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Marine spatial planning in the tropical Atlantic

From a Tower of Babel to collective intelligence

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Marie Bonnin and Sophie Lanco Bertrand (dir.)

Publisher: IRD Éditions
Place of publication: Marseille
Year of publication: 2023
Published on OpenEdition Books: 11 September 2023
Series: Synthèses

Electronic reference
BONNIN, Marie (ed.) ; LANCO BERTRAND, Sophie (ed.). *Marine spatial planning in the tropical Atlantic: From a Tower of Babel to collective intelligence.* New edition [online]. Montpellier: IRD Éditions, 2023 (generated 11 septembre 2023). Available on the Internet: <http://books.openedition.org/irdeditions/46585>.

Cover caption
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ABSTRACTS

The goal of marine spatial planning is to manage uses of marine space to reduce tensions between human activities and the health of marine ecosystems. This is a major and complex challenge, as oceans lie at the intersection of multiple and increasing interests: biodiversity conservation, climate change regulation, economic development, food security.

This handbook takes an interdisciplinary, sustainability science approach to explore the potential and limitations of marine spatial planning, a tool developed in the Global North, and its current or possible future applications in the tropical South Atlantic – specifically in Brazil, Senegal and Cabo Verde.

To protect our global ocean commons, communities of stakeholders need to transcend disciplinary boundaries and bring together diverse knowledge to move towards a shared goal of sustainability (part 1). The development of this collective intelligence in tropical marine ecosystem research must take into account local, national and international issues (part 2) and can be supported by innovative interdisciplinary tools (part 3).

This handbook is aimed at decision-makers, researchers and, more generally, all users of marine areas, highlighting crucial points to consider when implementing marine spatial planning.

MARIE BONNIN (DIR.)

Marie Bonnin is an expert in environmental law. She is a research director at the French Research Institute for Sustainable Development (IRD) and a member of the joint Laboratory of Marine Environmental Sciences (LEMAR). Her focus is the legal protection of the marine environment. In her position at the European Institute for Marine Studies (IUEM), she interacts extensively with researchers in natural and physical sciences. With her background in translating marine ecology research into law, today she is interested in the applicability and effectiveness of environmental protection legislation. She has worked specifically on marine environmental law in West Africa, in collaboration with universities and research institutes in Senegal, Mauritania and Cabo Verde, and more recently has extended her area of specialisation to the broader tropical Atlantic.

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Sophie Lanco Bertrand is a marine ecologist. She is a research director at the French Research Institute for Sustainable Development (IRD) and a member of the joint research unit on Marine Biodiversity, Exploitation and Conservation (MARBEC). Her focus is the analysis of how birds, fish, mammals and fishermen use the marine space by employing biologging technology and movement ecology models, for example. One of the aims is to assess whether regulations and tools to manage human activities at sea, such as marine spatial planning, can allow marine organisms and humans to coexist in such a way that ensures the sustainability of marine socio-ecosystems. She worked in Peru for some 15 years studying the Humboldt Current ecosystem and is currently developing her research in the tropical Atlantic.

EDITOR'S NOTE

Reworking of illustrations: Eric Opigez
External links and HD maps: Laurent Pourinet & Brice Trouillet

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Acknowledgements

1 The cross-section of views on marine spatial planning in the tropics presented in this handbook is the result of an expert group on science research, innovation and policy that was supported by the European Union: the Paddle project (Planning in A liquiD worlD with tropicaL stakEs) (H2020-MSCA-RISE-Paddle-734271).

2 A large number of institutions, partner projects and individuals were involved in making researchers available and organising seminars, workshops, summer schools and conferences: venues for the international and interdisciplinary brainstorming essential to this research topic and that resulted in this handbook.

3 We are very grateful to everyone involved for their multifaceted contributions, which made it possible to set up and coordinate the Paddle project, to host visiting researchers, to organise the project events, and to finance the summer school and the final conference.

4 We would also like to thank the public authorities that participated in the project seminars. Various partnerships and observation campaigns also contributed to the effective implementation of the project. The students working on their Master's or doctoral degrees in the framework of the Paddle project also contributed greatly to its achievement through their dynamism and creativity. Lastly, this handbook would not have been successfully completed without the attentive care of our colleagues from IRD publishing.

Introduction. Marine spatial planning in the tropical Atlantic

From a Tower of Babel to collective intelligence

Sophie Lanco Bertrand and Marie Bonnin

1 Marine environments and the blue economy are seen to offer a tremendous promise of growth at a time when the possibilities of terrestrial environments appear exhausted. Yet marine environments are subject to intense and increasing pressures (HALPERN *et al.*, 2008; 2015) such as maritime traffic, increasing land use demand in coastal areas, seabed exploitation, dredging and mining, fisheries, tourism, renewable energy development, etc. As a result, the oceans are today at the centre of various and complex interests, at the crossroads of biodiversity conservation, climate change regulation, economic development, food security, etc. In Europe, for example, marine environments are at the heart of the new Green Deal growth strategy, which aims to achieve "an equitable and prosperous society with a modern, resource-efficient and competitive economy, where there are no net greenhouse gas emissions by 2050, and where economic growth is decoupled from resource use" (EC communication, 2019); as well as its Biodiversity Strategy (EC communication, 2020), which aims to halt biodiversity loss, "bring nature back into our lives", and put Europe's biodiversity on a path to recovery by 2030 for the benefit of people, the climate and the planet. This political commitment to a trade-off between human use of natural resources and nature conservation marks a departure from previous EU roadmaps, which focused solely on the economy and aimed to maximise blue growth (EC communication, 2014).

2 In this policy context, marine spatial planning (MSP) aims to reconcile human demands and conservation needs, providing a framework for reflection and decision-making on how to combine different uses of marine resources in the same space through spatial zoning (CRAIG, 2012; KOEHN *et al.*, 2013; EHLER, 2014). MSP is often defined as "a practical means of creating and establishing a more rational use of marine space and interactions between its uses in order to balance development demands with the need to protect the environment, and to provide social and economic amenities in an open and planned manner" (EHLER and DOUVERE, 2009). The first MSPs were implemented in countries in the Global North in the 2000s. Since then, solid experience has been gained

in Europe, North America and Australia (see, for example, JAY *et al.*, 2013). As of July 2014, each European Union (EU) member state has to establish and implement maritime spatial plans (EU directive, 2014). Several European countries have now adopted binding texts on maritime spatial planning (e.g. for Portugal, FERREIRA *et al.*, 2015).

