Challenges in Ocean Governance in the Views of Early Career Scientists

Achievements of the São Paulo School of Advanced Science on Ocean Interdisciplinary Research and Governance (SPSAS Ocean)

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Production:

USP ie] Instituto de Estudos Avançados da Universidade de São Paulo

IO Instituto Oceanográfico

UNESCO Chair on Ocean Sustainability

UNESCO UniTwin unesco Chair

Financial support:

FAPESP

Support:

IAI Inter-American Institute for Global Change Research

Catalogação na Publicação
Divisão de Gestão de Tratamento da Informação da
Agência de Bibliotecas e Coleções Digitais da USP

Challenges in ocean governance in the views of early career scientists : achievements of the São Paulo School of Advanced Science on Ocean [recurso eletrônico] / Bruno Meirelles de Oliveira, Juan Carlos Farias Pardo & Alexander Turra (Org.) – São Paulo : Instituto de Estudos Avançados da Universidade de São Paulo, 2022.

235 p. : il.

Inclui bibliografia no final dos capítulos
ISBN 978-65-87773-38-4
DOI 10.11606/9786587773384

1. Oceanos 2. Governança 3. Pesquisa científica 4. Cientistas I. Oliveira, Bruno Meirelles de II. Pardo, Juan Carlos Farias III. Turra, Alexander

CDD (20.ed) – 551.46

Elaborado por Sarah Lorenzon Ferreira – CRB-8/6888

Edition notice

Graphic design project

Vinícius Marciano

Editorial production

Fernanda Cunha Rezende

Proofreading

Helena Barbosa

Diagramming

Camila Somera

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ACKNOWLEDGMENTS

Institutions: Oceanographic Institute (IOUSP), the Inter-American Institute for Global Change Research (IAI), the Intergovernmental Oceanographic Commission of UNESCO (IOC-UNESCO), and the Institute of Advanced Studies (IEA/USP), with the support of INterdisciplinary CLimate INvestigation cEnter (INCLINE), Brazilian Monitoring Network of Coastal Benthic Habitats (ReBentos), The São Paulo Research Foundation (FAPESP).

Speakers: Alan Simcock (USA), Andrei Polejack (Brazil), Ángel Turcios (El Salvador), Angelo Bernardino (Brazil), Anne Gossé (Norway), Antony Charles (Canada), Cristiana Seixas (Brazil), Daniel Suman (USA), Edmo Campos (Brazil), Fábio Hazin (Brazil), Frank Muller-Karger (USA), Hernan Chaimovich (Brazil), Leandra Gonçalves (Brazil), Leopoldo Gerhardinger (Brazil), Luiz Lacerda (Brazil), Jake Rice (Canada), Mariano Jordán (Argentina), Milton Asmus (Brazil), Pedro Jacobi (Brazil), Ronaldo Christofoletti (Brazil), Salvatore Aricò (France), Silvia Romero (Argentina), Tércio Ambrizzi (Brazil).

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Proofreaders: Danai Joanne Tembo, Cara Lynn Estes, Savannah Jade Hartman, Yasmina Shah Esmaeili.

SUMMARY

SPSAS OCEAN PRESENTATION

Given the complexity of current environmental challenges, such as climate change and biodiversity conservation and governance, the interdisciplinary approach to science has gained increased awareness and use in the global scientific community. Similarly, ocean sustainability is a topic of concern, often voiced in international fora. These discussions emphasize the need to promote ocean governance, coupled with a greater understanding of oceanographic processes. Ocean science, however, is still fragmented and many scientists lack adequate training to understand and implement interdisciplinary and integrated approaches to their research in a manner that supports decision-making. This lack of training has created an increased demand for the promotion of interdisciplinarity in ocean research and more effective collaboration among natural and social sciences, local knowledge, and public policies.

The São Paulo School of Advanced Science on Ocean Interdisciplinary Research and Governance (SPSAS Ocean) was held from 13 to 25 August 2018 at the University of São Paulo

(USP), São Paulo, Brazil. The SPSAS Ocean was organized by the Oceanographic Institute (IOUSP), the Inter-American Institute for Global Change Research (IAI), the Institute of Advanced Studies (IEA/USP), with the support of Interdisciplinary Climate Investigation Center (INCLINE), the Brazilian Monitoring Network of Coastal Benthic Habitats (ReBentos), and other collaborators.

SPSAS Ocean was sponsored by the São Paulo Research Foundation (FAPESP) within the São Paulo School of Advanced Science Program, which aimed at supporting short courses on themes concerning the frontier of science, that are the subject of internationally competitive research being carried out in the state of São Paulo. The SPSAS Program also aims to contribute to the advancement of knowledge, give visibility to research, doctoral programs and opportunities for postdoctoral internships in the state of São Paulo, and offer the means of disseminating information and ideas in a way that could not be obtained through the usual channels of communication, such as scientific publications and presentations at scientific events.

Moreover, SPSAS Ocean aimed to gather a critical mass of young scientists interested in interdisciplinary ocean research and governance, providing a platform to discuss scientific knowledge relevant to society and public policy. The secondary goals of the school were to foster the exchange of knowledge from different disciplines and experiences, promote cultural exchanges among participants, SPSAS speakers and organizers, and facilitate the development of collaborative networks.

The course was organized around three major themes on ocean research: 1) Setting the context: theory and historical background; 2) Sharing the advances in ocean sciences: processes and connections; and 3) Integrating science and public policies. The two-week course included theory classes, work in groups, poster sessions, science-policy discussions, and a field trip to Baixada Santista, located in the central coast of the state of São Paulo.

This book is one of the results of the exciting process promoted by SPSAS Ocean. It presents essays produced by some of the SPSAS participants on a variety of themes that are relevant to the transformation of socio-ecological systems and the relationship between ocean and society.

The collection is organized in three parts. The first part sets the scene of the SPSAS Ocean and the coastal scenario case study. The São Paulo School of Advanced Science on Ocean Interdisciplinary Research and Governance is presented in detail in Chapter 1, including its context, structure, activities and achievements. Chapter 2 presents the social-ecological and environmental aspects of the Baixada Santista Metropolitan Region, where the field activities were conducted and which supported a problem-solving exercise in the course.

The second part of the book constitutes a collection of essays on science for sustainability, fostering an integrative rationale promoting integrated, interdisciplinary and transformative science towards a sustainable ocean. Chapter 3 presents a debate on how to pursue transdisciplinarity considering the perspective of young scientists across the globe, focusing on the main topics of concern in different regions, the stakeholders involved, how stakeholders interact with the inputs and outputs of these studies, and the main challenges to carry out effective intersectoral communication. Conceptual aspects of governance and transformation science, such as resilience and ecosystem-based management, are presented and discussed in Chapters 4 and 5.

Specific tools and approaches for managing the ocean comprise the third part of the book. Chapters 6 deals with fisheries management and governance considering cases in South Africa, Canada and the High Seas. A strategy to combat the threats facing the ocean is discussed in Chapter 7, with a special focus on marine contaminants and pollutants. The relevance of data management for marine research is one of the core challenges to promote ocean science, an issue that is presented in Chapter 8. Finally, cases of environmental education and ocean literacy are discussed in Chapter 9 to develop strategies that promote a closer relationship between ocean and society.

This book represents the effort of a committed group of students to learn, discuss, and produce knowledge outside their original research area or comfort zones. The chapters represent one of the results of a rich, intense, and ludic learning process provided by SPSAS Ocean. Other information and products can be found on the SPSAS Ocean website.[1] We hope this book inspires young scientists from different research areas to propel ef-

1 Available at: <https://spsasocean.wixsite.com/spsas-ocean>.

forts towards an incremental pathway to skills development and the promotion of integrated and interdisciplinary research and to strengthen the dialog with society.

Bruno Meirelles de Oliveira
Juan C. F. Pardo
Alexander Turra
(Editors)

FOREWORD

"How inappropriate to call this planet Earth when it is clearly Ocean."[1]

This quote by Arthur C. Clarke (1917-2008), the English author notable for both his science fiction and nonfiction, as well as an undersea explorer and futurist, refers to the fact that the ocean covers about 71% of the planet's surface.

Beyond the actual physical magnitude, the diversity of the sea imagery in the foundational stories of ancient civilizations and beliefs, the frequency of its appearance in literature along the centuries, and the weighty themes to which it is related are all evidence of the importance of the ocean to human culture.[2] In particular, throughout human history, the oceans have been the *loci* of both confrontation and connection, of the terrible ending of lives amidst naval warfare and the hopeful beginning of new lives by massive intercontinental migrations.

The contemporary approach to the ocean highlights two dimensions: its formidable economic potential and its

1 In *Nature* 8 Mar. 1990 .

2 The terms *ocean* and *sea* are used interchangeably when speaking about the ocean, in spite of the difference between them in specific disciplines such as geography and hydrography. In the most general sense, both refer to the massive body of salt water that covers most of the planet.

crucial role in the global climate challenge. One way of establishing a connection between these two dimensions, as well as others, is through the overarching concept of sustainable development. This rationale appears in the full name of the Ocean Decade, which is taking place from 2021 to 2030: Ocean Decade of Ocean Science for Sustainable Development. The vision of the United Nations, embodied in the motto "the science we need for the ocean we want," aims at providing a common framework for diverse stakeholders to generate and use ocean knowledge towards achieving the 2030 Agenda for Sustainable Development.

The preparation for the Ocean Decade was the background for the São Paulo School of Advanced Science on Ocean Interdisciplinary Research and Governance (SPAS Ocean) program, held in 2018 at the University of São Paulo, with the sponsorship of the São Paulo Research Foundation (FAPESP).[3] The primary outcome of SPSAS Ocean was the establishment of a vibrant global network of early career researchers focused on various aspects of ocean science. The bonding established at this stage of their academic life should provide lifelong benefits for their career advancement, as well as foster a more panoramic perspective in ocean studies.

This book is an exemplary output of this recent collaborative network. Proposed and led by participants from more than 30 institutions, it expresses the interdisciplinary approach put

3 The SPSAS was organized by the University of São Paulo's Oceanographic Institute, the Institute of Advanced Studies, and the Inter-American Institute for Global Change Research. It had the support of the Interdisciplinary Climate Investigation Center (INCLINE) and the Brazilian Monitoring Network of Coastal Benthic Habitats, among other entities.

forth by SPSAS Ocean. It naturally stresses integrative conceptual tools, such as systems thinking and ecosystems. They are applied to specific regions (*e.g.*, the Baixada Santista Metropolitan Region, centered around Santos, site of the main Brazilian port), and to relevant industries (*e.g.*, fisheries). The educational challenge is also addressed. The choice of governance as the book's backbone enables the authors to analyze the construction of social orders, social coordination, and social practices related to the ocean.

The Covid-19 pandemic (better identified as syndemic) is raising the awareness of society about the complex challenges of the Anthropocene. At the same time, it is providing a concrete example of the power of global scientific cooperation to deal with these challenges. The publication of this book at the beginning of the current Ocean Decade is a tribute to optimism about the future of the world. The network of early career scientists generated by SPSAS Ocean says clearly, "we are here to help Planet Ocean and we have concrete proposals for how to do it."

Guilherme Ary Plonski
Director, Institute of Advanced Studies
University of São Paulo

CHAPTER 1

The São Paulo School of Advanced Science on Ocean Interdisciplinary Research and Governance (SPSAS Ocean)

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One Ocean, Ten Years, Many Challenges

The Ocean plays a central role in life on Earth, and the call for the recognition of its importance resonates worldwide. From the seafood we eat to the air we breathe humans benefit directly or indirectly from Ocean's ecosystem services (Figure 1). However, human activities threaten our Ocean (Halpern *et al.*, 2019). Overfishing, pollution, invasive species, acidification, and climate change are examples of threats that can unfold in countless negative impacts on the marine realm, leading to biodiversity and habitat losses and unhealthy ecosystems. The uncertain future of Earth's Ocean demands coordinated and collaborative actions among nations and societies.

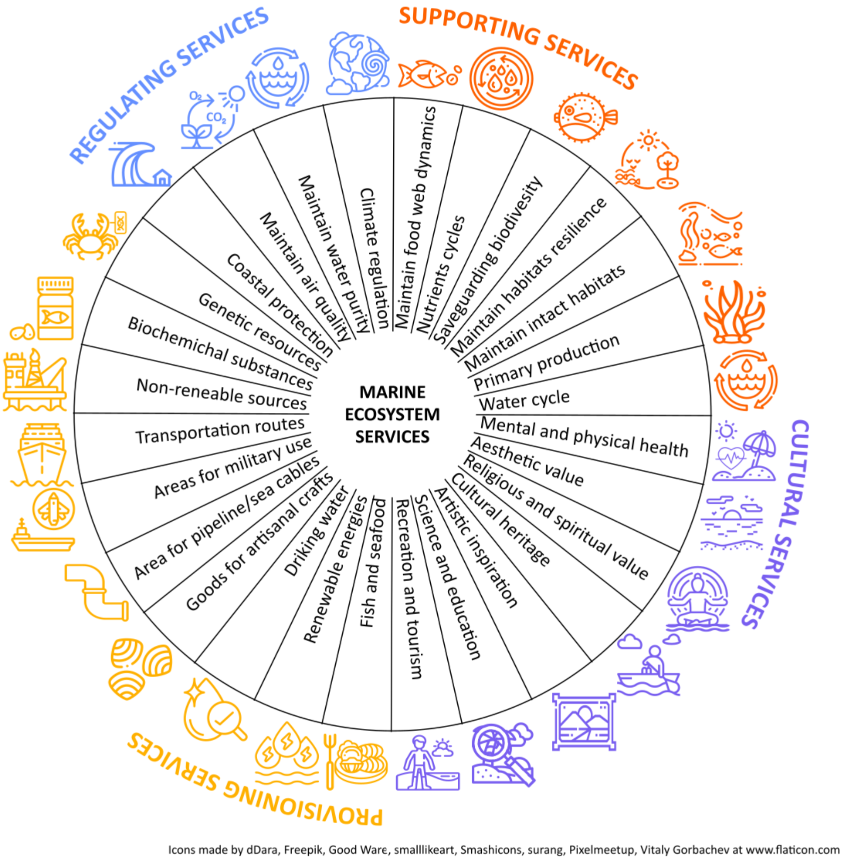

Figure 1. Marine ecosystems services (adapted from BÜCKER, 2014)

Recognizing the need for concerted action to Ocean sustainability is a critical subject on the national and international agenda. The United Nations Conference on Environment and Development held in Rio de Janeiro in 1992 (Rio 92) is a milestone that fostered international commitments towards a healthy and thriving Ocean. Agenda 21, which is derived from Rio 92 discussions, dedicates a whole chapter to ocean protection. From Rio 92 on, July 8 marks the "World Ocean Day." The international debate on Ocean protection continued with specific targets for the conservation of marine biodiversity (Aichi Target 11), the Rio Ocean Declaration (Rio + 20), and the United Nation's Sustainable Development Goal 14: Life Below Water (Agenda 2030). Since 2021, the United Nation's Decade of Ocean Science for Sustainable Development (Ocean Decade) comes to consolidate these many efforts..

The Ocean Decade focuses on the role of science to promote sustainability and calls for "The Science We Need for the Ocean We Want." Taking place from 2021-2030, it aims to orient scientists, industries, decision-makers, and the general public in acknowledging the information necessary for Ocean conservation and sustainable use. The Ocean Decade is an opportunity to steer ocean science towards co-creative solutions based on solid stakeholder interaction.

The Ocean is a complex social-ecological system with interlinked physical, chemical, biological, geological, and social processes. For this reason, understanding the Ocean demands complex and integrated information. To effectively manage this system, decision-makers must acknowledge the interdependence and feedback loops among multiple processes. Not surprisingly, ocean science is intrinsically multidisciplinary. However, moving from information gathering to policy development and implementation requires going over disciplinary and scientific barriers towards more integrative practices in the science-policy interface. A new paradigm for ocean science is the first obstacle the Ocean Decade should tackle.

The knowledge integration discourse is long-lasting and must comprise all knowledge systems. Dating back to the 1960s, the idea of interdisciplinarity urges two or more disciplines or schools of thought to work together to find innovative solutions to problems that neither could solve separately. Since then, it has become clear that as scientific knowledge, local and traditional knowledge are equally relevant sources of information to discuss complex and uncertain environmental problems. Integrating different knowledge systems requires a paradigm shift, from the classic, reductionist and disciplinary science (i.e., "normal science") to a post-normal one.

From discourse to practice, the new science paradigm remains a challenge. Post-Normal Science (PNS) (FUNTOWICZ; RAVETZ, 1993) is a problem-solving strategy that addresses urgent problems with high stakes and uncertainty and different values in dispute, such as climate change, COVID-19 outbreak, and ocean sustainability. Its practice promotes a broad and democratic dialogue among all the individuals/institutions with a stake in the problem. However, to foster such extended peer communities, we must reduce obstacles such as language barriers and lack of resources (including financial, infrastructure, time, personal, and technical), incentives, capacities, and soft skills to promote teamwork.

Overcoming these obstacles requires changes at different levels (GRILLI *et al.*, 2019). On the individual level, one can learn new ways of doing things and develop soft skills to improve communication and interpersonal relations. It is essential to nurture trust among researchers at the project level and develop collaborative planning, sampling, data analysis, and sharing strategies. At the institutional level, universities, research, and financing agencies must foster interdisciplinary research through adequate institutional arrangements and incentives. Changes to interdisciplinary research involve rethinking academic rewarding systems, investing in infrastructure, personnel, opportunities, and capacity building to enable research integration.

The "science we need" must be discussed and unveiled during the Ocean Decade. Despite recognizing the need for inter- and transdisciplinarity to ocean sustainability, most ocean research is still highly fragmented in practice. Scientists lack the training to understand and apply interdisciplinary and integrated approaches to support decision-making (KELLY *et al.*, 2019; DEININGER *et al.*, 2021). It is past the time for scientists and governments to build bridging organizations and institutions that invest in and train human resources to promote interdisciplinarity.

The SPSAS on Ocean Interdisciplinary Research and Governance

The São Paulo School of Advanced Science on Ocean Interdisciplinary Research and Governance (SPSAS Ocean)[4] took place

4 Available at: <https://spsasocean.wixsite.com/spsas-ocean>.

in São Paulo (Brazil) from 13 to 25 August 2018. The SPSAS Ocean was part of the São Paulo School of Advanced Science program, funded by the São Paulo Research Foundation (FAPESP)[5]; and organized through a partnership between the Oceanographic Institute (IOUSP)[6], the Inter-American Institute for Global Change Research (IAI)[7] and the Institute of Advanced Studies (IEA/USP)[8], under the overarching principles and aims of the UNESCO Chair on Ocean Sustainability[9].

During two weeks, SPSAS Ocean provided graduate students with advanced knowledge on interdisciplinary ocean research and integrated science and governance, including issues related to public policies. This section describes the activities involved in organizing and conducting the SPSAS Ocean.

Planning the SPSAS Ocean

Diversity is key to interdisciplinarity and ocean governance. Although traditional ocean science is interdisciplinary *per se*, it is usually associated with natural sciences - physics, geology, chemistry and biology. More recently, a stronger appeal to formally include social science as part of the ocean sciences has emerged (MOURA, 2019). For ocean governance, the need for this stronger natural-social science link is evident and must

5 Available at: <https://fapesp.br/en>.

6 Available at: <http://www.io.usp.br/>.

7 Available at: <http://www.iai.int/>.

8 Available at: <http://www.iea.usp.br/en/>.

9 Available at: <http://catedraoceano.iea.usp.br/>.

be part of the emergent sustainability science realm (CLARK; HARLEY, 2020). To devise better strategies for ocean management and conservation, understanding ocean processes is as necessary as understanding the social processes that guide ocean-science relationships and the factors that affect transformations towards more sustainable and resilient practices. Based on this assumption, the SPSAS Ocean aimed to assemble a diverse audience, of lecturers and participants, to expose these to multiple themes and leading researchers and authorities related to ocean science and management.

Participants selection

The main selection criteria were the expressed interest and the benefits that attending SPSAS Ocean could provide to participants' training as interdisciplinary scientists and actors in the science-policy interface. The selection targeted diversity and inclusiveness through a balanced group composition considering gender, nationality, and research themes.

Lecturers, themes, and activities

Lecturers included experienced scientists and representatives of governments and intergovernmental organizations related to the ocean science-policy interface. The intention was to expose participants to state-of-the-art science and ongoing discussions on applying the existing knowledge to ocean conservation and sustainability.

The opening panel was a call for participants to rethink their relation, as scientists, to ocean governance and its institutions. It brought together representatives of different coastal countries (Argentina, Brazil, and El Salvador) and the Intergovernmental Oceanographic Commission (IOC) of UNESCO to discuss the importance of the Ocean and the need for scientific knowledge for decision-making.

Following the ideas exposed in the opening panel, the scientific lectures covered three themes:

- Setting the context: theory and historical background - discussed theory and empirical aspects for interdisciplinarity, ecosystem-based management and governance, and how they apply these concepts in international ocean governance agreements;
- Sharing the advances in ocean sciences: processes and connections - discussed emerging and advanced ocean science topics, including climate change and oceanographic and social-ecological processes that support science-policy integration;
- Integrating science and public policies: exposed participants to discussions and practices that demand interdisciplinary action, such as fisheries management and biodiversity conservation.

Integrative activities complemented lectures and promoted additional opportunities for interaction among participants: poster and tutoring sessions and problem-oriented activities fostered interaction, collaboration, and group discussion about ocean governance-related challenges.

Other approaches to foster interaction

The SPSAS Ocean was planned to promote an immersion that would connect participants and expose them to a multicultural and safe environment (Figure 2). Besides SPSAS official program, the organizing committee employed other strategies to foster integration and provide participants with a pleasant experience in São Paulo. This may have been unnoticed by most who engaged in them and included:

- Each person on the organizing committee was "responsible" for several participants, acting as their focal point to take care of any doubts and (whenever possible) needs related to coming to Brazil. The committee members dedicated themselves to make SPSAS Ocean a memorable and enjoyable experience for all participants;
- The SPSAS Ocean website provided information about Brazil and São Paulo so that foreigners could better understand and appreciate the city. The "Enjoy São Paulo" section of the website, for instance, put together a list of places that are among the favorites of the organizing committee;
- Accommodation, meals, and transportation to the SPSAS Ocean venue were planned and booked by the organizing committee to enable participants to spend more time together. Participants stayed in the same hotel and shared rooms, distributed to provide a multicultural experience;

• Participants were encouraged to contact each other before they arrived in São Paulo. The organizing committee connected participants who would land on similar schedules and suggested that they arranged shared transportation from the airport to the hotel;

• Some cultural experiences were planned to expose participants to aspects of Brazilian culture. Coffee break and lunch had traditional Brazilian food (pão de queijo, tapioca, brigadeiro, carolinas, feijoada) and fruits. They had the opportunity to enjoy samba, play capoeira and join a maracatu workshop.

Figure 2: Extra-curricular interaction and cultural moments during SPSAS: (a) participants enjoying lunch together; (b) participants interacting during one of the breaks; (c) coffee break with traditional Brazilian food; (d) capoeira session with a local group.

During the SPSAS Ocean

Participants

In total, 109 participants, originally from different graduate programs in 23 countries, attended SPSAS Ocean (Figure 3). The selection process successfully established a balanced gender ratio (60 % female), nationality diversity (30 nationalities – Figure 4), and multidisciplinary backgrounds. Primary disciplines from SPSAS Ocean participants included climatology, ecology, geography, oceanography, social and ecological sustainability, risk and resources management, law, and civil engineering.

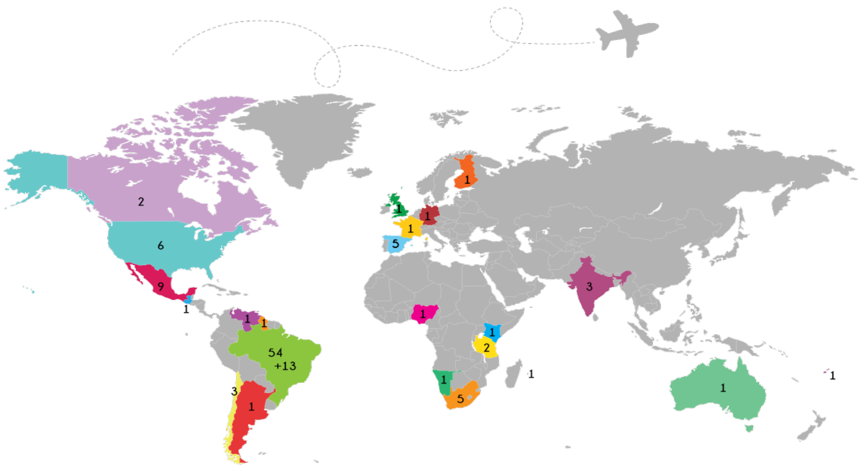

Figure 3. The number of participants from each country, considering their graduate program.

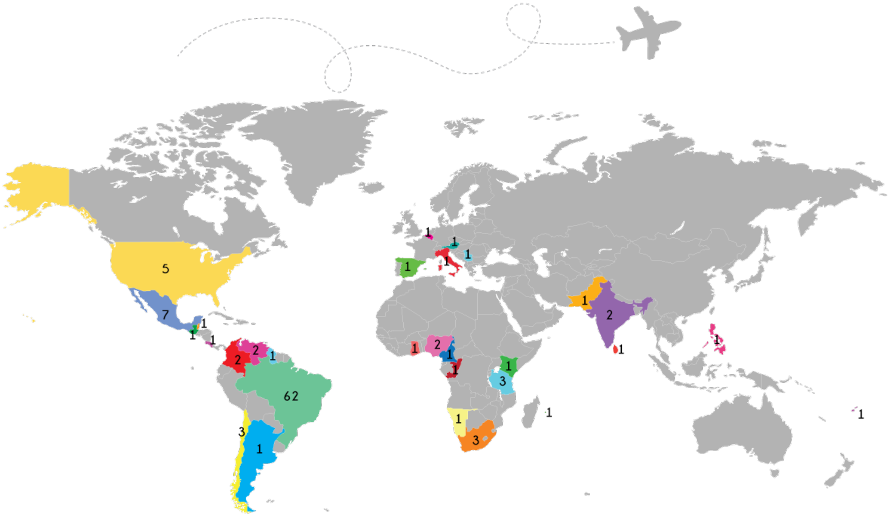

Figure 4. The number of participants from each country, considering nationality.

