, H. (2018). Evolution and future of the sustainable seafood market. Nature Sustainability, 1(8), 392-398.

Ruddle, K., & Davis, A. (2013). Human rights and neo-liberalism in small-scale fisheries: Conjoined priorities and processes. Marine Policy, 39, 87-93.

Sen, A. (1999). Development as freedom. In The globalization and development reader: Perspectives on development and global change (pp. 525).

Sharma, C. (2011). Securing economic, social and cultural rights of small-scale and artisanal fisherworkers and fishing communities. Maritime Studies, 10(2), 41-62.

Singleton, R. L., Allison, E. H., Le Billon, P., & Sumaila, U. R. (2017). Conservation and the right to fish: International conservation NGOs and the implementation of the voluntary guidelines for securing sustainable small-scale fisheries. Marine Policy, 84, 22-32.

Smallhorn-West, P., Allison, E., Gurney, G., Karnad, D., Kretser, H., Lobo, A. S., ... & Peckham, S. H. (2023). Why human rights matter for marine conservation. Frontiers in Marine Science, 10, 214.

Song, A. M. (2015). Human dignity: A fundamental guiding value for a human rights approach to fisheries?. Marine Policy, 61, 164-170.

Sparks, J. L. D., Matthews, L., Cárdenas, D., & Williams, C. (2022). Worker-less social responsibility: How the proliferation of voluntary labour governance tools in seafood marginalise the workers they claim to protect. Marine Policy, 139, 105044.

Springer, J., Campese, J., & Painter, M. (2011). Conservation and Human Rights: Key Issues and Contexts. Scoping Paper for the Conservation Initiative on Human Rights. Retrieved from https://www.ohchr.org/sites/default/files/Documents/Issues/Environment/ImplementationReport/IUCN3.pdf

STCW-F. (1995). IMO Convention on Standards of Training, Certification, and Watchkeeping for Fishing Vessel Personnel.

Svadlenak-Gomez, K. (2007). Integrating human rights into conservation programming. Human rights and Conservation, USAID.

Teh, L. C., Caddell, R., Allison, E. H., Finkbeiner, E. M., Kittinger, J. N., Nakamura, K., & Ota, Y. (2019). The role of human rights in implementing socially responsible seafood. PLoS One, 14(1), e0210241.

Tickler, D., Meeuwig, J. J., Bryant, K., David, F., Forrest, J. A., Gordon, E., ... & Zeller, D. (2018). Modern slavery and the race to fish. Nature Communications, 9(1), 1-9.

TNI Agrarian Justice Programme, Masifundise and Afrika Kontakt. (2014). The Global Ocean Grab: A Primer.

UN. (2003). Statement on a common understanding of a human rights-based approach to development cooperation. United Nations.

UN Declaration on the Rights of Indigenous Peoples, 2007.

UN Guiding Principles on Business and Human Rights, 2011.

UN Universal Declaration of Human Rights, 1948.

Williams, C., & Sparks, J. L. D. (2023). Fishery improvement projects: A voluntary, corporate "tool" not fit for the purpose of mitigating labour abuses and guaranteeing labour rights for workers. Marine Policy, 147, 105340.

Willmann, R., Franz, N., Fuentevilla, C., McInerney, T. F., & Westlund, L. (2017). A human rights-based approach in small-scale fisheries: Evolution and challenges in implementation. In The Small-Scale Fisheries Guidelines (pp. 763-787). Springer, Cham.

Whitlow, J. (2004). The Social Dimension of IUU Fishing (Jon Whitlow of the International Transport Workers' Federation) (AGR/FI/IUU(2004)15). Organisation for Economic Co-operation and Development (OECD), Directorate for Food, Agriculture and Fisheries, Fisheries Committee. http://www.oecd.org/greengrowth/fisheries/31492524.PDF

17. Blue Justice principles for small-scale fisheries in marine protected areas

Ratana Chuenpagdee[1] *and Svein Jentoft*

The interactive governance perspective

Governance and management of ocean space and marine resources fall into the category of a 'wicked problem' as defined by Rittel and Webber (1973). Governments, conservationists, scientists, and activists alike are often at a loss with how to proceed to make marine conservation effective and to achieve desired goals. One example is the implementation of marine protected areas (MPAs). Faced with pressure to meet the Aichi Target and the United Nations (UN) Sustainable Development Goal 14 (SDG14), some countries have set up MPAs in places where they can be easily established, even though conservation objectives are not necessarily met. While this is not necessarily a bad strategy for governments, concerns have been raised about the illusion of success it has created, which might deter further efforts and actions that are still required (Devillers et al., 2014).

With numerous lessons about MPAs around the world, one would expect a much greater advance in MPA implementation and management than we have in fact seen. Scientists have long pointed to the problem with treating MPAs as a fix-all for marine conservation (Degnbol et al., 2005), and many studies have been calling for better incorporation of social sciences into marine conservation (see for instance Christie et al., 2003; 2017). Nevertheless, a lot of research and implementation efforts still focus on how to make marine conservation work, whether through MPAs or other tools. Rittel and Webber (1973) argue, however, that a more nuanced governance approach is required for planning problems such as this. Aligning with this thinking, interactive governance scholars, led by Jan Kooiman (2003), have employed a holistic perspective to examine where in the natural, social, and political systems governance challenges may lie, and, through a governability assessment (Mahon, 2008; Chuenpagdee and Jentoft, 2009), to look for options and possibilities where innovative solutions may be found in all three orders of governance. At the first order, which refers to the daily operation in management and governance, decision-making can be less routine, but a more interactive process where information is exchanged and knowledge flows. The second order of governance refers to institutional design and arrangement, which should be done to correspond with the nature and the characteristics of the natural and the social systems that it aims to govern. This implies that rules and regulations are made, not to restrict stakeholders' activities but to enable them. Finally, principles, values and images are core governance elements at the third (meta-) order, and they provide a foundation for what the institutions should look like in the second order and how decisions should be made in the first order. The elevation of governance thinking to the meta-order would lead to a better alignment of the entire governance system and help improve the overall governability (Chuenpagdee and Jentoft, 2018a).

1 Department of Geography, Memorial University of Newfoundland, https://scholar.google.com/citations?user=LEJKPbYAAAAJ&hl=en&oi=ao

 https://doi.org/10.11647/OBP.0395.17

By thinking of MPAs from the interactive governance perspective, rather than from a biophysical management perspective alone, the actors and their roles are broadened from having governments responsible for setting up and operating the MPAs, to involving other key users and stakeholders of the marine areas to play leading or supporting roles, and emphasizing both the social and governance perspectives (Voorberg and Van der Veer, 2020). It also implies moving from a technical means/end perspective of government as the solitary and sovereign governor, to a more nuanced means with multiple possibilities of what the end goals may be, and the many pathways to get there. It also invites critical assessment of what alternatives exist regarding the design of MPAs in concrete settings, and the necessity of viewing MPAs as only one tool in the full toolkit of marine conservation.

The analytical lens that interactive governance theory brings to marine conservation, especially through MPAs, has helped to enrich the discussion about this topic and broaden the way conservation tools are considered (Chuenpagdee, 2011). It brings into focus key questions that need to be answered before the MPAs or other policy and management measures are implemented, including what the goals are or should be (Jentoft et al., 2011a), what stakeholders think and expect of MPAs (Jentoft et al., 2011b), and images that they have of them (Chuenpagdee et al., 2019). Interactive governance invites discussion about the pre-implementation of the MPAs from the "step zero" perspective (Chuenpagdee et al., 2013), as well as about the implementation strategy that focuses on creating synergy for MPAs to benefit all relevant stakeholders (Pascual et al., 2018). The above implies framing the question about the goals of MPAs, and the process through which MPAs are initiated and implemented, based on the understanding of the three orders of governance. Thus, the interactive governance lens helps raise questions about the MPAs that are usually not articulated, and which typically do not appear in the literature. Ultimately, learning from the application of this analytical perspective offers new knowledge to be integrated into the creation and the management of MPAs.

In the era of Blue Growth and Blue Economy,[2] when ocean development initiatives are questioned from social justice, inclusiveness and transparency principles, it is increasingly important to approach marine conservation from a transdisciplinary perspective that encourages innovation in knowledge production, institutional design and governance process (Lang et al., 2012). Here we summarize key concepts in interactive governance theory, as applied to marine conservation, as a basis for transformation from conventional to more innovative thinking about management and governance, with due attention paid to all three orders of governance. Through interactive and innovative governance and transdisciplinarity, we discuss how 'Blue Justice' for small-scale fisheries in marine conservation can be achieved.

Understanding stakeholders as the first order

Governance is no longer a new concept in ocean discourse, and many countries are taking serious steps to transition from conventional to innovative thinking in management and governance (Chuenpagdee and Jentoft, 2018a). This means broadening the scope from a predominantly biophysical approach to including considerations of socio-political and institutional elements and aspects. The consideration of such aspects has resulted for the most part in enhancing stakeholders' consultation and participation in the planning, policy development, and decision-making process.

While this is a step in the right direction, more effort is required to improve how ocean space and resources are governed. This includes looking, in the first instance, at what the natural and social—including governance—systems look like, and how they interact. Knowledge is thus extended from the biophysical ocean ecosystem to the social system of users of the resources and ocean space, recognizing their dependency on the system, their contribution to the economy and society, as well as the varying impact of their activities. Small-scale fishers are

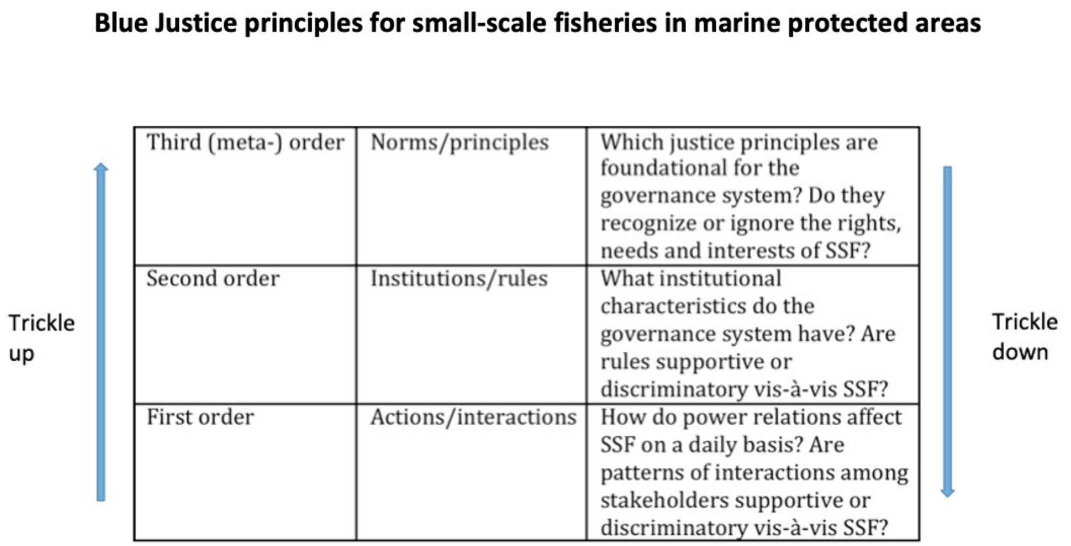
2 The term was first conceived during the UN's Rio+20 meeting in 2012 (Howard, 2018).

an example of such user groups, which should ideally be considered “definitive” stakeholders, according to Mitchell et al. (1997). One issue that may also be applicable to other small-scale user groups is that they may only have legitimacy and urgency in the use of the resource, but not the power to influence decisions. This is the combination of conditions for injustice. The inclusion of small-scale fishers and other less politically powerful groups, either directly or through their respective organizations, in policy development and in all planning phases is imperative. This can certainly be done, even at a global scale, as illustrated in the development of the Voluntary Guidelines for Securing Sustainable Small-Scale Fisheries in the Context of Food Security and Poverty Eradication (SSF Guidelines; FAO, 2015; Jentoft, 2014).

A proper analysis of stakeholders would reveal that not all users and actors in the ocean are equal, and thus they should not be treated as such. As stipulated in the SSF Guidelines, the argument for preferential access of small-scale fisheries to aquatic resources and marine space is based on human rights principles, as well as other social justice principles including gender equity. Small-scale fishers are often the underdog in the context of Blue Growth and Blue Economy. Their livelihoods and communities are at risk when other larger and more powerful parties discuss development and investment plans for more intensive use of the ocean. The lack of opportunity for small-scale fishing people to be involved in the decision-making process makes them vulnerable to pressure, power plays, and abuse. Then they risk becoming victims of “ocean grabbing” or “coastal grabbing,” i.e., shut out from access to the traditional fishing grounds (Barbesgaard, 2017; Bavinck et al., 2017).

Any stakeholder consultation and engagement effort needs to take into consideration the characteristics of small-scale fisheries and other less powerful ocean users and their interests, along with their needs, wants and concerns. The success of MPAs requires that processes and infrastructure be established to facilitate and enable their meaningful participation, accommodating their daily activities in setting up meeting times, recognizing the cost of their participation, and acknowledging their different literacy and comfort levels. A question of when to engage is also critical, as pointed out in the step zero research on MPA implementation (see for example Barragan-Paladines and Chuenpagdee, 2017; Chuenpagdee et al., 2013). While government officials may feel that they need to have a plan in place when proposing an MPA or a conservation plan before bringing it to the consultation, fishers and their communities may feel that the decisions have already been made, that the MPA is simply being imposed on them, that their input has not been taken into consideration and their opinions, comments or criticism have no real merit.

From the governance perspective, the issues and challenges facing the day-to-day operation of and decision-making about MPAs, or the first order, arise from the lack of attention paid to the actors in the social system and how they interact with the marine environment, as well as with each other (Figure 17.1). Power dynamics among stakeholders determine some of the latter interactions and influence decisions about marine conservation. As emphasized earlier, small-scale fishers and other small-scale users often lack the kind of power and influence that they need to negotiate for conditions that work in accord with their rights and obligations, and to attain justice from the decisions made by managers and policymakers. Displacement of groups such as small-scale fisheries and coastal communities from their work and livelihood is common when an MPA is established with rules that prohibit them from entering or restricting their fishing activities in the conserved areas. The case studies in Ecuador, Mexico, and Spain (Jentoft et al., 2011b and Chuenpagdee et al., 2019) illustrate this point well with stakeholders indicating what they think about the goals of MPAs, about who should have priorities and should be considered in the design of MPAs, and about who actually has power and influence in decisions related to MPAs.



Third (meta-) order	Norms/principles	Which justice principles are foundational for the governance system? Do they recognize or ignore the rights, needs and interests of SSF?
Second order	Institutions/rules	What institutional characteristics do the governance system have? Are rules supportive or discriminatory vis-à-vis SSF?
First order	Actions/interactions	How do power relations affect SSF on a daily basis? Are patterns of interactions among stakeholders supportive or discriminatory vis-à-vis SSF?

Fig. 17.1 Justice in three governance orders (Source: Jentoft and Chuenpagdee, 2022).

MPAs as the second order

MPAs are not just a first-order instrument for addressing complex socio-ecological and political problems with a moral content, such as justice. As argued by Jentoft et al. (2007), MPAs are also institutions, i.e., a governing system that involves different types of questions, including how they should be structured and established in order to enhance their performance and their overall quality for governance. Like other institutions, MPAs are social constructs, but they may become "objective realities" (Berger and Luckmann, 2011) when they have existed for a while and stakeholders start to take them for granted. In effect, they are what we make of them, whether they do what we intend for them to do or not. But they also limit the freedoms of stakeholders to operate according to their own interests and preferences. Once they are established, they take on the governing role, guiding and steering stakeholders in certain directions according to the rules and norms that have been agreed upon.

Scott (1995) emphasizes, however, that knowledge is also important for institutions. Small-scale fishers' knowledge about the marine ecosystem, for instance, can potentially lead to a better, more adequate design, and thus the better functioning of the MPAs (Pascual-Fernandez et al., 2018). They can also contribute to the monitoring and surveillance of the MPAs, making them more effective. This is the expected merit of a co-management design, where people are inclined to follow rules of their own making, which works in contrast to a system where rules are established by others, external to the system, and imposed on them. As suggested by Ferse et al. (2010), local communities are allies, not aliens. Thus, there is no reason to assume that if small-scale fisheries have a hand on the wheel, they will introduce weaker rules and enforce them with less determination than rules introduced and enforced by some external authority. In other words, a certain degree of self-restraint is likely to accompany any functioning co-management system, thus requiring fewer governing interventions, but more freedom for self-governance.

Once MPAs are seen as governing institutions, they are not any different from other types of institutions that require attention and care. The normative value and the moralities that MPAs uphold and transmit require that stakeholders follow the rules stipulated within the MPAs, not because we agree with them alone but also because we believe in the values they express. This normative pillar, along with the cognitive and the regulative pillars (Scott, 1995), need to work together to make MPAs a robust institution. When MPAs do not work as intended, it could be because one or more of the pillars (normative, cognitive or regulative) are weak.

Institutional reform might then be required, provided that the strengths and weaknesses of the three pillars are appropriately examined.

What type of institution an MPA should be, how it should operate, with what rules and norms, and who should be involved in the planning and the management of the MPA are important design questions. Lessons from the existing MPAs would suggest a participatory process in establishing an MPA and a co-management system for operating it. As suggested by Voorberg and Van der Veer (2020), a co-management system that is supported by the governing institutions (e.g., part of a formalized management system) would have greater success than one that is not. Like other institutions, the aim should be to make MPAs run smoothly, efficiently, and in an orderly fashion, and with the aim to advance both conservation and justice, especially for marginalized and the vulnerable groups, which include small-scale fisheries in many instances. If justice concerns are not built into the institutional design, the rules, normative and cognitive pillars will be challenged, and are likely to crumble over time.

Establishing principles as the meta-order

Like the guiding principles of the Code of Conduct for Responsible Fisheries (FAO, 2005) or the SSF Guidelines, the formulation of principles is not outside the realm of governance. As the meta-order guiding the arrangement of the governing institutions and the daily decision-making, it is imperative that principles are well articulated, through a deliberate and engaged process that facilitates an exchange of knowledge, sharing of values, and forming of governing images (Kooiman and Jentoft, 2009). Deliberating what these principles are, or what they should be, also needs to be guided by good process principles that give power to marginalized voices and minimize the influence of latent stakeholders who may have power, but have neither real urgency in their concerns nor legitimacy in their claim. Achieving just and inclusive marine conservation can be one of the goals of meta-order governance. This might mean going back to foundational thinking to find normative undertones, the images and values upon which there is general agreement. Given the link between process and outcomes, improving interactions within and among the systems that are being governed and the governing system, including through interactive learning, can help achieve desirable governance outcomes.

The SSF Guidelines provide a starting point for the discussion about principled and just governance, especially with its strong emphasis on human rights, as emphasized in Article 5.15:

> States should facilitate, train and support small-scale fishing communities to participate in and take responsibility for, taking into consideration their legitimate tenure rights and systems, the management of the resources on which they depend for their well-being and that are traditionally used for their livelihoods. Accordingly, States should involve small-scale fishing communities – with special attention to equitable participation of women, vulnerable and marginalized groups – in the design, planning and, as appropriate, implementation of management measures, including protected areas, affecting their livelihood options. Participatory management systems, such as co-management, should be promoted in accordance with national law. (FAO, 2015; p. 7)

The broad engagement of small-scale fisheries stakeholders in all stages of development reflects the importance of the 'step zero' principle, which in the case of the SSF Guidelines, refers to how small-scale fisheries groups and supporting organizations came up with the idea and initiated the early discussion about it. As an intergovernmental body responsible for fisheries, FAO plays a critical role in facilitating the process, especially the interactions among the key stakeholders—in this case, small-scale civil society organizations and governments—that enables the SSF Guidelines to be designed by and for small-scale fisheries. The grounding of the SSF Guidelines on human rights principles, along with other principles such as social justice, gender equity , and the rights of indigenous people, is another example of the recognition of the difference in values and priorities of small-scale fisheries. It is also necessary to connect SSF Guidelines with SDGs, given that some alignments already exist and can be fostered (Said and Chuenpagdee, 2019). Examining the principles underlying these major goals and instruments can provide warnings about both the intended and unintended consequences of ocean development, such as those promoted under Blue Growth and Blue Economy initiatives. In other words, as demands on the ocean continue to grow and expand, getting the meta-order right is imperative and urgent, and can help secure Blue Justice for small-scale fisheries. Developed as a counter-narrative to Blue Growth and Blue Economy concepts, Blue Justice calls attention to the existence of millions of small-scale fisheries people and their contribution to the food security, livelihoods and wellbeing of coastal communities around the world, as well as the need to take into consideration the nature of small-scale fisheries activities and their rights to access marine resources and ocean space as a priority for just and equitable ocean development.

As argued by Jentoft (2020), while there may be no consensus around what Blue Justice means, or a common language for small-scale fisheries to communicate the injustices they experience, the grounded reality of Blue Justice provides it with real meaning, and, according to Sen (2009), gives some idea about what can be done, without having to reinvent the wheel. Justice is, after all, an age-old concept and concern that has been deliberated, and contested, among philosophers from antiquity. Much of the current politics and daily interactions have justice as an underpinning concern, and some of these can be found in the SSF Guidelines. For example, Article 5.8 stipulate that:

> States should adopt measures to facilitate equitable access to fishery resources for small-scale fishing communities, including, as appropriate, redistributive reform, taking into account the provisions of the Voluntary Guidelines on Responsible Governance of Tenure of Land, Fisheries and Forests in the Context of National Food Security (FAO, 2015; p. 6).

In the context of marine conservation, this implies allowing small-scale fishers to enter and operate in areas that may be designated for protection, provided that destructive gears are not used and rules are followed. Furthermore, the decision about what gears are destructive and how to regulate MPAs needs to be based on the knowledge and experience of small-scale fishers, as much as scientists and experts (Xavier et al., 2018). While this may seem ‘unfair’ to other stakeholder groups, the preferential treatment is practiced under the second condition of John Rawl’s “Difference Principle” (1971), reiterated by Pikketty (2020), which suggests that the greatest benefit should be given to the least advantaged members of society. In effect, it is fairness, justice, and equity, not equality, that holds. The Difference Principle is explicit in the SSF Guidelines Article 5.7, which refers to the original Code of Conduct for Responsible Fisheries (FAO, 2005) in stating that “States should where appropriate grant preferential access of small-scale fisheries to fish in waters under national jurisdiction, with a view to achieving equitable outcomes for different groups of people, in particular vulnerable groups.” If the statement achieved consensus among the FAO member states during the technical consultation, there is no reason why this cannot become part of the mainstream dogma in marine conservation.

Transdisciplinarity for inclusive and just MPAs

Researchers and practitioners in fisheries and ocean governance have long recognized the need for a transdisciplinary perspective to address the issues and challenges in marine conservation, fisheries management, and ocean governance. Many have already integrated local and traditional knowledge in understanding the ecosystem, while others develop processes and mechanisms to facilitate stakeholders’ participation in the planning and decision-making. These are all key aspects of transdiciplinarity, even though they may not use the term. In many ways, transdisciplinarity is easy to practice, if the inclination is there, since it is intuitive, and even natural to do so. If scientists lack knowledge about a certain aspect of an ecosystem, for instance, they can continue to do research and investigation in their own specific discipline, or they can collaborate with those who have different experience and knowledge, both formal and informal. All scientists can in fact benefit from folk models in their own research as a source of identifying research questions and hypotheses, and in using that research to help form policy. For this to happen, they need to overcome a lack of trust or a concern about the validity of non-scientific data. They also need to figure out how to put the pieces together, which might require unconventional methods. This is when transdisciplinary science and transdisciplinary governance come into play.