3 MSP remains a very active area of research, because while it offers a promising vision for the management of human activities in ocean spaces, it is not yet clear whether and how it can take into account a number of characteristics typical of marine socio-ecosystems. For example, existing approaches to MSP do not yet incorporate the occurrence of ecological surprises (KATES and CLARK, 1996; PAINE *et al.*, 1998; WILLIAMS and JACKSON, 2007), non-territorial approaches, globalization or, on a larger scale, the speed of environmental change in the context of the Anthropocene (GISSI *et al.*, 2019; COSENS *et al.,* 2021), which generates considerable uncertainty about the sustainability of the functioning of coastal and marine environments (MAES, 2008; WOLFF, 2015; LEENHARDT *et al.*, 2015; BENNETT *et al.*, 2015). Spatial planning frameworks are designed for specific areas, whereas social and natural dynamics have no boundaries. Multinational companies have both global and regional strategies, and the environmental impacts of their activities can be observed worldwide, at multiple scales. Global change and the continuous evolution it triggers in marine ecosystems also calls into question the very nature of a planning exercise that involves setting rules for a given period. Moreover, it leads to a crucial question: how will MSP *ultimately* be used? Does MSP aim to ensure ecologically and socially sustainable use of the oceans or rather to organise as many uses as possible? Will this process result in just decisions and equity between stakeholders or will it create winners and losers? Some authors (FLANNERY *et al.,* 2018) have expressed serious concerns about this for some time: “There is a growing concern that MSP may not facilitate a paradigm shift towards public interest-driven management of marine spaces, but it may simply be a distortion of power dynamics through participatory rhetoric in order to legitimise the agendas of dominant stakeholders.” To examine these different issues, a series of research projects on MSP have been undertaken in Europe (PLASMAN, 2008; TROUILLET *et al.*, 2011; QUEFFELEC, 2013) and elsewhere in the world (DAY, 2008; JAY *et al.*, 2013; EHLER *et al.*, 2019).

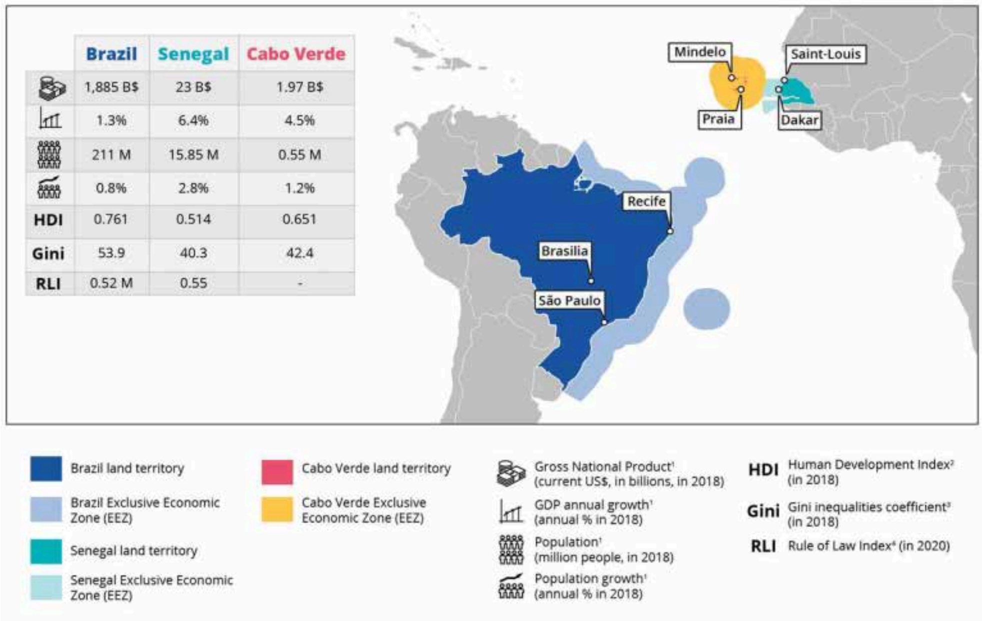
4 Following these initial implementations in the Global North, MSP is now being extended to tropical environments (via conventions such as the Abidjan Convention, with the African Union and others) as part of a wider process to organise the exploitation of marine environments and to design modern forms of governance in these regions. Although very few countries in the Global South are currently formally engaged in maritime spatial planning processes, a growing number of governments are preparing initial policy documents aimed at reconciling resource exploitation and environmental protection (see, for example, the Cabo Verde[1] marine strategy and Brazil’s integrated coastal zone management plan). To support this, and to ensure that the exploitation of marine resources contributes significantly to the policy priorities of poverty and hunger reduction (SPALDING *et al.*, 2013; SALE *et al.*, 2014), there is a pressing need for research on the possible applications of MSP in tropical areas. A crucial aspect of this research is that the policy framework initially designed for the EU may not be adapted to the specificities of the Global South. The political instability of certain countries, especially in Africa, and the economic power of transnational corporations affect the balance of power at the MSP negotiating table. In this way, MSP could

potentially pave the way for ocean grabbing, i.e. "the dispossession or appropriation of use, control or access to ocean spaces or resources at the expense of previous resource users, rights holders or inhabitants" (BENNETT *et al.*, 2015; see also WOLFF, 2015; FLANNERY *et al.*, 2016; QUEFFELEC *et al.*, 2021).