Activities and approach to interdisciplinarity

SPSAS Ocean started with more robust theory discussions interleaved with posters and tutoring sessions and evolved to more practical activities (Figure 5). Invited speakers provided leveling lectures followed by moments of discussion with participants. To foster collaboration, a multicultural group of students worked together to summarize each lesson and discussion.

The poster sessions fostered the debate of interdisciplinarity within individual researchers and represented an opportunity to identify synergies and room for collaboration. During these sessions, held once a day, participants presented and discussed their current projects and received inputs from others.

Tutoring sessions provided opportunities for participants to discuss their scientific projects and careers with lecturers selected by them. Participants were encouraged to interact with any speaker throughout the event, but specific time slots were scheduled for group discussions about individual research proposals with selected tutors. Tutoring sessions provided a more in-depth exchange between students and speakers and an opportunity to improve their projects and establish potential partnerships among students within each tutoring group.

The final activities of SPSAS Ocean targeted theory application to real case scenarios. A day-long field trip to the city of Santos (see PARDO *et al.*, 2022) – on the southern coast of São Paulo – exposed participants to challenges in ocean management. Participants visited the Port of Santos, the largest port in Latin America, and the shoreline. During the trip, discussions focused on the positive and negative impacts of coastal development and climate change. By experiencing an urban coastal zone and the conflicts between the conservation of natural ecosystems and human activities, participants engaged in discussions about the need for an interdisciplinary approach and integrated management.

To wrap up field trip debates, participants joined a problem-oriented exercise. Each group had to act as an advisor to the "Santos Council" and propose solutions to a problem identified in the city: diversification of tourism activities, marine debris, regularization of fishing activities, management of toxic residues, coastal erosion, unregulated coastal occupation, valorizing local communities and identification of beaches for conservation. Multidisciplinary groups discussed and proposed solutions that were presented and further debated by all participants.

A final group activity incited participants to explore the benefits of attending the SPSAS Ocean for their personal development and scientific careers. Brainstorming sessions addressed two questions: "What can be proposed to summarize discussion during the school?" and "How to maintain and scale up this initial step towards an ocean network of young ocean professionals?". Of the many proposals, two stood out: establishing a network for collaboration and this book, which was proposed and organized by a group of engaged participants.

Figure 5: Different activities during SPSAS Ocean: (a) lecture and discussion with experts; (b) poster session; (c) tutoring session; (d) class interaction activity; (e) field trip; (f) post field trip group activity.

Outcomes

The primary outcome of SPSAS Ocean was the establishment of a network of early career ocean researchers. Taking advantage of the benefits of social media to disseminate news, they can share information about their career development, job opportunities, publications, and upcoming events. This network also allows students to be quickly updated about the newest scientific products and provides opportunities for further collaboration.

This book is an example of the results of the collaboration network. The book was proposed and chaired by participants and reflects the collaborative and interdisciplinary approach proposed by SPSAS Ocean. Authors from 33 institutions worked together to register their experiences and challenges in the search for interdisciplinarity. Other secondary products spontaneously emerged through daily interaction: a poem, two adapted songs, a video documenting the event, and a word cloud composed of the word "ocean" in the participants' languages (Figure 6).

Figure 6. Word cloud showing Ocean in the languages of SPSAS Ocean participants.

In the final evaluation, participants rated SPSAS Ocean's contribution to their career and personal experience positively. Despite the positive feedback, the strong reliance on the lecture format showed room for improvement to foster interdisciplinarity. Although leveling is fundamental in multidisciplinary groups, interdisciplinarity skills rely heavily on practice. The best-evaluated activities were those that promoted collective discussion and collaboration among participants. Additionally, more significant interaction with non-academic lecturers could also have deepened the debate about knowledge sharing and application for Ocean management and conservation.

Way ahead with Ocean Interdisciplinary Research and Governance

The idea of SPSAS was to promote transformative learning among the participants to stimulate and reflect upon global challenges and prepare for a more interdisciplinary and applied practice. Universities and research centers are still lacking interdisciplinarity, despite the worldwide claim for it. SPSAS Ocean provided a myriad of opportunities to engage in different activities and develop skills to embrace the interdisciplinary in marine science. However, between lectures, coffee breaks, and activities, it was clear that despite the need and engaged spirit of the participants and organizers, there is still a long way to generate and apply interdisciplinary knowledge (Figure 7).

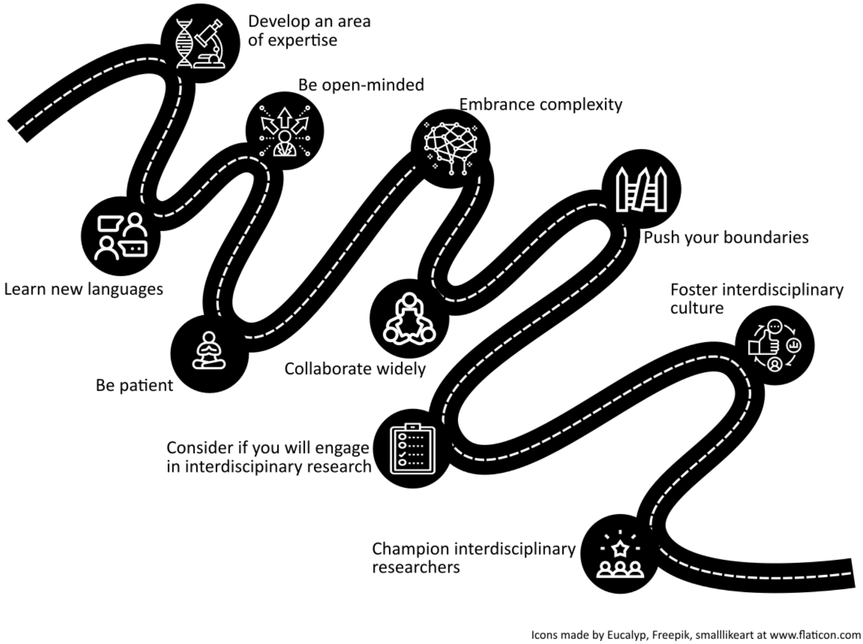

Figure 7: Tips to promote interdisciplinarity (Adapted from KELLY *et al.*, 2019).

Advanced courses such as SPSAS emerge as an opportunity to foster interaction and create interdisciplinary networks. Interdisciplinary practices and science-policy engagement are generally more complex and require more robust financial, human and technical resource investments to promote capacity building and support research projects. Interdisciplinarity is a challenge that relies on changes in the prevailing practices in universities and research institutions. Promoting ocean sustainability involves an evolution in each country's science and technology system. It is crucial to link the development of ocean science to policies and programs that guarantee long-term financing.

Beyond the intellectual benefits of SPSAS Ocean, the in-person interactions provided an excellent opportunity for discussing ideas and looking at future collaborations. These training and mentoring benefits can be fostered if, in the future, more institutions, bridging organizations, and movements orient their actions towards transdisciplinarity, such as the UNESCO Chair of Ocean Sustainability and the Ocean Decade.

The SPSAS sowed the seed of interdisciplinarity to the participants, which can then flourish in the building of the Ocean Decade. "The Science We Need for the Ocean We Want" can only be reached through a cooperative, systemic and integrated pathway, with an interdisciplinary perspective and connected to coastal communities' needs. If this is to change in the next ten years, training future ocean champions is the first step. In this book, readers will meet essays produced by some SPSAS participants, which are examples of the seedlings arising from their participation and experiences in the event.

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CHAPTER 2

Socio-ecological and environmental aspects of the Baixada Santista Metropolitan Region

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Abstract

From untouched Brazilian Atlantic rainforests to poverty-stricken settlements, the Baixada Santista Metropolitan

Region (BSMR) is a complex region in Brazil's challenging coastal management. Due to its characteristics, the region was used as a model for practical and field activities during the São Paulo School of Advanced Science on Ocean Interdisciplinary Research and Governance. An educational tour in the Port area and practical activities aimed to support the participant's critical view of complex socio-ecological scenarios. The historical and current context of BSMR allows extensive discussion on ocean governance and sustainability, both relevant topics under the SPSAS goals. In this chapter, we provide the history and the social-ecological and environmental aspects of the region discussing its relevance at regional and national levels. The complexity of the region turns out to be an important showcase to knowledge retaining and practical learning to the SPSAS participants. Similar activities are important to align interdisciplinary scientific work and support decision-making processes.

Introduction and general view

Practical learning is a fundamental tool in knowledge retention and long-lasting impact (MILLAR, 2004). During the São Paulo School of Advanced Science on Ocean Interdisciplinary Research and Governance (SPSAS Ocean), students had the opportunity to join a field activity to experience and better understand ocean governance and sustainability problems. Adding to supplementary practical activities during the school, it was expected that participants would understand the scenario and critically analyze it under the goals of the SPSAS Ocean (please see Xavier *et al.*, 2021 for more details about the activities).

The Baixada Santista Metropolitan Region (BSMR), São Paulo, was selected to illustrate social-ecological and environmental complex interactions (Figure 1, 2). The BSMR administrative region was created in 1996 and consists of nine cities (Bertioga, Cubatão, Guarujá, Itanhaém, Monguaguá, Peruíbe, Praia Grande, Santos, and São Vicente) in the central coastal region of São Paulo State. Historically, Brazilian coastal areas have been altered since the XVI century, after European colonization. The strategic position for trading, war, and living were the main factors affecting its transformation (METCALF, 2005; AFONSO, 2006). The BSMR occupation increased substantially with small maritime commercial patches in the late 18th century, mainly due to commercial trades of sugar and coffee and later establishment of the São Paulo Railway, an important boundary connecting the megalopolis São Paulo and the Port of Santos (AFONSO, 2006).

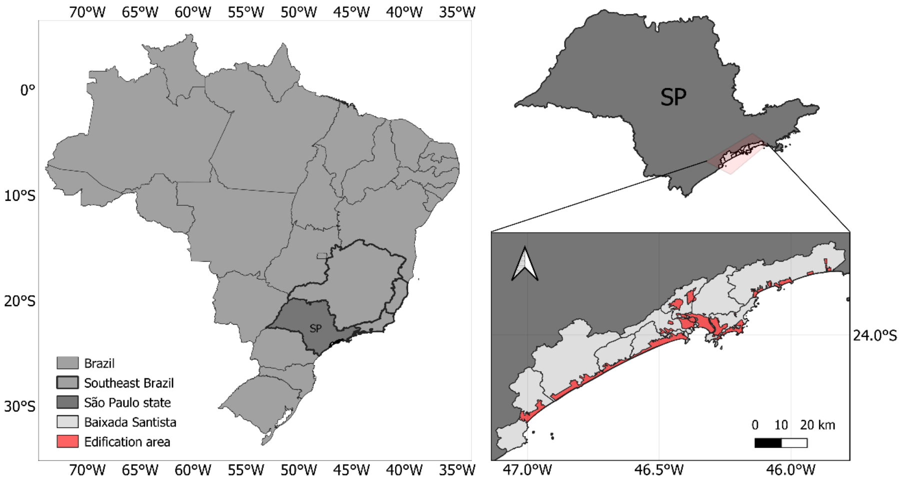

Figure 1: Location map of the Baixada Santista Metropolitan Region (BSMR), São Paulo, Brazil, highlighting the edification area in the coastal area. Source: Brazilian Institute of Geography and Statistics (IBGE), 2010.

Figure 2: General view of the social-ecological and environmental features of the Baixada Santista Metropolitan Region. A) Coastal habitats (e.g., sand beaches, mangroves) of Barra do Una, Peruíbe; B) Santos Port Complex, Santos; C) Low-income housing (i.e., *palafitas*) in mangroves areas, Santos; D) Santos Bay and the shoreline of the city.

The infrastructure development differed from other Brazilian coastal areas due to the economic activities, and the region has grown exponentially. While tourism was the major economic activity of neighboring coastal areas, the BSMR had at least two main economic activities shaping the dynamics of the whole region: the industrial, steel industry and petrochemical pole in the city of Cubatão and the Port of Santos Complex[1]. Cubatão is still an important center that symbolizes the Brazilian industrialization process (COUTO, 2003). Several private and public companies had chosen the city to host their industrial units mainly due to the strategic position, close to both São Paulo city and the largest port in Latin America, the Port of Santos. The maritime commercial facility in Santos corresponds to more than 1/3 of commercial trades in Brazil. However, most of the cities in Baixada Santista have tourism as the main economic and development sector. Peruíbe, Guarujá, Santos and Praia Grande are among the top 20 most in-demand destinations in Brazil during the summer, in which the last of them received more than a million visitors in 2018's New Year Celebration[2].

Socio-ecological and environmental aspects

The BSMR is situated between the Serra do Mar escarpments and the Atlantic Ocean, comprising important hotspots

1 CODESP. Available at: <http://www.portodesantos.com.br/>. Accessed 25 Feb. 2019.

2 Prefeitura de Praia Grande. Available at: <http://www.praiagrande.sp.gov.br/>. Accessed 21 Feb. 2019.

for biodiversity (AFONSO, 2006). The Brazilian Forestry Code, which includes Permanent Preservation Areas, and the National System of Protected Areas, also including State Parks along the Serra do Mar, legally protect vast natural areas. The threatened remaining Atlantic rainforests, as an example, are under the safeguard of two state parks, Serra do Mar and Xixová-Japuí. Both areas preserve massive forests where only Serra do Mar State Park itself protects nearly 3.5 thousand km^2. Coastal and marine environments, such as mangroves, sandy beaches and rocky shores, are also present and provide fundamental ecosystem functioning and services for the region (e.g., recreational activities, nutrient recycling, and food provision) (MENEZES *et al.*, 2005; SARTOR *et al.*, 2007). The region is situated in the Environmental Protection Area of Coastal Marine Center of the State of São Paulo (Área de Proteção Ambiental Marinha do Litoral Centro, in Portuguese), created in 2018, as the largest marine protected area in the region allowing human uses under sustainable practices. Santos also counts with the Laje de Santos Marine State Park, the first offshore marine protected area in the state of São Paulo. As a transition zone between tropical and temperate regions, these subtropical environments tend to present high biodiversity (e.g., AMARAL *et al.*, 2003; COLPO *et al.*, 2011).

Despite the recognized ecosystems goods and services provided by natural environments (BEAUMONT *et al.*, 2007), the region still lacks environmental assessments and biodiversity information for some cities. Apart from a few metropolitan scale reports (e.g., SARTOR *et al.*2007; FRANCINI *et al.*, 2011; SAAD *et al.*, 2019), Santos and surrounding areas are still better represented in biodiversity studies when compared to other BSMR areas. As reviewed by Sartor *et al.* (2007), the Santos and São Vicente estuaries and Santos Bay have at least 293 fishes, 196 species of mammals and 454 birds, being half of the later mentioned group exclusively found in mangrove areas. BSMR mangroves are present in cubatão, santos, são vicente, guarujá and bertioga (RODRIGUES *et al.*, 1996; AFONSO, 2006). Those forests show the typical subtropical mangrove tree species Laguncularia racemosa, Avicennia schaueriana, and Rhizophora mangle, being an important habitat for key benthic organisms, such as macro- (e.g., mangrove crabs, COLPO *et al.*, 2011) and meiofauna (CITADIN *et al.*, 2016). The biodiversity of BSMR's sand beaches is also relatively poorly assessed. Except for Cubatão, all cities have sand beaches. Studies performed in Santos and São Vicente showed that faunistic composition is mainly composed of polychaetes (families Spionidae and Capitellidae) and bivalves (Anomalocardia brasiliana and Donax gemmule) (MONTEIRO, 1980; RODRIGUES, 1983; CORBISIER, 1991) as also as crustaceans and gastropods commonly found in Brazilian sandy beaches (AMARAL *et al.*, 2016). Moreover, rocky shores are found along all the coast in the BSMR and show typical subtropical diversity such as barnacles (Chthamalus bisinuatus and Tetraclita stalactifera), bivalves (Brachidontes solisianus) and gastropods (Stramonita brasiliensis and Collisella subrugosa) (FUKUDA; NOGUEIRA,

2006; NOGUEIRA; FUKUDA, 2007; DOS SANTOS *et al.*, 2017; MILOSLAVICH *et al.*, 2016). However, considering the interconnection and complexity of the BSRM, further efforts should provide broader and metropolitan-scaled biodiversity assessments.

The BSMR has an expressive urban density along the coast with a demographic growth way above the national mean (IBGE, 2019), where indigenous and traditional people and low- and high-income communities occupy different yet interconnected patches of the region (MELLO *et al.*, 2013). Real estate speculation is intense and led by the search for second-home residences close to coastal environments. Otherwise, low-income communities occupy risk and legally protect areas, such as mangroves and Atlantic rainforests (MELLO *et al.*, 2013; DE OLIVEIRA-MONTEIRO; SILVA, 2018). Biologically important areas have been impacted by urban and industrial drivers and human occupation was indeed not planned for all-region. Anthropogenic pressures in tropical ecosystems generally occur due to urban expansion over pristine forest areas, changing their topography, vegetation cover, and soil permeability resulting in an expressive loss of biodiversity and ecosystem services (AFONSO, 2006). This historical expansion of urban patches has already caused a profound loss of ecological functions and biodiversity in the region (AFONSO, 2006; ARASAKI *et al.*, 2008). Sartor *et al.* (2007) georeferenced and summarized the available environmental data for the region claiming that mangroves, sandbanks, beaches, and the rainforest are directly impacted by anthropogenic drivers. Recent efforts are also being taken to understand the potential climate change impacts at individual and populational levels (e.g., RAMAGLIA *et al*., 2018; KIKUCHI *et al*., 2019; ARAKAKI *et al*., 2020; PARDO; COSTA, 2021). Additionally, several environmental pollution assessments provided substantial information on how the port activity and domestic waste affect the BSMR (BRAGA *et al*., 2000; ZARONI, 2006; ABESSA *et al*., 2008; CORDEIRO; COSTA, 2010; SOUSA *et al*., 2014). Heavy metals (KIM *et al*., 2016) and plastic pellets (TURRA *et al*., 2014), for example, are presented in higher concentrations close to urbanization and industrial activity areas (Port of Santos and Cubatão Industrial Complex). As coastal biodiversity is a key element for socio-ecological discussions and adaptations, a holistic and interdisciplinary approach has been taken in the region aiming to create innovative public policies. Using Santos and Guarujá cities as model systems, the project "Coastal biodiversity and public policies: methodologies and actions to integrate stakeholders"[3], for example, aimed at promoting integration among different actors (e.g., decision-makers, society, researchers) to create broader and pragmatical public policies incorporating the regional environmental context.

The Santos Estuarine System

The Santos Estuarine System is an important transitional area between the saline waters of the South Atlantic Ocean and

3 Research support by FAPESP. Available at: <https://bv.fapesp.br/en/auxilios/99262>. Accessed 27 Aug. 2019.

the freshwater of the rivers discharge of the BSMR. It comprises three major estuarine channels – São Vicente, Santos, and Bertioga – interconnected in its inner area. Therefore, it composes a very dynamic and complex environment, especially in the spring tide, when the current field presents greater intensity and spatial variability in comparison with the neap tide (NEVES & BARETTA, 2009; RIBEIRO *et al.*, 2019). The tides in Santos are irregular, mixed, and semidiurnal, and storm surges produce alterations in the mean sea level usually exceeding 0.5 m (HARARI *et al.*, 2003), with a historical record of 0.8 m sea level and 2.4 m in the inner estuary in 2016 (RUIZ *et al.*, 2021). Climatologically, December to March is the period with the highest rainfall levels in the Baixada Santista region, reaching 255.9 mm in January, while the dry season, from May to October, shows low precipitation rates (e.g., August, 78.4 mm) (INMET, 1992). Precipitation in the rainy season is mainly influenced by both the South American Monsoon System (SAMS) and the South Atlantic Convergence Zone (SACZ) (ZHOU; LAU, 1998; CARVALHO *et al.*, 2011).

The Santos Estuarine System is historically susceptible to storm surges and extreme oceanographic events that have occurred more frequently and more intensely in the last decades (AARUP *et al.*, 2010). Storm surge is a sea-level rise usually associated with intense tropical or extratropical cyclones, such as hurricanes and typhoons (RESIO *et al.*, 2004). Storm surges in the BSMR are usually associated with transient systems, such as extratropical cyclones over the southwestern South Atlantic Ocean.

Reboita *et al.* (2018) showed that the annual mean of cyclones over the South Atlantic Ocean (1979-2005) is around 250 with a lifetime of approximately 2.2 days. In terms of seasonality, a higher frequency of cyclones occurs in austral winter (June-July-August), while austral summer (December-January-February) is the least cyclogenetic season. Therefore, the BSMR is most susceptible to storm surges mainly during the austral winter, although they can be detected throughout the year. According to Souza (2019), 238 meteorological-oceanographic extreme events were registered between 1928 and 2016 in the Baixada Santista region. As reported by Ruiz *et al.* (2021), 39 storm surge events with measured sea level above 1.8 m (2.0 m) in Santos Bay were registered between 2015 and 2019. In a global warming context, model projections have indicated a decrease in cyclone frequency for mid-latitudes in the South hemisphere (BENGTSSON *et al.*, 2009; KRÜGER *et al.*, 2012; REBOITA *et al.*, 2018), which may be associated with the weakening of the future low-level pole-to-equator temperature gradient. Moreover, moister is also likely to affect cyclones due to the amplification of latent heat release (BOOTH *et al.*, 2013).

Besides the extratropical cyclones' activity, understanding the precipitation and temperature trends over the southeastern coast of Brazil is of great importance for the BSMR. Zilli *et al.* (2016) identified an increase in total precipitation related to an increase in rainy days and more frequent and intense extreme events over the southeastern coast of Brazil. For a predicted warming climate, precipitation is expected to increase with events of heavy rainfall becoming more frequent in the southeastern South America area (CHOU *et al*., 2014; AVILA DIAS *et al*., 2020). Overall, although the decrease projected in the number of extratropical cyclones by the end of the century, which could result in fewer storm surge events, all these changes in temperature and rainfall may significantly threaten the ecosystems' survivability of the BSMR, highlighting the ecological impacts that climate change could bring to this region.

Regional actions dealing with science, society and environmental policies

Several projects and initiatives explored socio-ecological questions in the BSMR. The interactive geotechnology tool *Atlas Ambiental*[4], as an example, was developed to provide interactive maps of the environmental and economic aspects of the region to the general public and policymakers. The initiative has launched a website[1] with open maps highlighting macrobenthic diversity and richness, potentially contaminated areas, important regions for conservation, and other aspects to understand environmental impacts in the area. Recently, the book Climate Change in Santos, Brazil: Projections, Impacts and Adaptation Options was published reporting on the projects, impacts and adaptation options for the city of Santos to deal with climate change issues (NUNES *et al*., 2019). The city is already experiencing the conse-

4 Atlas Ambiental e Socioeconômico da Baixada Santista. Available at: <http://santoswebatlas.com.br/>. Accessed 21 Feb. 2019.

quences of a changing environment. The frequency and intensity of extreme events, such as storms and high tides, increased and caused expressive infrastructure damages in the last years, forcing people and the municipality to take adaptative initiatives (FREITAS *et al.*, 2019). Sea level, for instance, is extremely susceptible to rise in some highly dense areas, which in turn may cause socio-economic and environmental damages to the city (MARENGO *et al.*, 2019). This comprehensive diagnosis is one of the bases for Santos City's Climate Change Plan[5], a pioneering initiative in Brazil coordinated by the Urban Development Secretary and Municipal Commission on Climate Change Adaptation. Following the steps of various cities in the world, the plan aims to manage and reduce the risks of climate change in the city of Santos. However, the BSMR still lacks an integrated articulation among actors, organizations, and institutions from the different cities to deal with climate change-related issues on a metropolitan scale (Carvalho, 2019).

As a response to extreme events in the region, the hydrodynamics research group *Núcleo de Pesquisas Hidrodinâmicas da Universidade Santa Cecília* (NPH-UNISANTA) implemented a storm surge early warning system as part of The Civil Defense Action Plan for the Santos Region. The system provides high-resolution (~50m) forecasts and disseminates the information through

5 Estado da Arte Plano Municipal de Mudança do Clima de Santos – PMMCS. Available at: <http://www.santos.sp.gov.br/static/files_www/pmmcs_plano_municipal_de_mudanca_do_clima_de_santos_15-12-_2016_ii.pdf>. Accessed 21 Feb. 2019.

the media and mobile phone messages to the population living in high-risk and susceptible areas, increasing the local capacity to respond to the warnings (RIBEIRO *et al.*, 2016; RIBEIRO *et al.*, 2019). Furthermore, the early warning system allows efficient communication with users through the AQUASAFE Platform which enables automated management and integration of different real-time data sources and numerical models, provides interfaces for different categories of users, including desktop, web and mobile app, and generates reports and alerts automatically (RIBEIRO *et al.*, 2019). Although the early warning system does not prevent the occurrence of extreme events, it aims to minimize the direct impacts on the population and to become an end-to-end warning system through the integration of the various actors involved, especially the Municipal Civil Defense.

Short- and long-term socio-ecological and educational programs are also developed in most of the cities; to name a few: Bertioga has the School Boat "Arte do Saber" project, where children from private and public schools visit important historical and ecological areas in a river barge trip, and "Terreno Vivo", a collective planning project to promote communitarian and urban gardens in the city[6]; Praia Grande has a well-established Environmental Education Center near mangrove forests promoting environmental awareness actions to both adults and children

6 Estado da Arte Plano Municipal de Mudança do Clima de Santos – PMMCS. Available at: <http://www.santos.sp.gov.br/static/files_www/pmmcs_plano_municipal_de_mudanca_do_clima_de_santos_15-12-_2016_ii.pdf>. Accessed 21 Feb. 2019.

through monitored visits and recycling workshops; Ecofaxina Institute[7] has been working for more than ten years recovering degraded mangrove areas in the BSMR and minimizing the input of anthropogenic debris into the ocean.