Transdisciplinarity involves more than the universal knowledge of science and the context-specific knowledge that social science offers. Transdisciplinary science integrates knowledge of multiple academic disciplines and the contextual and ethically founded 'phronetic knowledge' of stakeholders (Flyvbjerg, 2003; Jentoft, 2006). Transdisciplinary scholars have been developing theories and methods to help guide transdisciplinary research (see for example Lang et al., 2012). The application and practice of transdiciplinarity have also been integrated in the way issues concerning small-scale fisheries are identified and knowledge produced (Chuenpagdee and Jentoft, 2018b). In line with Rittel and Webber's (1973) description of the nature of wicked problems, as well as the interactive governance perspective, advanced by Jan Kooiman (2003), the starting point for transdisciplinarity is the wicked nature of problems and how stakeholders define and deliberate them. It is fair to assume, for instance, that different stakeholders, small-scale fishers being one of them, would have different ideas about what an MPA is, and what it is for. While there may not be a pre-existing solution to a wicked problem, a deliberative process can be facilitated to help stakeholders imagine and agree on how to define the problem. This is why step zero is essential in the MPA implementation process (Barragan-Paladines and Chuenpagdee, 2017), and why scientists need to focus on it.

Not all marine-related problems are wicked, but many of them are; therefore they require a different way to approach them. Co-identifying and co-defining the problem, whether it is differently perceived from multiple perspectives or not, is part of the transdisciplinary approach to understand the problem. The identification of the wicked problem must be accompanied by humility with respect to the role of scientists, managers and policymakers, since the problems that seem familiar to the 'experts' might actually have different origins and characteristics and thus may not be simple to solve, especially if the 'experts' have not correctly identified the nature of the problem itself. An ability to recognize the uncertainty and fuzziness around problem definition can be developed through an inclusive process with researchers, practitioners, resource users, governments and other relevant actors taking turns to talk about how they see the problems and what they think of them. Such a process needs to be competently facilitated to enable respectful engagement and interactive learning, without domination or inappropriate influence from any group. Learning to listen to others and trying to understand what could have informed certain perceptions and understandings is a good transdisciplinary practice, including when the issue is how to best design and implement an MPA as a just and strong institution that brings equity and fairness to small-scale fisheries (see Box 17.1).

Box 17.1

Making MPAs work

As a concept, it is hard not to agree that conservation and protection of marine areas, and the ecosystem and the resources therein, can only be a good thing. So why is it that the Aichi Target has not been met and the MPAs that have been established often fail to deliver? One reason is that MPAs are treated too often as a management tool to quickly fix a technical problem, and not often enough as a governance approach to address a complex and wicked problem. Treating MPAs as the former is straightforward, especially when the officials have already made most of the decisions about what type of MPA to use, where to place them and what is allowed or restricted. That approach does not, however, often deliver the desirable outcomes, in part because people may revolt against the rules and choose not to follow them.

Approaching MPAs from the interactive governance perspective, employing transdisciplinary principles, can at least bring about a better and more comprehensive understanding of the natural and social systems that interact with each other in the marine area, as well as the appropriate nature of any potential governing system. The inclusion of social justice and equity principles in marine conservation, focusing especially on the issues and concerns of small-scale fishing communities who are the rightful users of marine resources and occupiers of the ocean and coast, can help achieve precautionary principles underlying the concept of MPAs. The discussion needs to be elevated from thinking of MPAs as the first-order tool to be used to control behavior, to investigating why MPAs are implemented in the first place, how they are initiated and promoted, by whom, what they intend to do, how they should operate, and who should have priority access, if anyone. The transdisciplinary process could more often lead not only to the broadening of knowledge about the marine ecosystem, including the people dependent upon it, but also to the formulation of appropriate institutions with agreed-upon problem definitions, concerns, rules and regulations. Ultimately, it could lead to the achievement of desirable goals following the values, images and principles that stakeholders, policymakers and managers share. It is possible then to incorporate Blue Justice principles for small-scale fisheries in the planning of the Blue Growth and Blue Economy initiatives.

References

Barbesgaard, M. (2017). Blue Growth: Savior or Ocean Grabbing? Journal of Peasant Studies, 45(3), 1-20.

Barragan-Paladines, M. J., & Chuenpagdee, R. (2017). A step zero analysis of the Galapagos Marine Reserve. Coastal Management. https://doi.org/10.1080/08920753.2017.1345606

Bavinck, M., Berkes, F., Charles, T., Esteves Dias, A. C., Doubleday, N., Nayak, P., & Sowman, M. (2017). The impact of coastal grabbing on community conservation – a global reconnaissance. Maritime Studies, 16(8). https://doi.org/10.1186/s40152-017-0062-8

Berger, P. L., & Luckmann, T. (2011). The Social Construction of Reality: A Treatise in the Sociology of Knowledge. Open Road Media.

Christie, P., Bennett, N. J., Gray, N. J., Wilhelm, T. A., Lewis, N., Parks, J., Ban, N. C., Gruby, R. L., Gordon, L., Day, J., Taei, S., & Friedlander, A. M. (2017). Why people matter in ocean governance: Incorporating human dimensions into large-scale marine protected areas. Marine Policy, 84, 273–284.

Christie, P., McCay, B. J., Miller, M. L., Lowe, C., White, A. T., Stoffle, R., Fluharty, D. L., Talaue McManus, L., Chuenpagdee, R., Pomeroy, C., Suman, D. O., Blount, B. G., Huppert, D., Villahermosa Eisma, R. L., Oracion, E., Lowry, K., & Pollnac, R. B. (2003). Toward developing a complete understanding: A social science research agenda for marine protected areas. Fisheries, 28(12), 22-26.

Chuenpagdee, R. (2011). Interactive governance for marine conservation: An illustration. Bulletin of Marine Science, 87(2), 197-211.

Chuenpagdee, R., & Jentoft, S. (2018a). Transforming the governance of small-scale fisheries. Maritime Studies, 17(1), 101-115. https://doi.org/10.1007/s40152-018-0087-7

Chuenpagdee, R., & Jentoft, S. (Eds.). (2018b). Transdisciplinarity for Small-Scale Fisheries Governance: Analysis and Practice. MARE Publication Series 21, Springer, Switzerland.

Chuenpagdee, R., & Jentoft, S. (2009). Governability assessment for fisheries and coastal systems: A reality check. Human Ecology, 37, 109-120.

Chuenpagdee, R., De La Cruz-Modino, R., Barragán-Paladines, M. J., Glikman, J. A., Fraga, J., Jentoft, S., & Pascual-Fernández, J. J. (2019). Governing from images: Marine protected areas as case illustrations. Journal for Nature Conservation, 53. https://doi.org/10.1016/j.jnc.2019.125756

Chuenpagdee, R., Pascual-Fernandez, J. J., Szelianszky, E., Alegret, J. L., Fraga, J., & Jentoft, S. (2013). Marine protected areas: Re-thinking their inception. Marine Policy, 39, 234-240.

Degnbol, P., Gislason, H., Hanna, S., Jentoft, S., Nielsen, J. R., Sverdrup-Jensen, S., & Wilson, D. C. (2005). Painting the floor with a hammer: Technical fixes in fisheries management. Marine Policy, 30, 534-543.

Devillers, R., Pressey, R. L., Grech, A., Kittinger, J. N., Edgar, G. J., Ward, T., & Watson, R. (2014). Reinventing residual reserves in the sea: Are we favouring ease of establishment over need for protection? Aquatic Conservation: Marine and Freshwater Ecosystems, 1–25.

FAO. (2015). Voluntary Guidelines for Securing Sustainable Small-Scale Fisheries in the context of Food Security and Poverty Eradication. Food and Agriculture Organization of the United Nations, Rome, Italy.

FAO. (2005). The Code of Conduct for Responsible Fisheries. Food and Agriculture Organization of the United Nations, Rome, Italy.

Ferse, S. C. A., Costa, M. M., Máñez, K. S., Adhuri, D. S., & Glaser, M. (2010). Allies, not aliens: increasing the role of local communities in marine protected area implementation. Environmental Conservation, 37(1), 23–34.

Flyvbjerg, B. (2003). Making Social Science Matter: Why Social Inquiry Fails and How It Can Succeed Again. Cambridge: Cambridge University Press.

Howard, B. C. (2018). Blue growth: stakeholder perspective. Marine Policy, 87, 375-377.

Jentoft, S. (2020). Splitting hairs. Samudra Report No. 83; September.

Jentoft, S. (2014). Walking the talk: implementing the International Voluntary Guidelines for Small-Scale Fisheries. Maritime Studies, 13, 16.

Jentoft, S. (2006). Beyond fisheries management: The Phronetic dimension. Marine Policy, 30, 671-680.

Jentoft, S., & Chuenpagdee, R. (2009). Fisheries and coastal governance as a wicked problem. Marine Policy, 33, 553-560.

Jentoft, S., & Chuenpagdee, R. (2015). Assessing Governability of Small-Scale Fisheries. In Jentoft and Chuenpagdee (eds.) Interactive Governance for Small-Scale Fisheries: Global Reflections. Springer, Switzerland.

Jentoft, S., & Chuenpagdee, R. (2022). Interactive learning and governance transformation for securing Blue Justice for small-scale fisheries. Administration and Society. https://doi.org/10.1177%2F00953997211073947

Jentoft, S., Chuenpagdee, R., & Pascual-Fernandez, J. (2011a). What are MPAs for: On goal formation and displacement. Ocean & Coastal Management, 54, 75-83.

Jentoft, S., Pascual-Fernandez, J. J., De la Cruz Modino, R., Gonzalez-Ramallal, M., & Chuenpagdee, R. (2011b). What stakeholders think about marine protected areas: Case studies from Spain. Human Ecology. DOI 10.1007/s10745-012-9459-6.

Jentoft, S., van Son, T. C., & Bjorkan, M. (2007). Marine protected areas: a governance system analysis. Human Ecology, 35(5), 611–622. https://doi.org/10.1007/s10745-007-9125-6.

Kooiman, J. (2003). Governing as Governance. London: Sage.

Kooiman, J., & Jentoft, S. (2009). Meta-governance: Values, norms and principles, and the making of hard choices. Public Administration, 87(4), 818–836. https://doi.org/10.1111/j.1467-9299.2009.01780.x.

Lang, D. J., Wiek, A., Bergmann, M., Stauffacher, M., Martens, P., Moll, P., Swilling, M., & Thomas, C. J. (2012). Transdisciplinary research in sustainability science: practice, principles, and challenges. Sustainability Science, 7(1), 25–43.

Mahon, R. (2008). Assessing governability of fisheries using the interactive governance approach: Preliminary examples from the Caribbean. The Journal of Transdisciplinary Environmental Studies, 7(1), 1-12. Retrieved from http://www.journal-tes.dk/

Mitchell, R. K., Agle, B. R., & Wood, D. J. (1997). Towards a theory of stakeholder identification: Defining the principle of who and what really counts. Academy of Management Review, 22(4), 853-886.

Pascual-Fernandez, J. J., De la Cruz Modino, R., Chuenpagdee, R., & Jentoft, S. (2018). Synergy as strategy: learning from La Restinga, Canary Islands. Maritime Studies. https://doi.org/10.1007/s40152-018-0091-y

Piketty, T. (2020). Capital and Ideology. Cambridge, Mass: Harvard University Press.

Rawls, J. (1971). A Theory of Justice. Cambridge, Mass: Harvard University Press.

Rittel, H. W. J., & Webber, M. M. (1973). Dilemmas in a general theory of planning. Policy Sciences, 4, 155-169.

Said, A., & Chuenpagdee, R. (2019). Aligning the sustainable development goals to the small-scale fisheries guidelines: A case for EU fisheries governance. Marine Policy, 107. https://doi.org/10.1016/j.marpol.2019.103599

Said, A., Chuenpagdee, R., Aguilar-Perera, A., Arce-Ibarra, M., Gurung, T. B., Bishop, B., Léopold, M., Márquez Pérez, A. I., Gomes de Mattos, S. G., Pierce, G. J., Nayak, P. K., & Jentoft, S. (2018). The principles of transdisciplinary research in small-scale fisheries. In Chuenpagdee and Jentoft (eds.). Transdisciplinarity for Small-Scale Fisheries Governance: Analysis and Practice. MARE Publication Series 21, Springer, Switzerland.

Scott, W. R. (1995). Institutions and Organizations. London: Sage.

Sen, A. (2009). The Idea of Justice. London: Allen Lane.

Voorberg, W., & Van der Veer, R. (2020). Co-Management as a Successful Strategy for Marine Conservation. Journal of Marine Science and Engineering, 8(7), 491. https://doi.org/10.3390/jmse8070491.

Xavier, L. Y., Jacobi, P. R., & Turra, A. (2018). On the advantages of working together: social learning and knowledge integration in the management of marine areas. Marine Policy, 88, 139-150.

Diverse voices foster diverse solutions

The short perspective pieces gathered here represent the insights of leading scholars and practitioners that have engaged new and previously under-represented people in a transdisciplinary approach to marine conservation.

Daniela V. Fernandez founded Sustainable Ocean Alliance (SOA) when she was just 19 years old and here explains and promotes youth-led movements for the oceans.

Leo C. Gaskins and **Julia K. Baum** focus their perspective on people currently under-represented in the broader field of marine conservation scholarship and practice, including women, LGBTQ+, and POC researchers.

Asha de Vos is from Sri Lanka and leads the international NGO Oceanswell. Her essay focuses on engaging local partners in research and conservation by building equitable relationships.

Aliyah Griffith is CEO and founder of Mahogany Mermaids, an organization formed to encourage young people of color to enter the fields of aquatic science and conservation.

Lorna Inniss is an internationally known coastal manager and trainer. Here she shares her insights on the role of science, policy, and business in Small Island Developing States (SIDS).

Han Han, is the founder and CEO of China Blue, one of the first marine conservation NGOs in China. Here she shares her perspectives on building capacity among individuals and networks to promote ocean sustainability.

18. Advancing youth-led movements for the ocean is essential

Daniela Fernandez[1]

It is impossible to conserve what is actively being destroyed. Rising sea levels, a warming ocean, and an undeniable crisis of marine biodiversity are all issues intimately connected to and exacerbated by perhaps the largest global challenge facing society—that of the climate crisis.

Scientists have determined with 95% accuracy that this crisis is man-made—due to humanity's burning of fossil fuels (IPCC, 2014). As early as 1977, oil, gas, and coal industry leaders were aware of fossil fuels' treacherous impacts on the global climate. By 1988, a NASA scientist warned the U.S. Congress of the resulting planetary warming and Earth's alarming climate trajectory (Hall, 2015). Yet their use persisted, and the ocean has continued to pay the price, absorbing the impacts of the burning of fossil fuels, emissions from which reached a record high in 2023 (Friedlingstein & Le Quéré, 2023).

Who is to blame? The fault indisputably lies with the private and public sector leaders of the past and present generation. Their inaction in the face of a known, intensifying climate crisis has resulted in the human-caused warming of the ocean (Hayhoe, 2018) and compounding biodiversity crises (Harfoot et al., 2018). Aging leaders have chosen time and again to ignore science and continue making perilous business decisions enabled by bad policy in the interest of power and profit. A 2023 UN Environment Program report revealed that despite fossil fuel usage reduction commitments, the top 20 oil-producing nations still had plans to expand fossil fuel production beyond science-based targets to reduce global warming (SEI, 2023).

But all of that is changing, thanks to young people. In late 2023, at the 28th United Nations Climate Change Conference (COP28) world leaders finally agreed to a "fossil fuels phase out" (UN, 2023), the implementation of which is pending. Despite extreme pushback from the fossil fuel industry (Abnett et al., 2023), tireless youth, indigenous leaders, scientists, and countless advocates for the non-proliferation of fossil fuels (Who has endorsed?) on behalf of the planet and ocean have at last prevailed.

It is my perspective that the 'beginning of the end' of the fossil fuel era would not be within reach without young people's persistence. They have loudly demanded urgent action from elected officials, ushered in innovation, compelled industry disruption in the private sector, and are committed to upending the global status quo on climate. It is young people who represent hope for the planet and ocean.

My unique lived and professional experience as a young, female, founder and CEO of color in the ocean sector has driven my vision for and perspective on ocean sustainability—namely, that it requires the advancement of cross-sector, youth-led movements.

In this chapter, I will outline my foundational experience as a young person catalyzed to tackle the climate crisis; offer evidence of the sustained and increasing harm the ocean has faced under aging global leadership; share my reasoning for founding a nonprofit organization focused on the ocean as a teenager; call out the

1 Sustainable Ocean Alliance.

 https://doi.org/10.11647/OBP.0395.18

necessary activation of youth advocates in the ocean field; detail examples of youth-led ocean policy advocacy; explain the sustainable Blue Economy investment landscape; amplify select, existing for-profit ocean solutions; and recap what comes next as youth develop the blueprint for the future of ocean health, the planet, and humanity.

My origins in the climate and ocean movement

Despite pervasive reverse ageism, in society, the workforce, and the nonprofit sector (Raymer et al., 2017), I've never allowed stereotypes about my age to be an obstacle. My origins in the climate movement can be traced back to when I was 12 as a result of watching *An Inconvenient Truth*.

When the documentary first premiered in 2006, it was heralded by most critics as a wake-up call for the masses. A *New York Times* reviewer stated that it was the first time he heard "gasps of horror" in reaction to a graph in a documentary (NPR, 2006). Not only did Al Gore confirm any latent unease the audience of the film had about the climate, he also broadened the aperture on the true cost of global warming and created a classroom staple to mobilize a generation of young people (Scott, 2006). Despite the appeals of climate deniers to keep the documentary out of classrooms, young people today are more certain of the impact of the climate crisis than ever before (Benda, 2007).

How contemporary governance has failed the ocean

In 2019, in the U.S., the average age of Republican leadership was 53, and Democrats had an average leadership age of 71. In its most recent presidential election, the U.S. elected its oldest president ever (Schaul et al., 2019). Despite policy mandates like 2004's *An Ocean Blueprint for the 21st Century*, the health of our ocean has continued to steadily decline under the aging elected officials who comprise contemporary governance (U.S. Commission on Ocean Policy, 2004).

As recently as last year, the United Nations (UN) reported that, since 1980, plastic pollution has increased tenfold. They found that each year, eight million metric tons of plastic are dumped into the ocean. This level of plastic pollution puts the entire marine ecosystem in jeopardy, impacting everything from seabirds to turtles (United Nations, 2019). More and more, plastic is accumulating in the deep ocean and disturbingly large garbage gyres (Kaza et al., 2018). The impact of this new concentration of plastic remains to be seen.

Similarly, marine restoration efforts are battling exponential acidification and warming of our ocean, with some estimates stating that, by the end of this century, ocean surface waters could be nearly 150% more acidic than they are now (NOAA). As a result, marine biologists now expect up to 90% of coral reefs to die off by 2050 (Liu, 2018). This is bad news for an already unstable ecosystem that has lost roughly half of its reefs in the past 30 years (Denchak, 2022). The Scripps Institute of Oceanography states that coral ecosystems are a source of food for millions and are a "hotspot of marine biodiversity." It is simply impossible to imagine successful, sustainable ocean action without them (Scripps Institution of Oceanography, n.d.).

Founding a youth-led, ocean-solutions nonprofit

While the statistics on the declining health of the ocean are fairly recent, even back in 2014 when I was an undergraduate at Georgetown University, I already saw the writing on the wall. It troubled me that, despite warnings from academia, science, and, in the case of *An Inconvenient Truth*, pop culture, the current approach to marine preservation was not working to counter the most pressing problems facing the ocean. I knew that we had to start looking for innovative solutions and leaders beyond publishing a lot of studies from PhDs that would ultimately be ignored by politicians.

After attending a UN meeting focused on the world's problems with no discussion of solutions, I took action and founded Sustainable Ocean Alliance (SOA) when I was only 19. I was determined to empower youth to drive meaningful change and restore ocean health in this lifetime.

Flash forward to today, and it has never been more apparent that a youth-led, solutions-oriented movement is required. Millennial and Gen Z voters across the political spectrum agree actions on climate are currently insufficient. Nearly half of Republican voters between the ages of 18 and 29 believe the Federal Government is doing too little to reduce the effects of climate change (Pew Research Center, 2022).

Overwhelmingly, nearly three-quarters of Democratic voters in the same demographic age group feel the current administration could be doing a lot more (Kennedy, 2022). With half the country currently aged 38 or younger, compared to just 5% of the U.S. Congress (Fu et al., 2022), diversifying the age of elected officials could go a long way to passing ambitious climate policy that would satisfy concerns from young people across the aisle.

In the private sector, diverse leadership amongst top management teams (TMT) and TMT collaboration with youth, especially from universities, has been established as a driver of sustainable business model innovations (SBMI) (Dhir et al., 2023). To attract and retain top talent among rising generations, corporate leadership must consider that over 40% of global Millenials and Gen Z would or already have switched jobs and even industries over climate concerns (Deloitte, 2023).

It is encouraging to see that across sectors, youth are demanding intergenerational perspectives and the prioritization of climate action amongst leadership. Over the past decade, in my role as founder and CEO of SOA, I have seen the consequences of a true climate crisis play out in our ocean. Now more than ever before, it is important that we bring young people into the ocean field, as well as expand the scope of what taking action on behalf of ocean preservation and restoration can look like.

The (necessary) activation of youth advocates

For too long, the ocean restoration field has maintained a reputation of exclusivity. Historically, passionate activists have been expected to 'do their time' as scientific practitioners or policy advisors before earning the right to be heard and make change. However, in recognition of the need for a new approach, there has been a newfound embrace of young people as instrumental members of the environmental movement. A UN Environment Programme survey found that close to half a million youth around the world have already taken action on climate change through small grants program projects in their homes, schools, and communities (United Nations, n.d.).

In my role as founder and CEO of SOA, I have seen our Ocean Leaders recruited to lead or support national and global policy initiatives and marine preservation efforts. Young ocean leaders from over 165 countries have joined our Ocean Leadership Program. In 2019 alone, we helped over 100 young people get a seat at the table at the UN climate talks. We provided our delegation with travel arrangements, offered support securing visas, distributed grants to young people to develop educational materials, enabled access to talks, events, negotiations, and more. In 2023, SOA became the first youth-led organization to secure official observer status with the International Seabed Authority (ISA) (Tewes, 2023).

Our delegation, led by Anne-Sophie Roux, Daniel Caceres, and Khadija Stewart, advocated against a harmful nascent industry that, if approved, could be the world's next colossal energy mistake—this generation's equivalent to approving the extraction of fossil fuels (Fernandez & Gianni, 2023). But this time, youth have a seat at the table with this UN governing body and are advocating for a moratorium on proposed deep-sea mining to preserve the planet's last pristine ecosystem and benefit humankind. Caceres is spearheading SOA's Latin America effort, where Brazil, Chile, Costa Rica, Mexico, and Panama now support a moratorium on exploiting the deep (Bowen, 2023). Stewart founded Ecovybz to educate and unite Caribbean youth environmental creatives. Roux has become a spokesperson for the cause of defending the deep in Europe, after spearheading the successful youth-led #Lookdown campaign in France, securing the world's only total ban, at the time of writing (Meredith, 2024).

Another example is SOA Ocean Leader Ifeoluwa Omoyeni, who has focused her attention and activism on developing solutions to fishery and aquaculture development challenges. Through her SOA project, she has sought to bring awareness to small-scale, sustainable fisheries (Sustainable Ocean Alliance, 2019). Not only are these fisheries important for national economies, but they also provide more nutrient-rich food to the population, while offering a stable income to those whose nutritional and financial needs are the greatest. Through her dedicated work in conservation, Omoyeni has become a volunteer advocate for the UN's Sustainable Development Goals, as well as securing membership to the Fisheries Society of Nigeria—and all this before turning 22 years old. As Caceres, Stewart, Roux, and Omoyeni exemplify, youth in the climate and ocean restoration movement dare to lead, and to think outside the box. That makes them valuable to the institutions tasked with solving the incredibly complex challenge of climate change and ocean health. As proof of how youth perspectives are increasingly valued, in 2022, the UN Development Programme published guidance for elevating meaningful youth engagement with climate action (Ingaruca, 2022).