5 The tropical Atlantic is a shared ocean that links developed, emerging and developing countries. In recent decades, human exploitation of the sea has developed rapidly on both sides of the tropical Atlantic. The economic and social stakes linked to oil exploitation, fishing, seabed exploitation, food security, etc. are high. The populations of the countries bordering the tropical Atlantic share historical and economic links as well as natural resources. These countries also share some other characteristics, such as the scarcity of longitudinal scientific data and a sectoral approach to ocean management. In northeast Brazil and in West Africa, marine spatial planning is still in its infancy (AGARDY, 2010; QUEFFELEC *et al.,* 2021). However, as MSP spreads it will have an impact on ocean management policies as well as on the connections between political and administrative authorities, legal measures, civil society (local and international) and natural science research. At this early stage, the analysis of the diffusion of MSP and its planning process allows us to highlight opportunities and identify its limitations for the tropical Atlantic.

6 Three case studies are presented in this handbook: Senegal, Cabo Verde and Brazil. All three countries face significant issues related to fisheries, current and future offshore energy projects, the need to maintain artisanal and subsistence fisheries, and negotiations with other countries around the exploitation of the country's exclusive economic zone (EEZ) and continental shelf (fisheries agreements, oil exploitation, offshore wind farms, etc.). Attempting to reconcile human activities at sea generates both common and specific challenges for these regions and their respective realities (fig. 1): sharing their failures and successes provides valuable insights.

Figure 1. Geographic, demographic and socio-economic indicators illustrating the contrasting realities of Senegal, Brazil and Cabo Verde



	Brazil	Senegal	Cabo Verde
	1,885 B$	23 B$	1.97 B$
	1.3%	6.4%	4.5%
	211 M	15.85 M	0.55 M
	0.8%	2.8%	1.2%
HDI	0.761	0.514	0.651
Gini	53.9	40.3	42.4
RLI	0.52 M	0.55	-

Source:
[1] World Bank, Brazil and Senegal profiles. World Development Indicators database;
[2] UNDP, Human Development Data (1990-2018);
[3] World Bank, GINI index;
[4] World Justice Project, Rule of Law Index.

7 MSP is intended to be a collective and rational decision-making process that enlists all the stakeholders concerned, via a mechanism based on spatially explicit transversal information (ecological, legal, social, economic, etc.). Assimilating all the information necessary for this process is a real challenge. It must go beyond the mere juxtaposition of the perceptions and cognitive capacities of single entities (individuals, states, institutions, etc.) – which would lead to a non-operational “Tower of Babel” – to construct a true transdisciplinary approach of collective intelligence. A generic definition of collective intelligence or “swarm intelligence”, encompassing both animal and human realities, can be formulated as follows (KRAUSE *et al.*, 2010): “Two or more individuals independently acquire, or at least partially acquire, information and these different packages of information are combined and processed through social interaction, thus providing a solution to a cognitive problem in a way that cannot be implemented by isolated individuals.” MCCAULEY *et al.* (2019) chose a collective intelligence methodology to consolidate a narrative for the emergence of an oceanic culture. These authors expected this methodology to “empower a group of people to act as a coherent and intelligent organism working with one mind, rather than the leadership of a collective that would design policy directions”. A collective intelligence approach seeks a compromise between different desirable directions, with governance institutions playing their role as guarantors of the values of legitimacy, equity and justice in the process (COSENS *et al.*, 2021). This approach seems the most relevant mechanism for overcoming personal views and transforming an individual, sectoral objective into a collective one. To build this collective intelligence, decision-making within the framework of MSP requires addressing a first challenge, that of finding ways to capitalise on knowledge produced in silos.

8 In the following sections we examine, in relation to the three case studies this handbook focuses on: (1) How can MSP capitalise on existing knowledge silos? (2) What can be done to overcome the structural barriers that may hinder the path to collective intelligence? and (3) How can we make room for nature to "come back into our lives", in particular at the MSP negotiation table in a way that is informed by collective intelligence?

From knowledge silos to collective intelligence

Capitalising on knowledge silos

9 Marine socio-ecosystems can be understood as complex systems. A complex system is defined as a set of a large number of interacting entities, the integration of which results in an overall trajectory. Complex systems are characterised by emergent properties that are distinct from those of their constituents, by non-linear interactions, by different levels of organisation, or by non-trivial collective behaviour (e.g. multiple stationary states, bifurcations, emergent phenomena, feedback loops). The consequence of these properties is that an observer cannot easily or completely understand and anticipate changes in these systems by intuition or calculation.

10 Approaching a complex system such as a marine socio-ecosystem by first breaking down the problem into parts or disciplinary "silos" is a natural and indispensable premise. This allows for an in-depth understanding of the functioning of the different components of the system, the governance that controls them and their possible evolution. Silos allow, for example, an understanding of a legal-political pitfall common to the three case studies considered in this handbook around the question of the distribution of responsibilities (see the contributions of GALLETTI and DA SILVA LEITE NOURY: chapter 7; LY *et al.*: chapter 8; GUERREIRO *et al.*: chapter 9). In Brazil, this complex issue is linked to its federal structure, with a number of powers shared between the state and federal governments. In Senegal and Cabo Verde, the challenges emerge from the sectorisation of institutions and the lack of a culture of integrated coastal zone management. Differences between the case studies are also highlighted and underline the importance of (1) supra-regional incentives in West Africa, which seem to be linked to the emergence of a supranational concern framed notably by the Abidjan Convention on the Protection of the Marine Environment in Atlantic Africa (LY *et al.*: chapter 8) and (2) the risks associated with inconsistencies in Brazil's legislative system, which could thwart attempts to find a balance between economic development and environmental protection (GALLETTI and DA SILVA LEITE NOURY: chapter 7). A disciplinary approach is also a necessary prerequisite for shedding light on the state of ecosystems and their dynamics (BERTRAND and ZIMMER: chapter 1) and on the specific issues at stake in certain activity sectors, such as shellfish farming in Brazil (SOUDANT *et al.*: chapter 5) or the vulnerability of certain sectors, such as artisanal fishing in Senegal (THOMAS: chapter 6).