Final remarks

The BSMR is a complex area that requires decisions from multiple actors under the prism of environmental governance but also encompasses social-ecological systems and coastal sustainability (GONCALVES *et al.*, 2020). The region has key economic and ecological features at regional and national levels of interest. Apart from its similar challenges in governance with other metropolitan regions (COY *et al.*, 2018), the BSMR has characteristics that require local-oriented solutions. The mentioned regional projects and initiatives are of great importance but the integration among BSMR cities is indeed crucial to deal with metropolitan-scale issues, such as threats to local biodiversity and mitigation to climate change-related topics. The multidisciplinary group of students had the opportunity to experience and discuss in a broader context the importance and complexity of interdisciplinary research and governance. Similar activities are recommended and needed to promote stronger collaborations among disciplines and align the research for efficient coastal science to support decision-making processes. The BSMR is a clear

7 Instituto Ecofaxina. Available at: <https://www.institutoecofaxina.org.br/>. Accessed 27 Aug. 2019.

example of the complexity of metropolitan regions and turned out to be an effective case study to stimulate discussion and support active learning to SPSAS Ocean participants.

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CHAPTER 3

Transdisciplinarity for the Oceans: integrating science for solving social-environmental conflicts

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Abstract

This chapter aims to set a baseline of the main challenges for transdisciplinary science in the ocean sciences field for young scientists across the globe from participants of the São Paulo School of Advanced Science on Ocean Interdisciplinary Research and Governance (2018). We identified real-world problems addressed by transdisciplinary projects, the involvement of stakeholders and challenges to effective intersectoral communication. Based on insights from 21 case studies that tackle social-ecological relevant problems, we provide suggestions on how to conduct transdisciplinary science.

Introduction

Scientific knowledge contributes to understanding our environment and society, and it helps to solve their problems and conflicts (GALLOPÍN *et al.*, 2001; LOZANO, 2008). However, in many cases, science is not seen as adequately participatory or integrated with decision-makers to deal with current social-ecological challenges (TRIMBLE; LÁZARO, 2014). Although scientific knowledge increases, real-world problems grow and worsen faster (BEAL *et al.*, 1986; GALLOPÍN *et al.*, 2001). So, there is an urgent need for a new scientific approach to tackle the current real-world problems.

The emergence of concepts such as *knowledge generation, exchange, and utilization* (BEAL *et al.*, 1986), *science mode 2* (GIB-

BONS *et al.*, 1994), *post-normal science* (FUNTOWICZ; RAVETZ, 1994), *knowledge co-production* (ARMITAGE *et al.*, 2011), and in Latin America *social appropriation of knowledge* (POSADAS, 1995), are the anchoring for re-thinking the role of science in society (KLEIN, 2015; LOZANO, 2008). Several authors assert the need to democratize science and technology systems (HERRERA, 1995; LUBCHENCO, 1998; CASTILLO, 2001; VAUGHAN *et al.*, 2007; MITTON *et al.*, 2007). Democratization of science and technology requires improving the knowledge transmission channels by developing alternatives that better fit the current local needs in the proper cultural and ecological context (CASTILLO *et al.*, 2018). Such new channels have led to a positive adaptation and transformation in social, economic, and power relations, reflecting on a sounder environmental governance (GALLOPÍN *et al.*, 2001; LOZANO, 2008).

Nowadays, science is evolving to provide society with the means to form an opinion on the practices and policies that affect their daily life (CHAPARRO, 2001; VESSURI, 2002). Therefore, the concept of a successful knowledge production flows towards a more flexible and dynamic way to communicate between scientists, government, and the general public, to use science and technology to solve specific problems (ALBORNOZ; ALFARAZ, 2006). The scientific approach that addresses social problems using interdisciplinary collaboration and extra-scientific stakeholders is transdisciplinary (JAHN *et al.*, 2012).

Transdisciplinary research is growing in the scientific community as an approach that grasps the complexity of social-ecological issues, considering different perspectives towards the common good (POHL, 2010). Despite the lack of a sound definition, participatory knowledge production between scientists from different disciplines and integration of society into the scientific process are critical pieces for understanding the definition of transdisciplinary (SANTOS; AKIKO, 2008; JAHN *et al.*, 2012; LANG *et al.*, 2012).

The debate about transdisciplinary, including its goals and challenges, has been on the scientific agenda for decades (REGIER *et al.*, 1974; ROSENFIELD, 1992; POHL, 2010). However, critical questions on pursuing transdisciplinary remain unanswered, such as: How can we integrate stakeholders into science while dealing with social problems? What does this integration look like? What are the major challenges of transdisciplinarity? What are the main elements of success?

Particularly, ocean sciences require a significant improvement in stakeholder interaction to better face the impacts of climate change, ocean pollution, overfishing, habitat destruction, and culture extinction that threaten human wellbeing. Although there is a growing number of initiatives, frameworks, and platforms to facilitate the integration of local people knowledge to science production and vice versa[1, 2, 3, 4, 5], the level of Transdisciplinarity in the ocean sciences remains unknown to date.

To fill this gap, first, we conducted an extensive literature review to understand the *status quo* of applying the transdisciplinarity approach in the ocean sciences. We identified a plethora of challenges to develop transdisciplinarity research, including (i) the difficulty to integrate multiple perspectives, (ii) challenges in effective collaboration among different disciplines, and (iii) the keen interest in publishing as fast as possible due to the current criteria to evaluate "quality" of a researcher based on the number of publications, and (iv) low interest in reaching out the local people. The latter entails limited research funding for transdisciplinary research, communication challenges among scientists from different disciplines, a lack of methods for co-producing knowledge, and a lack of interest of local people and scientists to co-participate in knowledge production.

In this context, this chapter aims to set a baseline of the main challenges for transdisciplinary science in the ocean sciences field for young scientists across the globe. We summarized: what are the main topics of concern in different regions?

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1 Marine Biodiversity Observation Network. Available at: <https://marinebon.org/>. Accessed May 2021.

2 Inaturalist. Available at: <https://www.inaturalist.org/>. Accessed May 2021.

3 PescaData. Available at: <https://pescadata.org/>. Accessed May 2021]

4 Infocéanos. Available at: <https://infoceanos.conabio.gob.mx/>. Accessed May 2021.

5 Global Fishing Watch. Available at: <https://globalfishingwatch.org/>. Accessed May 2021

Who are the stakeholders involved with their studies? In what ways does each stakeholder interact with the inputs and outputs of these studies? What are the main challenges to effective inter-sectoral communication? Finally, we provide a section containing some suggestions for the general challenges detected. We have discussed these questions and provided insights from 21 case studies that tackle social-ecological relevant problems.

Methods

Data collection

A survey was sent to 100 students and researchers involved in ocean science who participated in the São Paulo School Advance Science on Ocean Interdisciplinary Research and Governance (SPSAS, 2018). The SPSAS's main goal was to provide graduate students with advanced knowledge on interdisciplinary ocean research and governance, including issues related to public policy in a multicultural context. This training allowed us to integrate a diversity of approaches that were used in our analysis.

The survey was designed to gather information about the transdisciplinary challenges these young-scientists group had experienced in their study cases in different regions, social-ecological contexts, and areas of knowledge. The survey inquired about the region (Q1), primary research question (Q2), stakeholders related (Q3), level of interaction with each stakeholder (Q4), general interaction with the stakeholders (Q5), the kind of relationship sustained with each stakeholder (Q6), the main challenges to interact with the stakeholders (Q7), the methods used to overcome such interaction-challenges (Q8), alternative methods proposed to solve the interaction issues (Q9), and general recommendation for decision-makers to use the transdisciplinary approach in the policy-making process (Q10). Different kinds of questions were used: Open questions (Q2, Q5, Q7–Q10), multiple choice (Q1), several boxes (Q3), and matrixes of several categories in columns and rows (Q4 and Q6).

Classification criteria

For multiple choice questions, the Regions (Q1) were defined according to the list of regions of the World Bank[6]. The stakeholders (Q3) considered here were: Government (Gov), Environmental Managers (Env), Academy (Aca), Primary Sector (PrS), Secondary Sector (SeS), Third Sector (ThS), Local People (LoP), and Ethnic Groups (EtG). The level of interaction (Q4) was measured using a categorical scale of "none", "low", "medium", and "high" for each stakeholder considered. The kind of relationship with the stakeholders (Q6) was obtained by asking the scientist to select if each stakeholder was: i) aware of the study; ii) providing information; iii) participating in data collection; iv) participating in data analysis; iv) considered in the research goals, and; v) aware of the potential benefits/disadvantages of the outcomes of the study.

6 Available at: <https://www.worldbank.org/en/where-we-work>.

We analyzed 21 study cases that fulfilled the following criteria: (i) involved stakeholders in the research process or reaching out communication; (ii) integrated different areas of knowledge in the research; (iii) aimed for a contribution both in theory and practice terms, and; (iv) focused ultimately on ocean sustainability issues.

Data analysis

We adopted a mixed-method cross-case analysis approach (Bryman; Bell, 2016). The main question (Q2) of each study was categorized into five main topics, including Climate change; Coastal management; Fisheries & conservation; Social-Ecological systems, and Marine pollution.

The multiple choice and several boxes' questions (Q1 and Q3) were summarized in terms of the selection frequency of each category. The same for matrixes of multiple options (Q4 and Q6). For Q4 we transformed the categorical scale of interaction to numeric as follows: "none" = 0, "low" =1, "medium" =2, and "high" =3. The numeric scale was used to estimate the mean level of interaction of each stakeholder. A value of 3 was considered 100%, and all the results were transformed to a percentage accordingly. All the analyses presented here were conducted using Microsoft Excel 2016 ®.

Results and discussion

The sample was obtained from almost all the World Bank regions, excluding East Asia and the Pacific. However, study cases from Latin America and the Caribbean, and North America were the most representative (Figure 1).

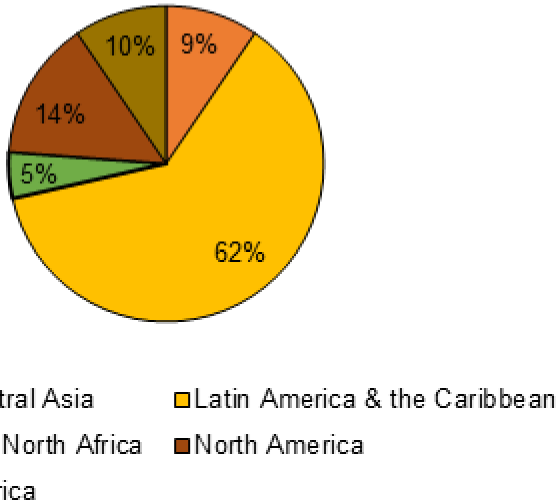

Figure 1. Percentual frequency of the origin region of the study cases (n=21) analyzed in this study. The study cases were scientific projects related to the different traits of ocean sciences and carried out by young scientists attending the SPSAS (2018).[7]

These cases provided relevant information about the research being conducted to sustainable use of the ocean and coastal areas. The primary research questions of the studies included indicator species for marine pollution, fisheries sustainability, environmental changes and their effects on ecosystems,

7 Sao Paulo School of Advanced Science on Ocean Interdisciplinary Research and Governance. Available at: <https://spsasocean.wixsite.com/spsas-ocean/students>.

traditional people, coastal and integrative management, the resilience of social-ecological systems, the role of local knowledge in decision-making processes, and the integration between science and coastal policy. However, the most frequent topic was fisheries and conservation, followed by coastal management (Figure 2).

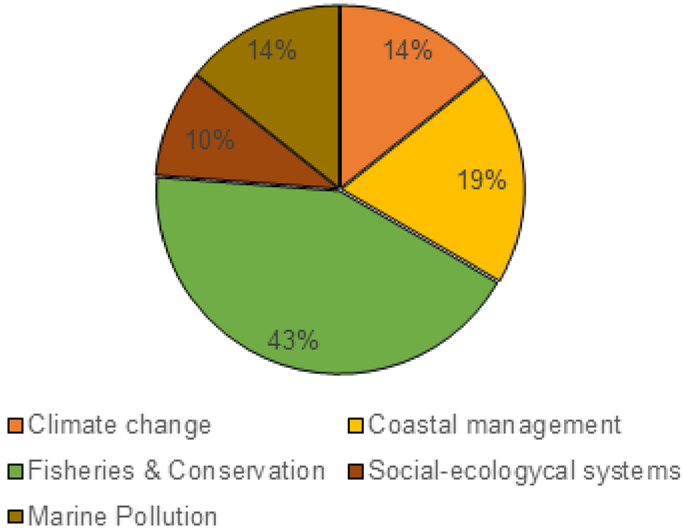

Figure 2. Percentual frequency of the main topics of the study cases (*n*=21) analyzed in this study. The study cases were scientific projects related to the different traits of ocean sciences and carried out by young scientists attending the SPSAS (2018).

The study cases were mainly related to Gov, Aca and Adm, and PrS. On the other hand, the least frequent stakeholders involved were the EtG, SeS, and ThS. Such frequency of relatedness could be explained by the common need to fill information gaps for regulation designing, solve academic questions, and assess proposals for exploitation and management of natural resources and livelihood improvement for local people. However, there is a common lack of participation of the ethnic and industrial groups.

The mean level of interaction of each stakeholder (key actor) varied among the study cases. The highest levels of interaction are with Aca, Gov, and Adm. The stakeholders related to human expression and cultural richness are the SeS and ThS and the EtG, which showed the lowest frequency of participation and level of interaction. In the case of the primary sector and local people, the high frequency of relatedness could be due to the methodology needed in the project that usually requires samples and data from the primary sector. In the same way, semi-quantitative data can be obtained from local people's perceptions of these global ocean-related issues. It is important to notice that the mean level of involvement of each sector is lower than the frequency of relatedness (excluding the academic sector). The highest level of frecuency and level of involvement of the Aca is likely explained by the project design currently used by universities and research centers, which is mainly focused in answering academic questions.

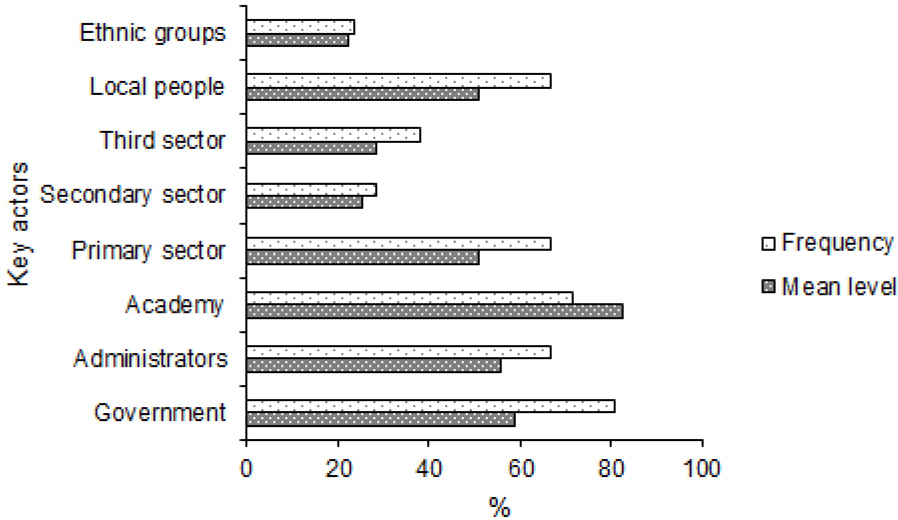

Figure 3. Percentual frequency (white bars) and mean level of interaction (dark grey bars) of each stakeholder in the study cases analyzed in this study (*n*=21). The study cases were scientific projects related to the different traits of ocean sciences and carried out by young scientists attending the SPSAS (2018).

In the following sections, we present and discuss the participation of stakeholders, key challenges to pursue transdisciplinary research, and recommendations for integrating science and environmental management.

Stakeholder participation

In the study cases analyzed, participants as informants (*i.e.*, those who provide information for research) are the most common kind of interaction. Informants include especially the government, environmental managers/administrators, the primary sector, and locals. The participation of government and environmental managers in the research occurs mainly concerning information to design public policies and adopt environmental management strategies. In one of the study cases, the government uses research information to adjust the current fishery management schemes to reach better social and ecological outcomes. Government participation may also involve research being carried out within a governmental institution (Figure 4).

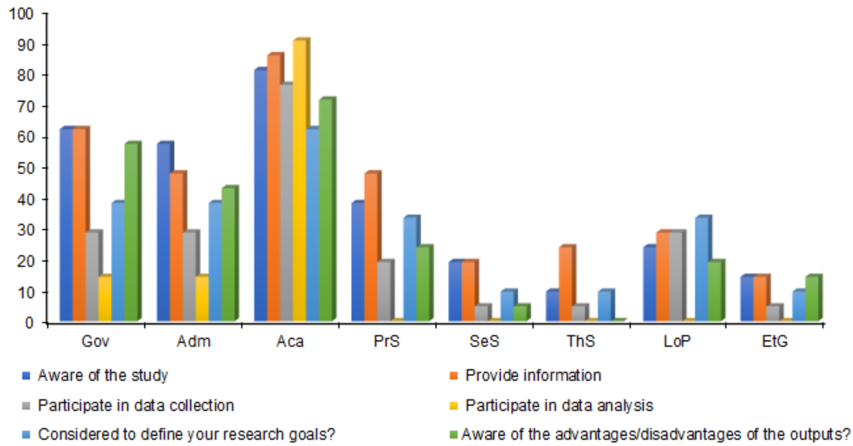

Figure 4. Percentual frequency of the kind of interaction (color bars) with each stakeholder involved in the study cases analyzed (n=21). Gov=Government, Adm=Administrators, Aca=Academy, PrS=Primary sector, SeS=Secondary sector, ThS=Third sector, LoP=Local People, and EtG=Ethnic groups. The study cases were scientific projects related to the different traits of ocean sciences and carried out by young scientists attending the SPSAS (2018).

Most of the study cases also seek to benefit ethnic groups indirectly by providing technical recommendations to inform policy design (*e.g.*, no-take protected areas located within traditional peoples' territory). At the same time, they foster the use of local and traditional knowledge. Our results show that ethnic groups (along with the secondary sector) are generally the least involved in any part of our studies. However, some studies hardly tend to include ethnic groups (*e.g.,* one study case was related to the conflict between federal management of a protected area and its traditional use). For instance, one of the study cases created a socioeconomic profile (*e.g*., through social cartography) of a local community that could inform the development of more appropriate public policies based on accurate information from the local reality. From the researcher's perspective, the participation of local people is fundamental, mainly in cases where they are directly affected by the subject being studied and analyzed. However, it can also be helpful to understand ecological processes based on empirical knowledge (MALAFAIA *et al*., 2014).

Generally, in the analyzed cases, local people are not fully aware of the research findings because of the academic wording and specificity of the research subject. That requires more academic incentives for lay language communication and reaching out activities, which are scarcely funded by research organizations or funding agencies (BAUMANN, 2003). In contrast, other cases included traditional and local knowledge as a relevant source of information.

Interactions with the academy include pure scientific interactions, such as debates via scientific journals or academic events (e.g., conferences, meetings, networking events). It also includes partnerships between the academy and governmental agencies, NGOs, or local organizations. So, this interaction becomes almost obligatory.

As a general pattern, we observed that the actors who permit, grant, and reward research development via licenses, scholarships, and academic degrees are the most related to these studies, so these actors could be characterized as the "providers" for young scientists, even more in developing economies. On the other hand, the ultimate goal of every science project is the improvement of life quality through sustainable development, including each and all of the concept's main axes. Sustainable development is pursued through the constant update and improvement of processes related to each sector of production, from the extraction, transformation, and consumption of each natural resource, as well as the human values through the production of human expression, knowledge, and technology (BASTAS; LIYANAGE, 2018).

Challenges to effective researcher-stakeholder interaction

We identified seven key challenges for effective communication and research dissemination among the group of stakeholders identified above. They are represented below, including suggestions on potential ways to solve each issue.

(i) Low levels of cooperation between some stakeholder groups. Gathering information or details from a study can be difficult, for instance, because some government agencies may not be willing to provide the data or because the information is not well detailed in the published material. **Suggestion:** Highlight the importance and benefits of community-government-science interaction in processes to incentivize the use of open-data websites.

(ii) Communication gaps between stakeholder groups, including jargon, lay language vs academic language vs political discourse, diverse interests – i.e., the research question may not be considered relevant to a specific group. **Suggestion**: Enhance communication channels between stakeholder groups and find common ground on effective communication, e.g., make better use of social media, infographics, and other ways of informal and visual communication, public speech-coach as a tool for researchers, facilitation training for researchers, as well as the use of more participatory research methods.

(iii) Difficulty in acknowledging the social, economic and ecological diversity of a study site and pursue an integrated perspective of the context. **Suggestion**: Research participation in other projects and activities being held in the area, use of more participatory research methods.

(iv) Lack of trust between and among stakeholder groups. **Suggestion**: long-term transparent and sincere interaction among parties. This requires time and a change in the way current ties are developed and fostered, the use of more participatory research methods.

(v) Lack of academic incentives to communicate research to the lay public (*i.e.*, academic success measures based on publication metrics). It includes financial and career efforts not available or recognized in academia. **Suggestion**: Pressure from the academy to acknowledge transdisciplinary research as a way of contributing to both science and the real world and integrate non-academic outcomes to the metrics of professional success. On the other hand, since the usefulness of open and user-friendly platforms (*e.g.*, social networks) to collect data for scientific purposes is undeniable, the use of social networks as a via to widespread relevant scientific results must be encouraged.

(vi) Taboos in local culture (*i.e.*, in some cultures, people are not comfortable to provide researchers with information about their traditional norms and taboos in managing their environment). **Suggestion**: Respect local norms and highlight their relevance in research outcomes.

(vii) Making time for interactions: some researchers claim that environmental managers were not available for a meeting to discuss research goals and possible collaborations. **Suggestion**: Highlight the importance and benefits for managers of community-government-science interaction in decision-making processes, and build partnerships with governmental organizations.

Recommendations for policy-making

Our interviewees recommend formulating public policies and conducting decision-making under a holistic approach, considering both social and environmental contexts. Above all, in the social approach, traditional communities, which survive through direct use of natural resources, such as small-scale fishers, were emphasized. The interviewees reported that it is a great challenge to raise awareness among traditional communities about the sustainable use of ecosystems, given their cultural relations and, above all, the need to obtain monetary resources through production surplus. Therefore, decisions based on the real needs of local communities, considering sustainable use and consumption are more likely to succeed. They can be operated through policies that subsidize these practices and allow for a reduction in production costs, thereby enhancing communities' wellbeing.

Interviewees also point out that education is indispensable for sustainable decolonization, especially by involving ethnic groups and the primary sector through representations to the government, academia, and public policymakers. About 2% of the cases do not work directly with public policies, however, they believe that their research outcomes are important avenues of support, since they allow for a better understanding of the environment, emphasizing the need to include a transdisciplinary vision for the creation of new public policies aimed at sustainable development and environmental preservation.

Final remarks

The present study aimed to discuss the contribution of transdisciplinarity research to the transtiton of a more ecologically sound and socially just ocean governance. Through 21 case studies, we identified the different concerns that surround sustainability relations regarding governance issues and the supply and fragility of ecosystem resources committed or not by unsustainable practices of economic growth around the world.

Among the results, the average level of interaction of each group with stakeholders varied between cases. The highest levels of interaction were with the academy (83%), government (59%) and administration (56%), demonstrating that these actors could be characterized as "providers" for young scientists, especially in developing economies.

In addressing the challenges faced by researchers to conclude their work and to effectively communicate and disseminate it to diverse social groups. We identified problems related to communication strategies used with the agents involved, complex cultural relationships, lack of financial incentives and difficulties in collecting reliable data, among others.

As young scientists, we understand our responsibility to foster interaction between and within stakeholders' groups and to involve non-academic actors in the development of scientific projects to demonstrate the power, utility and need of science and technology development to be able to face the future of this constantly changing world.

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CHAPTER 4

Resilience of coastal social-ecological systems under complex systems perspective

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Abstract

Coastal areas can be considered complex social-ecological systems due to the connections, non-linearity, and interdependence of the relations between society and the natural realm. This chapter explores the concepts and principles that build resilience in SES and discusses the limitations of the concept and its importance for governance and conservation.

Social-Ecological System Complexities

Social-ecological systems (SES) are considered "systems where people interact with natural components" (LIU *et al.*, 2007). This systemic view applied to SES is the vanguard of integrative studies regarding human-nature (DEARING *et al.*, 2015). SES are composed of multiple subsystems and internal variables which are relatively separable but interact and produce outcomes, affecting the subsystems and their components (OSTROM, 2009).

A common mistake occurs when the concept of complexity is associated with the idea of the number of variables. The number of variables in a system is not what makes it a complex system, but how variables interact (MORIN, 2007). Weaver (1948) uses the term "mixed teams" to refer to the multiplicity of disciplines, desirably applicable to complex problems. Skyttner (2005) agrees with multidisciplinary approaches and also considers that complex problems must be treated by interacting parts of the system, and those interactions must be studied from different perspectives (*e.g.*, transdisciplinary or multidisciplinary), holistically. More important than different perspectives, according to the author, system perspectives represent the approach that links them together into a coherent interdisciplinary communication.

According to Sterman (2000), a complex system can be characterized by the following set of attributes:

- Dynamic: attributes of systems change in time, and frequently in time scales;

- Strongly coupled: everything is connected to everything else;
- Ruled by feedbacks: considering that most elements are connected, feedbacks are the links that connect the system;
- Non-linear: the effect is rarely proportional to the cause, and relations between variables are rarely proportional;
- Path dependence: several actions are not reversible and will determine the overall behavior from that point on;
- Self-organizing: the system's dynamics emerge from the interactions between inner structures;
- Adaptive: decision rules and values that reign the overall behavior change over time;
- Counter-intuitive: causes and effects can be separated in space and time, making the task of uniting them difficult;
- Policy resistant: system's complexities overwhelm our understanding capacity and sometimes problem resolutions can create adversities; and
- Trade-offs: delays are frequent in feedbacks, and thus system' responses to an intervention can be different at short and long-time scales.

The scientific and managerial approach that complex systems provide to society's problems emerge with the understanding that their parts are interrelated; the solutions for today's problems frequently become tomorrow's problems (because secondary effects usually are not taken into account); the relations between components are frequently non-linear; and the vision that the system is bigger than the sum of its parts.

When coastal areas are considered from a holistic perspective that understands that ecological and resource conservation are intertwined with societal goals, uses, practices and perspectives about nature, they are being seen as a social-ecological system. Thus, the goal of this chapter is to consider coastal areas from a holistic social-ecological systems perspective and to discuss principles of governance that can contribute to its resilience.