Investing in a sustainable Blue Economy

Up until the past few years, entrepreneurship and scalable technologies developed by industry had been surprisingly absent from the ocean field. While other green sectors, like alternative energy, have long encouraged a three-pronged approach to solution-building—encompassing academia, government, and industry—historically, ocean solutions have been almost exclusively developed by academia or government. When I first founded SOA, I was discouraged from beginning an entrepreneurial project in support of ocean health. Those in power told me I was too young, and that tech and private industry ocean solutions were not the right path forward.

Fortunately, as SOA's continued success proves, this staid era has come to a close. As the health of the ocean has worsened in the intervening years since I founded SOA, it has become clear that a 'business-as-usual approach' will not bring about the change we need. Investment in the Sustainable Blue Economy is required—and a lot of it. The ocean/life below water needs an estimated $175 Billion USD annually to achieve sustainable ocean outcomes by 2030 (Conrad & Singh, 2022).

Until recently, the way investment was traditionally structured in the ocean ecosystem had been a barrier to progress. In *An Ocean Blueprint for the 21st Century*, one of the primary financial recommendations was that the U.S. government "double the nation's investment in ocean research." While this strengthened an academic ecosystem of discovery, it overlooked any support for industry-led innovation. The Sea Grant program, which saw continued expansion under Bush in 2004, to this day still only offers support for academic research and regional solutions spun out of labs, as opposed to larger entrepreneurial visions that might have the potential to scale and drive larger impact (U.S. Commission on Ocean Policy, n.d.).

The good news is that this too is changing. In 2016, ten years after *An Inconvenient Truth* first debuted, Al Gore once again challenged society on the way they were approaching climate change. While Gore still understands the importance of policy, he sat down with WIRED and emphasized the value of technology when it comes to really moving the needle on this crisis (Lapowsky, 2016).

During this interview, he spoke about a number of his beliefs, including the democratization of climate research and information that has come through the internet, as well as the burgeoning dedication of big tech companies to reducing their carbon footprint and developing new climate solutions. He declared that there will always be a need for academic research and government dedication to the pursuit of ocean restoration. But to imagine a protected and productive ocean industry, young people must be involved in evolving these sectors.

Further, Gore asserted this will need to be paired with entrepreneurial innovation from young people, or the ocean movement is destined to come up short.

That is why, five years after starting the first ever Ocean Solutions Accelerator Program through SOA, it is so encouraging to see a growing ecosystem of private investment in ocean tech (Coldewey, 2018). A 2020 survey by Responsible Investor found that nine out of ten institutional investors are now interested in financing the sustainable ocean economy (Responsible Investors Research, n.d.).

It is little wonder why other researchers are continually validating the value of ocean restoration or exploration technologies. For example, CNBC reported that for every $1 invested in decarbonizing global shipping and reducing carbon emissions to net zero, researchers expect an estimated return of $2 to $5 (Newburger, 2020). The same article quotes research (High Level Panel for Sustainable Ocean Economy, n.d.), which found that "over the next 30 years, investing $2 trillion to $3.7 trillion globally across several sustainable ocean-based policy interventions would generate a net benefit of $8.2 trillion to $22.8 trillion."

Youth-led private sector innovation for the ocean

Young people are some of the primary drivers of this emerging market. According to the UK Centre for Entrepreneurs, young people are starting twice as many businesses as the baby boomer generation. SOA has also seen firsthand the way that young people are uniquely suited to pursue ocean entrepreneurship and drive the adoption of more technology in the ocean conservation field (Centre for Entrepreneurs, 2015). Among the 29 companies that SOA has accelerated in the past two years, 14 have featured founders under the age of 35.

The spirit of innovation that young people bring to the ocean field is crucial to developing meaningful solutions. If the dire state of the ocean today teaches us anything, it is that if we are going to slow the damage to our ocean and begin to reverse it, we need to invest in new technologies and leaders.

One example is SOA Young Ocean Leader Alexander Dungate, who is making strides in technological innovation for the ocean. After graduating from the University of British Colombia Sauder School of Business in 2022, he launched On Deck Fisheries AI. He has intentionally hired alumni and students of his alma mater to build this youth-led business, including SOA Young Ocean Leader Bodhi Patil as Head of Impact (Fernandez et al 2023.) SOA was proud to provide a grant to achieve their goal of leveraging artificial intelligence and human expertise to efficiently and affordably monitor fisheries activities. Canada's Ocean Supercluster recently awarded the startup $1.5 million to further scale impact globally (Riehl, 2023).

Meanwhile, SOA Ecopreneur Network's Sampriti Bhattacharyya is the Founder and CEO of Navier. Her startup is advancing all-electric, hydrofoil boats to disrupt maritime transportation. A recently launched pilot program in San Francisco Bay will enable the startup to refine its onboard, autonomous navigation technologies before scaling to larger vessels, with the hope of ushering in a new era of waterborne, zero-emission commutes (Coldewey, 2024).

What comes next

As young leaders continue to advance and assume positions of power, I think it is highly likely that we see a stronger relationship between policy, academic, and industry solutions moving forward.

We have already seen the impact young people can have influencing elections and advocating for more stringent climate policy. Young people are turning out in droves to vote (Center for Information and Research on Civic Learning & Engagement, 2020). They are also advocating with global governing bodies for planet- and ocean-friendly policies. In the private sector, youth are founding disruptive entrepreneurial endeavors as a means to advance ocean preservation and restoration. Young people will be crucial to advancing, evolving, and maturing the emerging ocean tech field and sustainable Blue Economy.

Given the urgency of the climate, ocean, and biodiversity crises, which are driven by human activities, it is time we see a diversification of leadership across all sectors. It is my perspective that young people are already and will increasingly be integral to establishing a blueprint for progress across all the different avenues that exist to tackle climate change and ocean health.

What is certain is that what we have seen so far is just the beginning, and the cross-sector activation of youth comes at a pivotal time. Our ocean is in crisis, and we need to find ways to systemically integrate youth perspectives and youth-led solutions in ocean protection measures. Young people are laying the groundwork to revolutionize society and demanding, not just a seat at the table, but the table itself. Young people are quite literally the future of humanity; they should have a say in shaping it.

References

Abnett, K., Volcovici, V., & Saba, Y. (2023, December 9). COP28 clashes over fossil fuel phase-out after OPEC pushback | Reuters. Reuters. https://www.reuters.com/business/environment/opec-members-push-against-including-fossil-fuels-phase-out-cop28-deal-2023-12-09/

Benda, M. (2007, August 15). Should 'an inconvenient truth' be shown in science class? Yes. Mackinac Center. https://www.mackinac.org/8838

Bowen, L. (2023, December 18). Daniel Caceres Live from COP28 on ocean-based Climate Solutions. YouTube. https://www.youtube.com/watch?v=t-a9TpqPqx0

Center for Information and Research on Civic Learning & Engagement. (2020, October 30). Absentee and early voting by youth in the 2020 election. https://circle.tufts.edu/latest-research/absentee-and-early-voting-youth-2020-election

Coldewey, D. (2024, January 17). Navier partners with stripe to offer electric boat commute to far-flung employees. TechCrunch. https://techcrunch.com/2024/01/17/navier-partners-with-stripe-to-offer-electric-boat-commute-to-far-flung-employees/

Coldewey, D. (2018, January 17). The Ocean Solutions Accelerator will nurture companies looking to keep our planet blue. TechCrunch. https://techcrunch.com/2018/01/17/the-ocean-solutions-accelerator-will-nurture-companies-looking-to-keep-our-planet-blue/

Conrad, J., & Singh, G. (2022, June). SDG 14 Financing Landscape Scan: Tracking funds to realize sustainable outcomes for the Ocean. weforum.org. https://www3.weforum.org/docs/WEF_Tracking_Investment_in_and_Progress_Toward_SDG14.pdf

Denchak, Melissa. (2022, June 7). Ocean pollution: The dirty facts. NRDC. https://www.nrdc.org/stories/ocean-pollution-dirty-facts

Deloitte Touche Tohmatsu Limited ("DTTL"). (2023). The Deloitte Global 2023 gen Z and millennial survey. Deloitte. https://www.deloitte.com/global/en/issues/work/content/genzmillennialsurvey.html

Dhir, A., Khan, S. J., Islam, N., Ractham, P., & Meenakshi, N. (2023). Drivers of sustainable business model innovations. an upper echelon theory perspective. Technological Forecasting and Social Change, 191, 122409. https://doi.org/10.1016/j.techfore.2023.122409

Hall, S. (2015, October 26). Exxon knew about climate change almost 40 years ago. Scientific American. https://www.scientificamerican.com/article/exxon-knew-about-climate-change-almost-40-years-ago/

Fernandez, D., & Gianni, M. (2023, April 3). We must stop deep-sea mining before it begins. Context. https://www.context.news/nature/opinion/we-must-stop-deep-sea-mining-before-it-begins

Fernandez, D., & Peace, R. (2024, January 18). Planet & purpose. (S. Skelly, Ed.)LinkedIn. Retrieved March 8, 2024, from https://www.linkedin.com/pulse/indigenous-wisdom-weaving-bodhi-patil-ocean-climate-fernandez-gqx4c/?trackingId=iQWqucDtTuKp7UcPoJLhsQ%3D%3D.

Friedlingstein, P., & Le Quéré, C. (2023). (rep.). Global Carbon Budget 2023. Future Earth, World Climate Research Programme, University of Exeter. Retrieved March 5, 2024, from https://globalcarbonbudget.org/fossil-co2-emissions-at-record-high-in-2023/

Fu, A., Hickey, W., & Gal, S. (2022, September 13). 6 charts that explain the United States' march toward gerontocracy.

Business Insider. https://www.businessinsider.com/gerontocracy-united-states-congress-red-white-and-gray-data-charts-2022-9

Harfoot, M. B., Tittensor, D. P., Knight, S., Arnell, A. P., Blyth, S., Brooks, S., Butchart, S. H., Hutton, J., Jones, M. I., Kapos, V., Scharlemann, J. P. W., & Burgess, N. D. (2018). Present and future biodiversity risks from fossil fuel exploitation. Conservation Letters, 11(4). https://doi.org/10.1111/conl.12448

Hayhoe, K., D.J. Wuebbles, D.R. Easterling, D.W. Fahey, S. Doherty, J. Kossin, W. Sweet, R. Vose, and M. Wehner, 2018: Our Changing Climate. In Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 72–144. https://doi.org/10.7930/NCA4.2018.CH2 https://nca2018.globalchange.gov/chapter/2/

The High Level Panel for a Sustainable Ocean Economy. WRI Ocean Panel. (n.d.). https://oceanpanel.org

Ingaruca, M. (2022). Elevating meaningful youth engagement for climate action. undp.org. https://www.undp.org/sites/g/files/zskgke326/files/2022-05/UNDP-Elevating-Meaningful-Youth-Engagement-for-Climate-Action-2.pdf

IPCC, 2014: Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.

Kaza, Silpa; Yao, Lisa C.; Bhada-Tata, Perinaz; Van Woerden, Frank. (2018). What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050. Urban Development;. Washington, DC: World Bank. © World Bank. https://openknowledge.worldbank.org/handle/10986/30317 License: CC BY 3.0 IGO.

Kennedy, B. (2022, July 14). Americans divided over direction of Biden's climate change policies. Pew Research Center Science & Society. https://www.pewresearch.org/science/2022/07/14/americans-divided-over-direction-of-bidens-climate-change-policies/

Lapowsky, I. (2016, May 24). 10 years after an inconvenient truth, Al Gore may actually be winning. Wired. https://www.wired.com/2016/05/wired-al-gore-climate-change

Liu, M. (2018, March 23). Great Pacific Garbage Patch Now Three Times the Size of France. CNN. https://www.cnn.com/2018/03/23/world/plastic-great-pacific-garbage-patch-intl

Meredith, S. (2024, January 29). Norway defends deep-sea mining, says it may help to break China and Russia's rare earths stronghold. CNBC. https://www.cnbc.com/2024/01/29/norway-defends-deep-sea-mining-as-a-necessary-step-into-the-unknown.html

National Oceanic and Atmospheric Administration. (n.d.). Understanding Ocean Acidification. NOAA Fisheries. https://www.fisheries.noaa.gov/insight/understanding-ocean-acidification#:~:text=Estimates%20of%20future%20carbon%20dioxide,more%20than%2020%20million%20years

Newburger, E. (2020, July 14). Investors' next high-yield bets should be on ocean sustainability, researchers say. CNBC. Retrieved September 12, 2022, from https://www.cnbc.com/2020/07/13/heres-the-economic-case-for-investing-in-oceans.html

NPR. (2006, May 24). Assessing the art, science of 'Inconvenient truth'. NPR. https://www.npr.org/2006/05/24/5428154/assessing-the-art-science-of-inconvenient-truth

Pew Research Center. (2022, July 12). Younger Republicans particularly likely to say federal government is doing too little on the environment. Pew Research Center Science & Society. https://www.pewresearch.org/science/2022/07/14/americans-divided-over-direction-of-bidens-climate-change-policies/ps_2022-07-14_climate-change-policies_00-015/

Raymer, M., Purvanova, R. K., Spiegel, M., & Reed, M. (2017). The Psychologist-Manager Journal, 20(3). https://www.apa.org/pubs/journals/features/mgr-mgr0000057.pdf

Responsible Investors Research. Investors & the blue economy: Responsible Investor research. (n.d.). Retrieved September 12, 2022, from https://www.esg-data.com/blue-economy

Riehl, A. (2023, October 3). Ocean Supercluster announces $20 million investment in nine new AI-powered Ocean Projects. BetaKit. https://betakit.com/ocean-supercluster-announces-20-million-investment-in-nine-new-ai-powered-ocean-projects/

Scott, A. O. (2006, May 24). Warning of calamities and hoping for a change in 'an inconvenient truth'. The New York Times. https://www.nytimes.com/2006/05/24/movies/24trut.html

Scripps Institution of Oceanography. (n.d.). Coral Reef Systems. https://coralreefsystems.ucsd.edu/about-coral-reefs/value-of-corals

SEI, Climate Analytics, E3G, IISD, and UNEP. (2023). The Production Gap: Phasing down or phasing up? Top fossil fuel producers plan even more extraction despite climate promises. Stockholm Environment Institute, Climate Analytics, E3G, International Institute for Sustainable Development and United Nations Environment Programme. https://doi.org/10.51414/sei2023.050

Sustainable Ocean Alliance. (2019, September 2). Blog Series: Meet Our Young Ocean Leaders - Ifeoluwa Omoyeni. https://www.soalliance.org/soablog/meet-our-young-ocean-leaders-0-2

Tewes, E. (2023, November 16). Guardians of the deep: Youth leaders safeguarding our seas. Rise Up For The Ocean. https://riseupfortheocean.org/guardians-of-the-deep-youth-leaders-safeguarding-our-seas/

UN. (2023, December 13). COP28 Agreement Signals "Beginning of the End" of the Fossil Fuel Era. United Nations Climate Change. Retrieved March 5, 2024, from https://unfccc.int/news/cop28-agreement-signals-beginning-of-the-end-of-the-fossil-fuel-era.

United Nations. (2019, May 6). UN report: Nature's dangerous decline 'unprecedented'; species extinction rates 'accelerating'. https://www.un.org/sustainabledevelopment/blog/2019/05/nature-decline-unprecedented-report

United Nations. (n.d.). #YouthStats: Environment and climate change. https://www.un.org/youthenvoy/environment-climate-change

U.S. Commission on Ocean Policy. (2004, September 20). Blueprint for Change: A New National Ocean Policy Framework. https://govinfo.library.unt.edu/oceancommission/documents/full_color_rpt/welcome.html

U.S. Commission on Ocean Policy: Documents. Sea Grant > About. (n.d.). https://seagrant.noaa.gov/About

Who has endorsed?. The Fossil Fuel Non-Proliferation Treaty Initiative. (n.d.). https://fossilfueltreaty.org/endorsements

19. Recruiting, retaining and championing women, LGBTQ+, and POC researchers in marine conservation

Leo C. Gaskins[1] *and Julia K. Baum*

For we, too are oceans,
Or at least beings bobbing in the same boat.
To stand up for our ocean
Is to stand up for our own ship
The sea is a restless, strong collective of many pieces.
So are we.
—Amanda Gorman, 'Ode to the Ocean'

Oceans, powerful forces that hold much of the biological diversity of our planet, are being reshaped by climate change and a myriad of local anthropogenic stressors. Navigating our way to solutions to these complex challenges will require diverse minds, skills, and collaborations. Indeed, the benefits of diverse teams for scientific innovation are widely documented (Nielsen et al., 2017), and ocean resource management and conservation decisions specifically are regarded as benefiting from enhanced diversity (Giakoumi et al., 2021). Yet, marine conservation has historically been dominated by a privileged few—primarily white, cisgender, heterosexual men—and the field remains hampered by a lack of diversity. The privileged few who meet these norms strongly influence the accepted standards, expectations and culture of the field, and it is they who disproportionately reap the benefits. Diverse scientists from underrepresented groups in turn are forced to exist within a patriarchal system—underlaid by white supremacy, heteronormativity and cisgenderism—that is stacked against them. We must all act to change this.

Transforming marine conservation into an equitable and inclusive field in which a diversity of people is welcomed, included, and empowered will require both individual actions and structural changes. Progress toward this goal is often catalyzed by individuals in leadership positions who champion the issue, making it a priority in their organizations. These 'champions' are often themselves individuals who have experienced discrimination, and hence feel a personal connection to the issue, and can speak persuasively to it because of their lived experience. The onus should not, however, be on underrepresented individuals to fix the broken system they have inherited. Instead, we would argue that, despite benefiting from the status quo, those in leadership positions who fit the current norms have a moral obligation to acknowledge their privilege, educate themselves, and invest time and energy working towards this change. Silence or lack of action is complicity and reinforces the status quo. Structural changes also are needed to overcome the many barriers and forms of discrimination

1 David H. Smith Conservation Research Fellow at University of Chicago, and research partner with Audubon Great Lakes, https://scholar.google.com/citations?user=fU5ruHEAAAAJ&hl=en&oi=ao

 https://doi.org/10.11647/OBP.0395.19

that remain prevalent in research labs, eNGOs (environmental non-government organizations), government departments and the many other places where marine conservation work occurs outside of academia. Much has been written recently about the structural changes required to enhance equity, diversity and inclusivity in the workplace, and a comprehensive review of these changes is beyond the scope of this work. However, within this textbook, the chapters collectively highlight the range of groups who conduct important marine conservation work throughout the world, how we can create stronger partnerships between these groups, and how we can make conservation a practice that welcomes and empowers diverse people.

In this chapter, we focus on three groups of underrepresented people—women, LGBTQ+, and people of color (POC)—and, after introducing the issues hindering their progress, we propose solutions specifically to enhance their recruitment and retention into marine conservation, so that they can thrive in this critically important field.

The issues

Sexism and racism permeate all facets of society, with the realm of marine conservation being no exception. Such prejudice and discrimination can manifest in overt acts of bullying, harassment, or assault, or in more subtle actions shaped by unconscious bias. Recent studies have quantified what many of us have known and experienced for years, namely that these biases pervade and influence every component of our professional lives, from university admissions, hiring, promotions and tenure to salaries, awards, the success and size of research grants, citations, and invitations to prestigious events and positions. Discrimination has a compounding effect over time because of the strong positive feedbacks in the system, such that even small biases can amount to significant differences (Martell, Lane, & Emrich, 1996). For example, marine conservation professors who are awarded fellowships or larger grants need not spend as much time grant-writing, and thus with more time to devote to conducting research can produce more papers and train more students, placing them yet further ahead in future competitions. Such advantages to the 'favored' few accumulate over time and seldom, if ever, is their advancement recognized as resting, at least partially, on the discrimination that holds others in the system back. But sexism, racism, and many other biases have significant negative tangible outcomes, limiting the participation, retention, and advancement of individuals from marginalized groups. While acknowledging that these issues are widespread and systemic throughout academia, we also believe that certain amplifying conditions, including macho culture (pervasive in fields such as shark research, which both of us have worked in and left) and fieldwork (which often occurs on confined vessels at sea or in remote locations), can exacerbate these problems in the ocean sciences and marine conservation.

Despite some progress, gender bias remains a significant hindrance to women's advancement in marine conservation. Women in many countries have achieved, or exceeded, gender parity at the undergraduate level in degrees related to marine conservation. In the U.S., for example, women now earn 70% of marine biology and biological oceanography degrees, 65% of general biological science degrees, and 55% of environmental science degrees (NCES, 2019)—although we note that the majority of these degree holders are white women and not POC. However, this progress is short-lived, with the proportion of women in the field declining at each successive career stage: women, for example, still only make up only 32.5% of fully tenured professors in the United States (Colby & Fowler, 2020), and only 23% of conservation leadership positions (Taylor, 2014). This phenomenon, known as the 'leaky pipeline,' implies that women passively drop out of the system, yet a more apt description would be that women are 'shoved out' by pervasive gender bias at each stage. In their 1997 study, which found that female postdoctoral applicants had to be 2.5 times more productive than their male counterparts to receive the same competency score by the senior scientists evaluating them, the authors concluded that 'peer reviewers cannot judge scientific merit independent of gender' (Wennerås & Wold, 1997). While such studies are sometimes dismissed based on the premise that gender bias is no longer an issue, the empirical evidence strongly indicates otherwise. Moss-Racusin's (2012) randomized double-blind study found that science faculty at research intensive universities who were given fictitious resumes for lab manager positions rated female applicants as significantly less competent and hireable than male applicants with identical CVs, and offered higher starting salaries and more career mentoring to the male applicants (Moss-Racusin, Dovidio, Brescoll, Graham, & Handelsman, 2012). Not surprisingly then, women are hired less frequently as graduate students and postdocs by male Principal Investigators (PIs) (Sheltzer & Smith, 2014). Women are also only half as likely to receive "excellent" reference letters compared to male applicants (Dutt, Pfaff, Bernstein, Dillard, & Block, 2016). Gender bias also impacts publications, with women's writing held to higher standards than men (such that women incur a "time tax" as papers take more time in the review process (Hengel, 2017)), women are less likely to be published in higher-impact journals, and women's papers are cited less (Bendels, Müller, Brueggmann, & Groneberg, 2018). Men are also typically better resourced, receiving larger start-up packages, and more, or larger, grants (Grogan, 2019). Despite ample evidence of gender bias in research environments, men tend to dismiss it, questioning the veracity of the studies (Handley, Brown, Moss-Racusin, & Smith, 2015), which may explain why they tend to perceive gender bias as being less of a problem than it is (Giakoumi et al., 2021). This is worrying, as it is difficult to address problems that one refuses to acknowledge. Beyond the myriad ways that unconscious bias hinders women's progress, we also note that more overt forms of discrimination remain acute within sub-fields of marine conservation. For example, within shark science, women commonly endure harassment, misogyny, bullying, and assault, a reality that is not only unacceptable and unnecessary, but also hinders their progress (Graham, 2017; Macdonald, 2020).

While the data present a stark picture of how deeply ingrained gender bias is, we also acknowledge that what progress has been made towards making marine conservation a more equitable and diverse field has disproportionately benefited women, and specifically white women. To wit, most diversity studies still only focus on gender bias, such that few data exist for LGBTQ+ and POC.

What limited data there are indicate that even less progress has been made for LGBTQ+ researchers. Though there are not to our knowledge specific statistics within marine conservation, LGBTQ+ communities are represented 17–21% less than expected in academia overall (Cech, 2015; Cech & Pham, 2017). One of the few available climate surveys for LGBTQ+ researchers in academia, conducted within the field of physics, found that 20% of survey respondents had experienced, and 40% had witnessed, exclusionary behavior, and 33% had thought about leaving their job within the past year (Atherton et al., 2016). These behaviors are unacceptable and common throughout science, and undoubtedly decrease the recruitment and retention of LGBTQ+ scholars within marine conservation.