11 Knowledge arising from silos thus allows a rich and kaleidoscopic understanding of the challenges affecting the different facets of marine socio-ecosystems. The risk, however, is that when complexity is broken down into its many parts, this neglects the links, interactions and overlaps between them. Silos can emerge from a disciplinary approach if it is compartmentalised. But silos can also result from a lack of integration between

scales. SUÁREZ DE VIVERO *et al.* (chapter 11) show that in the South Atlantic – unlike the North Atlantic – a powerful network of common interests has not yet emerged and argue that the construction of a transatlantic community will be an essential prerequisite to standardise MSP approaches.

12 For all the knowledge specific disciplines provide, it is not sufficient to understand the individual parts of complex systems in isolation. These systems by definition are characterised by complexity: by the existence of emergent phenomena and feedback loops that cause the trajectory of the system to differ from that of the sum of its parts, making forecasting uncertain (see, for example, COSENS *et al.*, 2021). In addition, the impacts of climate change exacerbate the natural variability of these systems, in both frequency and magnitude, further increasing uncertainty. Thus, circumscribing knowledge in silos, whether disciplinary, sectoral or scale-dependent, results in cognitive limitations that may hamper the possibilities of addressing the future sustainability of marine socio-ecosystems.

Identifying barriers to a system view of the complex ocean

Technical and informational challenges

13 MSP strives to be a rational and evidence-based process (PINARBAŞI *et al.*, 2017). Decision support tools (DSTs), rooted in data analysis, have thus proven to be essential to inform the decision-making process. DSTs are spatially explicit tools, involving interactive software including maps, models, communication modules and additional elements that can help solve multifaceted problems too complex to be resolved by human intuition or conventional approaches alone. While these tools can support more systematic and objective decision-making (PINARBAŞI *et al.*, 2017), they have also introduced a high degree of technicality into the process of selecting ocean-use zoning scenarios. As illustrated by BRUNEL and LANCO BERTRAND (chapter 15) in a Brazilian case study, the results provided by these DSTs can be very sensitive to the formatting of the input data, the parameters of the models, and even the way the zoning issue is formulated mathematically. Fairness in the MSP negotiation process would require a minimum level of technical training for all stakeholders on the functionality of these DSTs and how they may affect the optimal zoning scenarios under discussion. FOTSO (2019) makes the same observation: DSTs have acquired such a critical role in the MSP decision-making process that there is a need to establish a clear legal framework to ensure that this technical issue does not override transparency, equity or fairness in negotiations.

14 Given that DSTs, and the spatially explicit data they require, have become central to the MSP process, TROUILLET *et al.* (chapter 10) highlight the emergence of an “informational challenge”: the simple fact of having data (ideally spatially explicit) on one’s activity gives a stakeholder an undeniable advantage in the negotiation process. Taking the example of artisanal fishing in Senegal, these authors question the role of geographical information and associated geo-technology in MSP in order to identify the main points of vigilance to consider, particularly in developing or emerging countries where data is often scarce.

An anthropocentric view of human–nature relations

15 Human societies are linked to marine environments in various ways: people live near seas, they use them for transport and travel, they extract from them, they depend on their resources. However, they do not actually live in this three-dimensional environment, with the consequence that the relationship is usually quite utilitarian and definitively anthropocentric. The main perspective is activity-based and economic (e.g. the great promise of blue growth), with the marine environment seen as a provider of resources, or even, as MACHU *et al.* (chapter 2) well illustrate, a neglected outlet for the negative externalities of land-based activities, such as pollution in Senegal. The paradigm of an immense ocean, of a sea capable of "feeding humans" while "consuming their waste", persists despite all scientific evidence to the contrary – evidence that has been accumulating for centuries.

The Red Queen's race in a context of climate change

16 The ocean is strongly affected by the effects of climate change caused by emissions of CO_2 and other greenhouse gases from human activities: the impacts include changes in water temperature, acidification and deoxygenation, leading to changes in ocean circulation and chemistry, rising sea levels, increased storm intensity, and changes in marine species diversity and abundance. These effects combine with hysteresis – a property of a system that does not follow the same path when an external cause increases or decreases – which is quite common in the functioning of marine systems (see, for example, FAUCHALD, 2010; BLACKWOOD *et al.,* 2012; GARBE *et al.,* 2020). As a consequence of this fundamental non-stationarity, non-linearity and high uncertainty in the future trajectories of marine socio-ecosystems subject to the effects of climate change, stakeholders and governance institutions face the challenge of constant adaptation. As RODDIER (2012) suggests, humanity will be engaged in a race in which the more efficiently we consume energy, the more rapidly we change our environment, the more rapidly we must acquire information about that environment – which in turn consumes energy – in order to adapt to it. This brings to mind the paradox of the Red Queen's race in *Alice's Adventures in Wonderland* (CARROLL, 1865): "Now, here, you see, it takes all the running you can do to keep in the same place. If you want to get somewhere else, you must run at least twice as fast as that!"

Innovative approaches to breaking down silos

Towards impact-based governance

17 Interacting with a complex system is a challenge, as it introduces a tension between the need to act and the fact that we will never fully understand the system. Nevertheless, this interaction with complex systems is practised in many areas of life. Medicine is one example. Faced with a problem (a disease), a practitioner, using established knowledge, suggests an intervention (a treatment) for the patient. The appropriateness of the treatment is assessed by the clinical follow-up of the patient, and readjusted until the objective of improving the patient's health is achieved. In other words, this involves an adaptive, dynamic process, based on the constant evaluation of the impact of actions and their continuous readjustment, to achieve the goals of survival and well-being.

There is no absolute guarantee that the goal of good health will be achieved, but the chances of improvement are maximised by this continuous clinical feedback.