Governance of SES

The ecological subsystem of SES must be managed in a sustainable way to obtain a continuous yield of ecosystem services in the short and long term (DAILY *et al.*, 2000; BEAUMONT *et al.*, 2007). The principles of sustainability proposed by Daly (1990) are one path for this management, and are still valid nowadays:

- Renewable resources such as fish, soil, and groundwater must be used no faster than the rate at which they regenerate;
- Nonrenewable resources such as minerals and fossil fuels must be used no faster than renewable substitutes for them can be put into place; and
- Pollution and wastes must be emitted no faster than natural systems can absorb them, recycle them, or render them harmless.

Adaptive governance seems to be one way to operationalize those principles (FOLKE, 2016). Such governance connects individuals, organizations, agencies, and institutions at multiple organizational levels (FOLKE *et al.*, 2005). Adaptive governance is considered able to work properly under a system that changes over time (*i.e.*, a resilient society). The behavior of ecosystems requires that the governance system adapts itself to nature's regular behavior and changes, meaning that the management of the social-ecological system must be coupled to ecosystems. Fiksel (2003) agrees with that vision and concerning systems management, the author states:

> Traditional systems engineering practices try to anticipate and resist disruptions but may be vulnerable to unforeseen factors. An alternative is to design systems with inherent "resilience" by taking advantage of fundamental properties such as diversity, efficiency, adaptability, and cohesion.

Resilience

The basin of attraction metaphor (GUNDERSON; HOLLING, 2002) is a useful way to understand resilience quickly. This metaphor explains the system behavior as a ball inside a bowl and according to different shocks, the system tends to be stable and return the ball to the initial position (being resilient). If the shocks are too strong for the system, the ball will be displaced to a different bowl, meaning the system will be operating under a different regime.

Despite being useful, this metaphor is narrow because underneath, the idea of stability of systems is implicit, as well as the control over its behavior. Systems are not stable, they are dynamic, sometimes under gradual changes (slow variables), sometimes with abrupt changes; sometimes changes are predictable, and sometimes they are not. Therefore, resilience thinking, in a broad view, is the "capacity of people, communities, societies, cultures to adapt or even transform into new development pathways in the face of dynamic change" (FOLKE, 2016). Thus, resilience is related to transformation, not stability.

Resilience thinking, understood as the use of the resilience concept by practitioners or scientists, started with Holling (1973) and recent information (FOLKE, 2016) shows that it evolved to conquer several international initiatives (*e.g.*, the Global Resilience Partnership, 100 Resilient Cities Collaboration, Transition Towns Movement, Global Flood Resilience Alliance, Resilience Action Initiative, and Resilience Alliance), forming a developing field inside the academic world and also as a movement outwards academic research being embedded in environmental and sustainability planning by several countries and institutions (*e.g.*, several sub-Saharan African countries and FAO).

The adaptive cycle

In their seminal book *Panarchy*, Gunderson and Holling (2002) not only refuted the idea of stability in what they called the "Myth of Nature Balanced" (GUNDERSON; HOLLING, 2002,

p. 12) but introduced the evolutionary perspective to social-ecological changing behavior: nature's changes are episodic, not gradual, nor continuous. Caused by the interaction of slow and fast variables, it requires a flexible governance system (adaptive governance). In this sense, resilience is related to the ability to maintain adaptive capacity: "The challenge, rather, is to conserve the ability to adapt to change, to be able to respond in a flexible way to uncertainty and surprises" (GUNDERSON; HOLLING, 2002, p. 32). Gunderson and Holling (2002) then describe the adaptive cycle as a metaphor for how those changes in systems occur through time and what the role of resilience is. The cycle is usually represented by the infinity symbol, displaced inside two axes (x for connectedness and y for potential) and divided into four phases:

- **r** for exploitation – phase with the rapid growth of the system using available materials and low competition;
- **k** for conservation – slower growth rates and high competition; the system becomes mature;
- **Ω** for release - "creative destruction" occurs when resource accumulation from the previous cycle (k) becomes fragile and susceptible to an agent (e.g., drought, insects, and fires); and
- **α** for reorganization – after a disturbing phase (Ω), reorganization of the system takes place with an opportunity for colonization and/or innovation.

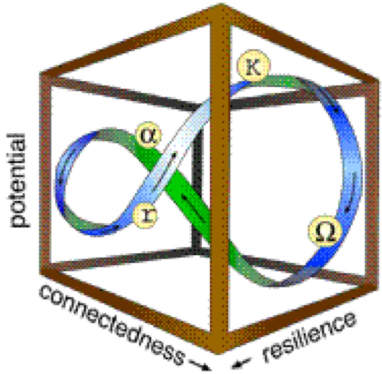

Figure 1: Adaptive cycle described by Gunderson and Holling (2002).
Source: HUKKINEN, 2012.

Through this cycle, connectedness and potential increase from phase r to k, forming some sort of capital of nutrients and biomass in natural systems or mutual trust, social relations and partnerships. At the end of the k phase, few species or social groups become dominant and most of the diversity is residual, peripheral to the mainstream system. The increasing accumulated capital built from growing also represents the increasing potential for different uses or futures, and with Ω part of it, becomes available for new arrangements and opportunities (α).

Resilience in this framework appears as the z-axis. The three-dimensional infinity symbol can now vary through the z-axis presenting different values of resilience across the adaptive cycle. The lowest value occurs after the Ω phase, and it starts to grow at the r phase. The highest value occurs in the late r or early k phases and then starts to decrease in the late k phase (due to the rigidity of this late phase).

The proposed framework or metaphor is difficult to test, considering its degree of abstraction (GUNDERSON; HOLLING, 2002), and the authors claim that it is not a forecast about the system behavior, certainly not to be followed to the letter. A deeper analysis of connectedness, potential and resilience is under development by distinct research groups (FOLKE, 2016).

Several concepts are closely related to resilience thinking, albeit being different. Transformability is about changing the development in new pathways, this means crossing a threshold and aligning the social-ecological system behavior in a new regime, under a different basin of attraction (FOLKE, 2016). Adaptability is the capacity of people "in a social-ecological system to learn, combine experience and knowledge, innovate, and adjust responses and institutions to changing external drivers and internal processes." (FOLKE, 2016), and maintain the system operating at satisfactory levels in the same regime, under the same basin of attraction.

Principles to build resilience in SES

Operationalizing resilience is a field in fast development through modeling, although it is not a trivial task. Specific resilience is easier to handle and several experiences can be found in the literature (*e.g.*, Resilience Alliance and Assessing Resilience in Social-Ecological Systems; Workbook for Practitioners, 2010), but operationalizing the concept at a higher level is a functional challenge. Béné *et al.* (2016) also claim that "none [analyses] provides an approach or a methodology that enables us to measure resilience simultaneously at several levels".

The authors also show another operational challenge, which is to consider the multi-dimensional character of the system, meaning social, ecological, and economic dimensions. According to Béné *et al.* (2016): "This means that, in theory, the framework proposed to measure resilience should be designed in a way that allows for integrating this multi-dimensional nature (even if we are interested in one particular dimension such as food security)".

On the other hand, several authors have been studying what system properties interact, forming the substrate from which resilience emerges. Fiksel (2003) established a list of four components of resilience:

1. Diversity - existence of multiple forms and behaviors;
2. Efficiency performance with modest resource consumption;
3. Adaptability - flexibility to change in response to new pressures; and
4. Cohesion – existence of unifying forces or linkages

A similar approach is presented by Biggs *et al.* (2012, 2015) with a deeper analysis and more detailed features underneath the resilience concept. They focus their understanding on the Resilience of Ecosystem Services, meaning the "capacity of a social-ecological system to continue providing some desired set of ecosystem services in the face of unexpected shocks as well as more gradual ongoing change". This comprehensive approach brings seven components of resilience:

1. Maintain diversity and redundancy – systems with high levels of biodiversity and redundancies tend to be more resilient in providing ecosystem services;
2. Manage connectivity – ecosystems recover from disturbances using internal links of species and social actors. In social networks it can also provide new information and trust;
3. Manage slow variables – identifying slow variables and their feedback is a challenging effort, but understanding these general system features enhances resilient behavior;
4. Foster Complex Adaptive Systems (CAS) thinking – comprehension of the need for integrated approaches, non-linearity and uncertainty regarding ecosystem services production in the social-ecological system enhances the ability to deal with changes, and then increases resilience;
5. Encourage learning – studying how systems work, reduces the uncertainties and enlightens non-linearity behavior, thus, experimentation and monitoring can enhance knowledge and foster resilience;
6. Broaden participation – participation enhances relationships, can build trust, can facilitate learning, and make collective action possible. All of these are directly related to governance and resilience; and
7. Promote polycentric governance systems – provides a structure in governance that allows the other principles

to develop and also enhances participation and social networks.

Principles 1 to 3 are general system features and principles 4-7 are more related to the governance of social-ecological systems. There is a degree of overlap between all those concepts. Connectivity (1) regarding the social sphere and social networks (6 and 7) are closely related; fostering CAS thinking and enhancing learning, is one form of bias in the development of scientific knowledge to pursue systems thinking.

All those principles have their issues regarding field measures, communication, and relation with ecosystem services production and at this moment, modeling hasn't shown one comprehensive work embracing all of them. A more extended consideration could be found in Liu (2017), concerning the concept of a metacoupled world. The metacoupled world considers horizontal and vertical interactions between each component of the social-ecological systems. This approach highlights unknown dynamics which can be related to the degree of resilience of a social-ecological system in a network of interactions. Considering a social-ecological system as a complex adaptive system and adopting resilience as an emergent behavior of this complexity, means understanding the non-linearity of its components, the non-linearity of their combined influences and the uncertainties associated with system features. Thus, measuring and validating the results of those principles remains a challenge to be pursued by scientific development.

Although all these components are still under construction, they form the actual state of the art in social-ecological resilience studies. Comparing the suggested components of these studies (FIKSEL, 2003; BIGGS *et al.*, 2012, 2015) can be a way of understanding common ground on the nature of resilience, and then moving the science forward, founded on the best available scientific bedrock.

Conflicts with the application of resilience in social studies

Although resilience is undeniably growing in scientific research, we still have those who oppose the adoption of the agenda (BROWN, 2014; CRETNEY, 2014; STONE-JOVICICH, 2015). All those authors agree that the social sphere is underrepresented in resilience studies. In a broad view, they argue, as social scientists, that the social-ecological systems view (not only resilience) lacks social perspective, being too ecological.

Brown (2014) is not entirely against the use of resilience, but the author argues that social and political features are being underestimated in resilience practice and science. Cretney (2014) pursues a political criticism of the risk of adopting resilience thinking because it could "justify projects informed by neoliberal ideologies that aim to decrease state involvement, increase community self-reliance and restructure social services", and also argues that the concept does not consider power, agency and inequality in the use of the term.

A deeper criticism is found in Stone-Jovicich (2015). The author draws attention to different perspectives of social sciences regarding social-ecological systems (*e.g.*, material-spatial world system analysis, critical realist political ecology, and actor-network theory), and she argues those to be more appropriate when compared to resilience. Indeed, resilience represents a point of convergence of governance and social drivers, which can either interlace or detach these perspectives (CLEAVER; WHALEY, 2018).

World system analysis uses several approaches to investigate the "emergence and dynamics of the capitalist world political economy over the past 500 years" (STONE-JOVICICH, 2015). The overall premise is that world-system level processes are important to understand human-nature relations in the long term and cross-scale. This approach also claims that considering only the internal dynamics of a small or local society are insufficient to explain its dynamic of change. This criticism is pertinent in the understanding of system behavior. One alternative to decrease this scale issue, and other problems related to the resilience theory, could be the practice of modeling these social-ecological systems. A meta-analysis conducted by Moser *et al.* (2019) highlights the necessity to ensure that the term "resilience" has the same interpretation across different fields. Thus, the scale issue can also present repercussions related to its interpretations in distinct fields, making the modeling of these social-ecological systems more challenging.

System dynamics has been dealing with this scale issue since its foundation, and more specifically in delimiting system boundaries. Building a system dynamic model is an iterative process of enhancing complexity (STERMAN, 2000). In this process, the modeler will embody in his model all those variables that are relevant to the overall behavior of the system. Variables that have their dynamics influenced by the behavior of other variables in the model are called endogenous variables and must be included to have a high-quality output. The variables that are relevant to the behavior of the system but are not directly influenced by variables inside the model, can be treated as exogenous variables.

Critical realist political ecology has different characteristics in its evolving stages (MARTINEZ-ALIER, 2002). In a wide view, this approach claims that environmental problems are independent of human understanding (STONE-JOVICICH, 2015), and adopts a perspective that "reality" problems can never be understood in their totality by societies. With that perspective, scientific explanations of environmental degradation are always considered to be limited, to be able to provide only limited insights of the unattainable complexity of the system, and therefore, can "exacerbate environmental crises and social injustices" (STONE-JOVICICH, 2015).

The position of political ecology seems to perfectly resume the human condition towards a complex system, but when managing comes into play, people tend to choose practical alternatives. To fulfill the challenging task of applying science to society's benefit, one usually decreases the expectations of having all science and uses the best available techniques and tools to make things better. Once again, system dynamics is an alternative in which these limits of knowledge are called bounded rationality, and it is well known as a limit to knowledge but also as a threshold to be trespassed by scientific experimentation. As pointed out by Praiser *et al.* (2018), social-ecological systems are under constant pressure to adapt and evolve; this ever-changing nature must be anticipated even when predictive methods are poorly known. The challenges posed by such complex system issues also demand more engagement from scientists and stakeholders in a co-creation action approach to enlarge the limits of the knowledge.

Actor-network theory perspective considers that the social relations domain is always mediated (even enabled) by non-human entities and thus, at least at the beginning of the analysis, humans and non-humans have a similar potential role in the overall behavior of the system (which is called generalized symmetry). The focus is not on the structure of networks, but more on the "structure of networking" (STONE-JOVICICH, 2015), meaning the ways that actors interact and affect each other. This perspective also considers that change is always happening (this might justify the abandonment of pursuing stable networks) and thus dynamics are at the core of the analysis.

The structure of networking is probably the major contribution of system dynamics to collaborate with resilient thinking and modeling. The way that actors interact and affect each other is, in system dynamics terms, considered causalities. Causalities are the expression that conditions change in the behavior of one variable (actor) according to changes that already occur in another variable.

In the moment of validation of the model, scientists compare the obtained behavior of some variable of the model with the real behavior of that variable obtained by field measurements or other models. If the model variable describes the real behavior, this means that in the model it is obtained by a set of premises that also occur in the real world, and then, causalities were discovered. But obviously, this is a difficult task to do, even for the most experienced modelers, and there is also always the chance of some slow variable that was not embodied in the model to be present in the real world and affect the expected behavior of the system. This is one of the limitations of the modeling approach.

The work of causalities research through validation embodies a bigger challenge when considering resilience because no real-world data exists to be used to validate it. No standard resilience value is known for each SES. Thus, the way to do that seems to be through scenario development (BOUMANS *et al.*, 2002).

Adoption of models to understand and enhance resilience knowledge is at most justifiable considering that "building a model is a process of learning about the system" (STERMAN, 2000). Not only is this the perfect alignment to principle 5 of Biggs *et al.* (2012, 2015), but learning is the primary way for society to enhance its understanding of societal concerns. Finally, due to the ever-partial and divergent state of knowledge, best practices must explore various models and methodologies and be knowledge-generating driven (PRAISER *et. al*, 2018).

In summary, coastal SES are complex, adaptive systems with feedback, uncertainties and surprises that make the process of management far from trivial. Resilience is a feature of SESs that encompasses several distinct system aspects like uncertainties, feedback and non-linearity and thus can be a promising way of dealing with complexity challenges while also increasing society's participation in the process. Its broad acceptance would be better if the criticism – especially from social sciences – was incorporated in the theory and assessments. Enhancing the use and application of the resilience concept can enforce the awareness of society regarding complexities, uncertainties and feedback of SES and promote the development of this scientific field and the governance of sustainable coastal environments.

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CHAPTER 5

Ecosystem-based management of social-ecological systems: how to reach common goals for sustainability

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Abstract

Modern management of coastal areas must be constructed in an adaptive context, allowing the governance system to vary its approaches for more suitable ones when the environment changes. To operationalize this kind of management, several aspects are agreed upon by leading scientists. Yet conflicting goals from distinct social groups block ideal solutions with sabotage, riot, or a complete disregard for the law. This chapter argues that different shared values are the reason for these behaviors, but the way to create legitimate solutions is through compromise.

Introduction

During the last decades of the 20th century, most of the planning and policies regarding oceans and coastal areas were created by governments (BURROUGHS, 2011). These policies were mostly created under "command and control" perspectives. Water quality parameters, pollution control measures, and licensing processes were derived from those actions. Currently, a different perspective exists that considers the management of resources in a plural context. It is formed by several complementary forces, habits and behaviors, with formal and informal institutions acting at the same time, within the government, and among society's diverse communities. This perspective assumes that to change human behavior, opportunities and problems need to be evaluated, institutions and arrangements need to be established, and acceptable behavior regarding resource and environmental use must be encouraged or sanctioned (JUDA, 1999).

In a comprehensive analysis, Burroughs (2011) used three schemes of decision-making processes regarding the stewardship of ocean and coastal areas: Sector-based Management, Spatial Management and Ecosystem-based Management. Sector-based Management (SBM) is a fundamentally reactive approach to resources management. When a company desires to create an activity that includes natural resource management and can create a potentially significant environmental impact, the Government reacts by showing norms and regulations. This is what happened for most of the environmental planning over the past several decades (BURROUGHS, 2011).

The main problems regarding SBM occur when discordant parts of society have different plans for the same region. When incompatibilities arise governments must choose who to answer and who to ignore. According to Burroughs (2011), there are two main problems associated with SBMs: the assumption of the government that they can manage society's problems by regulating one activity at a time, and the assumption that solving one sector's problem will not create a problem for another sector.

Consecutively, Spatial Planning (SP) emerged as an alternative to problems associated with SBM. SP uses particular objectives for a determined area and expects to reduce the conflicts of a region by only allowing certain activities to be performed if they fit properly (*e.g.*, zoning). This is a much better alternative when compared to SBM because the government can link economic activities to resources through these regulations and control activities using laws and licenses. In this case, it makes sense to put compatible activities closer and make incompatible activities run distant one of each other. Nevertheless, using SP will still allow problems to occur. Although conflicts are reduced compared to SBM, they are not non-existent. Considering areas of consolidated use, one can expect there to be a reaction from locals regarding changes in zoning or building a new manufacturing plant. Another problem that can arise is that society changes its concept or plans for a region. Thus, changes in zoning can be difficult.

The most recent perspective created was ecosystem-based management (EBM) (FOLKE *et al.*, 2005; BURROUGHS, 2011; PARAMIO *et al.*, 2015). This approach includes several distinct advances regarding environmental management. Nevertheless, the "logic of EBM is based on recognition of the need for a systems approach, for 'systems thinking', in the science and governance of natural resources" (CHARLES, 2014); therefore, under this perspective, the system is understood as a Social-Ecological System (SES) (LIU *et al.*, 2007). SES considers economic activity an anthropological feature that occurs inside a larger and finite natural environment (a.k.a. ecological system). These systems are intertwined, and they affect/are affected by each other via complex feedback. Effective management must recognize these links as well as the limits of combined social-ecological systems (BURROUGHS, 2011).

Inside a SES, the ecological subsystem must be managed sustainably to obtain a continued yield of ecosystem services in the short- and long-term (DAILY *et al.*, 2000; BEAUMONT *et al.*, 2007). To manage the social subsystem a governance system that connects individuals, organizations, agencies, and institutions at multiple levels seems to be appropriate (FOLKE *et al.*, 2005). This type of governance system is expected to work as society changes over time (governance must be adaptive). The behavior of ecosystems requires that the governance system adapts to its regular behavior and eventual changes, meaning that the governance of the SES must be based on ecosystem behavior.

If we consider climate change a vector that would increase the variation of an ecosystem, then creating a solution to current problems that also fits 50 years from now, is unlikely and even undesirable considering that "approaches that seek to stabilize a set of desirable goods and services ultimately increase the vulnerability of the system to unexpected change (FOLKE *et al.*, 2002; GUNDERSON; HOLLING, 2002)". Then, management that understands and adapts to the ecosystem and social changes seems to be appropriate.

Some convergences to EBM

There are several scientific contributions showing pathways for building adaptive governance and EBM sequentially. Meffe *et al.* (2012) proposed a framework that would lead to a successful collaboration through ecosystem management. The authors consider stakeholders fundamental for good management and they interact according to three components:

- **Substance**: Substance is the technical part of the situation. The authors claim that what is substantive may vary depending on the stakeholders.
- **Process**: Process relates to the procedures of the decision-making process. This part assures that there was fairness, people were listened to, and stakeholders had the opportunity to participate in the decision-making process.

- **Relationship**: Relationship is the influence of the values or needs of a given group on the decision-making process.

A more comprehensive perspective is provided by Charles (2014) who points out that this governance system should first embrace some human dimensions to avoid only focusing on ecological features but also to include society's values, needs, and behaviors impacted by the ecological system.

The human dimensions of EBM (CHARLES, 2014) should include social, cultural, economic, political, and legal/institutional dimensions.

- Social dimension: Brings information about social capital, meaning the intensity of social contacts, social networks, and reciprocity or cooperation within the community;
- Cultural dimensions: Embrace the knowledge base, as well as the values and norms, of the users;
- Economic dimension: Refers to the influence of the users and the benefits of the ocean, as well as management actions like taxes, property rights, and access to fishing areas and boats;
- Political dimension: The most important dimension, because all decisions managing a SES will be created through the political process, and irregularities in society's economics and behavior are addressed by policies to obtain EBM success;

• Legal and Institutional dimensions: Embrace the rules governing human behavior, but also the laws regarding the management of the ocean.

An evolutionary perspective is provided by Olsson *et al.* (2006) who claim the movement toward adaptive governance occurs in relation to the adaptive cycle[1]. Meaning that all the phases between the perception of a system problem through the decision-making and implementation must occur within an opportunity window from the system, when "the problem is recognized, the solution is available and the political climate makes the time right for change" (OLSSON *et al.*, 2006).

Olsson *et al.* (2006) also establish three steps a governance system takes to become adaptive. The first step occurs when the system is more or less prepared for the changes, and thus only some preparation is required. This preparation, according to the case studies considered (OLSSON *et al.*, 2006), demands that knowledge is built and spread across a multi-level network. When this network matures into a critical mass, leadership emerges and makes it through participatory decision-making leading to change if it happens within the proper window of opportunity.

Second is the transition to a new social context for the management of the ecosystem, which authors claim there is no predictable plan to do. Because this phase represents a new

1 See Chapter 4 (Resilience of coastal social-ecological systems under complex systems perspective) in this publication for more information about the adaptive cycle.

arrangement of social structure, it is important to keep flexible goals and improvisation can be interesting to bridge the gap between different social institutions, where adaptive behavior shall emerge. This multilevel arrangement will provide management options for the current issues within the system, and through participation in this new arrangement, new policies shall emerge contemplating the social structure underneath it.

The third step is characterized by the enhancement of the resilience of the new phase, considering it must last for an unknown period. This step is discussed by Oliveira & Silva (2022).

A consensus regarding what is needed for EBM seems clear (OLSSON *et al.*, 2006; MEFFE *et al.*, 2012; CHARLES, 2014), but SES problems remain pervasive. The common ground in scientific terms seems to have a different acceptance between society's heterogeneous groups. It is not evident that societies are open to "new arrangements on the social structure" (see OLSSON *et al.*, 2006) required for system transformation. We argue that social consensus is a very difficult (not to say impossible) agreement. That is because different goals are wanted from different social groups with distinct values. Instead of agreement, divergence is the rule.

The nature of the divergence: What goals should be pursuit?

A broader view from the humanities tries to explain why all the problems regarding SES have not been resolved. Adger *et al.* (2009) dismiss the traditional point of view that limits for adaptations are immutable thresholds. The authors claim that regarding social aspects, such as adaptation or resilience, limits or goals are socially constructed and thus dependent on "ethics, knowledge, attitudes to risk and culture". According to the authors, "Any limit to adaptation depends on the ultimate goals of adaptation underpinned by diverse values" (ADGER *et al.*, 2009).

When one considers that EBM regards complex problems surrounded by uncertainty (FOLKE *et al.*, 2005; OLSSON *et al.*, 2006; LIU *et al.*, 2007; CHARLES, 2014), and if the idea of goals is value-dependent (Adger et al., 2008), SES issues can be considered as "messy problems" (NEY, 2012). Messy problems[2] emerge from the idea of no public goods or policies are undisputable; equity lacks an objective definition; there can be no optimal solution to social problems without the price of imposition, and consequent lack of legitimacy, and finally that an optimal solution is always a partial solution.

According to Rittel and Webber (1973) and Ney (2012), messy problems can be recognized by ten distinguishable characteristics:

2 They are considered synonyms of wicked problems (RITTEL; WEBBER, 1973).

5. There is no definite construct of a wicked problem. Any definition is uncertain and invariably contested;

6. Messy problems have no stopping rule. If the time horizon is not definitively formulated, it is impossible to know if it has been solved;

7. Solutions to these kinds of problems are not true-or-false, but good or bad. Considering there are no absolute criteria to judge the solution, it will always depend on judgment and interpretation;

8. There is no immediate, and no ultimate, test for a solution to a wicked problem. In complex systems, solutions create waves of consequences over an unknown period, so the evaluation criteria must change over time;

9. Every solution to a messy problem is a 'one-shot operation' because there is no opportunity to learn by trial and error and every attempt counts significantly. Even with *in silico* simulations reducing the uncertainty, there will always be unexpected consequences of the implementation of the solutions and the whole solution cannot be undone;

10. Wicked problems do not have an enumerable (or exhaustively describable) set of potential solutions, nor is there a well-described set of permissible operations that may be incorporated into the plan. Considering the uncertainty regarding the causes of those problems, the set of solutions is always open to new inputs;

11. Every messy problem is essentially unique. There will always be an amount of overlap between similar problems, but what distinguishes them will eventually prevail because the "one solution fits all problems" is impossible;
12. Every problem of this kind can be considered to be the symptom of another problem. If we consider that in complex systems, solutions create waves of consequences some of them may be good and some bad, which reinforces the creation of problems indefinitely;
13. The existence of a discrepancy representing a wicked problem can be explained in numerous ways and the choice of explanation determines the nature of the problem's resolution. When these problems are at stake, the rationality behind the argument is richer than those in the scientific discourse. There will rarely be a policy problem formulated as a scientific hypothesis to be accepted or rejected and it is not possible to put the problem in a controlled test;
14. The planner has the right to be wrong. Policy making is different from science since there can be no controlled test and hypothesis refutation. The solution will also depend on assessments, which are value dependent, and thus change according to groups and time.