POC are also severely underrepresented. For example, within the United States, POC comprise 38% of the population, yet only 16% of staff and boards at environmental organizations (Taylor, 2014). Within the environmental and geosciences workforce overall, only 5% are black, 4.8% are Latinx, and 0.7% are Asian (BLS, 2018). Taken together, these numbers are indicative of the immense barriers facing POC. We would be remiss if we did not acknowledge that those with intersectional marginalized identities navigate more compounding obstacles and barriers both in and out of the workplace.

Recommended actions to recruit diverse people into marine conservation

Issues of Diversity, Equity and Inclusion (DEI) start at the beginning, with recruitment into the field of marine conservation—who receives mentorship as an undergraduate or intern, who is hired as a lab technician, and who is admitted into graduate school. Simply put, if we do not provide equal opportunities for women, LGBTQ+, and POC to enter marine conservation, or ensure that they feel safe and welcomed once they do, then we will not be able to diversify the field. Here, we offer four recommendations to recruit individuals from these three groups: 1) avoid using metrics that correlate with privilege and wealth to evaluate candidates; 2) empower undergrads through field experiences; 3) do not gatekeep people; and 4) foster inclusivity by creating a welcoming environment and through representation.

1. Decouple candidate idealness from privilege and dismantle financial barriers

To recruit women, LGBTQ+, and POC in marine conservation, those admitting students and hiring personnel must decouple candidate idealness with metrics that directly correlate with privilege. Privilege often shows up specifically in the form of being able to overcome financial barriers. For example, tenure track faculty have estimated median childhood incomes that are 23.7% above the general public, suggesting that socioeconomics have considerable influence on who attains these positions (Morgan, Clauset, Larremore, LaBerge, & Galesic, 2021). In marine sciences, skills and experiences such as boating and sailing, SCUBA certification, being comfortable with travelling to remote locations, taking volunteer positions for experience, enrolling in GRE prep courses, and being familiar with the ocean all help immensely with entrance to the field, but are not universal, typically only being available to those from relatively affluent families. The solution to this at a hiring and admissions level is to challenge what is considered ideal for marine candidates, and what is expected in terms of background and experience. Motivation, drive, and curiosity—critical traits for research success—should be sought out in candidates, rather than only considering GRE scores or grade cutoffs (Emery, Bledsoe, Hasley, & Eaton, 2021; McGill et al., 2021; Petersen, Erenrich, Levine, Vigoreaux, & Gile, 2018). Within a lab, financial barriers can be lessened by providing paid research assistantships for undergraduate students, by providing required equipment and field gear or having a shared lab set, by investing in training students in required skills, and by including a relocation stipend as a standard part of graduate school funding packages.

2. Empower diverse undergraduate students through safe, accessible field courses

To effectively recruit diverse groups into marine conservation, field courses must be designed inclusively so that women, LGBTQ+, and POC students have equal access to them, and can thus gain crucial hands-on experience. These field-based experiences help students gain more confidence than in traditional lab-based approaches, form a sense of belonging and community, and find role models in the field, along with exposing them to the joy and curiosity that can spark passion for marine research (Kloser, Brownell, Shavelson, & Fukami, 2013; Zavaleta, Beltran, & Borker, 2020). The impacts of field courses have been studied in ecology and evolutionary biology, and were found to increase self-efficacy, with students from underrepresented minorities who participated in these courses having higher graduation rates, higher rates of staying in the field, and higher GPAs at graduation (Beltran et al., 2020). To ensure inclusivity, field-based experiences must be designed with undergraduates' identities in mind, considering the barriers that might prevent groups who do not often participate in field work. For example, having low equipment needs to lessen financial barriers, designing courses to welcome those with varying levels of outdoor experience, disseminating information about the courses widely rather than only by word of mouth, and setting expectations about the course as a group ahead of time (Morales et al., 2020; Zavaleta et al., 2020). Leaders of field courses, and fieldwork in general, must also consider several other factors to ensure that all participants feel safe and welcome throughout the experience (see Box 19.1).

3. Provide equal access for professional advancement

Women, LGBTQ+, and POC face recruitment barriers due to gatekeeping by those in power. For example, Milkman et al.'s (2015) study found that faculty were significantly more responsive to emails from prospective white male doctoral students than they were to all other genders and races (Black, Hispanic, Indian, Chinese) included in the experiment (Milkman, Akinola, & Chugh, 2015). Such discrimination also manifests as unspoken rules in academia that help privileged individuals advance. The power of being versed in this hidden curriculum is highly apparent, as faculty are 25 times more likely to have a parent with a PhD (Morgan et al., 2021). These unspoken rules can come in many forms, including knowing to email professors ahead of applying for scholarships or to some graduate programs and that those emails have a particular format, or going to office hours as an undergraduate to build strong relationships for letters of recommendation, or being aware of and applying to summer internship research experiences through National Science Foundation (NSF). The solution to this is that PIs discuss this hidden curriculum with trainees and coach them without expecting them to already know these rules. Strong mentorship of both undergraduate and graduate students to nurture a multitude of skills they will need as they advance in marine conservation, such as salary and startup negotiation, budgeting and spending grants, and writing strong grant and fellowship applications will also empower marginalized students.

4. Foster a sense of belonging through representation

Representation of diverse individuals is also critical to increasing diversity. Seeing people within your field who look like you and share your experiences makes career aspirations feel attainable and creates a sense of belonging. Achieving a "critical mass" of individuals from underrepresented groups, defined as being between 15 and 30% of team members, is also believed to reduce stereotyping and enhance the involvement of these individuals in decision-making (Cain & Leahey, 2014). Though marine conservation leadership and professors do not currently represent the full diversity of people we seek within marine conservation, there are ways they can still increase representation of diverse researchers by inviting them as speakers for seminars, highlighting their work in lectures and reports, citing them, and amplifying their voices in person and online. Leaders in marine conservation should also create safe, welcoming environments for diverse individuals on their teams, and can signal this environment to prospective students and employees by including a diversity and equity statement on their webpage that describes their related principles and actions, and by including their pronouns in their email signature line and introductions.

Additionally, social media is a powerful tool to showcase diversity and foster representation. For example, the Gills Club (@GillsClub) works to connect girls with female shark scientists, Minorities in Shark Science (MISS) (@MISS_Elasmo) features women of color doing marine science, and accounts and hashtags on social media including #BlackInMarineScience (from @BlackinMarSci), #AAPIGeoRollCall (Asian American Pacific Islander in Geosciences Roll Call from @aapigeosci), #QueerInSTEM, and #WomenInSTEM showcase women, LGBTQ+, and POC marine researchers. The visibility of these diverse scientists is important, as this allows students and early career researchers to see those who represent them in their future career and connect with them online, even if those currently around them do not represent their identities.

Recommended actions to retain, empower and champion diverse individuals in marine conservation

Once women, LGBTQ+, and POC have entered the field of marine conservation, they need to feel comfortable at work. The burden should not be placed on these oppressed groups to change the system or to constantly challenge their bosses or others in more advanced positions than them. Here, we present five solutions to help retain and empower diverse scientists in marine conservation: 1) create an environment where all people can safely participate; 2) implement policies and practices that foster work-life balance; 3) make conferences inclusive and welcoming to diverse researchers so they can reap the benefits of them; 4) nominate individuals from underrepresented groups for prestigious talks and awards; and 5) broaden the way marine conservation researchers are evaluated to include DEI work.

1. Create a safe environment for diverse marine conservation colleagues

Physical, mental, and emotional safety should be paramount in all endeavors within marine conservation, but often, in the way that fieldwork, labs, and conferences are currently conducted, diverse researchers may have to compromise these types of safety to remain and advance within the field in ways that do not exist or are never expected for cisgender heterosexual white men.

Marginalized groups are more likely to face prejudice, harassment, or violence while conducting fieldwork (Demery & Pipkin, 2021; Macdonald, 2020). Sexual harassment and assault are unacceptable and disproportionately impact women. At field sites, 71% of women reported experiencing sexual harassment and 26% reported experiencing sexual assault, often perpetuated by more senior members of their research groups (Clancy, Nelson, Rutherford, & Hinde, 2014). Though these numbers are not available for scientific research specifically, in addition to women, the LGBTQ+ community faces high levels of sexual harassment and assault, and those with intersectional identities are particularly vulnerable, especially women of color and trans people of color (Gentlewarrior & Fountain, 2009; Grant, Motter, & Tanis, 2011; Richardson & Taylor, 2009). To combat this, marine conservation organizations must establish codes of conduct, create venues to report this behavior, and follow through in punishing those who commit harassment and assault (Clancy et al., 2014; McGill et al., 2021; Nelson, Rutherford, Hinde, & Clancy, 2017).

LGBTQ+ researchers also face enormous barriers in states and countries that do not recognize transgender or non-binary gender identities and have laws that openly persecute non-heterosexual individuals. These anti-LGBTQ+ laws restrict where LGBTQ+ scientists can safely travel for fieldwork or conferences (Emery et al., 2021). If we want to retain LGBTQ+ researchers, we cannot ask them to put themselves in danger to conduct fieldwork or to network at conferences. We can include our LGBTQ+ colleagues by only buying healthcare plans that cover trans people, making pronouns standard on all documents and nametags, and using gender-inclusive language.

Another necessary dimension to creating a safe and inclusive environment is combatting anti-black racism and white supremacy. Achieving this requires all of us to be willing to confront our racial biases, to be uncomfortable as we deconstruct biased systems that privilege the advancement of white scholars, to actively empower black scholars with actions such as cluster hires, to fund black PIs with grants, and to create a tenure process that rewards DEI work (Schell et al., 2020). Creating an anti-racist environment requires sustained effort, accountability, and systemic change and is critical to retaining POC in marine conservation.

2. Implement policies and practices that foster work-life balance

Longstanding gender inequities are exacerbated for mothers, since the marine conservation research and practice enterprises (and most workplaces in general) were not built for them. In a 2021 survey of marine scientists and conservationists, many respondents noted the unequal sharing of childcare responsibilities within families and its impact on women's research careers (Giakoumi et al., 2021). More broadly, COVID-19 has laid bare long-standing inequities and biases facing mothers, often referred to as the 'maternal wall', with women scientists with young children experiencing the greatest declines in time available to devote to research; further disparities were reported for mothers of color (Fulweiler et al., 2020; Myers et al., 2020).

What can be done? The marine scientist and conservation respondents ranked practices aimed at improving work-life balance, specifically establishing infrastructure supporting family responsibilities and consideration of periods of inactivity (e.g., family leave, COVID-19 restrictions), amongst the top recommendations for enhancing the representation of women in the field (Giakoumi et al., 2021). There is evidence that such policies work: the EU's early-career Marie Sklodowska-Curie Fellowship, which takes periods of research inactivity into account in its evaluations as a means of facilitating researchers returning to careers after parental or other leaves, has awarded half of its recent grants to women (Giakoumi et al., 2021). Many institutions are now implementing related measures, including ‘tenure clock’ extensions for junior faculty due to COVID-19-related delays (Myers et al., 2020). Additional strategies for empowering ‘marine conservation mothers’ include offering high-quality, affordable on-site childcare; having flexible meeting times and options for in-person or virtual meeting; and providing options so that researchers can still either conduct or design and oversee field seasons while pregnant, breastfeeding, or caring for young children. Mentors and bosses should also communicate clearly their support of all personal choices and lifestyles, including families with and without children, and that they also strive to achieve a healthy work-life balance (Fulweiler et al., 2020).

3. Make conferences safe and welcoming to diverse people

Conferences serve an important networking function within science and can have significant benefits for participants, but access to these meetings and the opportunities arising from them are not equal across all groups (Oester, Cigliano, Hind-Ozan, & Parsons, 2017). When planning conferences, organizers should do so in ways that are inclusive and welcoming to diverse people. A crucial aspect of doing so is a code of conduct, which outlines what behavior is acceptable, consequences for unacceptable behavior, and how to report any issues. The International Marine Conservation Congress (IMCC), in 2016, was one of the first marine conferences to develop a code of conduct and paved the way for other groups (Favaro et al., 2016). Since then, many other marine-related meetings, including the Western Society of Naturalists, Benthic Ecology, Ecological Society of America, and the American Elasmobranch Society, have followed suit. These anti-harassment and discrimination policies help protect diverse people and make them feel more welcome, but further steps are needed (Tulloch, 2020). For example, for the LGBTQ+ community, offering the option of rainbow lanyards to signal allyship, having gender-neutral bathrooms, putting pronouns on all nametags, and having codes of conduct that specifically do not allow discrimination based on sexuality or gender are all important to enhance inclusivity and safety (Tulloch, 2020). To address gender inequities, conferences should also ensure that they have affordable childcare available, offer targeted mentorship programs for women to connect, and randomize talk order in conferences (Sardelis, Oester, & Liboiron, 2017). Additionally, inviting and highlighting speakers who are POC, providing targeted travel funds to conferences, and hosting the conference in racially diverse areas is important (Taylor, 2018). Finally, conference organizers should consider registration fees and other costs of attending the event and provide reduced or waived fees for socioeconomically disadvantaged researchers. These efforts, which require commitment and planning, are essential to ensure that all members of the marine conservation research community can attend safely and benefit from this critical professional experience.

4. Nominate marine conservation researchers from diverse groups for prestigious talks and awards

Considerable biases also still exist in terms of which researchers are invited to give seminars, conference talks, and prestigious keynote speaking engagements (Else, 2019). Nittrouer et al. (2018) found that women are much less likely to be given such opportunities at prestigious universities, regardless of the pool of available speakers; it is telling that POC could not be included in this study because the authors “couldn’t find enough professors of color to get a strong sample” (Nittrouer et al., 2018; Yong, 2017). Moreover, the study found that none of the typical explanations for why there are fewer women were sustainable: women did not decline invitations more than men, were no more likely to decline talks because of family obligations, and felt just as strongly that talks were important for their career. Such opportunities are indeed important professionally, providing researchers with venues to publicize their research, enhance their reputation, and build networks, so this discrimination again advances white male researchers at the expense of underrepresented individuals. Pushback against this bias has come in the form of researchers calling out ‘manels’ (all-male panels) and ‘manferences’ (conferences dominated by male speakers) publicly on social media, and, in some cases, men refusing to participate in such events. While studies show that committees chaired by women have better representation (Nittrouer et al., 2018), this also places an additional service burden on women. Instead, marine conservation organizations and societies should explicitly consider and monitor the proportion of women, LGBTQ+ and POC that are invited. We encourage white men to consider the diversity of the panels they are invited to, and to turn down invitations to manels, instead suggesting alternative candidates.

In addition to speaking invitations, women, LGBTQ+, and POC researchers should also be championed through career awards. Awards signal whose work is valued in a field. Across disciplines, white men are disproportionately nominated for and receive awards (raiseproject.org). Grogan (2019) notes that since 2001, only two women (11.7%) have been awarded the Eminent Ecologist award from the Ecological Society of America. More directly related to marine conservation, we highlight that the International Coral Reef Society's (ICRS) most prestigious award, the Darwin Medal, has been awarded only once to a woman (11.1%). On a more positive note, three of the society's five Coral Reef Conservation Awards have gone to women, including one black woman. Still, the majority of ICRS awards have gone to white men and women. To rectify biases in awards, we encourage marine conservation leaders to nominate diverse individuals for awards, to provide strong and unbiased reference letters for the nominees (checking with one of the now numerous resources online), and to provide informal reviews of award applications to help strengthen them. We also advise awards committees to assess the diversity of nominees, and to seek additional diverse applicants if the pool does not include sufficient researchers from underrepresented groups; also to revise and review criteria for awards (Ali et al., 2021). Ideally, awards committees should represent a diversity of voices, but at the very least, all members should receive diversity training, and an independent DEI expert could be present to monitor award selections.

5. Ensure that professional evaluation metrics value DEI work

Incorporating these recommendations to recruit, retain, and empower women, LGBTQ+, and POC researchers will take sustained effort. But the metrics typically used to evaluate scientists do not reward DEI work fairly if at all. Some metrics used for tenure, promotion, and advancement in science are instead demonstrably biased against marginalized groups, such as citation rates and impact factors (Davies et al., 2021), publishing (Gaskins & McClain, 2021; Silbiger & Stubler, 2019), and teaching evaluations (Peterson, Biederman, Andersen, Ditonto, & Roe, 2019). Research shows that underrepresented faculty play a disproportionate role in advancing DEI work, but this effort is not effectively counted when they are evaluated for tenure (Dutt, 2021; Jimenez et al., 2019). Not only should this be something that these underrepresented faculty get credit for, but this responsibility should be shared by all faculty (Dutt, 2021; Jimenez et al., 2019; Schell et al., 2020).

Conclusions

Marine conservation urgently requires improved measures to safeguard ocean ecosystems, and this decision making would undoubtedly benefit from increased diversity. Here, we have presented specific recommendations for enhancing the diversity and inclusivity of the field of marine conservation by recruiting, retaining, and championing individuals from underrepresented groups. These recommendations and proposed solutions are based on our sets of experiences as a fully tenured professor who is a first-generation white woman, and an early career researcher who is a transgender Asian-American man, both of whom are academics in North America. We recognize there are other important facets of diversity in science beyond only women, LGBTQ+, and POC, such as age, disability, and nationality, but we chose to focus on these three groups given our personal experiences. We are optimistic that marine conservation can make the long-needed changes we have recommended to increase and empower diverse individuals in the field. But the bottom line is that we cannot continue to expect diverse scientists to thrive in environments that are not designed for them to advance and succeed. We must build a system of equity that empowers all groups. Given the immense challenges we must tackle as a field, we need diverse perspectives to come up with the solutions that will propel us toward a brighter future for our oceans.

Box 19.1

Designing Fieldwork for Inclusivity

Fieldwork is an important component, and expectation, of most marine conservation research, but often the way that marine field work is designed is not inclusive to marginalized groups and presents barriers to retention.

A clear pre-requisite to inclusive fieldwork is that all participants must be, and must feel, safe. Women, LGBTQ+, and POC can face acute danger when conducting their fieldwork, especially in remote areas that may have a history of exclusion, homophobia, transphobia, racism, or violence (Demery & Pipkin, 2021). Having to greatly modify behavior, experience fear, and constantly assess risk is too much to ask of marginalized scientists, especially if they conduct their work alone (Demery & Pipkin, 2021).

When planning fieldwork, leaders need to clearly communicate expectations for acceptable behavior to the entire group and communicate that individuals can safely report any problems to the leader if they arise (Nelson et al., 2017). Recognizing that expedition leaders can also be the perpetrators of harassment and assault, we advise that a second participant also be designated as an additional option for reporting. Both these members—and ideally the entire field team—should mandatorily take equity and diversity training, and bystander intervention training, prior to fieldwork commencing. They should also make expectations clear and agree on them ahead of time to allow participants to mentally prepare; express empathy if concerns are expressed and address them; and understand that fieldwork can generate conditions that separate participants from support networks and mental health resources (Emery et al., 2021). Additionally, research leaders need to have open discussions about expectations of time and duration in the field, create living arrangements that do not assume a gender binary, use pronouns when introducing themselves, note gender-neutral restrooms facilities, and generate a code of conduct. To include LGBTQ+ colleagues, privately ask all participants for their name and pronouns ahead of time regardless of what is on rosters or university listings because this may be their dead name (former name) and not reflect their gender correctly.

Several additional factors need to be considered for marine fieldwork. When conducting fieldwork on boats, a plan must be created for urinating and defecating. There are multiple solutions—all parties turn around regardless of gender so as not to out trans people, buy a portable toilet and generate a plan to empty it, or rent vessels with a full bathroom for privacy. Leaders designing fieldwork also need to ensure it does not penalize parents, since parenthood often makes it difficult for women to participate for extended periods of time. Pregnant researchers cannot SCUBA dive or be away from infants for extended periods while breastfeeding, and this can cause them to miss entire field seasons. Though these issues are most likely to impact women, people of any gender can become pregnant and be affected by these issues.

If thoughtfully designed, fieldwork could be an important way to empower diverse researchers, foster a sense of belonging, retain marginalized groups, and generate solutions that will change the way we conduct conservation efforts in the future.

References

Ali, H. N., Sheffield, S. L., Bauer, J. E., Caballero-Gill, R. P., Gasparini, N. M., Libarkin, J., Cisneros, J. (2021). An actionable anti-racism plan for geoscience organizations. Nature Communications, 12(1), 1-6.

Atherton, T. J., Barthelemy, R. S., Deconinck, W., Falk, M. L., Garmon, S., Long, E., Reeves, K. (2016). LGBT climate in physics: Building an inclusive community. American Physical Society, 118-126.

Beltran, R. S., Marnocha, E., Race, A., Croll, D. A., Dayton, G. H., & Zavaleta, E. S. (2020). Field courses narrow demographic achievement gaps in ecology and evolutionary biology. Ecology and Evolution, 10(12), 5184-5196.

Bendels, M. H., Müller, R., Brueggmann, D., & Groneberg, D. A. (2018). Gender disparities in high-quality research revealed by Nature Index journals. PLoS One, 13(1), e0189136.

BLS. (2018). Environmental scientists and specialists. Retrieved from: https://www.bls.gov/ooh/life-physical-and-social-science/environmental-scientists-and-specialists.htm and https://www.bls.gov/cps/ cpsaat11.pdf

Cain, C. L., & Leahey, E. (2014). Cultural correlates of gender integration in science. Gender, Work & Organization, 21(6), 516-530.

Cech, E. A. (2015). LGBT professionals' workplace experiences in STEM-related federal agencies. Paper presented at the 2015 ASEE Annual Conference & Exposition.

Cech, E. A., & Pham, M. V. (2017). Queer in STEM organizations: Workplace disadvantages for LGBT employees in STEM related federal agencies. Social Sciences, 6(1), 12.

Clancy, K. B., Nelson, R. G., Rutherford, J. N., & Hinde, K. (2014). Survey of academic field experiences (SAFE): Trainees report harassment and assault. PLoS One, 9(7), e102172.

Colby, G., & Fowler, C. (2020). Data Snapshot: IPEDS Data on Full-Time Women Faculty and Faculty of Color. Retrieved from American Association of University Professors:

Davies, S. W., Putnam, H. M., Ainsworth, T., Baum, J. K., Bove, C. B., Crosby, S. C., Griffin, A. J. (2021). Promoting inclusive metrics of success and impact to dismantle a discriminatory reward system in science. PLoS biology, 19(6), e3001282.

Demery, A.-J. C., & Pipkin, M. A. (2021). Safe fieldwork strategies for at-risk individuals, their supervisors and institutions. Nature ecology & evolution, 5(1), 5-9.

Dutt, K. (2021). Addressing racism through ownership. Nature Geoscience, 14(2), 58-58.

Dutt, K., Pfaff, D. L., Bernstein, A. F., Dillard, J. S., & Block, C. J. (2016). Gender differences in recommendation letters for postdoctoral fellowships in geoscience. Nature Geoscience, 9(11), 805-808.

Else, H. (2019). How to banish manels and manferences from scientific meetings. Nature, 573(7773), 184-187.

Emery, N. C., Bledsoe, E. K., Hasley, A. O., & Eaton, C. D. (2021). Cultivating inclusive instructional and research environments in ecology and evolutionary science. Ecology and Evolution, 11(4), 1480-1491.

Favaro, B., Oester, S., Cigliano, J. A., Cornick, L. A., Hind, E. J., Parsons, E., & Woodbury, T. J. (2016). Your science conference should have a code of conduct. Frontiers in Marine Science, 3, 103.

Fulweiler, R. W., Davies, S. W., Biddle, J. F., Burgin, A. J., Cooperdock, E. H., Hanley, T. C., Santiago-Vazquez, L. Z. (2020). Rebuilding the academy: Strategies for supporting academic mothers during the COVID-19 global pandemic and beyond.