18 In the framework of ocean governance, which controls our interventions in complex marine socio-ecosystems, this process of refinement has not yet really been adopted. The diagnosis is there: as elsewhere on the planet, biodiversity is declining at an unprecedented rate (IPBES, 2019), resources are being depleted (JACKSON *et al.,* 2001; MYERS and WORMS, 2003), and tensions between users over access to spaces and resources are intensifying (FLANNERY *et al.,* 2016; QUEFFELEC *et al.*, 2021). Policies are being put in place to implement measures in response to these "diseases" affecting socio-ecosystems. However, "clinical monitoring", i.e. the continuous evaluation of the impact of these remedies, their possible challenges and readjustment to improve the treatment, is still lacking. In the medical analogy, the value we place on human life is clear: this prevents us from taking risks with the treatment we choose, which is why dynamic and adaptive clinical evaluation is so fundamental to medical science. "Increasing the value placed on the protection and restoration of natural ecosystems", as proposed by the EU, for example, therefore requires, among other things, a shift in our ocean governance tools to dynamic procedures that are continuously readjusted according to observed impacts. Although the need for this transition has already been identified (see, for example, DOUVERE and EHLER, 2011), in practice we still use frameworks in which governance decisions are based on static snapshots of the oceans.

19 In the case of MSP, DSTs aim to inform a partition of the marine space, with distinct rules of access and use, making it possible to achieve objectives targeting human well-being (fewer conflicts) and/or biodiversity (maximising conservation while minimising the negative impacts on human activities). However, each DST uses partial representations of a socio-ecosystem that explain only a part (small or large) of the mechanisms that drive the system: syntheses of stakeholders' visions (Seasketch), static representations of socio-ecosystems to optimise the architecture of marine protected areas (Marxan and prioritizR), or dynamic models of the environment (Atlantis, ISIS-fish). Each of these approaches has its strengths, but none is capable of (1) bringing together points of view from different disciplines (e.g. oceanography, ecology, economics, sociology, political science) and the representations of the different stakeholders involved in these measures, (2) anticipating the dynamics and short-term evolution of the system in different scenarios of governance or global change, or (3) providing a transparent representation of the effects of uncertainty (in data, processes, or the effects of global change) or of the multiplicity of competing objectives in the simulated scenario. Yet in the three-dimensional liquid world of the ocean, natural and anthropogenic changes are rapid and permanent and occur in distinct (coastal, offshore, surface, deep) but interconnected domains. Furthermore, there is no formal and/or standardised feedback procedure to ensure that the effectiveness of these zoning tools is periodically reviewed or that their size, architecture or other properties (e.g. the stringency or lenience of bans, the permanent or temporary nature of the protected area) are readjusted in response to observed effects. What chance do we really have of "bringing nature back into our lives" if the treatments are applied without any formal "clinical monitoring" of their effects?

20 To remedy these limitations and better protect ourselves from the risks they entail, we need to imagine a new relationship between governance and marine socio-ecosystems, one that is capable of continuously evaluating the impact of actions and to constantly

revise its modes of action according to the effects observed. In other words, it is a question of moving from the current form of management where objectives are viewed as the means, to management in which the objectives are the ends. Tools and protocols must therefore be put in place to allow this type of adaptive feedback loop.

Developing new types of observations

21 Tools, data processing methods and their representations can be used to enrich and decompartmentalise the kaleidoscopic vision that we have of marine socio-ecosystems. LEBOURGES DHAUSSY (chapter 3) illustrates, for example, how acoustic survey data, which has been implemented in many countries in the Global North and South with the primary aim of assessing the size of exploited fish stocks, can now be used to document ecosystems as a whole. BRUNEL *et al.* (chapter 12) give a Brazilian case study that shows how Google Earth data can be used to quantify, in a spatially explicit way, indicators of anthropogenic activities on the coast and potential fishing power through vessel counts. An atlas of the legal rules applying to Senegal's marine environment has also been produced as part of the Paddle project (Planning in A liquiD worlD with tropicaL stakEs). A study on the use of this atlas highlights how, by making complex legal rules intelligible, this geographical approach can have an impact on administrative authorities (LE TIXERANT *et al.,* 2020).

Building interdisciplinarity

22 The need for interdisciplinarity is often asserted, however, it is rarely put into practice on a large scale. RAGUENEAU (chapter 16) examines this paradox by revisiting different approaches that allow interaction between disciplines (multi-, inter- or transdisciplinary), illustrating why this is essential in order to understand complex systems, and identifying the conditions that would allow its emergence. The urgent need for interdisciplinarity does not only concern scientific fields. PETTORELLI *et al.* (2021) have illustrated how scientific and political agendas need to be brought together on the questions of global climate change and biodiversity.

Reintegrating local communities into participatory governance

23 Although often underrepresented in MSP processes, local communities are essential stakeholders in the dynamics of a socio-ecosystem, and are the ultimate target of policies at the national level. SILVA *et al.* (chapter 4) provide an overview of the interactions between a local community and global resources through the example of the yellowfin tuna fishery in Cabo Verde. TOONEN *et al.* (chapter 13) describe how serious games and participatory mapping can improve public participation in defining new rules of governance. Finally, DUARTE *et al.* (chapter 14) report on a new collective management experiment through the creation of reserves dedicated to recreational uses, such as surfing. These initiatives are in line with what COSENS *et al.* (2021) envisage: developing bottom-up, innovative, collaborative processes, facilitated by clear objectives set by the government "to resolve trade-offs between stakeholders and to link local and indigenous knowledge to the biophysical system, allowing adaptation to emerging outcomes of complexity".

The promise of artificial intelligence

24 Today artificial intelligence (AI) is revolutionising the way we approach the information analysis and the simulation of systems. It adopts an approach that algorithmically mimics natural intelligence digitally, and thus allows us to consider new, perhaps more operational, ways of dealing with complex systems. AI methods involving deep learning algorithms are able to learn through their own data processing. In other words, they can process raw data and autonomously identify the set of metrics and derived variables that best describe and simulate the behaviour of the system under study.

25 AI, along with deep learning, is at the heart of a “digital twin” concept that began in aeronautics, then spread to industry, and is now emerging in force in many scientific fields, including those related to the ocean. A “digital twin” can be understood as a virtual representation of a real system, which evolves over time in parallel with the real system through a continuous supply of data collected by sensors. The digital twin “learns” on its own to resemble the real system using the initial data provided at the outset and acquired continuously, but also by integrating specialised knowledge or by taking inspiration from other real systems with similar functioning. In theory, a digital twin should be able to predict the states of the system, in a time frame that is short enough to be compatible with decision-making. A digital twin could also provide a representation of the same system from different perspectives, thus facilitating interdisciplinary dialogue and pooling of knowledge between, for example, the natural and human sciences.