Rein & Schön (1993) create the term "Intractable Policy Controversy" for conflicts produced by those messy problems. Those conflicts, the authors claim, are weakly affected by scientific information, once the very formulation of the problem depends on points of view and values, not just data. It is not a lack of information that underlies those problems, but the amount of scientific information available either surpasses the ability of the decision-makers to deal with, or the knowledge available, does not specifically address the problem the policy maker needs to address (NEY, 2012). Yet, diverse groups of institutions and actors select, filter, chose, and adopt a part of the total information available - the part they consider relevant to the problem. The act of interpreting and selecting information requires a judgment of what is relevant, precise, important, true and valuable, which is "guided by shared ideas, values and beliefs" (NEY, 2012).

With shared values and beliefs, data and scientific information gain significance in an intellectual context, as a broad view of the world instead of forming an independent and disconnected body of knowledge. Rein & Schön (1993) called these shared values and beliefs "frames", and they are shared which implies the formation of groups that take part in the same ideas and values. According to Ney (2012), "individuals tend to work together if they share a particular frame", what is referred to as "advocacy coalitions or discourse coalitions".

In the end, messy problems develop into intractable policy controversy, because they bring different frames of mind and a set of values and beliefs, not facts and data. Ney (2012, p. 10) claims that if contending frames are in discussion, there is no -or limited- room for negotiation:

Neither is this type of conflict amenable to resolution by bargaining: since contending world-views are at issue, there is no basis for negotiation. Policy-making about messy challenges then is an inherently argumentative process in which contending advocacy coalitions pit arguments – plausible and convincing accounts of what is and what should be going on – against each other. This is why conflict about messy issues is inevitably about values and beliefs. And that is also why frame-based conflict about messy issues is inherently intractable.

What are the frames and how are they related to views of nature?

According to culture theory (THOMPSON, 1997; SCHWARZ; THOMPSON, 1990; THOMPSON *et al.*, 1990), there are five frames (synonyms of rationalities, solidarities, or perspectives) that are the basis of human biases for understanding nature and an individual's participation in social life.

These five perspectives vary through two axes: group, meaning the degree to which one individual choice is bounded by the group; and grid/degree of regulations, the degree to which an individual life is circumscribed by externally imposed prescription, and thus the degree to which it is open to individual negotiation (THOMPSON *et al.*, 1990) (Figure 1). The five perspectives are as follows:

- The exhibition of an egalitarian perspective indicates strong group boundaries and weak prescriptive (grid) values. To this group the theory attributes the ephemeral myth of nature (THOMPSON, 1997), meaning they understand nature as a fragile thing that needs attention and caution when treated. Any mistake can lead the system to an undesired state or a collapse;

• Individualists' perspective is not bounded by group or grid. They are virtually free from control from others, but this does not mean they cannot control others. From this perspective, the theory attributes the benign myth of nature (THOMPSON, 1997) as being, meaning all boundaries are flexible and nature can always take care of itself, independent of human use or abuse;

• Hierarchies' perspective, in its turn, has strong group boundaries and grid prescriptions, resulting in hierarchical relations. For this group, nature can be perverse or tolerant depending on thresholds that must be managed properly by qualified personnel;

• Fatalists' perspective, indicates people strongly bound by grid prescriptions but excluded from group participation. To these people, nature cannot be managed or controlled, and thus the myth of nature being capricious (THOMPSON, 1997) is attributed to them. They cope with nature, and institutions did not learn or adapt.

• The Hermit's perspective is not controlled by the grid or group and left the participation in any decision. Fatalists and Hermit are not active frames once they are not participating in decision-making, one by choice, other by lack of opportunity.

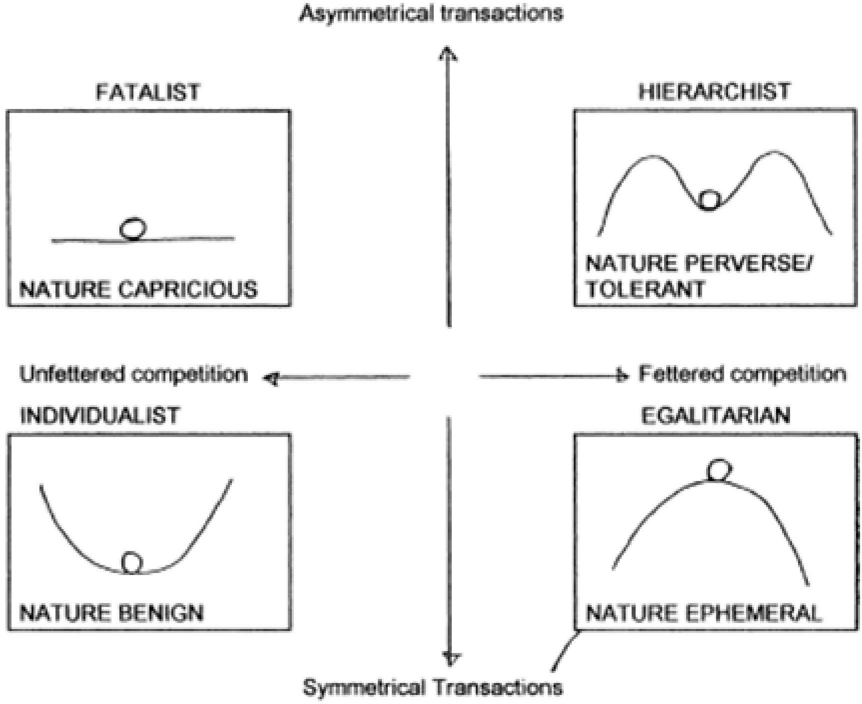

Figure 1: Four Culture Theory solidarities typology. Hermit is excluded. Source: THOMPSON, 1997.

The idea of using the typology from culture theory is that it provides structure to understand the behavior of contending advocacy groups. Ney (2012, p. 11) shows that those coalitions will exhibit particular behaviors that are predictable. Some coalitions will value:

> [...] order, harmony and process [Hierarchy]. In other coalitions, members will freely negotiate their relations with one another. These coalitions will emphasize individual

liberties, competition and the primacy of the bottom-line [Individualists]. Other coalitions will be well-defined groups that shun internal distinctions; members of these coalitions will stress equality, holism and the ever-present need to speak out against injustice [Egalitarians]. Members of the last two forms of social relations do not take part in policy debates. Fatalists, isolated as they are, see no reason to participate in politics since whatever they do never seems to amount to much. Hermits, in turn, go out of their way to avoid any social interaction.

For messy problems, clumsy solutions

Authors claim that the way to deal with those opposite frames is to understand the arguments they provide which justify their perspectives, moving the conflict away from the "intractable policy controversy" (NEY, 2012). Operationalization of this approach is made by dealing with the contending as narratives contend (stories to mobilize or justify a particular course of action), navigating the body of arguments and unraveling the assumptions and background, and redefining the problem, which may lead to different solutions.

The way of connecting people with different frames in decision-making must be focused on learning (NEY, 2012) because through dialogue and narratives analysis the opportunity to learn from different frames is opened. Policy theory describes three possible scenarios for the result of this advocacy coalition's interaction (NEY, 2012): First is the "dialogue-of-the-deaf" which is independent of the plurality of ideas - basically no one is listening to each other and just trying to impose their values and beliefs. This usually results in policy stagnation "as conflict becomes a way of preventing rival advocacy coalitions from making any gains" (NEY, 2012, p. 203).

If the advocacy coalition's interactions occur in a highly regulated space (with norms described by SABATIER; JENKINS-SMITH, 1993) the deafness may be reduced and substituted for a dialogue. From this dialogue, two more possibilities are possible: second is the reinforcement of the power of a dominant advocacy group (called boom-and-bust); and third, more participative, with an increase in empathy, interaction and responsiveness from each advocacy group (called rough-and-tumble).

In the end, the level of openness to listen to other perspectives, and mostly the level of responsiveness to contend position, will define the learning process of the advocacy coalition debate and eventually lead to the desired scenario, which is the rough-and-tumble (NEY, 2012). This scenario is built through a process of high responsiveness from all contentious groups. The output of this process (a.k.a. the solution) is a policy filled with elements of all active advocacy groups, called clumsy solutions (VERVEIJ *et al.*, 2006).

The clumsy solution happens when the hierarchy's call for "rules and wise guidance", the individualist's call for "optimal technical solutions and entrepreneurship" and the egalitarian's call for "whole new relationship with nature" coexist, cope, and despite the volume of the discussion, manage to build a constructive solution. The whole idea is to answer the SES problems by constructing solutions that are widely accepted and democratically legitimated. The point is reaching not only effectiveness but also legitimacy.

Comparing the convergences and divergences through a possible solution

The first step to building a governance system able to constantly adapt to environmental conditions is to understand there is no such thing as "one absolute right answer". That is most relevant now when the complexities and uncertainties regarding human-nature management are considered. The idea of one true alternative, which most of us were taught during school, must be avoided to prevent confusion and frustrated expectations.

When the complexities and uncertainties from the ecological subsystem, which are not fully understood, are added to those from the social subsystem, which are also only partially known, we end up with a massive problem that surpasses human intellectual capacity (FORRESTER, 1971; STERMAN, 2000) and defies our computational limits. This is important. because the idea of the perfect solution must be abandoned in function of a negotiated suboptimal, yet feasible, one.

Then, in opposition to the idea of rational policy-making where social problems can be solved by the application of rational scientific methods, using the relevant facts as support and imposing the optimal solution, emerges the pluralist politics in which solutions come from deliberation and argument. This is in perfect alignment with Meffe *et al.* (2006) framework of decision-making, once stakeholders interact to decide what the best option is. In other words, what may not bring the optimal scientific solution brings the most democratic and legitimate answer (NEY, 2012).

It is not clear where culture theory connects with the adaptive cycle. It is evident, as Olsson *et al*. (2006) claim, that the solution must occur in an appropriate window of opportunity; otherwise, there is no meaning in solving a problem that has already been solved or substituted by a worse one. However, the connection between those theories can be understood by the degree of responsiveness presented when the discussions take place. The position of Olsson *et al.* (2014) is that "political climate makes the time right for change" while Ney (2012) argues that the more responsive an advocacy group is, the closer to a clumsy solution the process will be. In this case, the openness to responsiveness is one aspect of the political climate, the willingness to collaborate.

It is not the objective here to discuss all those assumptions from messy problems (RITTEL; WEBBER, 1973; NEY, 2012), culture theory solidarities (THOMPSON, 1997; SCHWARZ; THOMPSON, 1990; THOMPSON *et al.*, 1990), or even the clumsiness of the solutions (VERVEIJ *et al.*, 2006), but to emphasize that, in a broad perspective, EBM deals with problems that are permanent, barely defined, socially divisive (once solutions unfold winners and losers) and seldom finally resolved (messy, by definition).

If Ney (2012) is right, the origin of problems, and the "intractable policy controversy", is in part explained by the transition from a "monolithic centralized" state to a "scattered in a network of power" state which includes different institutions in different levels. These institutions have specific interests with a "far wider range of actors and organizations", which can be supported by other authors (e.g., ADGER *et al.*, 2009).

Culture theory proposes that dealing with a "range of actors and organizations" can be done using what ties them together: frames. The theory also claims that there are no right or wrong worldviews because all of them were created using reason and logic. As pointed out by Ney (2012), "none of them is wrong in the sense of being implausible or incredible". All of them bring values and flaws, which first define them in opposition to each other, but mostly they can provide creative and plausible goals for complex SES problems.

Culture theorists (THOMPSON, 1997; SCHWARZ; THOMPSON, 1990; THOMPSON *et al.*, 1990; NEY, 2012) claim the necessity of all those groups to exist once they are defined by their opposition to each other (requisite variety). Legitimacy and social adherence to solutions gain power, the argument goes, when all solidarities are present and risks of the lack of compliance, and even sabotage, increase if one or more active groups are expelled (THOMPSON *et al.*, 1990).

Sub-optimal, yet legitimate

As the paper presented, the reason SES issues have not yet been solved might be because policy design occurs with a disregard for different opinions and does not consider the points of view from the different advocacy groups in society. Cooperation or "common ground" can be attained, culture theory suggests if decision-makers realize that what is on the table is value-dependent. If not, there will always be "intractable policy controversies" which will end in an unsatisfactory, imposed, usually tied decision-making process.

Understanding that stakeholders unite through advocacy groups, and the glue that ties those groups together is a set of shared values and beliefs, can provide a framework for decision-making that will point to a place where suboptimal solutions can be accepted with high legitimacy.

When clumsy solutions are presented, the "substance" (see MEFFE *et al.*, 2012) of the solution is not optimal for a particular advocacy group, but it has the advantage of being agreed upon and accepted by all others in society, which erodes sabotage and riot.

The "new arrangements on the social structure" (OLSSON *et al.*, 2006), required for systems transformation, can be achieved if this new arrangement is negotiated under the umbrella (SABATIER; JENKINS-SMITH, 1993) for clumsy solutions. Meaning that moving away from value-driven, intractable content, as well as deconstructing the narratives settings, villains and actors can move towards compromise, not consensus.

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CHAPTER 6

Fisheries Governance

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Abstract

Fisheries are social-ecological systems with global implications due to their transboundary nature, interaction with international markets, and regulation at regional, national, and global dimensions. Because fisheries have global implications, it is necessary to approach them through a governance lens that takes into account the many factors that affect them as well as including how government, civil society, business, and others interact and govern them. Among all of the factors that need to be addressed in the

governing of fisheries, this paper offers a glimpse into the increasingly global and complicated make-up of fisheries by discussing coastal fisheries governance, high seas governance, and the governance of the seafood trade at the local scale. This illustration provides a snapshot of some areas of study in the wider fisheries governance discourse.

Introduction

Governance is a broad concept, which is complex and driven by many different perspectives (HAAS *et al.* 2021). Overall, it can be described as a tool (HAWARD; VINCE, 2008) to coordinate different stakeholders, state and non-state actors (CLEMENT; STANDISH, 2018). Different instruments, institutions and initiatives, form the basis for governance action (YOUNG, 2013) (Figure 1). The roman empire was the birthplace of the legal basis of marine fishing rights, and fisheries governance (BRITZ, 2015). Under the empire, the sea was seen as being a ‘common right to all men’, however, this right only extended to those that were roman citizens. This view essentially gave rise to the idea of closed seas that are not accessible to other nations. When the roman empire fell, individual states began a process of appropriation of territory in the sea, using naval force to defend the said territory (ALISSON, 2001). Centuries later, with the independence of a large number of previously colonial states, the discovery of mineral resources under the seabed and the industrialization of fishing, the United Nations Convention for the Law of the Sea (UNCLOS) supported a widening of state jurisdiction over coastal seas (ALISSON, 2001).

The UNCLOS came into force in 1994, providing the basic legal framework for all ocean and fisheries governance. In this sense, ocean governance is defined as the shared, collective effort of government, private business, civic organizations, communities, political parties, universities, the media and the general public to govern ocean activities (JENTOFT; CHUENPAGDEE, 2009). Approaching issues from governance rather than a management perspective offers a more holistic and multifaceted approach to tackling the problem and allows it to be tackled at different dimensions. One of the dominant factors shaping the UNCLOS legal framework for the high seas was the historic customary international law principle of 'freedom of the seas' (ALLISON, 2001; RAYFUSE; WARNER, 2008). The term was strongly characterized by the famous Dutch international lawyer Hugo Grotius who, in 1608, published his seminal book 'Mare Liberum' (*i.e.*, 'freedom of the seas'). This work argued that due to the vastness of the oceans and their importance for international trade, they could not be subject to national sovereignty claims, which would restrict their use by all nations (RAYFUSE; WARNER, 2008). Under this historical principle, every coastal and land-locked country has a right to fish, free passage of navigation for ships and conduct scientific research (UNITED NATIONS, 1982, Article 87). However, UNCLOS also contains some restrictions on the freedom of the seas. The territorial sea, created under UNCLOS, provides sovereign rights to coastal states in the area from the baseline (*i.e.*, usually the low water mark of the coast) out to 12 nautical miles from the coast (UNITED NATIONS, 1982, Article 3). The exclusive economic zone (EEZ), also created under UNCLOS, provides coastal states with additional resource extraction rights out to 200 nautical miles from the baseline (UNITED NATIONS, 1982, Article 56).

This chapter aims to provide an overview of three relevant issues under fisheries governance: the management of coastal waters, the management of areas beyond national jurisdiction, and the trade of marine resources, which add further complexity to the whole system. The first section will discuss the governance of marine living resources in coastal waters, exemplified by a case study of South Africa. The second section describes the high seas fisheries management and the structure of regional fisheries management organizations (RFMOs). The final section discusses how the trade in seafood discourse is linked to the governance of fisheries, and, using Eastern Canada as a case study, explains how significant international trade policy can be to coastal resource governance. The two case studies were chosen due to their economic importance in the fishing industry. While Canadian fisheries have recently received attention due to a trade agreement with the European Union, South Africa does not only play an important role as a fishing nation but also as a port state and thus plays an imperative role in reducing illegal, unreported, and unregulated fishing. Furthermore, highlighting various aspects of fisheries governance in the global north, global south, and high seas conveys the geographic complexity of these issues. Although only two country-based case studies are used, we argue that these two countries are addressing important issues which are relevant for many other countries as well.

Fisheries Governance in South Africa

South Africa is well known for its extensive coastline, stretching for 3.650 km (MCLEAN; GLAZEWSKI, 2009), which links the east and west coasts of Africa; but perhaps less well known is the diversity of marine habitats surrounding South Africa (SMALE *et al.*, 2004). Some of these habitats include the sub-Antarctic Prince Edward Islands (Marion and Prince Edward) which are in the southern Indian Ocean and were annexed by South Africa in 1948 (COOPER, 2006). The rich biodiversity ranges from the coral reefs of northern Kwa-Zulu Natal to the cool water kelp forests of the Northern Cape (DEPARTMENT OF ENVIRONMENTAL AFFAIRS AND TOURISM, 2012).

The sea is divided into several different maritime zones and these zones are governed by several legal regimes (VRANCKEN; PIKE, 2014). One such zone is the exclusive economic zone (EEZ) and, although extending beyond a nation's territory, a nation has exclusive rights for exploration, conservation, exploitation and management of the contained resources (VRANCKEN; PIKE, 2014). De la Torre-Castro (2012) suggested that the prime solution to the problems associated with the sustainability of marine living resources such as fisheries was governance. There are numerous definitions of governance, but they can be narrowed down to "the interactive processes through which society and the economy are steered towards collective, negotiated objectives (ANSELL; TORFING, 2016). Nonetheless, when looking at the sustainability of fisheries, one essential aspect of governance is the continued monitoring of the proper implementation of legislation.

South Africa has a large EEZ and, similar to a country like Australia, has jurisdiction over an ocean space larger than the size of its land territory (GLAZEWSKI; HAWARD, 2005). This puts the country at an enormous global competitive advantage that both living and non-living marine resources offer them, in terms of the fisheries and tourism industries (Gazette No. 37692, 2014). This ocean space is resource rich in national assets that provide important economic and social benefits for the population through a wide range of ecosystem services (DEAT, 2012). In addition, this environment is the focal point for a wide range of human activities including industrial activities, ecotourism, offshore and coastal mining, transport (including port-related activities), and near-shore and deep-sea fishing (GLAZEWSKI; HAWARD, 2005); activities that make significant contributions to the country's economy (BARSTOW, 1986; HUTCHINGS *et al.*, 2009).

To ensure the sustainable use of fisheries and other marine living resources, the first all-inclusive statute that was promulgated was the Sea Fishery Act (Act No. 10 of 1940). This statute aimed to ensure the orderly exploitation and use of fisheries. However, the statute was enforced during an era of exclusion and inequality. The transition into democracy saw the enacting of the Marine Living Resources Act (MLRA), (Act No. 18 of 1998) in 1998 (Gazzete No. 18930, 1998). The formulation of the MLRA was guided by the rights-based Constitution (Act No. 108 of 1996) and aimed to ensure marine fishery reform; addressing inequalities that existed in the apartheid era (BRITZ, 2015). The Act is very comprehensive and covers all aspects relating to fisheries including resource management and rights of use (DEAT, 2004). Where the governance of fisheries is concerned, the act is good, reflecting the key principles in the FAO Code of Conduct for fisheries (WITBOOI, 2006).

Since the promulgation of the Marine Living Resources Act, the South African government has taken the necessary steps to ensure that the environmental legislation associated with fisheries is amended to stay abreast of environmental degradation trends and changes globally. This includes the signing of international agreements such as the United Nations Convention on the Law of the Sea. UNCLOS governs nearly all aspects of the law of the sea and forms the legal framework supporting the management of living marine resources for coastal nations (BELSKY, 1989; SHERMAN, 1991; SCHIFFMAN, 1998). UNCLOS highlights a coastal nation's responsibility to ensure that the necessary measures are in place to safeguard living resources in the EEZ, promote the use of living resources without prejudice and protect and preserve the marine environment (JUDA; BURROUGHS, 1990).

Although the legislation is good and the necessary steps have been taken to ensure that the statutes global environmental trends and changes, the country faces great policy implementation problems and there is an urgent need to find better ways to bridge the gap between policy and implementation (MOKATE, 2013).

High Seas Fisheries Governance

An important aspect of fisheries governance is the management of marine living resources in the areas beyond national jurisdiction (i.e., high seas), which covers over 40 percent of the ocean's surface (FAO, 2014). Until the establishment of UNCLOS, the high seas were characterized by the freedom to fish (RAYFUSE; WARNER, 2008), but nowadays Regional Fisheries Management Organizations (RFMOs) are essential to managing marine resources. UNCLOS stated that "states shall cooperate with each other in the conservation and management of living resources in the areas of the high seas [...] and shall enter into negotiations with a view to taking the measures necessary for the conservation of the living resources concerned" (UNITED NATIONS, 1982, Article 118). In 2001, the United Nations Fish Stocks Agreement (UNFSA) entered into force, which further enhanced the mandate of RFMOs. The UNFSA is a key agreement in fisheries governance and aims to conserve and manage straddling fish stocks and highly migratory fish stocks (UNITED NATIONS, 1995). Moreover, it lays important foundations for the application of conservation principles, such as the precautionary principle. In Article 8, it is emphasized the need for states to cooperate with each other directly or through subregional or regional fisheries management organizations (UNITED NATIONS, 1995).

Today, there are around 13 RFMOs, which have the ability to adopt legally binding measures on their members (FAO, 2013). The role of RFMOs is to provide a platform for states to pursue their fisheries interests aligned with goals from global agreements (HOEL, 2010). The mandate of RFMOs refers to different geographical areas and different target species. There are general RFMOs, which manage all species in their area, and tuna RFMOs which only manage tuna and tuna-like species (Figure 2). The oldest RFMO is the Inter-American Tropical Tuna Commission (IATTC), which was established in 1949, while the youngest RFMO, the North Pacific Fisheries Commission, was established in 2015.

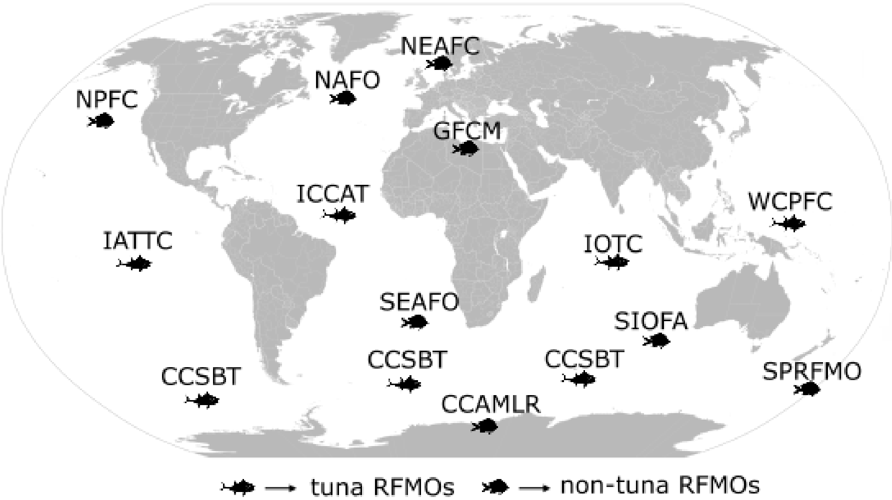

Figure 2: Overview of RFMOs. Geographical distribution of non-tuna RFMOs ( ) and tuna RFMOs ( ) (HAAS *et al.*, 2020).

Most of the RFMOs share a similar structure consisting of a Commission representing the interests of the member states and a Scientific Committee, which provides the Commission with scientific advice, and a secretariat. Willock & Lack (2006) describe three different set-ups of the Scientific Committee. Firstly, the "national scientist model", where the information for the organization's scientific advice body is provided by scientists of member countries. In some instances, a further body – a committee or a sub-committee – deals with stock assessments. In the case of the "scientific staff model" scientists are permanent employees of the RFMOs. The "independent scientist model" is characterized by independent scientists or organizations which provide scientific advice, such as the International Council for the Exploration of the Sea (ICES).

The commission makes decisions either based on a consensus, voting (simply majority or two-third majority), or a mixture of mandatory consensus and voting (WILLOCK; LACK, 2006). Most organizations make decisions by consensus and have an opt-out provision where parties can object to management measures and do not have to implement them. The opt-out mechanism is said to be one of the key issues related to RFMO decision-making, as often results in weak or ineffective conservation measures, due to the need to find a common denominator (WILLOCK; LACK, 2006). Newer organizations, such as the South Pacific Regional Fisheries Management Organization (SPRFMO), which was established in 2012, have addressed this problem in a way that parties have to explain in detail the reasons for their objections (SCHIFFMAN, 2013) and have to implement alternative measures that have the same effect as the decision that was the focus of the objection (SPRFMO, 2015). Thus, SPRFMO can be used as a role model for the establishment of the decision-making model in new RFMOs. Despite small institutional variations, other factors such as biophysical environmental conditions, species management, and member composition, make each RFMO unique.