Gaskins, L. C., & McClain, C. R. (2021). Visible name changes promote inequity for transgender researchers. PLoS biology, 19(3), e3001104.

Gentlewarrior, S., & Fountain, K. (2009). Culturally competent service provision to lesbian, gay, bisexual and transgender survivors of sexual violence. VAWorg. net, http://citeseerx. ist. psu. edu/viewdoc/download.

Giakoumi, S., Pita, C., Coll, M., Fraschetti, S., Gissi, E., Katara, I., Stelzenmüller, V. (2021). Persistent gender bias in marine science and conservation calls for action to achieve equity. Biological Conservation, 257, 109134.

Graham, R. T. (2017). "Are we there yet?" Women in shark science. Medium.

Grant, J. M., Motter, L. A., & Tanis, J. (2011). Injustice at every turn: A report of the national transgender discrimination survey.

Grogan, K. E. (2019). How the entire scientific community can confront gender bias in the workplace. Nature ecology & evolution, 3(1), 3-6.

Handley, I. M., Brown, E. R., Moss-Racusin, C. A., & Smith, J. L. (2015). Quality of evidence revealing subtle gender biases in science is in the eye of the beholder. Proceedings of the National Academy of Sciences, 112(43), 13201-13206.

Hengel, E. (2017). Publishing while female are women held to higher standards? Evidence from peer review. 2017. In.

Jimenez, M. F., Laverty, T. M., Bombaci, S. P., Wilkins, K., Bennett, D. E., & Pejchar, L. (2019). Underrepresented faculty play a disproportionate role in advancing diversity and inclusion. Nature ecology & evolution, 3(7), 1030-1033.

Kloser, M. J., Brownell, S. E., Shavelson, R. J., & Fukami, T. (2013). Effects of a research-based ecology lab course: a study of nonvolunteer achievement, self-confidence, and perception of lab course purpose. Journal of College Science Teaching, 42(3), 72-81.

Macdonald, C. (2020). The Dark Side of Being a Female Shark Researcher. Scientific American.

Martell, R. F., Lane, D. M., & Emrich, C. (1996). Male-female differences: a computer simulation.

McGill, B. M., Foster, M. J., Pruitt, A. N., Thomas, S. G., Arsenault, E. R., Hanschu, J., Loecke, T. D. (2021). You are welcome here: A practical guide to diversity, equity, and inclusion for undergraduates embarking on an ecological research experience. Ecology and Evolution.

Milkman, K. L., Akinola, M., & Chugh, D. (2015). What happens before? A field experiment exploring how pay and representation differentially shape bias on the pathway into organizations. Journal of Applied Psychology, 100(6), 1678.

Morales, N., Bisbee O'Connell, K., McNulty, S., Berkowitz, A., Bowser, G., Giamellaro, M., & Miriti, M. N. (2020). Promoting inclusion in ecological field experiences: Examining and overcoming barriers to a professional rite of passage. The Bulletin of the Ecological Society of America, 101(4), e01742.

Morgan, A., Clauset, A., Larremore, D., LaBerge, N., & Galesic, M. (2021). Socioeconomic Roots of Academic Faculty.

Moss-Racusin, C. A., Dovidio, J. F., Brescoll, V. L., Graham, M. J., & Handelsman, J. (2012). Science faculty's subtle gender biases favor male students. Proceedings of the National Academy of Sciences, 109(41), 16474-16479.

Myers, K. R., Tham, W. Y., Yin, Y., Cohodes, N., Thursby, J. G., Thursby, M. C., Wang, D. (2020). Unequal effects of the COVID-19 pandemic on scientists. Nature human behaviour, 4(9), 880-883.

NCES. (2019). Integrated Postsecondary Education Data System (IPEDS).

Nelson, R. G., Rutherford, J. N., Hinde, K., & Clancy, K. B. (2017). Signaling safety: Characterizing fieldwork experiences and their implications for career trajectories. American Anthropologist, 119(4), 710-722.

Nielsen, M. W., Alegria, S., Börjeson, L., Etzkowitz, H., Falk-Krzesinski, H. J., Joshi, A., Schiebinger, L. (2017). Opinion: Gender diversity leads to better science. Proceedings of the National Academy of Sciences, 114(8), 1740-1742.

Nittrouer, C. L., Hebl, M. R., Ashburn-Nardo, L., Trump-Steele, R. C., Lane, D. M., & Valian, V. (2018). Gender disparities in colloquium speakers at top universities. Proceedings of the National Academy of Sciences, 115(1), 104-108.

Oester, S., Cigliano, J. A., Hind-Ozan, E. J., & Parsons, E. C. M. (2017). Why Conferences Matter—An Illustration from the International Marine Conservation Congress. Frontiers in Marine Science, 4(257). https://doi.org/10.3389/fmars.2017.00257

Petersen, S. L., Erenrich, E. S., Levine, D. L., Vigoreaux, J., & Gile, K. (2018). Multi-institutional study of GRE scores as predictors of STEM PhD degree completion: GRE gets a low mark. PLoS One, 13(10), e0206570.

Peterson, D. A., Biederman, L. A., Andersen, D., Ditonto, T. M., & Roe, K. (2019). Mitigating gender bias in student evaluations of teaching. PLoS One, 14(5), e0216241.

Richardson, B. K., & Taylor, J. (2009). Sexual harassment at the intersection of race and gender: A theoretical model of the sexual harassment experiences of women of color. Western Journal of Communication, 73(3), 248-272.

Sardelis, S., Oester, S., & Liboiron, M. (2017). Ten Strategies to Reduce Gender Inequality at Scientific Conferences. Frontiers in Marine Science, 4(231). https://doi.org/10.3389/fmars.2017.00231

Schell, C. J., Guy, C., Shelton, D. S., Campbell-Staton, S. C., Sealey, B. A., Lee, D. N., & Harris, N. C. (2020). Recreating Wakanda by promoting Black excellence in ecology and evolution. Nature ecology & evolution, 4(10), 1285-1287.

Sheltzer, J. M., & Smith, J. C. (2014). Elite male faculty in the life sciences employ fewer women. Proceedings of the National Academy of Sciences, 111(28), 10107-10112.

Silbiger, N. J., & Stubler, A. D. (2019). Unprofessional peer reviews disproportionately harm underrepresented groups in STEM. PeerJ, 7, e8247.

Taylor, D. E. (2014). The state of diversity in environmental organizations: Green 2.0 working group.

Taylor, D. E. (2018). Enhancing racial diversity in the Association for Environmental Studies and Sciences. Journal of Environmental Studies and Sciences, 8(4), 379-384.

Tulloch, A. I. (2020). Improving sex and gender identity equity and inclusion at conservation and ecology conferences. Nature ecology & evolution, 4(10), 1311-1320.

Wennerås, C., & Wold, A. (1997). Nepotism and sexism in peer-review. Nature, 387(6631), 341-343. https://doi.org/10.1038/387341a0

Yong, E. (2017). Women are invited to give fewer talks than men at top US universities. The Atlantic, 18.

Zavaleta, E. S., Beltran, R. S., & Borker, A. L. (2020). How Field Courses Propel Inclusion and Collective Excellence. Trends in Ecology & Evolution, 35(11), 953-956.

20. Building equal partnerships for conservation success

Asha de Vos[1]

My career has been riddled with encounters with parachute science, a.k.a. helicopter science, a.k.a. colonial science—the conservation model where researchers from the Global North come to countries like mine in the Global South, collect data to support their careers, and leave without any investment in local human capacity or infrastructure. It takes away opportunities from people and communities on the ground. It sidelines local work and capacity. It focuses on the personal goals of the outsider vs. collective change, creates an unequal power balance, and drives dependency on external parties (de Vos, 2020; Minasny, Fiantis, Mulyanto, Sulaeman, & Widyatmanti, 2020; Nording, 2018). The list goes on.

My earliest encounter came within months of recognizing that blue whales in Sri Lanka, my island home, did not engage in long-range migrations between cold feeding areas and warm breeding and calving areas, but remained within warm tropical waters throughout the year. A notion so unheard of that it puzzled and excited people in equal measure, so much so that the scientists I contacted for advice and support in launching research around these blue whales requested that I get a research permit so their teams could head out to work on this population. While my response was 'no thank you', I can understand why that is not always an easy response. Researchers like myself operate with little access to funds and no mentorship in a space that has historically excluded us from the narrative. While this was my first real experience of parachute science, it was by no means my last.

More recently, I was working on a collaborative grant proposal with a team from the Global North when I found myself as the only person with no salary allocation. Ironically, I was also the only researcher from the Global South and the success of the project was based on what we did in Sri Lankan waters. After a conversation with a trusted career mentor, I realised that there was still a lot of work to be done to undo the conscious and unconscious biases around capacity based on where someone comes from vs. what they can actually do.

When I embarked on my marine science and conservation journey, the odds were already stacked against me. Locally, there was a distinct lack of resources, infrastructure, support and mentorship. In addition, there were the challenges of working in a field that felt 'exclusive' in a country where it did not exist as an academic discipline, and I was doing all this as a woman in a South Asian country. There was also the added requirement to transition to English—having spent my school years learning science in my mother tongue. The required transition can be more or less jarring, depending on where you come from. Considering all this, I am keen to understand how I can pave the way for others—to make it easier for them to progress unhindered. To challenge existing biases, dismantle systemic obstacles and support new, more equitable systems. Recognising that talent is equally distributed while opportunity is not, one attempt has been to establish Oceanswell, Sri Lanka's first marine conservation research and education organisation to create space and opportunity for others to enter

1 Oceanswell, https://orcid.org/0000-0003-3332-8232

https://doi.org/10.11647/OBP.0395.20

and grow in the field. Our work focuses on impactful, sustainable conservation research that is locally led and shared to drive change on the ground. That said, I recognise our limitations and, equally, the expertise that exists beyond our shores, and I believe that working together is the only way. Therefore, we work with external collaborators who share our vision of nurturing the next generation of diverse ocean heroes. It is important to recognise that this is by no means a cry for people to work exclusively in their backyards, but a plea that when we work beyond our shores, we recognise that it is a privilege, not a right, and act accordingly.

We cannot succeed in marine conservation if we do not ensure that all voices are heard and valued. To achieve this, we must recognise that 70% of coastlines are the in the developing world. Currently, representation from this part of the world is negligible. But if we truly want to save our oceans, every coastline needs a local hero.

A study by Maas et al. (2021) showed a lack of diversity among top-publishing ecologists, with 87% of top-publishing authors coming from only ten countries—the top five being USA, UK, Australia, Germany, and Canada. The study showed that the global south (and women) are strikingly underrepresented among these ecologists. This is likely a by-product of parachute science—where science is being undertaken across the world but it is led and published by those from only a handful of countries.

Another 2021 study by Stefanoudis et al. (2021) highlighted that parachute science in coral reef research was more prevalent in low- to middle-income countries (Philippines and Indonesia) compared to high-income countries (Australia). The researchers found that over the last 50 years, 40% of all publications from Indonesia and the Philippines did not include host-nation scientists, while the respective figure from Australia was half that. Research leadership, defined as the first and last author being from the host nation, was also down to 30-40% in Indonesia and the Philippines, but in Australia, it was 70%. A perspective piece addressing the need for decolonisation in ocean conservation and advocacy shows us that it goes beyond science and publishing. We also need to decolonise how we advocate around ocean conservation (Belhabib, 2021).

If our metrics of success continuously favour the parachute model and talk about capacity building as a one-way endeavour, our efforts will be short-term in nature and short-term in success. While this model builds the resume of the outsider, it can cripple the careers of those on the ground and even derail ongoing work. Part of this issue stems from the fact that the local researchers, despite their years of dedication, may not have the necessary skillset to communicate their work in English-language journals, which are often the measure of success. This then means their work goes unseen. The COVID-19 pandemic was a good 'pause-to-think' moment as it highlighted even further the need to move away from the existing models of conservation. As travel became increasingly difficult, researchers could not visit their study sites across the globe and lamented the resulting gaps in their long-term datasets. Had they built a project that was locally led, where everyone had equal capacity through mutual exchange of skills, this could have been prevented. Valuable science and conservation could have continued more or less unhindered (de Vos, 2020).

How can we do better?

To protect our oceans, we need a far bigger team. We can only grow this team by being inclusive and equitable, and recognising the importance of diversity in resolving the issues at hand. I acknowledge that my perspective represents one particular experience with parachute science, that of the local researcher at the 'receiving end,' and that other perspectives can help us move forward (for a range of other perspectives please refer to de Vos and Schwartz, 2022). However, hopefully having these thoughts collated and accessible invites more partnership than parachuting. I acknowledge that self-reflection to understand why parachuting occurs in the first place is important and is certainly an exercise that is currently underway. Until then, however, the following non-exhaustive list of suggestions represents a collation of experiences, conversations with collaborators and allies, and best practices from published literature. I hope they help us recognise the absolute importance of diversity, equity and inclusion for the success of our work and the protection of our oceans and continue to remind us that 'to work outside our homes is a privilege and not a right'.

Before you start: Self-reflection

1. What is your motivation for conducting the research? Will the work contribute to conservation and change the current trajectory of our planet, or will it support your personal career goals? If you are concerned about our planet and want to make a change, then parachute science is not for you; equal partnerships will help you achieve your goals.
2. Recognise and acknowledge the importance of building effective collaborations that span the whole research pipeline from grant-writing, fieldwork, sample collection, data generation and analysis to authorship in international journals (Representatives of the Global Microbiome Conservancy, 2021).

Finding academic collaborators

1. Look at existing local institutions and their work (Stefanoudis et al., 2021).
2. Read articles published in local journals and/or in local languages (Stefanoudis et al., 2021) to ensure that you are not overlooking existing work just because it is not published in English.
3. Consider in-country visits, which are useful for finding collaborators and understanding local needs (Stefanoudis et al., 2021).

Project design and research permits

1. Build projects based on the priorities of the country you want to work in. Making local scientists work on projects that are low-priority for the country takes them away from more important and often urgent work. Ensure their role and intellectual contributions are meaningful and substantive rather than menial.
2. Work within the law. Get a research permit (Hind et al., 2015) but do not partner with a local researcher to obtain that permit or to get into a country—invest in their education, passion, and communities.
3. Build collaborations and/or equal partnerships with local researchers and institutions (Minasny et al., 2020) that mutually benefit local and international scientists. This leads to valuable knowledge-sharing between researchers, institutions and countries. Do not lead projects in other countries. Make the local scientists the leads and consider yourself a guide—should that be necessary.
4. Co-produce science and share ownership (Hind et al., 2015). Research ideas and grants should be developed alongside local partners who understand the needs of the country and the existing political sensitivities (Minasny et al., 2020). The solutions and approaches that work in another part of the world cannot be imported. Co-production also makes space for easy adaptation based on changes that may happen on the ground.
5. Identify if the issue is as pressing in-country as it appears outside. If it is pressing, you need good people on the ground in the long term. Just because the issue is pressing, do not make that an excuse to sideline local partners.
6. Do not arrive in a country with a grant looking for an implementing partner; work with potential partners to write the proposal so all parties are on board if the grant is successful.

Building capacity

1. The training provided should be comprehensive enough to allow team members to conduct the research independently, should the need arise. Ensure all colleagues are equals and/or actively

elevated above your status. Offer to provide training programmes for communities, not just your on-the-ground partner.

2. Invest in human capital but also the infrastructure that can ensure that local researchers have spaces or equipment to do the work for which you have created the opportunity. Your intention should be to ensure that your local partner is well set up to continue the work in the long term.
3. Recognise the skills and capacity of local partners. This will include local knowledge, traditional knowledge or access to it, and knowledge of systems, local networks, research needs and priorities, and research culture. Do not underestimate their contribution, as these facets are integral to the success of any project.
4. Provide opportunities for exchange. Bring your local Principal Investigator (PI) to your lab to learn the necessary techniques and/or methodology. Empower and send them back fully equipped so that they can train others and conduct world-class research.
5. Take advice from your local partner regardless of how you feel. Remember, you are on their turf, and they often understand the on-the-ground sensitivities and issues far better than you do. Do not push or force any action, communication, or research techniques they may not be comfortable with or know will be problematic locally. Trust that they, too, want to push boundaries, but the local research climate may lack the maturity necessary to achieve this. Failure to listen and cooperate can end disastrously for the research and local research teams. While you will likely be free of repercussions when you return to your own country, local long-term efforts may be at risk.
6. Offer local students opportunities to participate in the research, and, when possible, offer the opportunity to lead a component of the research, however small. This provides students with the opportunity to grow as researchers with the necessary guidance.

Building trust

1. Driving change requires trust. Trust is not built overnight. Change is typically driven by people who have dedicated long periods to a community, a study site and a particular cause. They are tenacious and are invested in the long term. They have a unique understanding of the on-the-ground situation and can respond with locally appropriate solutions because global, cookie-cutter solutions do not work.
2. If your objective is to drive change through your research and push for policy changes, having a locally-led project means you have a naturally relatable leader to interact with government and local authorities, who can also take the work forward. Being an outsider telling governments what to do can be misconstrued and do more damage than good.

Give, don't take

1. 1. Be aware that parachute science takes scientific opportunities away from people on the ground. Be conscious that most researchers in low-income/developing countries do not always have the freedom to travel and conduct research across the globe due to weaker passports and resulting visa restrictions. These restrictions mean they have limited opportunities to travel to other countries and conduct research. Recognise this and help create opportunities so they can continue to do local research in the long term.
2. If you train yourself and your teams to work in foreign ecosystems, you will reduce or destroy local capacity in those countries in the long term as you and your teams become more employable in those countries, thereby reducing opportunities for local researchers.

3. Partnering during research and publication is a service to develop connections and scholarship opportunities for those on the ground (The Lancet Global Health, 2018)

Sharing

1. Bring the research findings back to the communities that you worked in. Support the local PI in holding workshops and public lectures to disseminate findings.
2. Data should be shared, and agreements should provide ownership to the country where the research was undertaken.
3. Providing data alone might be insufficient. It may be more prudent also to provide tools and training so local researchers can use the data effectively to inform their conservation objectives.
4. Ensure that presentations at international conferences are done by the local PI. If the PI cannot make it (due to personal or visa and other restrictions), disseminate it in other ways that connect the research to the local PI. This may provide the PI with other opportunities for collaboration in the long term.

Publishing

1. Plan your work so key community partners meet the criteria for authorship (Cooke et al., 2021). This ensures you do not enter the realm of tokenism or “gift” authorship (Pettorelli et al., 2021).
2. The local PI should be incentivized to lead the project and given authorship/made first author on publications.
3. Recognise that the dominance of English in science benefits those from the Global North (Ramírez-Castañeda, 2020) and support non-native English speakers by working with them to improve language and clarity. While comments to authors are expected to focus on the science or content of papers (Pettorelli et al., 2021), this is frequently the first point at which non-English speaking authors from developing and low-income countries lose opportunities in publishing (Ramírez-Castañeda, 2020).
4. If you write a review or paper based on extensive databases collected by others, work with them as partners for the final product. If the data are publicly available (via open access) but collected in another country, make collaboration a condition of data use (The Lancet Global Health, Maxmen, 2021; 2018).
5. When possible, publish in high-impact, open-access journals. Go beyond paywalls. Access to up-to-date knowledge and information is the building block of innovation. If people do not have access because they cannot afford it, they are immediately disadvantaged. We cannot drive change in the absence of equity. Ultimately, for the research to have a positive impact in the country where it was conducted, it has to be accessible, so open access is one solution (but by no means a perfect one).
6. To broaden impact, use social media (Lamb, Gilbert, & Ford, 2018), blogs and traditional media to share the work in an easily digestible format. Whenever possible, translate these pieces into local languages to broaden access for those on the ground.

Driving systemic change: Journals, editors and reviewers

1. Support research that discourages parachute science by putting clear guidelines in place for authors (Pettorelli et al., 2021; Sweet, 2021).

2. Refuse to publish papers that use other people's databases without evidence of collaboration or co-authorship.
3. Reject papers submitted by authors who have conducted primary research outside their home country without the inclusion of local partners.
4. Insist that researchers provide their research permit and research ethics permit number(s) (Stefanoudis et al., 2021) and acknowledge the permitting authority.
5. Recommend editors and reviewers from under-represented groups (Manlove & Belou, 2018) and/or encourage journals to do open recruitment calls for positions such as those of the Associate Editor to move beyond "appointing who we know" (Pettorelli et al., 2021).
6. Include Associate Editor Mentoring Opportunity schemes that provide early career researchers access to guided editorial experience (Pettorelli et al., 2021).
7. Request that all authors working outside their countries provide an inclusion and diversity statement (Sweet, 2021).
8. Whenever possible, provide opportunities to publish research summaries written in the local language of the country where the research is undertaken.

Driving systemic change: Funders

1. Consider introducing a two-stage grant-making process where successful pre-proposals are funded to organize a 'compulsory workshop' with in-country collaborators and relevant stakeholders where research is to be conducted. A similar system adopted by the NWO-WOTRO Science for Global Development Dutch research funding agency then deducts the funds from successful grant proposals (Giller, 2020). While full funding is not guaranteed at this stage, the lessons provided by these workshops likely outweigh the disadvantages and teams are better prepared to pursue the research agenda in the future.
2. Fund research in other countries if local, in-country PIs are included (Erondu et al., 2021) and long-term relationships are demonstrable to avoid tokenism.
3. Grant proposals should outline significant local contributions and collaborations.
4. Support allocating funds for salaries and training requirements of local teams (Hind et al., 2015). Compensation should be equitably allocated based on roles vs. where the researcher is from. This enables local researchers to participate in the research fully.
5. Support the allocation of funds for publication in open-access journals and translation and dissemination of material into local languages.
6. Proposals should include carveouts that help build local infrastructure and promote science more broadly in the country of research.
7. Fund local researchers to participate in and present research both locally and internationally (Hind et al., 2015).
8. Mandate the dissemination of results and community outreach as a prerequisite for funding (Hind et al., 2015).

Driving systemic change: Institutions and societies

1. Advocate for the use of alternative metrics or "altimetrics" in recruitment and promotion of staff (e.g., Lamb et al., 2018) and change systems of incentivization.
2. Instill a culture that discourages parachute science by preparing best practice guidelines and other measures that encourage equal partnerships (Lasker et al., 2018; Nording, 2018).

Conclusion

While the manifestation of parachute science in the field of marine conservation is of most interest here, it is of increasing importance across many fields including medical research (The Lancet Global Health, Lasker et al., 2018; 2018), social sciences (Urassa et al., 2021), human microbiome research (Representatives of the Global Microbiome Conservancy, 2021), genomics (Nording, 2018) and geosciences (North, Hastie, & Hoyer, 2020). While some professional societies and institutions have released statements about how to better address and eradicate parachute science, journals are providing opportunities for authors to declare that their work was "parachute-free" (Sweet, 2021). Yet others are taking matters into their own hands with voluntary guidelines designed to evolve and adapt to make a difference (Nording, 2018). The tide is turning, but we have a long way to go, and we must continue to share perspectives and experiences so we can all be part of the solution that can help us achieve our collective, over-arching conservation needs.

References

Belhabib, D. (2021). Ocean science and advocacy work better when decolonized. Nature Ecology & Evolution. https://doi.org/10.1038/s41559-021-01477-1

Conservancy, R. o. t. G. M. (2021). Leave "parachute science" behind when jumping into global microbiome research. Retrieved from https://microbiome.mit.edu/microbiome-news/leave-parachute-science-behind-when-jumping-into-global-microbiome-research/

Cooke, S. J., Nguyen, V. M., Young, N., Reid, A. J., Roche, D. G., Bennett, N. J., Bennett, J. R. (2021). Contemporary authorship guidelines fail to recognize diverse contributions in conservation science research. Ecological Solutions and Evidence, 2(2), e12060. https://doi.org/10.1002/2688-8319.12060

de Vos, A. (2020). The problem with colonial science. Scientific American

de Vos, A., and Schwartz, M.W. (2022). Confronting parachute science in conservation. Conservation Science and Practice 4, e12681.