Bringing nature back into MSP

26 Restoring nature to its rightful place in methods such as MSP is not just important but urgent. How can this challenge be met? How can “nature” be integrated in a practical way into ocean governance mechanisms? While we are far from having a clear and definitive roadmap on this subject, we suggest some conceptual and practical avenues to initiate progress in this direction.

Rephrasing the problem: what if we invited Bartleby to the negotiating table?

27 The “avoid, reduce, compensate” hierarchy is now included in the legislation of several nations. In France, legislation since 1976 (L122-3 of the Environmental Code) has specified that any development project must avoid environmental damage, reduce the impacts that could not be avoided, and compensate for any damage that could not be avoided or reduced. In Europe, this hierarchy is an objective of Directive 2011/92/EU of 13 December 2011 (Article 5-b, see EU directive, 2011). It is also included in the EU Green Deal, “a roadmap for making the European economy sustainable by turning climate and environmental challenges into opportunities in all policy areas and ensuring a just and inclusive transition for all”. To this end, the explanatory memorandum accompanying each EU legislative proposal or delegated act must include a specific section explaining how the initiative respects this principle.

Unfortunately, project managers and governance bodies are usually quick to skip the first step, which is to avoid creating a negative externality in the first place. This is partly what led VAROUFAKIS (2020) to consider that “The EU Green Deal is a huge greenwashing exercise.”

28 *Bartleby* is the title of a short story by Herman Melville published in 1856. Bartleby is hired as a clerk by a solicitor to copy documents. As time goes by, the clerk, who had at first been hard-working and conscientious, begins to refuse to do what’s asked of him, simply saying “I would prefer not to.” This story has long fascinated philosophers, many of whom have commented on it (Deleuze, Derrida, Blanchot, Zizek, Lordon; see BERKMAN, 2011). An embodiment of passive resistance, the story highlights “the power of doing nothing” (EGO, 2011). In today’s public space, a “Bartleby-like” stance might be to cease activities that do not create anything truly new and/or useful, and thus mark the starting point for a different world.

29 More concretely, in the context of MSP, it is time to deploy tools that objectively document what could be gained by foregoing certain human activities. DSTs, as well as strategic impact assessments, should include formal protocols for considering, evaluating and weighing up the pros and cons of banning human activity in certain marine areas. DSTs now widely used in the systematic selection of reserves, such as Marxan, are formulated mathematically in such a way that minimum biodiversity maintenance targets are set (e.g. to maintain “at least 50% of current biodiversity”), and then the tool seeks the protected area architecture that will maximise the maintenance and/or development of human activities. Inviting Bartleby to the MSP table might mean reversing the burden of effort in mathematical optimisation formulas: setting a level of human activity considered indispensable, with the biodiversity to be maximised being the degree of freedom for optimisation.

Questioning certain “axioms” to imagine new solutions

30 In her books, the environmental philosopher Virginie Maris has put forward a number of valuable insights into our societies’ relationship with nature (MARIS, 2010; 2014; 2018). Notably, she has highlighted how certain notions presented as axiomatic undermine our ability to rethink and reinvent our relationship with nature. We have borrowed elements from her thinking below to attempt to identify ways in which they might be useful in the context of MSP.

Towards less reductionist and more inclusive management methods

31 The concept of ecosystem services was initially a strategy to argue for a redefinition of nature and its protection in terms that were audible in the economic sphere. This concept has been so attractive to business, policymakers and scientists that the strategy has become a pseudo-axiom. The immediate corollary of the notion of ecosystem services is the valuation of these services. To this end, economists have adopted various methodological tools to make visible values that are often hidden. These tools have been the subject of much criticism from both a methodological and conceptual point of view. Generally speaking, the very principle of quantification, inherent in monetary evaluation, presupposes, while almost never explicitly stating it, that the various values of nature are reducible to their instrumental aspect alone; that this value can be expressed in a common unit, and as a result becomes substitutable

(giving rise to the concept of compensation or offsetting). By adopting an economic approach, first metaphorically, then very concretely, allowing a market logic to infiltrate increasingly deeply into public policy on nature protection, we have opened the way to the dissolution of nature in the economic sphere. In a rationale of maintaining natural capital and associated ecosystem services, decision-makers are encouraged to focus solely on nature's instrumental value: i.e. to protect natural environments only to the extent that benefits can be derived from them.

32 An alternative vision, and one particularly relevant to MSP, is to involve local people in an approach that makes nature protection a lever to reduce the vulnerability of human communities (see, for example, DIAZ *et al.*, 2018; LINDQUIST, 2017). Preserving the natural character of a site should not imply excluding all use, but rather ensuring that human activities do not disrupt the trajectory of the ecosystem as a whole. Conservation can thus serve as a bulwark to protect cultures and ways of life threatened by the multiple projects developed in the neoliberal logic of economic growth that engenders competition between peoples and territories. In this respect, the "extractive reserves" created under Brazilian legislation (Resex: protected geographical areas whose objective is to protect the livelihoods and culture of traditional populations, as well as to ensure the sustainable use of the area's natural resources) are an interesting framework that could be explored in the context of marine spaces.

Reference environments, shifting baselines and the non-regression principle

33 Nature conservation, especially with the emergence of the notion of rewilding (NOGUÉS-BRAVO *et al.*, 2016; PERINO *et al.*, 2019), is faced with the problem of defining spatial and temporal reference states on which to base restoration objectives. Yet it is difficult, if not impossible, to identify what a "natural reference state" would be, as this is so affected by the shifting baseline syndrome (PAULY, 1995) and the environmental amnesia it engenders. This is particularly true in marine environments, where direct observation is quite difficult. Inviting nature back into MSP, through the rewilding of certain areas, does not necessarily mean actively restoring wild ecological conditions with the reintroduction of species, for example. It could mean much less intrusive behaviour that integrates the notion of rewilding with the notion of "letting go" in order to establish a feral nature (SCHNITZLER and GENOT, 2020). In this perspective, managers should not try to manufacture nature, but support it on its journey, repairing damage where it occurs to allow it to get back on track and removing obstacles and impediments.