RFMOs play an imperative role in managing fisheries, however, their management is highly influenced by their members (FAO, 2007; PONS, 2017; UNGA, 2006). Moreover, studies such as the one by Cullis-Suzuki and Pauly (2010) revealed that many of these organizations are not meeting their objectives. There are many different reasons why these RFMOs are lacking in fulfilling their mandate. One of these reasons is, for example, the formerly mentioned problem of the decision-making model (BARKIN; DESOMBRE, 2013; DE BRUYN *et al.*, 2013). It is also important to acknowledge the importance of member countries and RFMOs, which have different economic aspirations (PONS *et al.* 2017), which might influence the political will to address important issues such as the precautionary or ecosystem approach (BARKIN; DESOMBRE, 2013; MCDORMAN, 2005).

Generally, the importance of high seas fisheries to food security and economic revenues have been questioned (SCHILLER *et al.*, 2018) and some scientists call for high seas closures (SUMAILA *et al.* 2015; GREEN; RUDYK, 2020). Since this is not probably happening in the near future, RFMOs will continue to play an important role in high seas fisheries management. It is important that these organizations take their task seriously and improve their performance (HAAS *et al.*, 2019).

Free Trade and Fisheries Governance in Eastern Canada

The global nature of fisheries necessitates a clear understanding of the policies that both facilitate and manage an industry that is increasingly tied to the global market. Fisheries and the seafood industry that they support face challenges that are both social and ecological. From climate change to the continued issue of Illegal, Unregulated and Unreported Fishing (IUU), there is no lack of challenges in the management and governance of fisheries globally. The trade of fisheries and seafood products represents an economic dimension of global fisheries policy, especially since seafood products are consistently among the world's most traded food commodities (FAO, 2017). Although fisheries are global in nature, free trade, international agreements, and globalization have had a large effect on the industry. As fisheries are interwoven into the international context, the global governance of fisheries needs to be extended not only to international conservation targets but also embedded in trade agreements and partnerships (ASCHE; SMITH, 2010).

The global production of fish commodities was 174 million tons in 2017, of which capture fisheries represented over 50% of that production (FAO, 2017). Of the total production, 60.7 million tons were traded internationally, representing 35% of the total production of fish commodities. The global trade in fish commodities is growing annually, reflecting a continuation of free trade agreements coming into place. For example, the Comprehensive and Progressive Agreement for Trans-Pacific Partnership (CPTPP) signed in early 2018 includes some of the world's largest seafood producers including Japan, Peru, and Chile. As the world becomes increasingly interconnected with fisheries as a major global commodity, two things need further inspection. First, an understanding of the effects of free trade and globalization's broader impacts on fishing communities is needed to ensure that as growth continues communities are not being left behind. Second, an account of how free trade agreements can be utilized to enhance conservation goals will be useful to understand how global trade can be leveraged to ensure the conservation of the marine environment.

Although the seafood trade is fed by both capture fisheries and aquaculture, the former is the focus here. Increasingly the global nature of the seafood trade may be affecting local dynamics, creating similar conditions in different places globally (CRONA *et al.*, 2015). A major issue in the trade of fishery products is a lack of high-quality data that, if available, would enable policymakers and political economists to uncover finer nuances and see who are the winners and losers of such trade (CRONA *et al.*, 2016). Young *et al.* (2006) called for research priorities that included more effort in asking how globalization is affecting the behavior of social-ecological systems at different scales. Although not specifically concerning fisheries, this call is appropriate for fisheries and the communities they support.

Trade agreements aim to root out geographical distinctions, putting co-management, which embraces unique characteristics of fisheries, at odds with free trade agreements (SINCLAIR, 2013). Trade agreements facilitate the imports and exports of seafood products globally which can have repercussions for certain domestic fisheries. In the North American context, there has been work looking at how fishing communities face increased pressures due to cheaper imported seafood products (HARRISON, 2012) as well as how they cope with such pressures through local institutions such as cooperatives (CHILD, 2018). This need for further research on trade's effect on fishing communities will enable policymakers to find ways to mitigate certain negative aspects of corporate-led globalization of seafood products.

International trade agreements are increasing including language pertaining to conservation, becoming in a sense, vectors of conservation policy. An example is in the Trans-Pacific Partnership (TPP), the first iteration of the CPTPP previously mentioned. The TPP contained language prohibiting fisheries subsidies, a factor that is seen as contributing to overfishing (NAKAGAWA, 2016). Recent studies have examined how to use the mechanisms within trade agreements to reach certain goals such as sustainable development (KUMAR *et al.*, 2018) and fishery subsidy reduction (BAYRAMOGLU *et al.*, 2018). The use of subsidies controls, or by including both conservation-based language and socially conscious language offered by the UN Sustainable Development Goals (SDG) (*i.e.*, 14b) in the text of free trade agreements can be the first step in using international trade agreements as vectors for both conservation and social policy in regards to fisheries. Studying fisheries from these two entry-points (i.e., community impacts and policy mechanisms) allows for multi-scale analysis to further the understanding of seafood and international trade.

Trade agreements can lead to changes in domestic policy, which can offer an opportunity for examining how trade policy is influencing fishing communities. The Canadian province of Newfoundland and Labrador (NL), with its historical dependence on the fishery (SCHRANK, 2005) and increasing connection to the global marketplace (FOLEY, 2012), offers a unique perspective on the seafood trade. The fishery of NL is linked to the global trading market, with much of its seafood product exported to the United States, China, European Union (EU), among others (FAO, 2017). Canada and the European Union (EU) have recently signed the Canada-EU Comprehensive Economic & Trade Agreement (CETA), which has implications for the seafood trade policy between Canada (and its provinces) and the EU (and its member states). NL is uniquely affected by CETA as it is the only province to have minimum processing requirements (MPR) for seafood products landed in the province, a domestic policy that is to be phased out due to CETA. This MPR is a provincial policy that attempts to keep the gains from the inshore fishery in the province by ensuring fish caught by NL licensed harvesters are processed in the communities of the province. Three years after entry into force of CETA the MPR will no longer be in force for seafood products destined for the EU market.

The phase-out of the MPR has become a contentious topic in the past decade since the agreement was negotiated. NL's seafood processing plants have come under increased strain due to declining fish quotas and an aging workforce. A joint fund by the provincial and federal governments was instituted to invest in the fishery and seafood processing sector as a form of compensation for the loss of the MPR, but the issue is still of concern.

This domestic policy change, for one fishery in the North Atlantic may be small in the larger scheme of seafood trade policy globally, but it shows that policies in free trade agreements, negotiated at the highest levels of government can have an impact on fishing communities by paving over regional interests to achieve national goals (SCHOLTENS *et al.*, 2019; DALY; CHUENPAGDEE, 2021).

Final remarks

This chapter provided an overview of the different aspects of fisheries governance. One of the main instruments in fisheries governance is UNCLOS, which provides the baseline for further agreements and organizations, such as the UNFSA. UNCLOs also divide the ocean into different areas giving countries jurisdiction over their coastal waters and EEZs. In the high seas or areas beyond national jurisdiction, no state has jurisdiction. UNCLOS and UNFSA strive for the cooperation of states, in this area, to ensure sustainable management. In this context, RFMOs were designed and implemented, being responsible for managing different species of marine living resources in different areas. In addition to jurisdictional and management responsibilities, trade is an important aspect of fisheries governance. Global trade in seafood products is of increasing importance, with trade making significant impacts on global seafood markets and having a direct impact on the fisheries value chain (ANDERSON *et al.*, 2018; CHUENPAGDEE, 2018). This rapid change, prompted by increased trade, has implications for fisheries governance, particularly when looking at how to ensure equitable trade benefits for fishers.

The global nature of fisheries means globally recognized instruments such as the Sustainable Development Goals (SDGs) that focus on social, economic and ecological development, can be used as a standard for sustainability and equity. SDG 14 (Life below water) aims to 'conserve and sustainably use the oceans, seas and marine resources. The SDGs are not mutually exclusive, thus achieving SDG 14 would mean getting that much closer to achieving other goals, such as SDG 1 (no poverty) and SDG 2 (zero hunger) (SINGH *et al.*, 2017). SDG 14 also acknowledges the importance of trade and access to markets for small-scale fisheries, a focus that could also aid in achieving SDG 10 (reducing inequalities).

Fisheries governance is multi-faceted, increasingly complex, and global in nature. Seafood is among the most traded food commodities and millions of people depend on marine resources for livelihood and food security. Thus, in order to ensure sustainably managed fisheries and equitable access to fish for food and livelihood, a multi-scalar and principle-based approach is necessary. This nested approach to viewing fisheries governance, with international organizations setting out principles and goals (*i.e.*, SDGs) and regional and local governors instituting context-specific ways to achieve, although not perfect, is an equitable and viable way to address issues in fisheries governance both now and in the future.

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CHAPTER 7

Marine Sustainability against contaminants and pollutants

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Abstract

Present oceans are jam-packed with contaminants and pollutants released by irresponsible human activities. Marine pollutants are of two folds; chemicals and litter. Chemical pollutants are responsible for marine eutrophication induced by excess nutrients, whereas the majority of marine litter comprises plastic products. They are not only threats to oceanic life forms and sensitive marine ecosystems but also effective indicators of the impact of the Anthropocene on the earth. Addressing all impacts and pressures on the oceans requires joint action and multi-focused

strategies that include the participation of multidisciplinary stakeholders such as industries and organizations in synergy with civil society and education sectors. We are at a point where actions need to come from the top down and the bottom up, and the health of the oceans must be the one to guide major decisions involving multiple economic and industrial sectors.

Introduction

The world's coastal waters and oceans are deteriorating due to increasing coastal development, shipping and navigation traffic, land-based discharges, habitat destruction and other threats which directly deal with bringing pollutants and contaminants to the oceans. Over 80% of all marine pollution originates from the land through either industrial, agricultural or urban activities (CICIN-SAIN, *et al.*, 2011). These pollutants can be separated into two major categories: chemicals, and trash (NATIONAL GEOGRAPHIC SOCIETY, 2019). Chemical pollution or more specifically, 'nutrient pollution' is a result of intense use of fertilizers on agricultural lands and accidental or deliberate chemicals or oil spillage which eventually gets washed off to the waterways and then to the ocean. Excessive amounts of nutrients such as nitrate and phosphate can bring toxic algal bloom events to coastal waters which severely affect the existence of marine life as well as the health and economy of human beings. Oil spills would not only be lethal to marine animals but also will smother highly sensitive marine ecosystems such as mangroves and coral reefs. Marine trash or widely known as 'marine litter', comprises all manufactured industrial products that ultimately find their way into oceans, among which plastic has raised some serious concerns. Solid waste varies in range from polyethylene bags to cigarette butts and all the way to fishing gear. Irresponsible littering and poor waste management techniques are the key reasons why oceans have become the destination of this land-based trash. Long-lasting survival of this waste in the environment can leave its footprints on marine habitats that would exist on time scales of millennia. Thus, both chemicals and trash which can collectively be called 'pollutants/contaminants' are not only an upcoming threat to the sustainability of oceans but also an important tracer that investigates the impact of Anthropocene on the good health of the Earth.

Chemical contaminants of emerging concern, including endocrine-disrupting compounds, artificial sweeteners, detergents, pharmaceuticals, enormous amounts of antibiotics, illicit drugs, personal care products, other chemical compounds that facilitate everyday life and their byproducts, oil and chemical spills and other compounds that are not regulated or routinely monitored can be present in wastewater and urban runoff (LI; GUILGUI *et al.*, 2015). These contaminants, if not treated, reach the ocean and marine environments and drinking water sources. The various effects of these kinds of compounds could affect wildlife and the human population (ZHANG *et al.*, 2016). In addition, the Organic Persistent Pollutants (OPP), characterized by high toxicity, volatilization and transport capacity over long distances, as well as persistence in various environmental compartments, can bioaccumulate and biomagnify across trophic levels, leading to hormone disruption, malfunctioning of the endocrine system and reproductive problems in the wildlife (TAO *et al.*, 2018).

Marine litter has become a growing international problem where most of the marine litter worldwide comes from land-based sources (GESAMP, 1991) with the remaining coming from ocean-based sources such as derelict fishing gear, boats and ships, offshore rigs and platforms (GALGANI *et al.*, 2013). The biggest fraction of marine litter comes from plastics with an approximation of 60-80% (DERRAIK, 2002). Plastic can still fragment into smaller pieces, reaching several compartments besides the water column as beach sediments, deep ocean floor, and ice, even in remote regions such as the Arctic and Antarctic (BARNES *et al.*; 2009; ENGLER, 2012; ERIKSSON *et al.*, 2013; LEE *et al.*, 2013; SMITH, 2012; DRIS *et al.*, 2016, 2017). These microplastics are easily transported, distributed, and ingested by a variety of marine biota. Future projections estimate that the ocean will contain one ton of plastic for every three tons of fish by 2025 (DONOSO; MERKEL, 2015). In addition, a minor fraction of marine litter comprises lost or dumped ammunition, garbage from ships and boats which mostly comprise of plastic and polyethylene containers, dumping of nuclear and industrial waste, lost cargo, polluted stormwater, stormwater drains and rivers flowing into the sea as well as other domestic litter and domestic sewage including glass bottles and cans (TAO *et al.*, 2018).

China ranks number one on the scale, responsible for marine pollution with a release of 8.82 metric tons of plastic and polyethylene garbage annually into the oceans. It is estimated that annually, more than 135,000 tons of plastic and polyethylene garbage have been dumped regularly by fishing, naval and commercial vessels, worldwide. It is also estimated that almost all fishing crafts across the world engaged in the fishing industry lose or discard about 149,000 tons of fishing gear comprising nets, ropes, traps and buoys made out of plastic and polyethylene to the oceans (KAVIRATHNE, 2017). This garbage dumped into the oceans turns into floating marine garbage vortexes where subtropical gyres will further pull in marine litter in their center. Once this litter debris floats into the ocean gyres, they keep being twisted and turned by ocean currents and get accumulated in the gyres for years, forming garbage patches (MARKERT, 2017). In this chapter, we will discuss concepts related to marine and environmental pollution, control and mitigation, solutions through an interdisciplinary approach and the social and moral responsibility of the global community toward cleaner oceans.

Threats of marine contaminants

The effects of contaminants on the marine environment depend on the type of pollution, the size of the pollution, and where the pollution occurs (GESAMP, 2020). Some marine environments and types of marine life forms are more sensitive to pollution than others. For example, impacts from land-based sources such as coastal development, deforestation, agricultural runoffs, etc. can impede coral growth and reproduction, disrupt the overall ecological function of a reef, and cause disease and mortality to sensitive species. It is now well accepted that many serious coral reef ecosystem stressors originate from land-based sources, most notably toxicants, sediments, and nutrients (KATSANEVAKIS *et al.*, 2007; CRAIG *et al.*, 2005). However, a sandy coast where marine life is largely limited to infaunal communities with less abundance of diverse habitats will be affected differently to the same contaminant exposure. Thus, depending on the marine habitat, pollution can damage either individual sea creatures or plants, or whole communities of different living things.

A major issue related to the chemical contamination of coastal waters is eutrophication. The most common form of eutrophication happens when surplus amounts of nutrient fertilizers from agricultural farms are washed off into the coastal waters to increase primary production (RICHARDSON; JØRGENSEN, 1996). Although this may sound 'falsely' promising in terms of high levels of O_2 production and more food for higher trophic levels, it leaves a negative feedback in the long run where uncontrolled growth of phytoplankton blooms over the surface can result in limited light penetration to the subsurface waters, reduction of subsurface ventilation due to disrupted O_2 gas exchange across air-sea interface, elevated respiration followed by rapid consumption of O_2 and eventual anoxic conditions and mass mortality in the ocean. Furthermore, harmful algal blooms which are a common consequence of eutrophication can produce toxins (phycotoxins) (HEISLER, *et al.*, 2008) which will not only lethally affect the higher trophic levels, but also human beings through the consumption of affected fish and shellfish. Although eutrophication used to carry a bigger impact on the developed world, recent industrial and agricultural advancement in Asia, Africa and Latin America has started leaving a significant impact on marine waters via nutrient pollution (NIXON, 2012).

The biggest threat marine litter imposes on the oceanic environment comes from plastic waste. A recent study on the decomposition of plastic has revealed that tons of plastic waste floating in the oceans decompose faster at lower temperatures than previously revealed (LE GUERN, 2019). It is estimated that 322 million tons of plastic are used annually by human beings mostly due to its versatility, lightweight, flexibility and moisture resistance (PLASTICS EUROPE, 2016). Human beings across the world consume fish that had eaten other fish, which had already eaten toxic saturated plastic that had entered into the marine food chain. Thus, the final victims are also human beings who should be held responsible for polluting the marine environment. Moreover, microscopic plastic and polyethylene pellets rich in toxic material that are released and altered in contact with ultraviolet light (BARRETT, 2021) are also released where the ultimate products will be additives added to the polymers during the manufacturing steps of plastic, such as antioxidants, antimicrobials, antistatics, stabilizers, lubricants, thermal stabilizers, anti-UV's and pigments. Compounds with bisphenol a, released due to photo-degradation of plastics have potential toxicity and may bioaccumulate in aquatic organisms such as mollusks, crustaceans, amphibians and even fish which will damage all kinds of marine life (CANESI; FABBRI, 2015).

When plastics undergo hydrolytic degradation, thermo-oxidative degradation, photodegradation, biodegradation and mechanical degradation (IÑIGUEZ *et al.*, 2018) many chemical changes may occur, as discussed in previous parts. All of these fragments can be swallowed by the zooplankton that forms the basis of the marine food chain and thus affects the whole food chain. All marine creatures from the largest to the microscopic organisms swallow the seawater soup composed of toxic chemicals produced by plastic degradation. According to the US Department of National Oceanic and Atmospheric Administration, floating plastic debris in oceans kills 100,000 marine mammals such as whales, sea lions and millions of sea birds annually (FLYNN, 2021). Scientific research findings have revealed numerous shapes of plastic and polyethylene fishing gear, abandoned or lost in the oceans, have crippled nearly 30,000 fur seals a year (KAVIRATHNE, 2017). In the next sections, the chapter discusses the solutions and suggestions on how to mitigate these threats and how to move forward to ensure sustainability in future oceans.

Solutions

A single solution does not exist to address the challenge of marine pollution. The solutions to plastics leakage, eutrophication and chemical contaminations are multiple and geographically different, depending on the contexts of each country, which may differ in different sources of contamination, activities in the coastal area, waste composition and collection rates, local policies, infrastructure, population demographics and consumer behavior (HENRIKSSON; ÅKESSON; EWERT, 2010).

What it does resemble is that government policies and leadership by consumer goods companies will be critical to drive actions on reduction, reuse and redesign materials, as also improve collection and recycling, prevent excessive natural resource utilization, keeping the rate of self-renewal of resources to be above the rate of pollutants. Entering into a circular approach to economic growth is essential, which is in line with sustainable environmental and economic development (WHITIN, 2015).

The high rates of human population growth, the intensification of agriculture, urbanization of coastal areas cause higher levels of pollution in our ocean. In many countries, municipal solid waste management is a major problem, and the growth of the urban population and industrialization raises the amount of municipal solid waste (ZHANG *et al.*, 2010). We face the expectation that the flow of plastic into the oceans will triple in the next 20 years, reaching the 29 million metric tons per year mark, and without response, the amount of plastic in the ocean will grow to 450 million metric tons, with severe impacts on ocean and human health (REDDY; LAU, 2020). Thinking through the lens of the circular economy principle, new business opportunities may emerge from the circulation of materials rather than extraction. For instance, 95 percent of the added value of plastic packaging is lost to the economy after a first-use cycle, this represents more than -$80 billion per year. And only 14% of plastic packaging is collected for recycling, representing a significant opportunity to increase circularity (EMAF, 2012).

5R concept for sustainable waste management and pollutants

5R concept deals with five fundamental strategies to sustainably manage waste. It discusses 5 practices; refuse, reduce, recycle, reuse and rot and can be included in the circular economy, based on the extraction of maximum value before material return to the biosphere, while reducing dependence on primary materials (WHITIN, 2015) (Figure 1). 'Refuse' focuses on the basic and the first step of sustainable waste management which is rejecting the purchase of products that are not necessarily needed for consumption. Refusing to buy single-use plastic and products with persistence and bioaccumulation potential, while encouraging the use of ecofriendly options as well as growing consumables at home fall. 'Reduce' suggests cutting back on the quantity and the kind of products to buy. Consuming less invariably leads to less waste produced (GARCIA, 2006). This could be extended to reduce the consumption of products with excessive packing, plastic packing or non-recyclable packing, or with many environmentally harmful chemicals. And it could be achieved with policy measures such as restrictions and taxes. 'Reuse' discusses repurposing the products instead of throwing them out. Utilizing products multiple times and for different purposes can lessen the reliance on single-use products. 'Rot' includes the act of composting, where all types of food, plant trimmings, leaves, flowers, weeds and even solid paper products are composted rather than brought into the garbage system. 'Recycle' focuses on creating a new product out of a material that already served its purpose. 'Rethink,' building off of 'Refuse' could be an additional step (WEF, 2016). Rethinking the need to purchase single-use products or reconsidering daily actions and routines could lead to reinventing habits and behaviors. Rethinking what is beyond labeling, what kind of chemicals are in our everyday products, and the processes behind their production, the social responsibility of the industries we chose to finance, and their influence on society (ZERO WASTE EUROPE, 2019; KONDOH *et al.*, 2017).

Other levels of circularity could be taken into account as repair, refurbish, remanufacture and re-purpose, leading to an extension of the life cycle of goods (CRAMER, 2014; LIEDER; RASHID, 2016). And also, within industrial processes, in industrial symbiosis and eco-industrial parks framework, where an interconnected resource reuse and sharing scheme for water, solid waste and steam are created, through environmental and economic gains (CHERTOW, 2012).

Circularity can also be applied to C, N and P economies, together with efficient farming and food management practices (SCHNEIDER, 2019), focusing on managing the eutrophication of water bodies and sea. The main sources of P and N, for example, come from agricultural activities and from wastewater treatment plants, that could be processed into biofertilizers and chemical fertilizers, biogas, returning C, N and P as resources to the market. Reuse, historically, has not been an objective in wastewater treatment, differently in agriculture, but in both sectors, the technologies can be used for the production of energy products, with a capture and reuse framework, in a circular nutrient system (ROSEMARIN *et al.*, 2020).

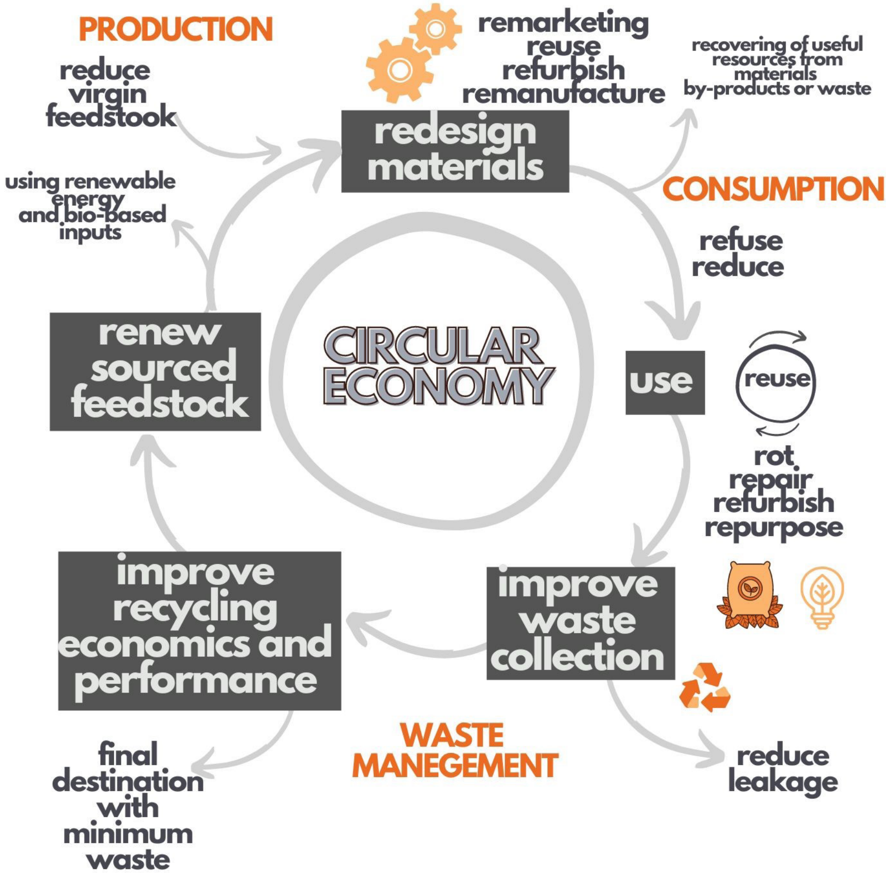

Figure 1. Cycle of materials through the economic system.

Individual responsibility

In addition to the approaches taken by various government and corporate actors to mitigate marine contamination and pollution, there is room for civil society to play a role. In a morally and socially responsible community, each and every individual also has a role to play in ocean sustainability and pollution control. Resolving environmental constraints requires a united effort by all interest groups in a society. Community members at the grassroots level should be made aware of the damage caused to the sensitive marine ecosystems and their biodiversity through the dumping of garbage into the water, use of chemicals that are not safe, etc. Apart from organizing and launching campaigns such as beach clean-ups, raising awareness programs, and educational workshops, among many other issues, it is the duty of every global citizen to maintain healthy waste disposal practices and inculcate sensitivity to the surrounding environment. As described in previous sections, the majority of marine pollution comes from the land, and considering that there are scientific-knowledge gaps in the distribution of marine pollution, marine litter modeling, environmental impacts and human risks, there are many changes and advancements that can be addressed to engage local community and decisions makers in a collaborative way to transform policy and science (FOSSI *et al.*, 2019).