Erondu, N. A., Aniebo, I., Kyobutungi, C., Midega, J., Okiro, E., & Okumu, F. (2021). Open letter to international funders of science and development in Africa. Nature Medicine, 27(5), 742-744. https://doi.org/10.1038/s41591-021-01307-8

Giller, K. E. (2020). Grounding the helicopters. Geoderma, 373, 114302. https://doi.org/10.1016/j.geoderma.2020.114302

Hind, E. J., Alexander, S. M., Green, S. J., Kritzer, J. P., Sweet, M. J., Johnson, A. E., Peterson, A. M. (2015). Fostering effective international collaboration for marine science in small island states. Frontiers in Marine Science, 2(86). https://doi.org/10.3389/fmars.2015.00086

Lamb, C. T., Gilbert, S. L., & Ford, A. T. (2018). Tweet success? Scientific communication correlates with increased citations in Ecology and Conservation. PeerJ, 6, e4564. https://doi.org/10.7717/peerj.4564

Lasker, J. N., Aldrink, M., Balasubramaniam, R., Caldron, P., Compton, B., Evert, J., Siegel, S. (2018). Guidelines for responsible short-term global health activities: developing common principles. Globalization and Health, 14(1), 18. https://doi.org/10.1186/s12992-018-0330-4

Maas, B., Pakeman, R. J., Godet, L., Smith, L., Devictor, V., & Primack, R. (2021). Women and Global South strikingly underrepresented among top-publishing ecologists. Conservation Letters, n/a(n/a), e12797. https://doi.org/10.1111/conl.12797

Manlove, K. R., & Belou, R. M. (2018). Authors and editors assort on gender and geography in high-rank ecological publications. PLOS ONE, 13(2), e0192481. https://doi.org/10.1371/journal.pone.0192481

Maxmen, A. (2021). Why some researchers oppose unrestricted sharing of coronavirus genome data. Nature Ecology & Evolution, 593, 176-177. Retrieved from https://www.nature.com/articles/d41586-021-01194-6

Minasny, B., Fiantis, D., Mulyanto, B., Sulaeman, Y., & Widyatmanti, W. (2020). Global soil science research collaboration in the 21st century: Time to end helicopter research. Geoderma, 373, 114299. https://doi.org/10.1016/j.geoderma.2020.114299

Nording, L. (2018). Voluntary guidelines aim to combat 'helicopter' science and ensure that studies benefit African citizens and scientists. Nature.

North, M. A., Hastie, W. W., & Hoyer, L. (2020). Out of Africa: The underrepresentation of African authors in high-impact geoscience literature. Earth-Science Reviews, 208, 103262. https://doi.org/10.1016/j.earscirev.2020.103262

Pettorelli, N., Barlow, J., Nuñez, M. A., Rader, R., Stephens, P. A., Pinfield, T., & Newton, E. (2021). How international journals can support ecology from the Global South. Journal of Applied Ecology, 58(1), 4-8. https://doi.org/10.1111/1365-2664.13815

Ramírez-Castañeda, V. (2020). Disadvantages in preparing and publishing scientific papers caused by the dominance of the English language in science: The case of Colombian researchers in biological sciences. PLOS ONE, 15(9), e0238372. https://doi.org/10.1371/journal.pone.0238372

Stefanoudis, P. V., Licuanan, W. Y., Morrison, T. H., Talma, S., Veitayaki, J., & Woodall, L. C. (2021). Turning the tide of parachute science. Current Biology, 31(4), R184-R185. https://doi.org/10.1016/j.cub.2021.01.029

Sweet, D. J. (2021). New at Cell Press: The Inclusion and Diversity Statement. Cell, 184(1), 1-2. https://doi.org/10.1016/j.cell.2020.12.019

The Lancet Global Health. (2018). Closing the door on parachutes and parasites. The Lancet Global Health, 6(6), e593. https://doi.org/10.1016/S2214-109X(18)30239-0

Urassa, M., Lawson, D. W., Wamoyi, J., Gurmu, E., Gibson, M. A., Madhivanan, P., & Placek, C. (2021). Cross-cultural research must prioritize equitable collaboration. Nature Human Behaviour. https://doi.org/10.1038/s41562-021-01076-x

21. Diversity in marine science

Aliyah Griffith[1]

Video 21.1 Diversifying Perspectives in Marine Science.
https://hdl.handle.net/20.500.12434/481c16a2

Transcript

1. Can you tell us how you got interested in marine science? Brief intro of your background and where you are now?

I have lived on the East Coast of the United States all my life. As my family is from Barbados, a small island in the eastern Caribbean, I continued to build a fascination with the sea. Outside of being able to explore harbors and seaside towns, my parents were keen on exposing me to science centers of all kinds, including the aquarium. After running up to a dolphin trainer at the age of eight and questioning her about her position, I knew from that day on I wanted to be a marine biologist. I am now the first African American to receive a graduate degree in marine science from the University of North Carolina Chapel Hill. I am a marine scientist, a National Geographic Explorer, a science communicator, and the CEO and founder of Mahogany Mermaids.

2. Can you tell us a little bit about the process of forming Mahogany Mermaids? Why were you motivated to create this community? How did the formation process come about? Were there any people or organizations instrumental in helping to create Mahogany Mermaids?

Based on the Yale Program on Climate Change Communication Survey,[2] in 2020, African Americans are 57% more likely to be "alarmed or concerned" about global warming. Even though our communities are impacted

1 Mahogany Mermaids, https://aliyahgg.wixsite.com/website
2 https://climatecommunication.yale.edu/publications/race-and-climate-change/

https://doi.org/10.11647/OBP.0395.21

disproportionately, only about 2.9% of environmental science degrees were awarded to black individuals in 2020 according to datausa.[3] This field is directly impacted and related to our livelihood, and we should be included in its exploration, elevation, and discoveries.

In 2016, I participated in a UCLA Pathways to PhD program called the Diversity Project while still attending Hampton University, a historically black university (HBCU) in Hampton, Virginia. It exposed Black and Brown students to the marine sciences and provided the opportunity for substantive research and scientific diving certifications.

The program made me realize three things. There were not many people of color in STEM. There was enormous room for discovery and exploration in the aquatic sciences, but there were no support systems to encourage Black students to explore ocean science before entering college. With the help of my mentor, family, and a few other HBCU students, Mahogany Mermaids was born. We initially started conducting education workshops and school visits in the Hampton Roads area of Virginia. Over the years, we have expanded programming across the DC, Maryland, and Virginia regions as well as the Chapel Hill, North Carolina area. We pride ourselves on providing resources to and hosting learning events for students both virtually and in person. It is critical to expose Black and Brown students to the ocean sciences early so that there is a pool of students of color interested enough in the field to pursue it in high school and college.

3. What are the values of Mahogany Mermaids? How are you materializing these values into actionable events/activities/products? (Basically, what is Mahogany Mermaids hosting and creating?)

Our values are community, mentorship, programs, education, and inclusion. Our goal is to supply information about different aqua-scientific opportunities. We use our pillars of community, mentorship, and education, to guide students into their desired field while presenting them with opportunities to excel. Success is more achievable when you know you are not alone. Our commitment is to instill a sense of community to ensure every young scientist is supported throughout their scientific journey, so they know they are not alone. We enlist mentors to enlighten and guide young scientists who are still learning academic and industry pathways. The programs we create illuminate the many areas in which young scientists shine by supporting and encouraging the aquatic sciences, especially when entering higher educational systems. Education informs young scientists about different research opportunities and resources for financial assistance.

Mahogany Mermaids supports existing undergraduates by connecting them with other students in their major, curating resources to aid in their academic journey and professional development, connecting students with mentors, and offering an undergraduate scholarship for students pursuing an environmental science degree. I have presented to children throughout Maryland and Virginia talking about my research and the possibilities of what they can achieve. I am also fostering partnerships with diving facilities like Blue Planet Scuba and the National Association of Black Scuba Divers (NABS) to inspire children to dive and explore the waters of the world. We have had a presence at Essencefest to showcase and encourage Black presence in unconventional STEM careers. I hope to also create a science workshop and internship program to engage Black students in marine science opportunities.

4. What role do you think Mahogany Mermaids is playing right now, in 2023, to help propel black and brown students/early career scientists in the field of marine science? (or outside of marine science?)

We are providing early exposure and hope. Representation is key. There are many programs to support college students once they choose marine science. Mahogany Mermaids tries to expose early education students to marine science to create a marine science pipeline for middle and high school to college. Because of our partnerships with National Geographic and Disney, we have been able to reach elementary and secondary

3 https://datausa.io/profile/cip/environmental-science?redirect=true#demographics

school children through social media and in-person events. This past May, we hosted a screening of the live action movie, "The Little Mermaid" and provided lesson plans and science-related activities to all the attendees. These packets were a collaborative project with other marine science organizations to also ensure the attendees knew who to contact and connect with in their geographic area. Additionally, there were about 25 scientists and divers of color who answered questions and made connections with the attendees after the movie. It was powerful for the students to see and be encouraged by so many scientists and scuba divers of color. The parents and teachers have been pleased with the lesson plans as well. They are designed to provide and strengthen the skills needed for success in the sciences and encourage curiosity and scientific inquiry. We have another event in California in partnership with UCLA and a local aquarium coming soon. We aim to partner elementary and secondary school students with local scientists of color. The idea is to show students what is possible by creating hands-on science activities to complete with a mentoring component.

5. Where do you see yourselves in the future, where do you see Mahogany Mermaids playing a role in the future? Do you envision a future where organizations like Mahogany Mermaids are no longer necessary (because representation/equity/etc has been addressed) or do you see the mission of Mahogany Mermaids changing with time?

In the future, I see myself receiving my PhD and continuing to run Mahogany Mermaids. I hope that we can not only make a national impact but an international movement to encourage people of color, specifically Black, to get involved in their oceans and waterways. Mahogany Mermaids is committed to teaching broad audiences about the importance of the environment, how they can create a career in it and how they can help protect it. The organization's role is crucial in marine science and environmental science, especially with the communities that are most affected by these environmental shifts. When we widen the pool of scientists, we widen the perspectives and connections that the scientists have to the communities. Issues will become more personalized and there will be more passion and care behind policies and decisions made that someone outside of a coastal culture may have inadvertently ignored. New perspectives bring new and innovative solutions, particularly if they are partnered or already linked with other organizations that bring large amounts of change. Becoming a marine scientist is a critical occupation to save our planet; as such, I don't think our work will ever be done. If we get to a point where Black and Brown children begin to flood the university marine and environmental science programs, particularly in the U.S., we can shift to collaborating with members of these coastal communities to ensure there is a scientific bench or a pipeline of scientists with a vested interest in the success of their coastal community.

22. The Small Island Developing States (SIDS) science/policy/business nexus

Lorna Inniss[1]

He who knows not, and knows that he knows not, is a child, Teach Him.
He who knows not, and knows not that he knows not, is a fool; Shun Him.
He who knows, and knows not that he knows, is asleep. Wake Him.
He who knows, and knows that he knows, is wise. Follow Him.
(My Dad's favorite Chinese proverb)

I was born in Barbados, a tiny relic coral platform 14 miles at its longest point, 22 miles at its widest. The sea is always with us; it is visible from almost every place on the island. Pristine white sand beaches were plenty, and group recreational activities centered around the ocean. Despite the inspiration all around me as I grew, I entered marine science and governance by accident, when a friend requested that I attend a job interview in her place. The entry level position of Water Quality Technician at the Barbados Coastal Conservation Project Unit, a temporary office, did not seem very exciting to a young female graduate on the cusp of her career in 1992, but my focus swiftly shifted from medicine, business and the military, to full immersion into this fascinating field.

In the early 1980s, when Caribbean small island states were among those nations transitioning from agricultural to service economies, the paucity of human and technical capacity, institutions or approved policies, made it challenging to achieve anything in environmental protection and restoration. The government received several agitated requests for intervention from members of the fledgling tourism sector regarding observed erosion of beaches. Even at a basic level, external resources were required to address the issue. The Inter-American Development Bank agreed to support Barbados, with a focus on the causes of beach erosion. The resulting assessment was both comprehensive and educational for me, in terms of a) identifying the natural assets held in trust, b) presenting some immediate and potential threats to those assets, and c) providing concrete recommendations to government regarding further research and management needs.

In retrospect, I note that while some inappropriately located coastal tourism infrastructure had contributed to the sediment loss observed, a more insidious phenomenon and its devastating effects were beginning to be felt. Even as a young biology student, my understanding of this issue was myopic, noting only the economic consequences of coastal erosion, without any clear recognition of a much deeper climate issue that, in 2022, would become the defining global environmental concern.

My early years in the Coastal Conservation Project Unit ignited an unceasing passion for coastal and marine issues of all kinds. Measuring and analyzing coastal pollutants from legitimate, economically viable land-based sectors and activities, such as agriculture and tourism deepened my understanding of the science-policy-business nexus. Science slowly, and at times reluctantly, became the foundation for decision making nationally;

1 UNESCO-Intergovernmental Oceanographic Commission Sub-Commission for the Caribbean and Adjacent Regions, https://orcid.org/0009-0007-1272-8057

https://doi.org/10.11647/OBP.0395.22

policies were developed to manage and control human and sectoral activities. The private sector responded in two ways: with indignation that they were no longer allowed to conduct business without due regard for the negative impact on nature and other sectors, or reluctant compliance, while advocating to reduce the additional costs of doing business associated with the Marine Pollution Control Act, a landmark piece of legislation that held the country to the highest of standards for nearshore water quality. This policy was critical for protecting more than 70% Gross Domestic Product from coastal tourism, but represented pinch points for developers in the tourism, agriculture and manufacturing sectors. During this process, I learned the value of social science to the achievement of our goals. Without an understanding of human behavior, our successes could not be sustained through time.

In my experience, the rationale driving governance in small states is often misunderstood as pro-economy or pro-protectionist. As a country of very small size and population, we were constantly calibrating what makes the country attractive to visitors and which natural assets need to be protected: in a few cases, they were the same. However, I understood that the tourism industry, often viewed as a driver of negative impacts, could also be an agent for change towards sustainable revenue, if they were well-informed, and took ownership of the assets underpinning their businesses. This lesson was transformational for me: communications, education, training and awareness became an adjunct job, as I often utilized evenings and weekends to make presentations to clubs, churches, sectors and others upon request, and inform news media about our progress. This large-scale school room served a dual function: I saw the relationship change between the population and the coast; and I was constantly learning new information, in order to respond to questions posed during our public meetings, on television and radio programs.

Additionally, we built our own capacity within the Project Unit, strengthened our institution through drafting coastal and marine legislation and policy, training staff and acquiring high-tech equipment for permanent field-monitoring programs. The result was a respected, highly functioning team that influenced all levels of society including the Cabinet of Ministers. The growing recognition of our integrity and high-quality delivery facilitated our approach to educating the public and completed the cycle of national behavior change. The roles of regulator and developer, which had been traditionally oppositional, began to converge, with more applicants requesting a consultation with us proactively, to ensure that our stringent requirements could be considered at design phase.

The new change in behavior was also evidenced in our activities around International Coastal Cleanup Day. Within a decade of consistent training and public awareness, the amount of solid waste collected on our beaches reduced year after year, to the point that the cleanup was cancelled one year, as there was not enough garbage to collect. This milestone demonstrated to me that, while progress was incremental, I could assist in some small way in changing the world.

In the meantime, my promotion to Marine Biologist placed me at the heart of biodiversity conservation and ecosystem protection and restoration. My mentor, role model and boss, Dr Leonard Nurse, a skilled international climate change negotiator and Coastal Geomorphologist, urged me to submit an application for the Fulbright Fellowship, and I spent more than five years completing higher degrees in environmental planning and management, as well as oceanography and coastal sciences, returning to the Project Unit, which was now a permanent department of government, as Deputy Director and, eventually, as Acting Director, until my transition to the United Nations.

Initially, our management framework was issue-based, given limited available capacity and resources. However, a more integrated management paradigm became imperative as we strove for excellence in the Barbados program. One example is the award-winning South Coast Boardwalk, a shoreline stabilization project anchoring several beaches over a one-kilometer stretch of coastline. Its design, a series of headlands joined by revetments, did not only solve the challenges of erosion; the headlands were attractive 'lookout points' and the entire structure was covered by a winding boardwalk, enjoyed by Barbadians and visitors for recreation and business, including global cinematography and weddings. Notwithstanding its success, this project taught me the valuable lesson that politics and public finance can trump the greater public good. For example, there were opportunity costs associated with a proposed but unimplemented development tax on those properties that benefitted directly from the project. The funds were to be utilized to maintain the structure through its 50-year design lifetime. A huge challenge was how to broach the development tax with the private sector, when the small island economy is inextricably tied to foreign direct investment, which causes the fear of losing much-needed foreign exchange for the 90% food imports needed.

Despite slow progress and setbacks, these major successes ignited my passion to support small island developing states (SIDS) countries, and my publications and presentations at conferences catalyzed other Caribbean governments and international partners to approach the Ministry, requesting assistance with their national programs. This midpoint in my career was the most rewarding for me: to have our work on the ground validated by others who considered our accomplishments as a model for coastal and marine governance globally. I supported 13 Caribbean countries over my ten-year period as Deputy Director, with staff training, technical advice, establishment of institutions and programs. It was also a privilege to contribute to the United Nations Development Programme's (UNDP) South-South Cooperation by working with the South Pacific Regional Environment Programme (SPREP) and the countries of Kiribati and Fiji to provide training for Government officials. My foray into the private sector, with the team's coastal engineer, occurred when the Government of Colombia requested technical assistance on beach erosion, supported by members of the hotel industry concerned by beach erosion. We provided technical advice and recommendations for the beaches we were able to visit.

This global work shaped my thinking for the next phase of my career as Acting Director of the Department, where I moved fully into the critical area of international negotiation and understood that a fully integrated coastal and marine program must also be outward-looking. The legally designated maritime boundaries are artificial, created by countries jockeying for sovereignty and marine resources; however, organisms, ecosystems and non-renewable resources do not respect the United Nations Convention on the Law of the Sea (UNCLOS). Hence, a stellar program in-country is meaningless unless it also takes place within the global policy space, and other coastal states agree to take similar action.

When I began my career in the Project Unit as a junior officer, one of my tasks was monitoring tar balls on the east coast of the island. However, as a senior official negotiating within the International Maritime Organization (IMO), I realized that ships complied with the agreed global standards for discharge from bilge tanks, but the beaches of Barbados were not protected by those standards. Where compromises are made to draft international law, the impact of those compromises are generally local, and this challenge is evident in the ongoing climate change talks regarding limiting the increase in global warming to 1.5 degrees Celsius. Island states require sustained international support, but skilled, focused negotiators are few, with officials often juggling mandates for several multilateral agreements.

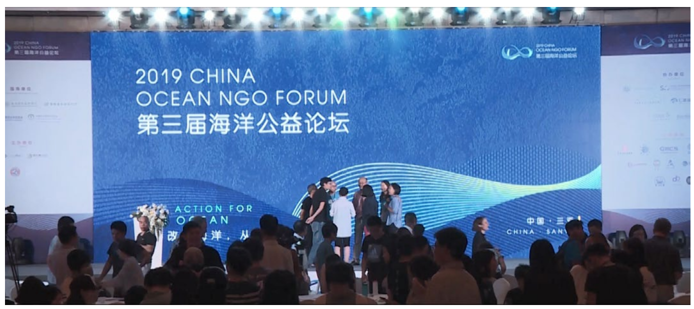
Yet, my most valuable negotiation lessons learned over 30 years still hold true today. My first imperative, as head of the delegation, was to protect the country's sovereignty and national interests; second, my technical expertise was the guide when supporting a global position, whether positive or negative. Honoring both within the negotiations is critical. To be a good negotiator, I had to reflect on the ultimate objective for my country, my boundary line for the negotiation. Understanding the boundaries of other countries directed my honest attempts to find common ground. I learned the hard way that I was focused on details; my function as a scientist was taking control, a common mistake for an inexperienced and unprepared negotiator.

My contributions to negotiations on, *inter alia*, the transshipment of nuclear waste through the Caribbean Sea, the IMO Convention on Ballast Water and Sediments, and the Protocol Concerning Pollution from Land-Based Sources and Activities honed my skills over the years, and these difficult conversations ignited my passion to become an international civil servant. The Barbados program was mature, with a stable and legal base; my new challenge was to support other countries as I had contributed nationally, which involved an almost seamless progression to the United Nations Environment Program. It is rewarding to work through more complex geopolitical, cultural and language differences to support the achievement of similar, effective national coastal and ocean management frameworks and programs as Barbados. With this transition, I miss delivering in the field, but celebrate each small regional step.

The landscape of my career is like the country of my birth, with plains (ordinary days) interspersed with small hills and shallow valleys, and high and low points (learning periods). Challenges were met by the team as puzzles to be solved, not hardships to escape. Living and making history as I move along this landscape means dwelling on a problem today as if it is already written in my biography: I must work with others towards an effective solution. I look to the future with hope; we have not solved all the problems of the oceans, but the progress we have made is tremendous compared with where we started.

23. Strengthening NGO networks and capacity building for ocean sustainability in China

Han Han[1]



Video 23.1 Highlights from the China Blue Ocean NGO Forum (2015–2019): Showcasing pivotal moments of collaboration, innovation, and commitment to ocean sustainability. https://hdl.handle.net/20.500.12434/0216ef7a

The China Ocean Nongovernmental (NGO) Forum started in 2015 to enhance the communication among ocean-related NGOs in China and raise public attention to ocean sustainability issues. Since then, every two years, hundreds of people gather at the Forum to celebrate milestones and exchange lessons learned on their way towards ocean sustainability. It became the information hub and center stage for those actively exploring sustainability solutions for our ocean.

One day in the summer of 2015, I made a call to Yonglong Liu, the head of Shanghai Rendu, one of the few ocean NGOs in China, specializing in marine debris and coastal cleanup. At the time, he was a key person connected to many people and grassroots organizations that cared about the ocean. With a limited budget, he organized two annual meetings for these groups. The feedback he received from the participants encouraged him to find ways to boost interest and increase participation, thereby enhancing their capacity to better conserve China's coast and ocean. According to him, even a limited amount of time spent in a shared space among blue ocean supporters would be invaluable. At the very least, they would know that they were not alone.

At that time, I had just started China Blue in an empty office which I rented near my seven-year-old daughter's school. Both Yonglong and I felt so strongly that we needed a way to bring more people together to amplify the voices of Chinese NGOs dedicated to ocean sustainability. That was the inception of the China Ocean NGO Forum.

Now, the China Ocean NGO Forum has become the largest platform for various stakeholders, including NGO practitioners, charity foundations, government agencies, universities, research institutes, corporations,

[1] China Blue.

 https://doi.org/10.11647/OBP.0395.23

and media. This platform allows these groups to exchange their knowledge and lessons learned about ocean conservation and relevant fields, and to facilitate collaboration and capacity building throughout the ocean NGO community in China.

With the support of international and domestic charity foundations, as well as the central and local government, the China Ocean NGO Forum has cultivated a series of creative conversations and collaborations, including advocating for the Blue Pioneer Program, a talent development program to foster social innovators dedicated to ocean sustainability.

Why do we need the Forum?

Ocean sustainability is still a new concept in China. To mainstream the topic and attract resources to support a wider range of actions, besides establishing an organization, cultivating a social environment that encourages the growth of more ocean NGOs is key. Therefore, convening various stakeholders to join a dialogue to present each other's work and exchange different opinions will increase mutual understanding, and gradually attract the world's attention. This would also foster a favorable environment to make start-up NGOs like China Blue's journey a bit easier, as public perception and attitudes towards ocean sustainability and NGOs will grow along with the Forum. We are at the infancy stage of the development of China's ocean philanthropy and NGOs; we are therefore bound to jointly build a community of common destiny.