34 In law, the application of the principle of non-regression (PRIEUR, 2012) would be fundamental to guide such an approach within MSP. This principle requires that we do not go back on our commitments made at the UN Conference on Environment and Development held in Rio in 1992. In order to assess whether a new rule or the modification of an old rule is regressive, a special chapter should be included in the impact assessment of a bill or decree to demonstrate non-regression on the basis of relevant scientific and legal indicators of the state of the environment. Currently, there is no legal implementation of this in Senegal and West Africa. In Brazil, it is certain that this principle is being undermined by a growth policy that is cut off from the environmental protection process. One example is the reauthorisation of hundreds of banned pesticides in Brazilian legislation by the Bolsonaro government (see, for example, BRAGA *et al.,* 2020). In Europe, countries attach varying degrees of importance

to the non-regression principle. European and international institutions such as the Council of Europe and the UN have recognised that a healthy environment is a human right, and human rights law is increasingly being used to protect the environment.

Overcoming the nature–culture divide in marine ecosystems

35 Different anthropological perspectives (Lévi-Strauss, Descola, Pignochhi) have alerted us to the fact that the relationship between humans and nature is likely be the most crucial question in the years ahead. These anthropologists have described the way humans perceive the environment around them as their way of "composing" the world. So-called Western societies have historically composed the world on the opposition between nature and culture, which confines them to taking a strictly utilitarian view of natural ecosystems in general and marine ecosystems in particular. The challenge of transitioning from this will involve transforming our utilitarian and anthropocentric vision of the world into a view that recognises the intrinsic value of marine ecosystems. In this new vision, the definition of the governance of marine spaces would go beyond the sole objective of maintaining the functions performed or the services rendered by ecosystems to recognise that the preservation of healthy marine spaces and living beings is an axiom that needs no justification, in the same way as human well-being. In such a paradigm, the notion of compensation becomes irrelevant: if one accepts the axiom that a human being can never be replaced by another living being, then every living being is equally irreplaceable.

36 The grounds for such a paradigm shift are emerging from all sides: in science, environmental ethics and law. The Gaia hypothesis formulated by the environmentalist James LOVELOCK (1979) revisits the human–environment relationship. Instead of considering the Earth as a universe where living beings coexist, it starts from the idea that the Earth is itself a living meta being. Its organs, tissues and circulatory systems are integrated and function together. In the field of law, the proposal to consider nature or its elements as legal persons would be a decisive step towards "bringing nature back into our lives" (HERMITTE, 2011). At the frontiers of ecology and geography sciences (MATHEVET *et al.*, 2010; MATHEVET, 2012), the concept of "ecological solidarity" has developed, inspiring France's national park legislation since 2006, and its 2016 biodiversity legislation. Ecological solidarity is defined as a concept "that recognises the close interdependence of living beings with each other and with natural or managed environments". This concept also emphasises the "community of destiny" between humans, societies and their environment, considering the co-evolution of human societies and nature through the use of space and natural resources. Ecological solidarity is expressed in practice when the inhabitants, users and visitors to an area judge their actions or non-actions on their consequences on the components of the community. Applied to MSP, these concepts can challenge the current generic objective of the MSP process (resolving conflicts to best satisfy each of the stakeholders) and advocate for a shift to another type of pact, in which stakeholders make decisions based on the evaluation of the impacts of their actions and non-actions on the marine socio-ecosystems they live within.

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NOTES

1. The Republic of Cape Verde changed its official name in all languages to the Republic of Cabo Verde on 24 October 2013 in a request submitted to the Secretary-General by the country's Permanent Representative to the United Nations. In accordance with this request, the country is referred to as Cabo Verde in this publication, unless it occurs in titles of previously published works, references or printed sources mentioning Cape Verde.

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Part I. Disciplinary perspectives on marine ecosystems in the tropics. A prerequisite for marine spatial planning

Chapter 1. Diversity and trends of marine ecosystems in the tropical Atlantic

Arnaud Bertrand and Martin Zimmer

EDITOR'S NOTE

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Introduction

1 Marine ecosystems are made up of a mosaic of interconnected subsystems. Physics determines the exchanges between these subsystems (for example, how the productivity generated in a given area influences mangroves that may be separated by a distance of tens or hundreds of kilometres, or the transport of larvae from hatching areas to nurseries), and complex hydrological and environmental processes influence the lifecycle of marine species, governing their spatiotemporal distribution and shaping faunal assemblages. The integrity of one subsystem can thus determine the integrity of another. This means that a human decision in one place can have a dramatic impact on a distant marine subsystem. Thus, management policies, which are

currently fragmented and sectoral, must take into account the physical and ecological connectivity between subsystems. This is particularly important today, as human activities have both a direct impact on the integrity of ecosystems and an indirect impact through anthropogenic global warming.

2 In this context, marine spatial planning (MSP), which aims to organise and harmonise the diverse human activities in marine and coastal environments, needs to acknowledge and explicitly take into account ecosystem dynamics. Beyond considering the diversity of stakeholders and understanding their needs and requirements, spatially explicit information on the availability of natural resources and processes is of key importance for effective MSP. Despite the existence of extensive long-term datasets on oceanographic processes (e.g. Pirata[1]), a comprehensive view of tropical Atlantic coasts, coastal waters and their natural resources is still lacking. This chapter aims to summarise information on marine and coastal natural resources and their state-of-use/exploitation for case studies in the western tropical Atlantic (Brazil) and eastern tropical Atlantic (Cabo Verde[2], Senegal) (for a more comprehensive review see BERTRAND and ZIMMER, 2019). Although far from exhaustive, this chapter attempts to offer key points that allow a better understanding of the processes involved.