Despite all issues and concerns the plastic industry, maritime shipping industry, and submarine hydrocarbon/mineral exploration and extraction industry continue to grow and the community strength should be used to collect data, promulgate behavioral changes and draw attention to politicize the resources debate with actors in government, civil society and private sector. Social engagement facilitates multiple stakeholders to simultaneously work together and this collaborative process empowers citizens to see themselves no longer as individuals but as those that cause and that solve the impacts on the earth (LEFEBVRE, 2013). Our attention cannot be only on a few individual objects like straws and pellets and policy initiatives can not only focus on technological solutions and individual behavior while producers increase the total supply of new materials entering the system and market forces drive exploration of resources in ever more extreme environments, maintaining societies of disposability and overconsumption. Our attention should be holistic and around producers, industry and decision-makers, and questioning what political aspects underpin the entire life cycle of global plastic, oil and food chains - from production, through consumption, to waste and pollution. Our attention should encourage systemic changes rather than individualized action since individualized responsibility has the potential to feed into greenwashing, attempting to sell products and commodity consumption as environmental or "green" while denying its real impact (GEARY, 2019).

Individual changes alone will not be enough. As highlighted by Nielsen (2020) and Stafford and Jones (2019) the focus on making our way of life sustainable is to go to the root of the problems, to question all the behavioral aspects, and all the norms and practices that maintain the role of consumer goods in society and the political and economic agreements that guarantee their abundance and low price. We have to transform our lifestyles and change the status quo. Greening our lifestyles but keeping them excessively consumerist will not be enough.

Policies toward sustainability

In some cases, it is possible to understand the path of marine debris or a pollutant and attribute what we find in the environment to consumerism and the use of substances. Consumer goods like tobacco products, cans and bottles are easily related to community, waste management, dumping, littering, tourism and other activities. But the path that drives a good into the hands of the consumer involves several other processes that need to be taken into account, like manufacturing, transportation and waste collection. And reducing pollution includes analyzing all economic forces beyond individual responsibility because consumption is deeply related to cultures and institutions and it is supported by corporate and government practices (O'ROURKE; LOLLO, 2015).

Political instruments could move the responsibility to the producer, taking the consumer out of the focus of sustainability, like EPR (Extended Producer Responsibility) (OECD, 2001). These policy approaches can be encouraged by governments to reformulate the stages of the packaging supply chain, converting the linear economy into a circular process. The circular economy requirements include that the manufacturer must accept the packaging as a post-consumer situation, and make the proper destination and recycling. This could protect the environment from inappropriate disposal and encourages producers to use packaging that can be easily recycled, minimizing their impact and re-using materials. In this circular reality, the industry shares the responsibility of waste management with municipalities. (OECD, 2001).

Policy to encourage manufacturers toward sustainable practice could include taxation, end-of-life collection and incentive for using secondary raw materials. Taxation could motivate technological change and internalize elements of resource value, such as end-of-life impacts (VELENTURF *et al.*, 2018). Container deposit legislation (CDL), for example, has shown to increase the return rates of containers and also contributes to the reduction of the number of beverage containers that leak to the coastal area from the waste stream (SCHUYLER *et al.*, 2018). For N and P capture and use, there are economic and administrative tools that can be used, for instance: quotas, fixed tariffs, and volume-based subsidies that can provide a more sustainable solution (ROSEMARIN *et al.*, 2020).

Policymakers also have the power to encourage the consumer through individual 5R behaviors and can also facilitate attitudes that enable sustainable lifestyles that go beyond the logic of buying and recycling products or refuse. Policymakers can promote spaces that value the purchase of products without packaging, or with returnable packaging, that strengthen the local economy and local producers, who use products allied with the circular economy. It also supports innovative solutions for waste collection, economic incentives for industries that employ cleaner production, etc. (PRIETO-SANDOVAL *et al.*, 2018).

‘Blue Growth’ and ‘Blue Energy’

The concept of Blue Growth under the UN framework was defined as a “green economy in a blue world” at the United Nations Conference, held in Rio de Janeiro, Brazil, in 2012 (UNCTAD, 2014). A blue growth is the long-term strategy to support sustainable growth in the marine and maritime sectors as a whole, as the oceans suffer various pressures from the contaminations of land-based and marine-based activities (HOEGH-GULDBERG *et al.*, 2019, SPALDING, 2016).

The Blue Growth encompasses Green Economy’s main objectives and includes achieving Sustainable Development, which encompasses an environmental, economic and social dimension of society. To achieve the process of sustainability the 2030 Agenda for Sustainable Development was adopted by the member states of the United Nations and included 169 targets, and for the first time, a specific goal (SDG 14) was dedicated to the conservation and sustainable use of the oceans (UNITED NATIONS, 2002). SDG 14 includes a goal to prevent and significantly reduce marine pollution of all kinds, and it is oriented to economically manage the various situations that promote contamination in the environment, such as oil and domestic wastes from ports, organic wastes and drugs from animal farms, domestic wastes, pesticides and organic matter from coastal fish farms, heavy metals and chemicals from industrial sites, solids from sand mining, pesticides and nutrients from agriculture (UNITED NATIONS, 2002).

The Blue Growth strategy separates socio-economic development from environmental degradation, by incorporating the real value of natural capital in aspects of economic activity (COLGAN, 2016), and consists of:

(1) develop sectors that have a high potential for sustainable jobs and growth and circular material flows, such as aquaculture, coastal tourism, marine biotechnology, ocean energy, seabed mining and renewables, considering all the pollutants that these activities discharge into the environment and its circularity (UNEP, 2012; EUROPEAN COMMISSION, 2012; WWF, 2015).

(2) Provide knowledge, legal certainty and security in the blue economy to essential components such as marine knowledge to improve access to information about the sea, maritime spatial planning to ensure efficient and sustainable management of activities at sea, regional alliances and integrated maritime surveillance to give authorities a better picture of what is happening at sea, since it is essential to establish an integrated global observation system for the protection of coastal areas (UNEP, 2012; ALVERSON, 2008).

(3) Sea basin strategies to ensure tailor-made measures and to foster cooperation between countries, integrating economic players and public authorities, including specific policies and regulations for each economic sector (UNEP, 2012; VOYER *et al.*, 2018).

Blue economic transformation is critical for economic continuity, and only with this transformation, the benefits of the seas and oceans can be sustainable for humanity (AĞIRKAYA, 2021). In promoting blue economy approaches, management of solid and liquid wastes, transboundary waste management, and plastic and microplastic management is essential for reducing pollution of the coastal and marine environment and have huge social, environmental and economic benefits (MULAZZANI *et al.*, 2016).

Since marine sectors offer many scenarios to promote the integration of natural resources and economic growth it is necessary to lead marine activities to a competitive and sustainable economy, coordinating different sectors such as fisheries, transport, and fossil fuel extraction to ensure job growth is compatible with environmental conservation (WINTHER *et al.*, 2020). Promoting sustainability, consumer protection and important access to marine space and natural resources should be goals that underpin this movement.

For blue growth strategies for sustainability toward a toxic-free environment must be designed and include banning harmful chemicals in consumer products, production and use of chemicals that are safe and sustainable by design, creating maximum concentration limits for individual substances or groups of substances, such as metals (arsenic, cadmium, chromium), as well as organic compounds: formaldehyde, benzene, phthalates, chlorinated aromatic hydrocarbons (CAMBONI *et al.*, 2016), regulate and monitor resin pellets spills, make regulations for excessive packaging material and for targeting intentionally added microplastics in products, etc.

The Blue Economy also enhances and supports the development of solutions and innovative ways to address issues that are not necessarily generated at the affected site, such as marine pollution. Working groups with multidisciplinary stakeholders, like industries and organizations in synergy with civil society and sectors of education, generate partnerships that increase transparency in business and improve the participation of local actors in decision-making processes and governance. The sustainable management of ocean resources requires collaboration between nation-states and across public-private sectors (UNEP; UNECE, 2016).

Oceans support life by producing oxygen, recycling nutrients and regulating the climate and temperature, and for sustainable development, it is mandatory to think through the lens of an "Ocean Economy", and to take measures to manage marine resources, and reduce marine pollution and ocean acidification. Protecting our oceans is a necessity for the economy, climate, and lifestyles (SPALDING, 2016).

The blue economy could be the point of integration of socio-economic development and spatial planning on land and sea in a sustainable manner (NOVAGLIO *et al.*, 2021). Planned human settlement on the land and in coastal and marine regions is crucial to maintain the social, economic and ecological development of the environments, considering minimizing all impacts of nutrients, heavy metals, waste and other forms of pollutants in these areas. Switch to a blue economy unlocks the potential of a marine-based economy and reduces ocean degradation (KATHIJOTES, 2013).

Final remarks

Oceans currently face a lot of pressure on activities developed on land and in the marine environment, to contain the impact of the Anthropocene we need to move towards a more sustainable development that includes:

i) Mapping coastal ecosystems, their services and sources of contamination;

ii) Improve waste management;

iii) Limit landfilling and stimulate innovation in recycling;

iv) Create circular economic policies and pollution reduction strategies, where the potential for circularity is high (electronics, batteries, packaging, plastics, construction, food, water and nutrients);

v) Make circularity work on a global scale;

vi) Empower consumers, engage civil society and promote citizen science for awareness and empowerment.

The world must focus on nurturing its collective capacity to tackle these challenges and mitigate their impact and develop immediate and forward-looking actions that protect the marine environment, its demands for bottom-up initiatives and a long-term resource management perspective.

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CHAPTER 8

The relevance of data management for marine research

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Abstract

It has been observed that data shortage and improper data management have been among the most crucial issues affecting the impact of marine research in various parts of the world, especially in developing countries. This chapter considers enlightening, discusses and exemplifies the relevance of data management, metadata, and data lifecycle, including provenance. We present the global fishery

panorama with a contextualization of the data shortage on this topic, mainly in developing countries. Besides, innovative and sustainable data resource management for marine research will be presented. We also highlight gaps and future urgent necessities and possible suggestions in data management. Contributing to ongoing initiatives to share biodiversity data, such as the Ocean Biogeographic Information System (OBIS), is critical to understanding the status of local, regional and global biodiversity. A case study of a data management application will be presented to highlight the potential of data science and machine learning in improving marine research and conservation. The use of advanced technological input, such as machine learning and artificial intelligence, could reinforce data management.

Data shortage and improper data management

Data shortage is one of the leading causes of unsustainable use of any natural resource, but the problem is accentuated when it comes to seas (AGNEW *et al.*, 2009). In the ocean, our ability to foresee the affections caused by our actions is as limited as our capability of breathing underwater. We depend on the ocean for different reasons such as biological productivity, coastal protection, climate regulation, oxygen source, economic benefits, recreation, and food source. However, the overexploitation of the ocean has increased over the last 30 years. The fisheries industry has reached an annual average of 90 million tons of marine catch over the last three decades (FAO, 2018).

Global catches had sustained volumes between 70 and 80 million tons since the late 1980s (FAO, 2016). This "equilibrium" in global catches seems to be a consequence of overexploitation of traditional target species, as well as the limited capacity of developing countries to manage fisheries. Nevertheless, data shortage can be a primary reason for both overexploitation and the illusion of unlimited capacity of the seas. To ensure sustainable management of fisheries, sufficient monitoring is required, along with political and financial commitment, infrastructure, and scientific training (VENAHEN *et al.*, 2020). All these factors are not achieved in developing countries with high marine biodiversity, high population density, and low management capacity (HORDYK *et al.*, 2016). Developing economies contribute 72% of global marine catches (FAO, 2016)[1], which means that most of the marine capture production of seafood comes from countries that frequently do not have enough capacity to produce reliable stock assessments. The problem becomes worse when it comes to incidental catches and discards that are commonly unreported and have been estimated at 9.1 million tons yearly (PÉREZ RODA *et al.*, 2019).

1 According to World Bank data: <https://data.worldbank.org/income-level/high--income>.

However, the traditional target species t remained almost the same over the last 50 years (FAO, 2018). Shifts in target species are commonly related to stock depletion (*e.g.,* Canadian Cod) or environmental changes, such as climate change and annual or decadal variability (CHAVEZ *et al.*, 2003; RUBIO *et al.*, 2021), and not to discoveries or diversification. This situation is related to deficient stock management which is related to limited economic capacity and lack of interest (or priority) from developing countries.

Both deficient stock management and limited capacity are closely related to data shortage due to information to make better decisions being scarcely available. However, the scientific community has been developing platforms to gather and share data and information about natural resources (*e.g.*, DataMares[2], Sea Around Us[3], Fish Forever[4], *etc.*). This information can be used as a baseline for management decisions in developing economies. It is important to realize that even though these platforms are a very useful advancement in facing the data shortage-related problems, it is essential to consider that this data (metadata more often) has specific scopes and inherent limitations.

2 DataMares. Available at: <http://datamares.ucsd.edu/>. Accessed 21 May 2021.

3 Sea Around Us. Available at: <http://www.seaaroundus.org/data/#/eez>. Accessed 21 May 2021.

4 30 Fish Forever. Available at: <https://portal.rare.org/en/>. Accessed 23 Jun. 2021.

Biodiversity metadata: availability, challenges and scopes

There are almost 2 million species known on the planet, and the number is increasing thanks to scientific efforts (COSTELLO; MAY; STORK, 2013). However, human activities and climate change are threatening biodiversity and leading many species to extinction, including those that remain undiscovered by science (COSTELLO *et al.*, 2013). The ocean's ecosystems provide humanity with a large number of resources such as food, livelihoods, oxygen and a stable climate (DUFFY *et al.*, 2013). So, measuring biodiversity and sharing this knowledge is critical to understanding what and how it can be protected. Nonetheless, the measurement and quantification of global biodiversity is a challenge. It implies coordinated logistics, proper infrastructure and funding.

Some efforts to increase our knowledge of marine biodiversity are the census of marine life (COSTELLO *et al.*, 2010) and the Marine Biodiversity Observation Network (MBON) (DUFFY *et al.*, 2013). The Census of Marine Life was the most significant global research program on marine biodiversity during 2000-2010, involved more than 2,700 scientists from more than 80 countries, discovered at least 1,200 species new to science and cost US$650 million (COSTELLO *et al.*, 2010). Moreover, the MBON looks for collaborations with institutions and scientists to create a network for biodiversity. One of its goals is to increase the knowledge about biodiversity at different spatial scales based on molecular tools (eDNA), *in situ* data (monitoring programs) and satellite remote sensing (SeaWiFS, MERIS, MODIS, and other satellites) (DUFFY *et al.*, 2013; MULLER-KARGER *et al.*, 2014).

The availability of open-access data is a significant contribution to the knowledge of biodiversity (COSTELLO; HORTON; KROH, 2018). The Ocean Biogeographic Information System (OBIS) is an open-source platform where biodiversity records and information are deposited by scientists around the globe (https://obis.org). Those records come from inventories, museums, monitoring programs and observations, among others. OBIS holds more than 55 million records of approximately 123,000 marine species. However, the number of recorded species is not a very reliable estimation due to the scarcity of highly qualified personnel and taxonomical conflicts between traditional methods and molecular techniques (FLYNN *et al.*, 2015; THOMSON *et al.*, 2018). New molecular methods are also showing how they are efficient for taxonomy in many cases (DJURHUUS *et al.*, 2018). Additionally, there is uncertainty about how those records are changing over time and space. The online publication of existing and new marine biodiversity data is now possible through OBIS and the Global Biodiversity Information System (GBIF), which are assisted taxonomically by the World Register of Marine Species (WoRMS).

Collecting biodiversity data is not an easy task, and more complicated is to keep up a continuous and permanent effort at different locations. To avoid biased conclusions about changes in biodiversity is essential to understand the ecology and behavior of organisms (SANTINI *et al.*, 2017), which can migrate at different scales or have seasonal variations in abundance. Distribution changes or anomalies of biological populations can be detected through the continuous assessment of biodiversity and the application of adequate sampling protocols (COSTELLO *et al.*, 2017). The integration of biological and environmental data over time and space is useful to produce biodiversity indicators (NAVARRO *et al.*, 2017; SCHMELLER *et al.*, 2017). Thus, networking, coordination and support from local communities, institutions and governments play a crucial role to enhance our understanding of biodiversity in every region (CHANDLER *et al.*, 2017; NAVARRO *et al.*, 2017; SCHOLES *et al.*, 2017). Developing conservation strategies according to biodiversity indicators would be the next step, involving stakeholders, scientists, society and policymakers. All of them are important to contribute to increasing and sharing our knowledge about biodiversity at local, regional and global scales. However, several studies have documented gaps between scientific information and the decision-making process (e.g., PULLIN; KNIGHT, 2005, MATZEK *et al.*, 2013, KARAM-GEMAEL *et al.*, 2018). The following case study highlights the potential of proper biodiversity data management to enhance and support decision-making and conservation strategies.

Case study: scientific report's data management in Federal Marine Protected Areas in Brazil

In Brazil, although science provides enough evidence to support environmental policies, the lack of dialogue between scientists and legislators, as well as funding in 'science communication', could result in severe consequences for the country's biodiversity (KARAM-GEMAEL *et al.*, 2018). In addition, the current fragile situation of conservation policy in the country (ABESSA *et al.*, 2019) draws attention to the importance of directing scientific efforts in the development of strategies and technologies to avoid catastrophic scenarios, such as bioinvasions or the loss of biodiversity before cataloging it. However, providing smooth, accessible and summarized scientific evidence to managers may change almost half of their environmental management decisions (WALSH *et al.*, 2015). In this context, data science and management may provide a promising approach to creative ways to summarize data and scientific information to conservation managers and legislators.

Aiming to potentially reduce this gap, a local partnership between the Cabo Frio Upwelling Ecosystem ILTER site (International Long-Term Ecological Research) and the Arraial do Cabo Marine Extractive Reserve/ICMBio developed a method to synthesize the scientific reports of federally protected areas in Brazil. Menezes (2019) classified the information provided by scientists through the reports of the SISBio/ICMBio (Biodiversity Information and Authorization System) into different categories.

A simple application was developed using the python programming language to support the proposed methodology, shown in Figure 1. Informally called 'BioMining', the application works mainly as a database (for biological sampling data, processed/classified text data and metadata), implemented with data filters and visualization (graphs and maps). The application also has an introductory machine learning package to classify raw text data (new reports or other protected areas) based on training with previously classified data.

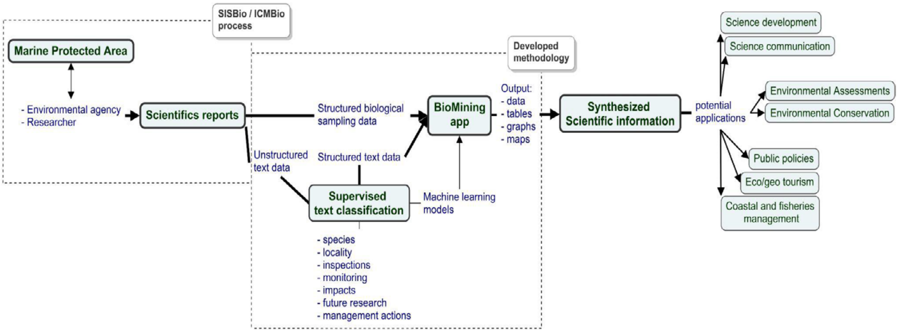

Figure 1 – Flowchart of the methodology for synthesizing scientific reports of protected areas in Brazil proposed by Menezes (2019).

The methodology was tested for two Brazilian federal marine protected areas, the Arraial do Cabo Marine Extractive Reserve (ResexMar-AC) and the Fernando de Noronha Marine National Park (ParnaMar-FN). The application allows managers to quickly search and view sampling records geospatially, as well as to filter the qualitative information on several issues regarding the scientific reports and their metadata (MENEZES, 2019). Reducing the time required for decision-makers to access scientific information when requested is critical to increasing science-based decisions. For example, heavy rain in 2018 dumped a considerable amount of urban drainage, including sewage, on some beaches of ResexMar-AC. After a few clicks using the BioMining application, four local scientific reports were thoroughly studied and some authors were contacted. This quick availability of quality information allowed managers to produce, on time, a report based on scientific evidence and notify the local water company. This example highlights the potential to improve conservation strategies when they are supported by data management approaches that effectively bridge the gap between scientific information and decision-makers.

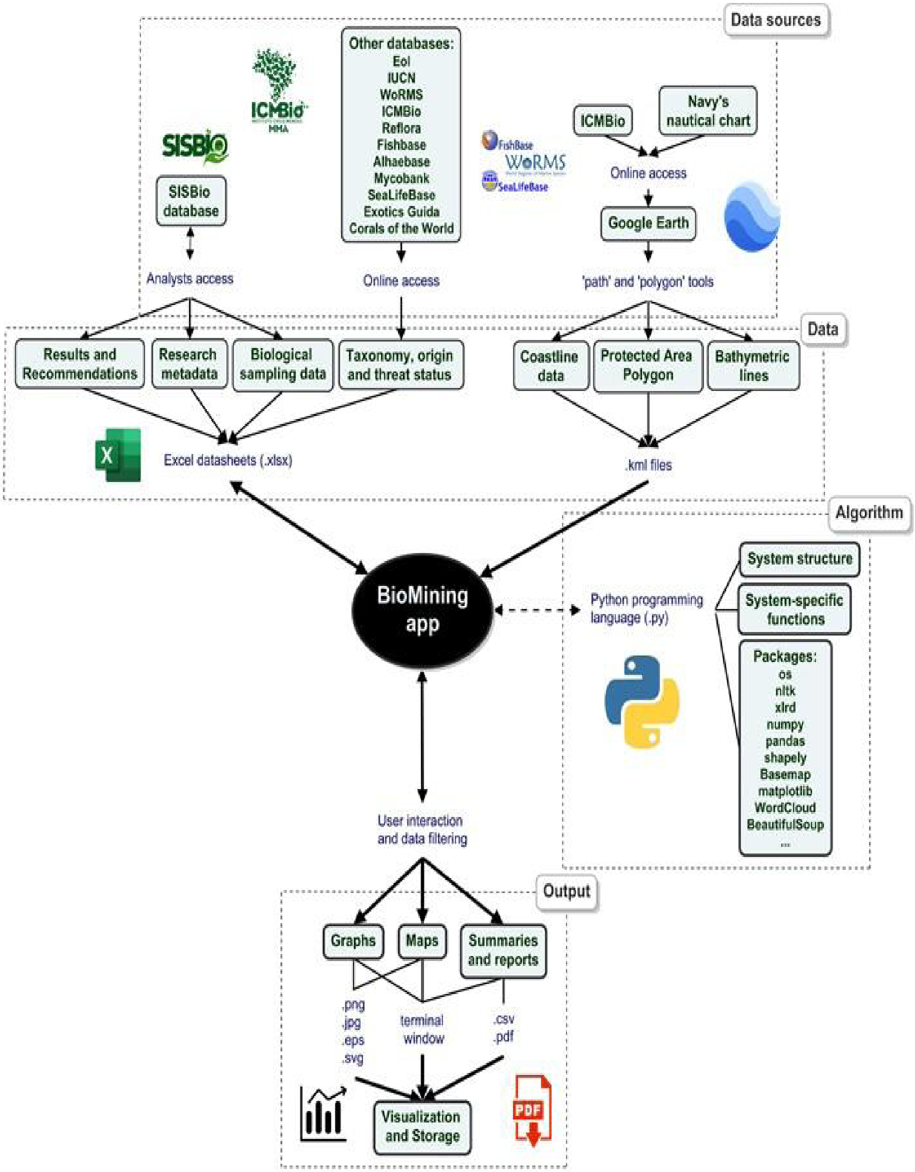

Figure 2 – Flowchart of data sources and outputs of the biomining application, a methodology proposed to synthesize scientific reports from protected areas in brazil (adapted from MENEZES, 2019).

The application itself is not complex but requires maintenance. As shown in Figure 2, it is based mainly on Microsoft Excel (.xlsx) and Google Earth (.kml) files. It is also necessary to be fed with information from other databases, such as reports and other biological bases available online. Thus, the name of the application in the presented flowchart can be replaced by any other approach, algorithm, or method of data management, as long as it is well addressed by the peculiarities of the data and locations.

In addition to the lack of dialogue between scientists and decision-makers that could be addressed directly through quick and synthesized scientific information, the gap between science and society can also be a target of this approach. After the text classification and after quick filtering by 'Management' and 'Communication' in 'Recommendations', and by' Protected Area ', several actions were mentioned in the scientists' reports. These activities could be carried out to raise awareness among residents, tourists, managers and unit council members.

The data processed and presented by Menezes (2019) also reveals the main topics to be addressed when we take into account anthropic impacts, activities inspection, environmental monitoring and future research in the context of each protected area. Beyond the conservation purpose, scientific development may also be addressed with the listed taxa in reports. Menezes and Coutinho (in preparation, 2021) also used this data to explore the potential use of open algorithms available in the 'Github' repository ('Scholar.py' and 'Sci-stat') to conduct a web search on Google Scholar of the listed taxa associated with the term 'biotechnology'. Some bias was observed in the results of this research, incompatible taxa, for example, but in general, the results are promising as a non-invasive method to conduct a type of bioprospecting in a given area.

This case study has highlighted the potential of data management to fill critical gaps in marine research, biodiversity conservation, policy-making and public awareness, which are perhaps some of the most challenging issues concerning the oceans and climate change in the near future. In this context, the machine learning approach can be an essential tool to qualify the significant amount of unstructured data held by government agencies, for example, through supervised text classification modeling (MENEZES, 2019).

The big data in marine sciences and machine learning as a tool for the future of data management in marine sciences

Data can be 'big' in different ways (LYNCH, 2008). In the oceanographic context, 'big data' can mean essential data collected in a very hostile place or the enormous quantity of data (or model results) obtained over the years (e.g., temperature, salinity and depth). However, there are many places where data collection is not enough to understand the complexity of the oceanographic processes. Fortunately, nowadays we experience an increasing number of models and data collections overseas, and we need to organize the "big data" in such a way that helps us to find what we look for quickly. Organizing and interpreting this data represents a big challenge, and the machine-learning approach can be a tool to develop it.