Why do we need to take the first step?

Although, at the time, China Blue consisted of only three people, two early career staff members and myself, I believed that was still the best timing to start the initiative. We had nothing to lose. Instead, we were lucky enough to have tremendous support from various sources.

Dr. Walt Reid from the Packard Foundation, the first grantor to sign up to the Forum supporter list, shared our beliefs. Dr. Jilan Su, an Academician of the Chinese Academy of Sciences and a renowned professor of physical oceanography in his 80s, immediately replied to my invitation email to become our keynote speaker.

Yonglong Liu, a respected champion among a network of grassroot ocean NGOs, (successfully) called on them to join the Forum. My callout, on the other hand, was mainly answered by charity foundations and international NGOs. Many friends in Hainan also proactively offered help with logistics and gaining government support.

After two months of preparation, we overcame a multitude of challenges, and successfully hosted a forum with over 150 participants in attendance.

What values did the Forum offer?

First of all, there has always been a simple purpose for the Forum, which is calling everyone who is concerned about the ocean to come together. Such a gathering aims to help us clarify and confirm our understanding of ocean sustainability, and to share updates on our progress, including research and efforts to tackle sustainability challenges. Over the past five years, the growing list of attendees has confirmed the value of the Forum. NGOs are proactively applying to host the Forum. The participants stem from the NGO community to the wider public, including fishers. A group of fishers in their 70s or 80s sang a folk song, 'The Salt Water song', at the 3rd Forum in 2019, telling a century-long story of fishing in the South China Sea. One of the fishers passed away three months later. The performance was his last reunion with his fellow peers.

Secondly, the Forum became a well-known stage to present the key players in the ocean NGO community and their partners, recognizing their achievements and dedication to multi-stakeholder collaboration. People need to be acknowledged for their progress, no matter how small, as this is a long journey with unexpected difficulties. Such an opportunity is necessary to encourage more stakeholder engagement, as well as for young people seeking to join the community. Many volunteers and college students become interns or staff at ocean NGOs after attending the Forum. Furthermore, it was crucial for us to have an open setting where we could freely share and discuss our valuable insights. Given our status as a developing community in a rapidly evolving field, we are confronted with numerous uncertainties. Thus, it is essential to conduct thorough research to determine the appropriate questions to address and to identify the target audience. Unfortunately, due to the limited availability of expertise in this area, finding straightforward solutions becomes quite challenging.

What has been the biggest challenge throughout this journey?

How to facilitate the collaborative initiative is always the hardest part. Nowadays, you cannot accomplish anything by yourself. Facilitative leadership is universally desirable, especially for an event like this that engages all kinds of players with different backgrounds and agendas. Partnerships can easily unravel due to misunderstandings. Having a 'facilitator' or a team of 'facilitators' who have a deep understanding of the overall vision and mission of the Forum is key to maintaining and strengthening collaborative partnerships. Without this, some individual organizations might become strong, but as a whole, the community might still be very weak, which is not a healthy ecosystem in the long run.

It has just begun. See you down the road

Five years ago was just the beginning of a life-long journey. In the past five years, the number and size of China ocean NGOs have grown significantly. For example, domestic NGOs like Dive-for-Ocean, Shanghai Rendu and China Blue all doubled and even tripled their number of full-time staff.

But the Forum is still quite young and needs continuous support and active engagement from various players. Since COVID-19, the world has entered a new era with an even higher level of uncertainty. Nevertheless, the 4th China Ocean NGO Forum was scheduled for October 2022 in Hainan, where we met to celebrate another milestone.

As the co-founder of the Forum, it has always been enlightening for me to organize the forum. I am honored to witness the growth of such an amazing community and career for all of us.

24. Conclusion

Building a new global vision for marine conservation: Inspiration, networking and capacity sharing

Larry B. Crowder[1]

Marine conservation scholars and practitioners often practice in their own geography, in their own culture. But there is much to be learned from others taking on similar problems in different systems. We can learn from others in remote places, but only if we create or enhance networks for that exchange. Historically a lot of research in marine conservation has been funded and led by researchers from the global north, who often failed to effectively engage scientists and practitioners from the countries in which they worked. But in fact, we share one world ocean and should refrain from parachute science or colonialist perspectives (Crowder, 2022, Figure 24.1).

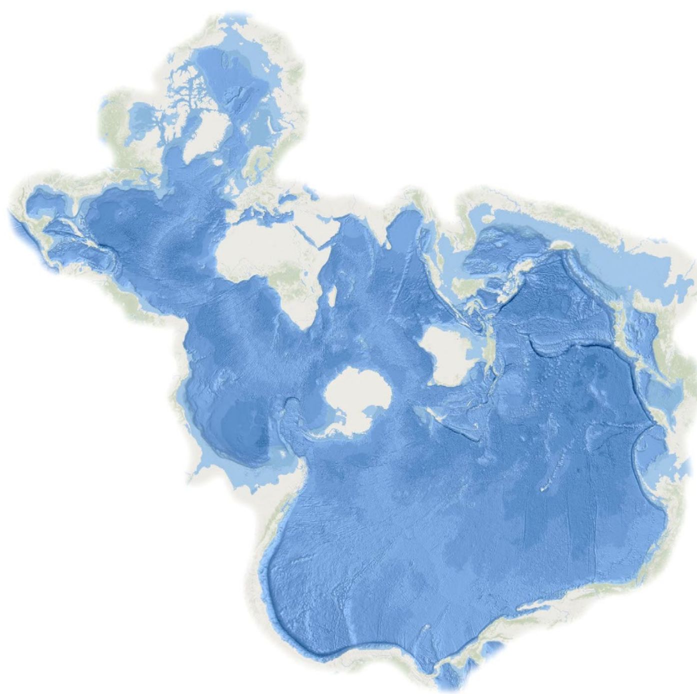


Fig. 24.1 Spilhaus projection of the world ocean from Crowder, 2022 prepared by Hannah Blondin, Hopkins Marine Station.

1 Hopkins Marine Station, Stanford University, https://orcid.org/0000-0003-3131-2579

 https://doi.org/10.11647/OBP.0395.24

It is also critical to engage scholars and practitioners across the disciplines in natural science, social science, and governance, and from key traditions including western and indigenous science (Reid and Ban, Chapter 15). Finally, beyond engaging practitioners and scholars from different traditions and disciplines, we have to build capacity for fruitful interactions among key actors in research, or in the implementation of challenging management programs, and for in-country partners to carry out the program over the long term.

But how does one go about doing that?

I started the first course in Marine Conservation Biology and Policy at Duke University Marine Lab (DUML) in 1997. In the first year, we had 50 students from all over the United States and one international student from Barbados, Lorna Inniss (see Inniss, Chapter 22), who happened to be in the United States working on an MS degree. One day while I was waxing philosophical in front of this large class from my US-centric view, she quietly said:

"Let me tell you how it is in Barbados…."

The whole class got quiet, and listened, and learned—including me. This single international student taught me a valuable lesson—take time to listen and learn—to fully engage international partners. She was the inspiration for the Global Fellows in Marine Conservation program at Duke Marine Lab, which began with five people in 1998 and continues 20+ years later. It has engaged 178 Global Fellows from 65 countries (Figure 24.2), and Fellows continue to interact with each other and with U.S. students.

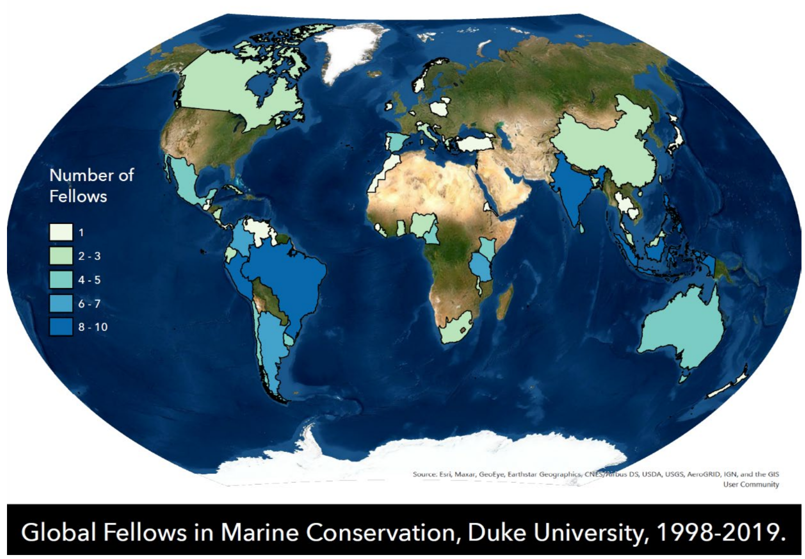


Fig. 24.2 Global Fellows Map.

In reviews of the course, U.S. students always called out the Global Fellows as their favorite part of the experience! I remember classes raging with debates and evenings of lively conversation on the deck of the boathouse. Much more learning occurred there than in the classroom. Since then, I have had the opportunity to teach in similar courses in Mexico and China and to lecture in short courses in Croatia and Argentina.

Through this experience, I began to realize that building capacity and international networks could provide a more viable approach than the colonialist "parachute science" still common at the time (Crowder, 2022). I was humbled by my experiences doing international research and recognized that scientists and policymakers operating in their own country are the best way forward. The Marine Conservation Biology and Policy course rapidly evolved from one based on lectures to discussions, debates, and simulation games. We also spent 25% of class time in the field studying how problems were solved in our region. My co-instructor, Mike Orbach, an anthropologist, and I taught together and debated each other in the class. Initially the arguments between us were spontaneous and the students were shocked—Are the professors going after each other in class? The spontaneous, heated debates were later 'staged', as we found them a useful teaching tool. It made clear that the frequent conflict and misunderstanding among scholars from different disciplines prevents us from getting to viable solutions. Until all the diverse partners from different disciplines, institutions, cultures, and stakeholders realize they need each other, we will make limited progress.

Rather than just showing the students the disciplinary 'ingredients' needed for solutions, we began to focus on how those ingredients can be combined to design pathways to solutions. Even now, most programs show their students the ingredients for a great gourmet meal, but they don't teach them how to cook! I also learned that the Global Fellows needed support and resources to implement their ideas, so I worked with funders to establish mini grants to help get Global Fellows into the funding system and actively stayed in touch with them to provide advice as needed.

Asha DeVos was a Global Fellow from Sri Lanka in 2008. She is now a winner of many prestigious awards, including a Pew Fellowship, and leads her own NGO in Sri Lanka. Her vision for "Building equal partnerships for conservation success" can be found in this volume (DeVos, Chapter 20). Asha contributed a "box" for this chapter.

For this chapter, I polled 28 Global Fellows alumni to get an update on what they are doing now and to get feedback on their experiences in the Global Fellows program in their own words. The program provided a five-week summer experience living at Duke University Marine Lab, during which the Fellows took the Marine Conservation Science and Policy course and one of several other courses including marine mammals, sea turtles, invertebrate biology, or marine policy. Their comments varied, but often addressed common themes. Many said the experience changed their career and life trajectories; some commented on the principles, practices, and theories they learned; and others commented on influential faculty or seminar speakers. Others mentioned being able to list being a Global Fellow in Marine Conservation at Duke as opening doors to jobs and to graduate school. But overwhelmingly, the comments included references to meeting other Global Fellows from all over the world in addition to the U.S. students. Studying and living with this diverse group for five weeks has had a life-long impact on most of them. Many are still in touch with their cohort. Escaping the feeling of being alone in your passions and meeting others from around the world who share your challenges, enthusiasm, and excitement put wind beneath their wings. I remember one Fellow from Chile, Carla Christie, who described telling her personal friends about her work and "they thought I was crazy! But now I am here with other crazy people from around the world!! It feels great!"

Where are the Global Fellows now?

JoAnna Alfaro (Peru 2000) is Director of the Peruvian NGO ProDelphinus, based in Lima, with offices in two other cities in Peru. She has a staff of over 20 researchers and collaborates with researchers worldwide. She is also on the Faculty of Marine Biology in Universidad Cientifica del Sur, in Lima. She remains an associated researcher at the University of Exeter and a member of several specialist groups of the International Union for the Conservation of Nature (IUCN) (Turtles, Cetaceans, Sharks, Otters, and Seahorses).

"Participating in the summer of 2000 of the Global Fellows program at the Marine Lab was a game changer for my career and personal life. For the first time in my life, I felt I was not alone in my work in conservation and that my work could have a broader impact. I learned basic principles in conservation that I still teach to my students in the university. The experience helped me understand the importance of networking and how valuable it can be, especially when working in global/regional marine conservation."

In the last ten years, **Andrea Montero Cordero** (Costa Rica 2005) has worked in the management of marine conservation projects in two conservation trust funds in Costa Rica: one encompassed marine protected areas (MPAs) at the national level and the other focused on the Isla del Coco World Heritage Site. Both operate as public-private partnerships. "The Global Fellows program was decisive in my professional career. I met many professionals from different parts of the world, each with their experience and country reality. I learned first-hand that there are no 'recipes' when it comes to applying management policies and measures, and how important it is to learn from experiences around the world. The professors were of the highest level and, even today, I continue to apply learnings from that short but intense experience. Being a Global Fellow is an award that I will always be proud to wear. My eternal thanks to Larry Crowder for being the promoter of this initiative… for his humility, despite his greatness. For still being a mentor and a friend after so many years. Thanks to the donors who trusted in this idea; rest assured that the investment had an impact that exceeded any expectations. Thanks to Debbie Pease, Mike Orbach, Andy Read, for inspiring so many people that are 'changing the world' today, from their country. Thank you for the friends, with whom I still have contact, after more than 15 years!"

Mònica Arso Civil (Spain 2008) is currently a Senior Research Fellow at the Sea Mammal Research Unit (University of St Andrews, Scotland). She leads projects focused on the monitoring and population dynamics of marine mammals. "The Global Fellowship provided an opportunity to meet other fellows working on other similar fields, but with varied backgrounds and particular challenges in each of their home countries, which was eye-opening. It also provided me with a degree of recognition which helped me submit subsequent applications for courses, grants, and projects successfully, and offered opportunities for future collaboration. If anything, it built my confidence to express myself and my research ideas in a welcoming environment despite the foreign language (my English was not that good at that time). I treasure my time spent as a Global Fellow at the Marine Lab in Beaufort. It was very intense but incredibly motivating and rewarding. I met some amazing fellows, other students, and staff with whom I am still in touch."

Carla Christie (Chile 2005) was an undergrad in marine biology when she came to Duke. After graduation, she studied for a Master's degree in Science Communication at Otago University in New Zealand (with a Chilean government scholarship), then returned to Chile and worked for ten years creating activities and educational projects to bring science closer to the community, particularly with children. She published a book about the Chilean dolphin and was recognized as one of the 100 Young Leaders from Chile, and represented Chile in the International Visitors Leadership Program (IVLP) for women in science in the United States: "Hidden No More: Empowering Women Leaders in STEM". In the last three years, Carla co-founded a Foundation of Marine Science Education and Conservation "Fundación Oceanósfera" (https://en.oceanosfera.cl) to create free educational resources of marine fauna from Chile. Carla is about to complete a PhD in Communication and to create a new Ocean Educational Plan for the Chilean government. "I believe the experience at the Duke Marine Lab was a key moment for my life's career. It opened my mind to new opportunities and made me feel there were no barriers to working in marine conservation—it was a perfect push to get ahead. Plus, it was a wonderful experience to meet other young fellows who were 'on the same page' that I was, with energy, and trying to make our efforts to reach conservation goals in developing countries. I still keep in contact with at least four global fellows and one U.S. student; moreover, with Alexa Sapoznikow from Argentina, we created a Science Communication one-week workshop together in Argentina. I just want to say THANK YOU, to all the people who made this experience possible."

Cecilia Rivas Medina (Peru 2001) is an Associate Professor at Universidad Peruana de Ciencias Aplicadas (UPC). Perú and Research Coordinator. School of Hospitality and Tourism Management. "While my basic training is in biology and my Master's degree is in Natural Resources Conservation, I began working on linking tourism as a strategy to conserve natural environments and especially coastal and marine ecosystems. I have worked on several projects with that approach over the past 20 years. The knowledge I acquired through Global Fellows in Marine Conservation helped me very much. I am currently studying for a PhD in Tourism at the University of Alicante (Spain); my research focus is tourism and small islands in order to establish environmental criteria to ensure its sustainability. I would like to rescue the knowledge that I acquired through the Global Fellows in Marine Conservation 2001."

Nora Lisnizer (Argentina 2009) is now a researcher working in the Ecology and Conservation of Seabirds Group at CESIMAR-CONICET, Puerto Madryn, Argentina. Her current main project focuses on seasonal movements of Patagonian waterbirds and seabirds and their relationship with trophic resources. Her studies aimed to provide information to guide management and conservation strategies for marine birds in coastal Patagonia. "Being a Global Fellow was a very enriching experience for my scientific career and for my personal growth as a global citizen. The courses at DUML allowed me to learn unique aspects of biology and conservation that I hadn't been taught before at graduate school. In particular, I had to learn key tools for conservation and management strategies that I feel have made a difference in my understanding of local and global conservation issues. And most important, it enriched my way to approach local marine conservation and management challenges that I encounter at my work as a seabird researcher. All in all, the different experiences I had being a Global Fellow have made a positive impact on my career, my work in marine conservation, and my personal growth. It also motivated me to be more conscious regarding environmental issues at work and in daily life."

Rowan Trebilco (Australia 2007) is currently a research scientist and team leader with CSIRO Oceans and Atmosphere (O&A) in Hobart, Tasmania. He leads an ecosystem modeling and assessment team in O&A's Coasts & Ocean Research Program. He also co-leads the Environmental Change and Adaptation research theme in the Centre for Marine Socioecology at the University of Tasmania, where he is an adjunct senior researcher. The main focus of his work is on assessing status, trends, risks and opportunities for marine social ecological systems, and on developing strategies for climate change adaptation. "The Global Fellowship had profound impacts on both my career and personal life. I met my wife at the Duke Marine Lab during my Fellowship (she is from California and was also spending the summer at the Duke Marine lab to undertake experiments for her MSc research) and our relationship, along with my experiences at Duke as a Global Fellow, strongly influenced my decision to complete my PhD in North America (in Canada). My Global Fellowship nucleated the development of a strong international professional network that has been very beneficial to my career."

Since 2007, **Ana Paula Cazerta Farro** (Brazil 2005) has been a Professor at Universidade Federal do Espírito Santo (UFES), São Mateus, ES. She has been teaching and supervising undergraduate students from Biology and graduate students from two programs: Environmental Oceanography (PPGOAm) and Animal Biology (PPGBAN). Her research focuses on the genetics and conservation of cetaceans and marine fishes. "The Global Fellowship was a great experience that contributed to my career in different aspects. Firstly, I had the opportunity to learn and discuss about Conservation Biology and Marine Mammals, two subjects that nowadays I teach at UFES. Secondly, I met students from many different countries. They are incredible people, and it was a great opportunity to share experiences and learn about other cultures. We lived special moments at Duke Marine Lab and became good friends. Since then, talking to them brings me very good memories and feelings. Thirdly, staying in a place such as Duke Marine Lab, in Beaufort, NC, USA, with very nice and thoughtful people was an unforgettable experience. I feel I was very lucky to be chosen in that year to take part of the program. I am very grateful, and I will never forget our Global Fellow family. Thank you very much!!"

Jason Thompson (Canada 2000) is currently working for the government of Canada, in the Department of Fisheries and Oceans. He holds the position of Senior Marine Spatial Planner. Working on a large regional MSP initiative on the South Coast of British Columbia, his position is focused on First Nations and Stakeholder engagement. "It was an opportunity to meet students, academics, professionals, and practitioners that I would not have had the chance to meet otherwise. The interdisciplinary nature of the program was very new. I had a pretty traditional academic background, very focused on marine sciences. The program exposed me to a whole new side of conservation and marine management. And of course, the dynamics of meeting all these wonderful international students and understanding the nature of the issues in their home countries—irreplaceable. It was such a benefit to Global Fellows, but almost more importantly, I could see it open the eyes of the local students to issues and concerns from around the world. Until you meet someone dealing with these issues directly, it's all a bit academic."

Keshni Gopal (South Africa 2009) is a Senior Research Scientist for the City of Cape Town, Western Cape, South Africa. After completing her PhD in 2013, she found it difficult to get a job in the marine field in her country. She has been employed in a series of part-time jobs and postdocs. She found there was very little opportunity to find another postdoc or permanent position South Africa, so she welcomed the opportunity to be a Scientific Marketing Officer at an industrial company working with seaweed for a while before moving to her current job.

"Unfortunately, the impact of the Global Fellowship has been insignificant in my case. After obtaining a PhD, and publishing over ten articles and reports in internationally recognized journals, I am, in my opinion, unemployable in my country due to my demographics and my wealth of skills and experience. I was one of the first black female South Africans to have obtained a PhD and, despite the fact that our marine environment is so under-studied, many students with a master's level or lesser degrees are given the opportunities. Even the Black Economic Empowerment (BEE) system in South Africa has not worked in my favor despite me ticking a lot of boxes in this system. The marine sector in South Africa is still dominated by a lot of males, white persons and over recent years a lot of foreigners (students and researchers) have been brought in to fill posts."

Shaleyla Kelez (Peru 2002) is the leader of the marine biodiversity area at WWF Peru, and she is also a researcher at the Peruvian nonprofit ecOceanica, which she co-founded. She obtained her PhD at Duke University (2011) and then returned to Peru. She is in charge of several important projects for the conservation of endangered species in Peru. Her work is not only in conservation research, but at the policy level she also works very closely with several agencies in charge of the management of marine fauna in Peru. "It was a very important experience and had a huge impact in my career as it contributed to my acceptance in the PhD program at Duke, besides getting a scholarship from the Fulbright Program and the OAS. The Global Fellow program was not only important for the material learnt during the classes but also, and most importantly I believed, for all the people you meet. Being at Duke with so many professors that are brilliant and very high-ranked in the global scientific community is an irreplaceable advantage in the Fellows' career. Besides the professors, meeting the other students and researchers is a treasure. In my case, I maintain those connections and they have been very helpful in many opportunities not only at the conservation work level but also at the personal level."

Marina Tomas (Argentina 2009) is a full researcher at Centro Austral de Investigaciones Científicas (CADIC-CONICET), in Ushuaia, Argentina. Her principal line of investigation is the study of high-latitude marine ecosystems, with a particular focus on trophic and non-trophic interactions in sub-Antarctic and Antarctic regions. She uses network theory as the main framework to better understand the complex web of interactions that occur in the regions she studies. "The impact of the Global Fellowship (GF) on my career was important in the sense that it enabled me to be a step ahead when applying for subsequent jobs and fellowships. After finishing the GF, I got my first job as a professional biologist working onboard Antarctic cruises as a tour guide. What's more, in my opinion the record of the GF in my Curriculum Vitae allowed me to gain a scholarship from the Organization of American States (OAS) to do a Master's in Biological Oceanography in Mexico. In brief, the GF opened several doors to me that at the end took me to where I am now: a full researcher in one of the principal institutes for marine investigation in my country. What I enjoyed most about the GF was the team spirit that I experienced among the international fellows. I think that the multiculturality was a key element in achieving such spirit. The initial encounter with the international fellows a few days before the start of the summer course at Beaufort was of paramount importance."