Machine learning is a subfield of artificial (or computational) intelligence and its main objective is the use of computational methods for extracting information from data. In the 1990s, machine learning started to be introduced to the environmental sciences (HSIEH, 2009). Currently, machine learning is heavily used in the satellite data processing. In addition, machine learning is used to develop circulation models (GCM); simulate ocean physics and forecast oceanographic, ecological and hydrological processes, among other applications (WILEY *et al.*, 2003). Some examples of machine learning use are related to sea-ice classification (Dawson *et al.*, 1992), development of aquaculture (Zhao *et al.*, 2018), oil and gas industry to facilitate rock classification (CHEN; ZANG, 2018), predicting and mapping fish species (GUILFORD *et al.*, 2009) and estimate model errors (SOLOMATINE; SHRESTHA, 2009). Machine learning was also used to predict global marine nitrogen fixation (TANG *et al.*, 2019), to improve spatial and temporal coverage of chlorophyll satellite data (CHEN *et al.*, 2019a), to detect tropical cyclone formation (KIM *et al.*, 2019) and to estimate surface ocean pCO_2 (CHEN *et al.*, 2019b) using satellite data.

For modeling purposes, organizing big data is essential because the more data obtained, the better the calibration of the models. As an example, the H2020 project Databio (https://

www.databio.eu) intends to utilize information flows to provide a streamlined big data infrastructure for data discovery, retrieval, processing, and visualization in fisheries (e.g., tuna pilot; FERNANDES *et al.*, 2017).

In time-series of oceanographic processes studies, long-term measurements of some properties are required. Consequently, if ocean data cannot survive in the short term, it is pointless to talk about the long-term use of it. In a high-threat environment such as Brazilian universities, computers will often be compromised (LYNCH, 2008). These machines usually do not have the proper maintenance that they should have. Unfortunately, this can mean data destruction or corruption. So, organizing and connecting big data in oceanography is vital for a sustainable approach to the exploration and development of the ocean. The application of big data in oceanography is important because it is not desirable to either store isolated data in a location where it cannot be reused for purposes beyond which it was originally collected, or store data in a way that cannot be integrated into a holistic view (LEADBETTER *et al.*, 2019). As such, the links between datasets should be formally documented and exploited as best as possible. As an example, Leadbetter and collaborators (2019) use the Semantic Web technology and explore the information in modeling patterns regarding the marine domain.

The widespread progress may have contributed to an exceedingly optimistic impression concerning the limitations of technology in machine learning. In particular, machine learning models can often be opaque or difficult to comprehend, and we need to be aware that the limitations of these models may be poorly understood (ICES, 2018). However, the need for data to compare with and feed applications of machine learning is evident.

Final remarks

Data is a crucial part of science, particularly in marine and environmental research. Globally and especially in developing countries, there have been challenges in data generation caused by various uncontrolled circumstances such as funding, inadequate infrastructure and management issues. However, there is an increasing number of models and data available that can be used as a basis for management decisions. The emergence of novel tools such as the platforms and applications that gather information and share it quickly, along with the development of novel tools for analysis such as machine learning algorithms are our best chance to understand the complexity of our ever-changing world.

From the scientific point of view, it becomes more evident that a holistic and transdisciplinary outlook should be considered in the data-gathering process, including support for data sharing across developing countries. The adoption of advanced technological inputs, such as machine learning and artificial intelligence, could enhance data management and information production. In the communication age, information and data sharing, as well as effective communication between scientists and society are essential to fulfilling the current gaps of information that stagnate the policy-making process regarding marine conservation and to better understand the relevance of our global connection through oceanography.

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CHAPTER 9

Useful tools for Environmental Education: Spreading knowledge in innovative and engaging ways

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Abstract

Research outcomes are still often kept within academic circles for a long time, even though they may play a useful role for different purposes and foster relevant positive changes in society. To help solve this issue, we explore fun and innovative ways to spread scientific knowledge to the general public. This chapter showcases four ways to engage society in useful applications of scientific knowledge for the management of ocean and coastal ecosystems and species, with a focus on conservation and people's wellbeing. Our cases are from coastal areas in Brazil and Argentina and include technological applications and websites, as well as community engagement activities and events.

Introduction

With the increasing demand for science-public interactions and the growing role of science in helping to manage real-world problems (*e.g.*, under a transdisciplinary approach), there is a raising need for integrating civil society into science and discussing research findings with a broader audience, particularly with the general public (POHL 2010; BROWNELL *et al.*, 2013). Building skills in science includes delivering disciplinary courses, developing research methods, and building analytical skills, as well as communication skills within the scientific community. However, a key gap for science to effectively reach the public is insufficient training in communication with a non-scientific audience (NISBET; SCHEUFELE, 2009; KEMP; NURIUS, 2015).

This scenario can create mistrust and misunderstanding between scientists and the lay public due to a lack of scientific literacy. In the case of climate change, for instance, the lack of understanding of scientific findings has directly influenced decision-making in the wrong direction in terms of regulation, policies, and funding (NISBET; SCHEUFELE, 2009). Moving forward, many other scientific discoveries, with the appropriate dissemination, may have the potential to well inform environmental management and, ultimately, our everyday decisions (e.g., eating habits, transportation choices). The consequence of science-public miscommunication, which leads to a lack of socio-economic and ecological progress, reinforces the mistrust in scientists by the lay audience and misunderstanding of the scientific relevance in fostering positive changes in society.

Even though many scientists have shown a great ability to proliferate science to the world through literature (e.g., Stephen Hawking and Carl Sagan), most researchers still do not have a formal opportunity to develop and practice their communication skills (KEMP; NURIUS, 2015). Brownell *et al.* (2013) addressed this problem, providing several examples of infusing communication training into the academic curriculum. They guided graduate and undergraduate students to translate academic work into newspaper articles for the lay public with the final aim of increasing awareness of non-scientific audiences about neuroimmunology. Communication strategies to disseminate scientific knowledge are especially relevant in the case of environmental sciences and education to help us understand our impact on the planet.

Environmental education is a process with the purpose of promoting knowledge about the functioning of the environment, key environmental changes, as well as our impact on and our dependence upon nature. The process of environmental education involves building awareness, guiding behavior, sharing knowledge, and the ability to understand the links between people and the environment (DIAS, 2004). The use of ludic (*i.e.*, playful, creative, engaging) activities in the education process allows the teaching of science through fun activities that stimulate the interest, attention, and curiosity of participants of different ages (MALUF, 2015). In this context, the goal of this chapter is to discuss different ways of promoting environmental education in informal spaces, using ludic activities as allies in the process of transforming people's perception regarding their impact on and dependence upon nature.

Currently, a substantial number of interactive and user-friendly ways to teach and learn basic science exist. Interactive platforms demonstrated to be useful in raising awareness of environmental threats and encouraging behavioral action, especially when tailored to target groups (NELSON *et al.*, 2020). Some of the tools being used are games, nature guides, documentaries, and interactive mobile applications (ILLINGWORTH, 2017). In addition, music is a popular method used in elementary and middle schools to teach basic science. Using songs, such as “Meet the elements” by the American rock band “They May Be Giants” -- which comes with an infographic-style music video, or even giving children the opportunity to create their songs on certain scientific topics can foster learning and understanding in a fun and easy way. Another example of science being taught through music can be found at sciencewithtom.com, where a biologist with a master’s degree in science communication develops projects and helps create science-themed music and videos covering various scientific topics.

Here we explore examples based on four case studies of creative tools and methods applied as potential means to disseminate science to the public. We first document the four initiatives and analyze their key features in various settings. Secondly, we evaluate the engagement of the general public within these initiatives.

Case studies

Overview of case studies

We analyzed four Latin American cases of environmental education tools targeting a varied audience (i.e., the fishing sector, coastal communities, students and/or the general public).

All cases had the ultimate goal of promoting environmental education on fisheries, social-ecological changes, and ocean ecosystem processes. Tools used include technology (*e.g.*, mobile application and interactive website), participatory activities (*e.g.*, World Café workshop, events), and visual arts (*e.g.*, graphic facilitation). Table 1 summarizes the key characteristics of the analyzed case studies. We selected these cases because they illustrate innovative methods that engage a lay audience in the research process and findings dissemination. We made use of published information about the cases, as well as the in-depth case-specific knowledge of the authors who contributed to these initiatives.

Table 1. Case studies using environmental education tools.

Case study	Location	Audience	Goal	Methods	Outcomes
Case 1 - Mobile app for reducing by catch in shrimp fishing	Brazil (São Paulo state)	Fishermen, environmental and fishery agencies, NGOs, general public	Educate about by-catch species in shrimp fishing	Mobile app	Scientific and general public engagement
Case 2 - World Café and graphic facilitation for environmental change awareness	Brazil (São Paulo state)	Coastal communities	Understanding how social--ecological changes affect community wellbeing	World café and graphic facilitation	Key changes identified; Children's engagement at schools

Case study	Location	Audience	Goal	Methods	Outcomes
Case 3 - TallEx (Experiments of Geophysical Fluids)	Argentina	Students, graduates and teachers	Explaining how natural systems work in the ocean	Website containing extracur-ricula r activities	General public and student engagement
Case 4 - Ludic activities in the environmental education processes	Brazil (Espírito Santo state)	Traditional commu-nities and tourists	Aware-ness of endangered species and ocean issues	Activities in events and schools	Traditional community engagement on envi-ronmental issues

Case study 1: Mobile app for reducing bycatch in shrimp fishing[5]

Shrimp fishing is an important economic activity worldwide generating impressive income in our society. Marine and coastal shrimp are usually caught by shrimp trawler nets, but this invasive method captures large amounts of non-targeted and economically non-relevant species, which are discarded back into the sea. Non-targeted species are known as bycatch, which is composed of fish, crustaceans, mollusks, and starfish, among other benthic and demersal organisms. It is estimated that shrimp trawling bycatch ranges from 5 to 20 kg per kg of caught shrimp, resulting in a significant loss of biodiversity and ecological functioning (DAVIES *et al.*, 2009). However, in addi-

5 This app is available for open access at Play Store (Portuguese version): https://play.google.com/store/apps/details?id=br.com.zeropoint.facom&hl=pt.

tion to their ecological importance, these species have relevant biological activities and chemical compounds, which can be explored by pharmaceutical companies and the food industry (*e.g.*, *Paralonchurus brasiliensis* and *Micropogonias furnieri*, CAMARGO *et al.*, 2021).

To deal with the issue of bycatch, an interactive and innovative mobile app 'Fauna Acompanhante - Pesca de Arrasto' ('Bycatch fauna – Trawling') (Figure 1) was created to help fishermen, environmental and fishery agencies, NGOs, and the general public to understand this hidden biodiversity. This pioneering project in Brazil was created by a group of scientists, graduate and undergraduate students from the São Paulo State University (UNESP), supported by national research foundations. Based on published studies and several samplings conducted by the researchers involved, specimens of the most common bycatch species found in the state of São Paulo State were identified, listed and separated by groups. High-quality images of species were taken and uploaded in the app, when possible, to facilitate species identification by users. Moreover, their common and scientific names and relevant information about their biology, distribution, commercial interest, and status of conservation according to The International Union for Conservation of Nature (IUCN) were also uploaded to the app. The app highlights, for instance, that endangered species of elasmobranchs (e.g., sharks, rays) are usually captured, and that there are still gaps in information for some groups, mainly invertebrates. As a first-generation, modern tool it may gain attention and gain popularity with the general public. Several people from different areas informally described the app as a useful tool for the identification and information of the species. The app is an example of how to foster local actions to deal with global issues (*e.g.*, bycatch in fisheries) and seems to be a great step to gain knowledge about the environment, as well as foster thoughtful discussions on the impacts of human activities in the ecosystem and how to mitigate them.

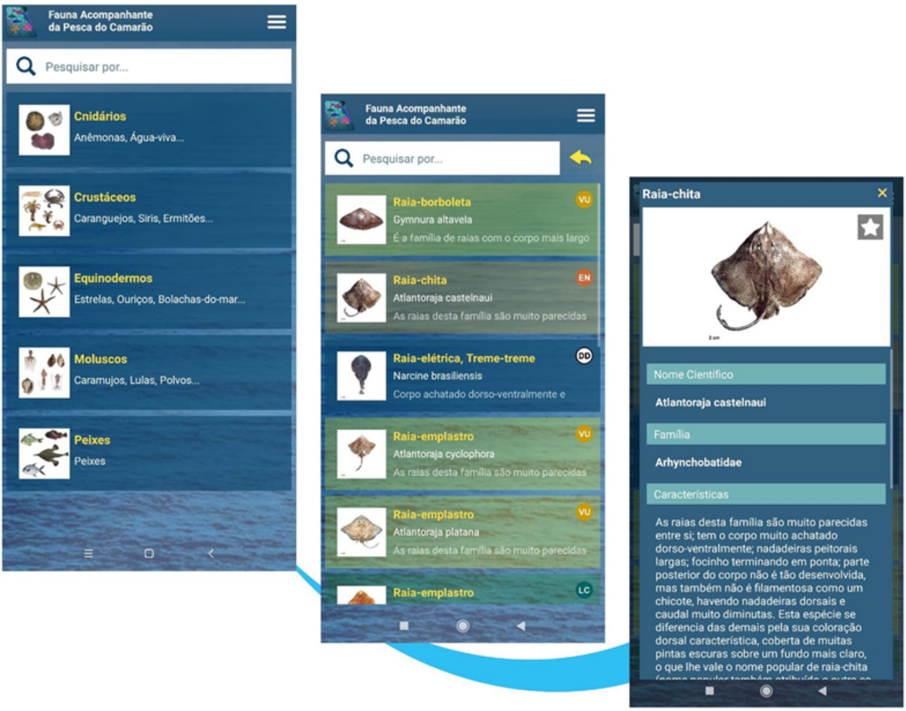

Figure 1: Layout of the Mobile app 'Fauna Acompanhante – Pesca de Arrasto' ('By-catch fauna – Trawling').

Case study 2: World Café and graphic facilitation for environmental change awareness

Researchers from the University of Waterloo (Canada) conducted participatory workshops, including graphic facilitation in three communities on the Southeast coast of Brazil (Almada Beach, Puruba Beach, and Picinguaba Village). The objectives of these workshops were (i) to understand how environmental changes interfere with coastal community well-being, (ii) to generate systematized data based on local knowledge with scientific rigor to inform coastal management, and (iii) to engage traditional coastal communities facing accelerated cultural and environmental changes in coastal management. The workshops were guided by the world café (BROWN; ISAACS, 2005) method and the discussions were visually represented through graphic facilitation. Participants were divided into four groups randomly (Figure 2). A large sheet and colored pens were made available to each group. All participants were invited to freely express themselves through records (*e.g.*, including drawings, scribbles, words) on the sheet arranged at each table. A host in each group was responsible for systematically recording the discussion. In all groups, three questions were discussed simultaneously at each table, and a summary was shared with all participants. As a result, participants agreed on the main changes affecting the community with social and environmental impacts. The main changes included mass tourism (causing water pollution, disturbance to marine life, and disturbance in the community - e.g., drugs, irregular parking, diseases) and changes to the river flow, causing fear of floods on the one hand, and opportunities for environmental interpretation on the other (DIAS, 2020; DIAS *et al.*, in press). Participants suggested sending the final summarized graphics to the local school and sending a report to decision-makers with a summary of the discussions. The schools used the content to discuss with students the role they can play in coastal conservation and cultural reproduction. For more details, see Dias (2020).

Figure 2. Photograph of the workshop conducted at Puruba Beach community showing participants at different tables and the graphic facilitator in action on the left. Photographed by: Ana Carolina Esteves Dias.

Case study 3: TallEx (Experiments of Geophysical Fluids)

Changes in the ocean and atmosphere are discussed frequently in the scientific community, but scientists cannot discuss these changes with the general public without first explaining how these systems work. TallEx[6] is an academic extracurricular group of students, graduates and teachers of atmospheric and oceanographic sciences at the University of Buenos Aires (Argentina) that assembled easy-to-do laboratory experiments, which explain how geophysical fluids behave in nature (Simionato *et al.*, 2009). The selected experiments aim to describe oceanic and atmospheric fluid movements due to two effects: stratification and rotation, as follows:

- Deep convection in the Ocean: Pure water was placed in a small fish tank that represented a portion of the ocean from the Equator to the Pole. In one corner, blue-colored cold water was added to the tank, and in the opposite corner, warm red-colored water was added. Within the tank, cold water sank below the surface and flowed towards the "red" corner while the warm water floated along the surface towards the "blue" corner. This experiment communicated oceanic convection properties concerning water temperature changes.

6 Available at: http://tallex.at.fcen.uba.ar.

• Internal Waves: Pure water was placed in a fish tank. Several glasses of water were prepared which contained different amounts of salt and different colors. The "water masses" from the glasses were added slowly, from the less salty to the saltiest. This allowed the audience to see not only stratification related to different salt contents but also internal waves generated between the water layers, which are not usually visible from the surface.

The materials used for the experiments are inexpensive and readily available, which ensures the possibility of reproducing the experiments even with small budgets. The TallEx website shows all the experiments, how to make them, and the scientific explanation behind them so teachers can easily reproduce them with their students.

Case study 4: Ludic activities in environmental education processes

Environmental education practices are effective tools for promoting ocean literacy (GHILARDI-LOPES *et al.*, 2019) and for raising awareness about protecting and conserving the environment (Potter 2010). Integrating different methods for environmental education, such as ludic activities, is generally more efficient than traditional expositive teaching (HAYES *et al.*, 2013), especially with activities that stimulate different senses and processes, such as listening, speaking, reading, touching, observing, and interpreting.

This case study was carried out by Projeto Meros do Brasil, sponsored by Petrobras, which has as its flag species, the goliath grouper (*Epinephelus itajara*), a protected marine and estuarine fish species critically endangered in Brazil. They conducted several ludic activities such as Body Painting, Ecological Bowling, Ecosystem, Sensorial Box, and Interactive Carpet during public events held in the cities of Conceição da Barra, São Mateus, and Vitória, in the state of Espírito Santo, Brazil. The events fostered the participation of local traditional fishing communities, students, and city residents who live near estuaries and mangrove areas where the goliath groupers are common, as well as tourists visiting these areas. The Body Painting activity consisted of painting the goliath grouper, among several other elements that represent the marine and estuarine ecosystems, on children's skin. The Ecological Bowling activity consisted of bowling pins made from plastic pet bottles, containing images representing the most diverse components of the environment where goliath groupers live. The Ecosystem activity consisted of double-sided cards that were hung around the neck of the participants. On one side of the card there was a riddle and on the other side an image that represented the answer to the riddle. During the activity, one of the participants would read the riddle to the group, and together they would try to find the answer. The Sensorial Box was an inclusive activity that allowed participants to feel nature in the palm of their hands. This activity consisted of a box with an opening where the participants would stick one of their hands in and only by touching the components inside the box tried to guess what they were touching. The game aimed to provide the visually impaired the possibility of participating in the game based on equality with other participants since no one can see what they are touching. The Interactive Carpet (Figure 3) was an inclusive activity consisting of two mats produced with felt, one representing the estuarine environment and the other the marine environment. This activity included several elements of the marine and mangrove ecosystems, natural or unnatural, that were not fixed to the mat, allowing the participants to move the elements around the environments and adapt them according to their perspectives. During the activity, the participants discussed the role and importance of each element for nature, what our role is in its protection, and that we, human beings, are part of nature.

During the development of all activities described above, provocative discussions were fostered, raising awareness of the importance of preserving marine and mangrove ecosystems, preventing illegal vegetation cutting, proper waste disposal, reflecting upon our role concerning nature, preventing illegal fishing, protecting endangered species, understanding the food chain, sustainability, among other reflections. These environmental education ludic activities were considered facilitators of the teaching process since participants expressed great interest in the subject and the activities. These activities also helped to integrate students with special needs, such as learning or communication difficulties, as well as physical needs, during the reflections. These informal environmental education initiatives show how participatory discussions play an important role in the process of increasing public awareness of environmental issues, creating new patterns of behavior and attitudes of the participants toward nature (MOHAMMED *et al.*, 2006).

Figure 3. Environmental activities developed during events in the cities of Conceição da Barra, São Mateus, and Vitória, in the state of Espírito Santo, Brazil. (A) Body painting, (B) Ecological Bowling, (C) Sensorial Box, and (D) Interactive Carpet.

Environmental education as a transformative societal strategy

The four cases described in this chapter provide examples of creative tools and methods applied in environmental education and science communication to a lay audience, including the general public, students, coastal communities, fishermen, and governmental agencies. These methods innovate by providing scientific knowledge and understanding of some complex processes and interactions to people with no or scarce requirement for previous knowledge. Overall, these cases provide and co-construct information on coastal ecosystems and species, as well as how the environment benefits and is being affected by humans. Thus, these tools have the potential to foster ecosystem stewardship actions among users/participants.

Three main reasons explain the potential of our cases to foster stewardship actions towards coastal environments in fun and engaging ways. Firstly, three of our cases highlight human-nature connections to the benefits nature provides to people (cases 1, 2 and 4) in a ludic way. Ludic activities can bring many benefits, including public engagement and better experiential learning in which participants are an active part. This is especially relevant as the use of games and fun activities attracts the participants, stimulating curiosity and strengthening social interaction casually. This may help to foster a sense of responsibility over the environment users and participants are in and from which they obtain benefits. Case two, for instance, engages participants in an active discussion on what the key environmental changes are within the community and drives participants to draw connections between these changes and how they affect their well-being. Participants showed a great interest in the graphic facilitation outcome, especially by recognizing their local issues with the content represented in the drawing. The drawing that resulted from graphic facilitation was used as a teaching tool by local schools, where students could reflect upon environmental changes in their communities and their actions towards marine conservation (see DIAS, 2020).

Moreover, ludic activities are efficient for young learners, who have a high level of motivation when engaging in enjoyable new and different experiences (ENEVER, 2015). Case 4 illustrates the increase in engagement in environmental education through ludic activities (e.g., body painting). While participants were playing, their imagination and enthusiasm were heightened by all the questions and provocations that they were exposed to during the activities. Participants asked many questions, debated environmental issues and reflected upon the reality that surrounds them. Moreover, playful situations make children learn the proposed knowledge in a fun and relaxed way (KOLB; KOLB, 2010), that is, they have an additional and unconscious encouragement that favors their ability to speculate, deduce and interpret the information that is presented to them. This is supported by Krashen's affective filter hypothesis which states that students' emotional states and attitudes are considered a modifiable affective filter in learning (KRASHEN, 1982). According to this hypothesis, when a person feels anxious, threatened, or overwhelmed, he or she ends up blocking the absorption of information, which is necessary for the acquisition of knowledge (KRASHEN, 1982). On the other hand, when the student is relaxed, by playing a simple game, for example, the participant learns more effectively by making connections to real-life concerns, such as social, ecological, economic, cultural, and political issues (KRASHEN, 1982). Therefore, ludic activities can make the absorption of information easier and encourage the participants to build a critical opinion about complex environmental issues that will foster a new generation of well-informed citizens.

Secondly, these cases demonstrate the impacts people have on coastal ecosystems and species – which is a basis to foster environmental awareness. In fact, there is an established recognition that technology is a powerful tool to increase environmental awareness. Contemporary technological resources have been considered efficient materials in environmental education initiatives (UZUNBOYLU *et al.*, 2009; CHANG *et al.*, 2011; HILL *et al.*, 2011). Mobile devices, for instance, provide a vast number of interactive possibilities (e.g., audio-visual podcasts, mobile applications) to increase awareness of specific environmental topics and to support formal education via mobile learning (M-Learning) (DODGE, 1995; SHARMA, 2014; LUNA *et al.*, 2018). Our study and the literature show that mobile applications dealing with local environment information (e.g., biodiversity, weather) are fruitful tools to increase the community's sensitivity to their surrounding environment (JENKINS, 2003; SHARMA, 2014). *Brincando com os bichos do mar* (Playing with sea animals), for instance, aims to teach children about marine animals in a playful way in Brazil. SharkCount is another citizen science tool for divers that helps to monitor and provides information about marine fauna in Galápagos. Our case study 1, "Fauna Acompanhante – Pesca de Arrasto" – the bycatch app, is also an emerging initiative where focal users are personally close to the topic (*i.e.*, in this case, users are fishers who may produce bycatch). Despite the recognized economic and ecological importance of shrimp trawl fisheries, direct and indirect actors involved in the activity still lack a full understanding of bycatch species and comprehension of alternative ways to minimize the impacts of trawling (HAULE, 2001; EAYRS, 2007). The mobile app helped to foster knowledge surrounding bycatch species among stakeholders.

Finally, our cases demonstrate the relevance of tailoring the activities to the target audience. The target audience is important to take into consideration when designing and constructing an activity such as educational activities for school kids (such as in Case 3), activities for local communities (such as in Case 2 and 4), or adult professionals (such as in Case 1) to increase its impact. In the school environment, hands-on experiments to engage students to discover natural cycles were demonstrated in case 3, a laboratory environment tailored to the context of students and schools. For fishers who use cell phones, a mobile app was easy to use and provided relevant information on the bycatch species, including their commercial value – which might be of interest to them.

A preliminary screening of the target audience allows for the design of a more adequate experience for that particular audience and increases the positive outcomes by personalizing the content of the activities to some extent. An example of an interactive educational game with a well-thought design can be found in the study by Barab *et al*. (2005), where they state the following as the main social and educational slogans which founded their activity design:

1. Creative Expression – I Express Myself.
2. Diversity Affirmation – Everyone Matters.
3. Personal Agency – I Have a Voice.
4. Social Responsibility – We Can Make a Difference.
5. Environmental Awareness – Think Globally, Act Locally.
6. Healthy Communities – Live, Love, Grow.
7. Compassionate Wisdom – Be Kind.

These messages could be used in various educational activities as founding principles on which to base the overall experience, adding the customized features adapted to a particular target audience.

Thus, through ludic activities, participants reflect more effectively on how their decisions and actions affect marine ecosystems, as well as the importance of keeping our oceans healthy and sustainable for the future. These case studies are examples of existing efforts to educate the lay audience, raise awareness and stimulate positive behavior towards the environment. We highlight that the chosen methods must be tailored to the target audience in order to adequately convey scientific information. For future studies, the development of preliminary screenings of target audiences to develop more personalized experiences and their subsequent debriefing, as well as an evaluation of the outcome, could be useful additions to increase the effectiveness and improve these educational activities.

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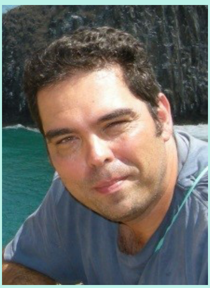

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