Damian Martinez-Fernandez (Costa Rica 2006) is working as a Conservation and Policy Director in Costa Rica´s Fishing Federation. Previously, he worked as an advisor for the Deputy Minister of the Environment in the Ministry of Environment and Energy, and as national coordinator of the Consolidation of Marine Protected Areas UNDP/GEF Project. "The impact on my professional career was on several levels. The most relevant was the consolidation of a network of colleagues who led marine conservation initiatives in Latin America—

Latinos, but also Europeans or Americans. This network has made it possible to develop or collaborate with specific projects. At the time, being a Duke scholar also allowed me to access project opportunities due to the importance of the university on conservation issues. Also, having contact with different specialists in several topics allows a better understanding of the current situation in marine conservation in the region. This effort that Larry has led for a long time is very important. Not only because of the technical or scientific importance of this network, but also because of the capacity-building actions that can be carried out in an empathic way and responding to regional needs. In my case it motivated me to do the same on a smaller scale."

Antonio Mazaris (Greece 2003) serves as an Associate Professor at the Department of Ecology, School of Biology, Aristotle University of Thessaloniki, in Greece. He has his own research team of more than 15 members (postdocs, PhD students, MSc students). He has published 100+ papers and has been involved in a number of national and international projects targeting biodiversity conservation. "This was just an amazing opportunity for me. It was not only the interaction with international students or the quality of the educational/research activities that greatly affected me. It was the quality of the program, the interest and professionalism of the team, the positive welcome. I'll never forget that when I arrived at my hotel, I just met Larry Crowder—so far, I was only amazed by his papers! But he was such a cool, kind, smart, and gentle person. I realized that great scientists could also be great persons that enjoy what they are doing. After almost 20 years, I can still recall so many things from this program. I started being a team player and I realized that research and science could be fun and super creative. Obviously, I also learned many new things, but for me this was only part of something bigger that greatly affected my future."

Debby Ng (Singapore 2010) was a journalist and wildlife crime researcher in Asia-Pacific. She reported on the environment and humanitarian news, and carried out undercover investigations into the trade in illegal timber, bear bile, elephant ivory, musk deer, and tiger skins and body parts. She is now a PhD student at the Centre for Nature-based Climate Solutions at the National University of Singapore. Her research focuses on investigating the applications of seagrasses in improving water quality in urban coastal cities, in particular, the ability of seagrasses to reduce pathogen burden along coastlines. "For my PhD research, I may collaborate with Dr Juan Diego Gaitan-Espita, a fellow DUML Global Fellow in 2010! I forged several precious friendships and remain in touch with several Global Fellows. Their journeys have inspired and supported my growth, as they gave me intimate insight into the multitude of challenges and diversity of approaches in conservation, and made accessible a global community of change agents that I could lean into for support. Dr. Crowder, Dr. Orbach, and Dr. Rittschoff, who were my mentors and cheerleaders before, during, and after the program, inspired wisdom, optimism, humility, and joy in face of the sometimes seemingly insurmountable challenges of conservation. Their tangible support gave me strength to pursue and transition into a new field. Lessons and experiences from the fellowship will continue to resonate through my life, and influence how I perceive science, people, conservation, and policy."

Emile Pemberton (Nevis 2005) is now Deputy Director in the Department of Marine Resources on St. Kitts and Nevis and President of the Nevis Turtle Group. "I acquired a lot of knowledge about marine species that I was able to use in my work. Widecast did a sea turtle conservation project on Nevis with funding from the Oak Foundation. I would recommend the Global Fellows Program. There are lots of experiences had and shared, plus lots of knowledge gained during the summer. One learns about many other cultures since there are persons present from many different countries. It inspires one to continue to do what is a largely thankless job, realizing that there are many persons doing similar work around the world."

Thanks to the small grant from Duke University Marine Lab from 2012–2015, **Chitra Rampuhl** (Mauritius 2011) set up a team for a project on coral rehabilitation in her country with the help of the local NGO—Shoals Rodrigues, Mauritius. To this day, the coral rehabilitation project continues with other funds. She also set up a company as an environmental consultant in her country. She did her PhD in Japan and worked as a researcher at the university, and isolated three novel phages to treat coral diseases by using phage therapy. Recently, she moved to Japan as a researcher and developer to develop green projects like promoting the company SDGs, carbon capture, and developing a new ecofriendly product to grow corals as well as seeking solutions to clean oil spill. "The Global Fellowship was a very positive experience, not just by learning from the professors but also from other fellows and students. Being granted the research mini-grant for three years helped in creating a project that works and helps the local community, and the marine biodiversity, and the government too—as the local government is very supportive of the project and we expanded the project in the north and south of the Island of Rodrigues, Mauritius."

Renison Enriquez (Belize 2005) worked as a Biologist for the Glovers Reef Marine Reserve and has now completed his MSc, DipEd, and CertEdLead. He currently serves as the Vice-Principal of Student Affairs at Edward P. Yorke High School. "The Global Fellowship has allowed me to get a world view of environmental issues and solutions, and to have the strength of environmental awareness to help me in my past and present career. The knowledge I gained has also allowed me to run a successful environmental club for my students."

In 2002, **Cecilia Rivas Medina** (Peru 2001) was invited to join a university in Lima as a full-time professor, where she was in charge of an ecology course for undergraduate students. The knowledge she acquired at Duke was useful, especially because the course was not aimed at biology or ecology students, but at business sciences, tourism, and hospitality students, so the aspects of conservation were very important. In 2014, she paused her work at the university and took a position in the public sector as the Tourism National Director of the Foreign Trade and Tourism Ministry, and she was in charge of the environmental issues of the tourism sector. That same year she worked as a professor in the Graduate Program of the Master's Degree in Policy and Management, and in Science Technology and Innovation with the Innovation course in Renewable Natural Resources Management. In 2016, she returned to the university to a full-time position as Research Coordinator at the School of Hospitality and Tourism Management at the Peruvian University of Applied Sciences (Universidad de Peruana de Ciencias Aplicadas—UPC). Cecilia is currently studying for a PhD in Tourism at the University of Alicante (Spain), and her research focus is on tourism and small islands, in order to establish environmental criteria to ensure tourism sustainability. "The experience lived at Duke through Global Fellows in Marine Conservation was wonderful and very important for me. I learned a lot in the courses and also with the exchange of experiences. The approach of training provided was very focused on providing a theoretical and practical training. The practical component through field visits was very valuable and enriching. For me it was amazing to observe the invitation of the keynote speakers; some authors of books that I know, but I couldn't believe that I got to see them in person. The special sessions for the 'internationals' were very valuable. The work of our advisor, Dr. Crowder, was always attentive and always invaluable. In addition, our coordinator, Sara Maxwell, supported me as I was still not very advanced in my knowledge of English. When I returned to Peru, all this helped me a lot in my ongoing projects and at the academic level. It also allowed me to incorporate methodologies for my classes at the university and in the field evaluations that I then designed for my classes at the university."

Luis Santillan (Peru 2005) is a research professor at San Ignacio de Loyola University (USIL), Environmental Engineering School in Lima, Peru. Additionally, he is a senior consultant in marine mammals and marine fauna for several consulting companies. "I learned several aspects of marine conservation and marine mammal science to enrich my background. I realized that we could live in different countries, but share the same marine conservation problems, at different scales or levels, of course; each country has their own peculiarities. Each experience I heard from each country and continent added tons of information in my background. The summer I spent at Duke Marine Lab gave me knowledge, but also gave me global friends. We built a strong friendship, in spite the distance and the time; I am sure that this is the kind of friendship for the whole life."

Kumaran Sathasivam (India 2002) published his book on Indian Marine Mammals after he returned to India. A few years later, his friend K.S. Natarajan and he created a website devoted to the marine mammals of India (marinemammals.in). It was an online database, an early citizen science initiative that catalogued marine mammal records of the Indian subcontinent. This was the first website of its kind in India and remains the only one to date. This site has evolved into the Marine Mammal Research and Conservation Network of India. Kumaran co-manages the scientific content of the site along with Dr. Dipani Sutaria. "The Global Fellowship allowed me to publish my book with confidence. I had attended a marine mammal course taught by two experts, Dr. Andy Read and Dr. John Reynolds, and experienced guest speakers. Dr. Read had kindly reviewed my manuscript. The Duke experience had introduced me to conservationists from around the world and conservation efforts in different parts of the globe. It strengthened my commitment to the conservation of marine mammals. My resolve to create a website that would network people with an interest in Indian marine mammals was also strengthened by the Global Fellowship. On the whole, the Global Fellowship cemented my commitment to marine mammal conservation."

Sheku Sei (Sierra Leone 2006) is Assistant Director of Fisheries and Head of Competent Authority for Fish & Fishery Products, Ministry of Fisheries and Marine Resources, Sierra Leone, West Africa. He is also a PhD candidate at the Institute for Marine and Antarctic Studies (IMAS), University of Tasmania, Australia. His research involves investigating the impacts of climate change on coastal communities to identify a sustainable framework for the resilient enhancement of coastal communities. Finally, he is co-founder and Director of Operations of the Natural Resource Management Consortium (NaReMaC), Fourah Bay College Campus, University of Sierra Leone. "The DUML fellowship served as a stepping-stone for my career progress and motivation for research."

Ertan Taskavak (Turkey 2005) is a Professor at Ege University in the Faculty of Fisheries, Department of Basic Sciences, in Turkey. Over the last 18 years, he has continued to teach his students and to raise their awareness of what he learned at Duke in 2005 as a Global Fellow. By being the director of Bergama and Aliaga Vocational High Schools between 2010-2013, and the Dean of Faculty at Ege University between 2013-2016, he also had the opportunity to reach more student groups with more administrative powers. "It would be wrong to say that being a Global Fellow at The Duke Marine Lab has had a positive or negative impact on my career in one way or another. However, those two months I was in America and the days I spent with many American and international students at Beaufort made a very positive contribution to my personal development. The theoretical education at the Marine Lab and subsequently the applied training in sea, beach, forest, and island ecosystems changed my perspective on environmental protection, marine biology of sea turtles, and rehabilitation centers. All the knowledge, ability and capability I gained at Duke were certainly and surely able to find a large-scale application in my home country. After Beaufort, I completed the project, entitled 'TED (Turtle Excluder Device) application into the prawn trawls used in Eastern Mediterranean coast of Turkey' that was the first application of TED technology in the Mediterranean basin. In another project, we determined the interaction between fisheries activities and marine turtles in Turkish Mediterranean coasts."

Krystal Tolley (Norway 1999) is a Principal Researcher at the South African National Biodiversity Institute, Cape Town, South Africa. "The Global Fellowship allowed me to attend the conservation course, which I would not have been able to afford otherwise. In doing so, I made numerous connections which brought me to a postdoc position in South Africa. I still work in the field of conservation biology, and I have been applying many of the principles learned on the course throughout my entire career. In fact, I still often think back to some of foundational lessons and lectures that were presented, and how my own foundations were expanded because of those lectures. More importantly though, my attendance at the course changed the direction of my life and my research. Over the course of my PhD project, I realized that I did not want to continue in marine biology and the Global Fellowship created opportunities for me, which I followed up on shortly afterwards. I then managed to carry out a postdoc at Stellenbosch University, South Africa that related to phylogenetics and herpetology. That opportunity set the final direction of my research career and I would not now change anything about my research or career. There have been a handful of significant turning points in my life, where chance has created an opportunity which I have taken. My time as a Global Fellow was one of those turning points, and I will forever be grateful for that opportunity, which ended up leading me in such a different direction."

Juan Pablo Torres Florez (Chile 2007) is an associate researcher at the Aquatic Mammals Research and Conservation Center of the Chico Mendes Institute for the conservation of biodiversity (ICMBIO/CMA) in Brazil. This institute carries out research, as well as creating and administering laws and policies for the conservation of threatened aquatic mammal species. He is also the coordinator of the International Whaling Commission Conservation Management Plan for the Southwest Atlantic Southern Right Whale population. The coordination of this plan requires him to be involved in scientific research, policies and management, monitoring and mitigation actions along four different countries (Argentina, Brazil, Chile, Uruguay) for the conservation of this species. Although his career was initially more scientifically focused, now he finds himself involved in a more political field. "The Global Fellowship had a very positive impact on my life, because I was able to use what I learned during this course (from professors and other participants) in actions that I have been carrying out since my doctorate. For my doctorate on blue whales, the Fellowship was fundamental, as I managed to bring scientific questions to a field of conservation. Thus, my PhD has been of great importance for decision-making in conservation and has served to illuminate public policies as well as management actions at the international level. I have been using the tools provided during the Global Fellowship courses in my day-to-day work, where, in addition to doing science, I have to deal with public policies, government and personnel relationships at national and international levels. When I say that I am in an aquatic mammal center, people think that it is only work with animals, but I have to deal with fisheries problems every day (e.g., bycatch, animals use for fishing bait, entanglement), interaction between marine mammals and boats, tourism, etc. In all these cases, I always bring what I learned during the course, since there are many cases of dialogue with communities and with other government bodies. So, if I had the opportunity to take the course again, I would do it with happiness because it was fundamental in all the aspects in which I work today."

Armando Ubeda (Nicaragua 1999) is on the faculty of the University of Florida (UF) as a Florida Sea Grant Extension Agent. He is also a PhD student at the Department of Wildlife Ecology and Conservation at UF studying elasmobranchs. "At a personal level, it was a fantastic experience to meet people from different countries, backgrounds, and experiences. I enjoyed my time at Beaufort. I learned a lot from my classmates, the instructors, and the community. It was my first time visiting and attending an USA institution, and the experience could not have been better. The impact of the Global Fellowship in my career was great. At the time I was selected as a Global Fellow, I was also applying for a Fulbright Scholarship to attend graduate school in the United States. As a result of my participation in the Global Fellowship Program, I was able to ask for a reference letter from one of my instructors at Duke, Dr. William Kirby-Smith, and to use my grades obtained at Duke as a proof of academic achievement at higher education level at a prestigious academic institution in the United States. I believe that both the reference letter from Dr. Kirby-Smith, as well as my grades, were an important part of my application package for the Fulbright Scholarship, which I ended up being granted in 2000."

Angeline Valentine (Belize 2003) is working as a Project Consultant of the Belize Marine Fund, which is a program within the Mesoamerican Reef Fund (MAR Fund). The MAR Fund is a regional funding mechanism which drives partnerships for the conservation, restoration, and sustainable use of the Mesoamerican Reef. Prior to her role at MAR Fund, she also worked for approximately ten years with the Oak Foundation's Mesoamerican Reef Programme in Belize. This was also a program that supported efforts to address marine resources management and conservation issues in Belize and the other MAR countries.

"I believe that the Global Fellowship program was very impactful in framing my career. Being a Global Fellow offered me the opportunity to work with leading professionals and scientists including Mike Orbach, Larry Crowder and Andy Read to name a few. During my time at the Marine Lab as a Global Fellow I also got to meet a very wide cross-section of program participants, including Duke undergraduate students and Fellows from other countries including Tanzania, Mexico, Guyana, Belgium, and Peru among other countries. Additionally, my participation in the Global Fellow Program also cemented, for me, my desire to pursue graduate studies—and I know that I wanted to do those studies at Duke. Learning was such fun at the Marine Lab."

Conclusion

Achieving sustainable marine conservation that will benefit people and the planet will take full engagement of the world's scholars, practitioners, and communities. We need to respect the knowledge, experience, and culture of our partners whether we are working in their country or our own. And we need to support and promote their efforts. In addition to listening and working to change our own behaviors, we need to address the structural colonialism that lingers in institutions, including universities, philanthropies, and multinational NGOs, many in the Global North. The conservation challenges before us are daunting and there is more than enough work to do to define and achieve local and global goals. And the work will require respectful partnerships across disciplines, languages, and cultures—from defining the problem, to designing pathways to solutions, to implementing and monitoring actions. Marine conservation is interdisciplinary and international—some would say transdisciplinary—or you are not really doing it! So, I think working from within a single discipline or a single cultural perspective is limited and ultimately doomed to fail, at least for global-scale problems. As global citizens, we share one ocean with global scale challenges from climate change, global fisheries, and unfettered global markets. Since most of us work at a relatively local scale, the drivers of system change are often beyond our reach alone.

Box 24.1

The Duke Global Fellows Program—a career catalyst
Asha DeVos

In 2008, I was selected as a Duke Global Fellow in Marine Conservation. I had just lost my job but was eager to kickstart the Sri Lankan Blue Whale Project because I knew what I wanted to do but had no idea how to do it. The Fellows program came at the perfect time.

While there, Dr. Dan Costa from the University of California Santa Cruz was flown in as a guest speaker. Over lunch, I mentioned to Dan that I wanted to build my project on blue whales in Sri Lanka. He promptly told me about work by his colleagues Don Croll and Bernie Tershy, also at UCSC, and just as promptly, sent me their paper titled 'From wind to whales: Trophic links in a coastal upwelling system'. I read this paper and realized that while I was interested in animal behavior, it was important for me to understand how the environment was influencing this behavior—what was making the blue whales stay vs. migrate. That's when I decided to look at the physical oceanography around Sri Lanka. Because of this newfound interest in oceanography, and some deep digging, I found myself in conversation with Prof. Charitha Pattiaratchi, who was, as it turns out, a fellow Sri Lankan from the University of Western Australia. I was keen to understand how to access satellite and other oceanographical data that could allow me to understand why these whales did not migrate out of warm tropical waters. This conversation led me to Chari's lab for my PhD.

During my PhD, documentary teams started to take a keen interest in what I was doing. A viral video by Channel 7 Australia (2011) prompted a call from Erik Olsen from the New York Times who was keen to shadow me. This led to Erik turning up in Sri Lanka in early 2012 to write a piece and produce a short video about my work. I desired to go beyond understanding the non-migratory nature of blue whales, to also consider their conservation in Sri Lankan waters. On the back of this piece, I wrote to Don Croll introducing myself, and telling him how my work was inspired by his *Wind to Whales* work. I was looking at postdoc opportunities that would allow to me study the issue of ship-strikes on blue whales and I wanted to work in a lab that celebrated conservation action. Our call was a success and one year later, in 2013, I wrapped up my PhD and headed to Santa Cruz.

Over the next two years, I would drive to the Hopkins Marine Station from Santa Cruz to teach the occasional class or deliver a guest lecture on Larry Crowder's invitation, because by now, Larry had taken up a Professorship at Stanford. Today, 16 years after my summer at Beaufort, I'd say I am a testament to Larry and Mike (Orbach—Global Fellows Programme co-lead)'s desire to support early career researchers and practitioners from across the world who needed support to serve their own countries. I am now the proud founder of Oceanswell, Sri Lanka's first marine conservation research and education organization, where I nurture the next generation of diverse ocean heroes, engage everyone in the magic of our world's oceans and pay forward all the goodwill garnered through my life.

References

Crowder, L. B. (2022). One ocean. Conservation Science and Practice, 4(5), e12692. https://doi.org/10.1111/csp2.12692CROWDER3of3

De Vos, A. (2025). Building equal partnerships for conservation success. In L. B. Crowder (Ed.), Navigating Our Way to Solutions in Marine Conservation. Open Book Publishers. https://doi.org/10.11647/OBP.0395.

Inniss, L. (2025). The SIDS Science/Policy/Business Nexus. In L. B. Crowder (Ed.), Navigating Our Way to Solutions in Marine Conservation. Open Book Publishers. https://doi.org/10.11647/OBP.0395.

Reid, A. J., & Ban, N. C. (2025). Indigenous leadership is essential to conservation: Examples from coastal British Columbia. In L. B. Crowder (Ed.), Navigating Our Way to Solutions in Marine Conservation. Open Book Publishers. https://doi.org/10.11647/OBP.0395.

Index

About the Team

Alessandra Tosi was the managing editor for this book.

Lucy Barnes and Hannah Shakespeare proof-read this manuscript. The assistant editor was Catherine Lee Hing.

The cover was designed by Jeevanjot Kaur Nagpal, and produced in InDesign using the Fontin and Calibri fonts.

Cameron Craig typeset the book in InDesign and produced the paperback and hardback editions. The text font is Tex Gyre Pagella; the heading font is Californian FB.

Cameron Craig also produced the PDF and HTML editions. The conversion was performed with open-source software and other tools freely available on our GitHub page at https://github.com/OpenBookPublishers.

Jeremy Bowman created the EPUB edition.

Raegan Allen was in charge of marketing.

This book was peer-reviewed by two referees. Experts in their field, these readers give their time freely to help ensure the academic rigour of our books. We are grateful for their generous and invaluable contributions.

This book need not end here...

Share

All our books — including the one you have just read — are free to access online so that students, researchers and members of the public who can't afford a printed edition will have access to the same ideas. This title will be accessed online by hundreds of readers each month across the globe: why not share the link so that someone you know is one of them?

This book and additional content is available at
https://doi.org/10.11647/OBP.0395

Donate

Open Book Publishers is an award-winning, scholar-led, not-for-profit press making knowledge freely available one book at a time. We don't charge authors to publish with us: instead, our work is supported by our library members and by donations from people who believe that research shouldn't be locked behind paywalls.

Join the effort to free knowledge by supporting us at
https://www.openbookpublishers.com/support-us

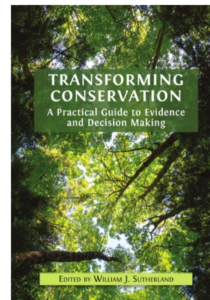
You may also be interested in:

Transforming Conservation

A Practical Guide to Evidence and Decision Making

William J. Sutherland (Ed.)

https://doi.org/10.11647/OBP.0321

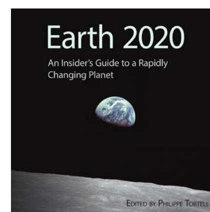


Earth 2020

An Insider's Guide to a Rapidly Changing Planet

Philippe D. Tortell

https://doi.org/10.11647/OBP.0193

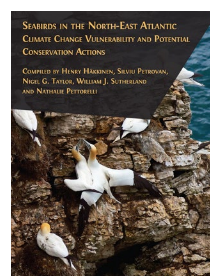


Seabirds in the North-East Atlantic

Climate Change Vulnerability and Potential Conservation Actions

Henry Häkkinen, Silviu Petrovan, Nigel G. Taylor, William J. Sutherland & Nathalie Pettorelli

https://doi.org/10.11647/OBP.0343

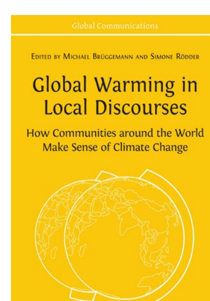


Global Warming in Local Discourses

How Communities around the World Make Sense of Climate Change

Michael Brüggemann and Simone Rödder (Eds)

https://doi.org/10.11647/OBP.0212



Navigating Our Way to Solutions in Marine Conservation

Edited by Larry B. Crowder

Navigating Our Way to Solutions in Marine Conservation reflects the broader insights and diverse voices revolutionizing marine conservation. Crowder has assembled scholars, practitioners, and experts in their disciplines, who also work across disciplines, creating a network of trans-disciplinary and multi-cultural insights to solve complex problems in marine conservation.

Larry B. Crowder, one of the first and leading voices in the field, has gathered a collection of chapters on a wide range of topics such as critically endangered species of The Bahamas, Argentinian penguins, and the ecosystems of our coral reefs; to a much larger degree the book investigates humans' relationships with nature, the efforts to develop climate-smart solutions, and the governance of group collective action.

Seeking to provide a platform for all voices, this volume also includes conversations across the disciplines of natural sciences, social sciences, and governance, and from key traditions including Western and Indigenous knowledge. This volume is highly relevant to marine conservation scholars, practitioners, managers, and students, and to anybody interested in the issue of how to preserve our marine environment.

As with all Open Book publications, this entire book is available to download for free on the publisher's website. Printed and digital editions, together with supplementary digital material, can also be found at http://www.openbookpublishers.com

Cover image: Kelly H Dunn based on a photo of Hōkūleʻa — Polynesian Voyaging Society, https://www.hokulea.com/
Cover design by Jeevanjot Kaur Nagpal

ebook
ebook and OA editions also available

OpenBook Publishers