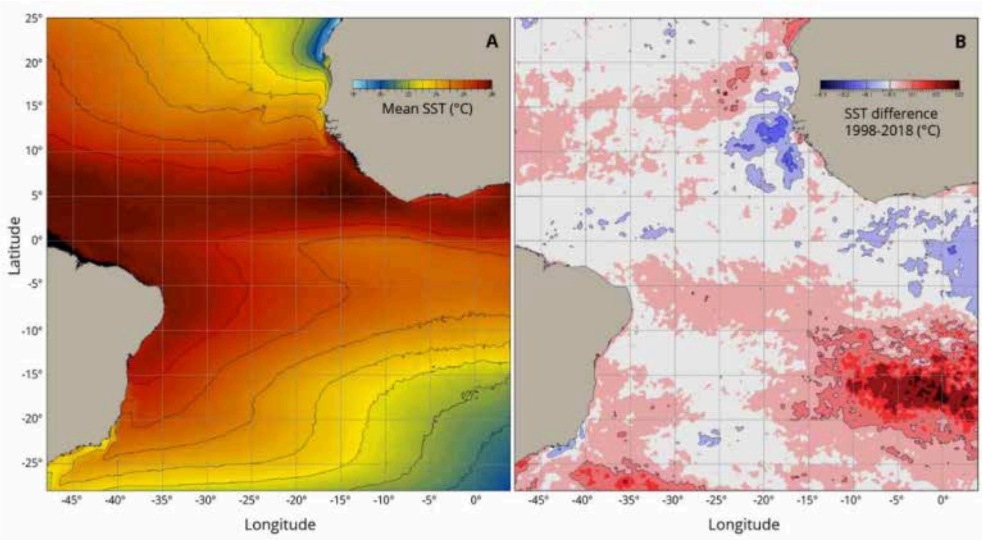
General trends in oceanographic conditions in the tropical Atlantic

3 The tropical Atlantic is characterised by a belt of water with high sea surface temperature (SST) (>27°C), centred at 5° N in the western Atlantic. Warm surface water masses extend over a range from 15° N to 15° S in the western Atlantic, dominating the coastal waters of eastern and northeastern Brazil (fig. 1A). The Senegal-Mauritania region has a comparatively low mean SST (< 19°C), while the Cabo Verde area has an SST of 25–26°C, originating from the North Equatorial/Mauritanian countercurrent (Guinea Dome). The warming observed from 1985 to 2007 (DEMARCQ, 2009) in the western tropical Atlantic has significantly attenuated over the last two decades (fig. 1B). Notable cooling is observed in the Senegalese and Guinean regions and in Cabo Frio in Brazil. Other regions, including northeast Brazil, show no or only moderate warming (< + 0.05°C per decade). The cooling observed in upwelling areas seems to indicate the rise of nutrient-rich waters, leading to an increase in phytoplankton biomass (fig. 2A). This positive trend in productivity has been even more intense over the last 16 years (fig. 2B). A moderate positive trend in SST has been observed in the equatorial region, where eastern cooling is associated with a slight increase in chlorophyll a near the equator. The temporal trend in productivity does not show a clear pattern along the northeast coast of Brazil, with a slight coastal increase when considering the full period (1998–2018), but a moderate decrease in the last 16 years (2003–2018). This discrepancy may be due to the use of two satellite sensors during the period 1998–2018 (fig. 2A) versus a single sensor during the period 2003–2018 (fig. 2B).

4 The tropical belt is considered the most vulnerable area of the planet to the impacts of climate change. Decreased precipitation has been observed, for example, in northwest Africa and the interior of the northeast coast of Brazil (IPCC, 2014a), and significant ocean warming is expected in large parts of the tropical Atlantic (figs. 1A and 1B). These changes in water temperature will force many species to move to the poles or

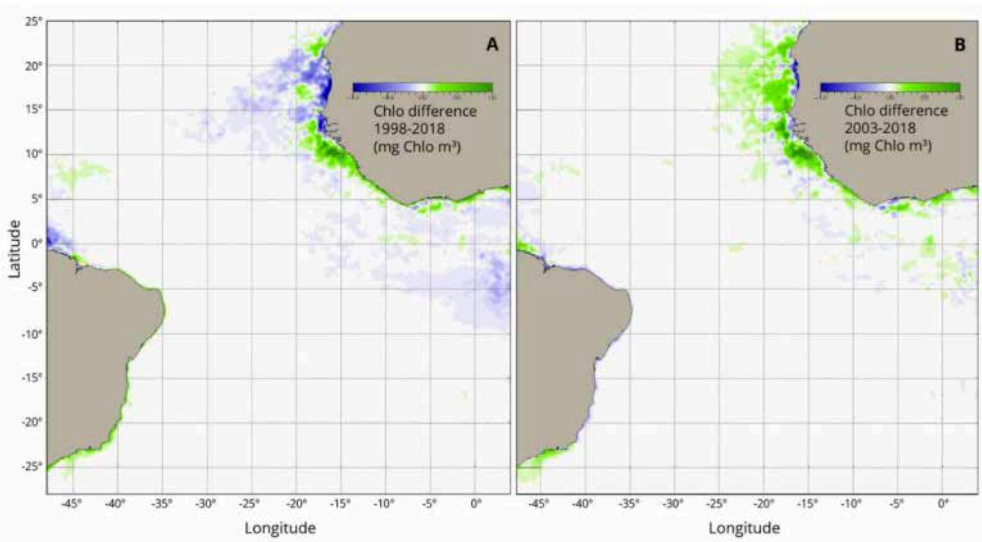
deeper waters to survive, or to significantly alter their behaviour, leading to local extinctions and range shifts that will have a significant impact on the trophic structure of ecosystems and their surplus production available to fisheries.

Figure 1. Mean temperature (A) and sea surface temperature (SST) differences (B) in the tropical Atlantic for the period 1998–2018



Data source: AVHRR SST (advanced very high-resolution radiometer) sensor (pathfinder v5.3), combined night and day SST data

Figure 2. Trends in chlorophyll a concentration in the tropical Atlantic for the periods 1998–2018 (A) and 2003–2018 (B)



Data source: SeaWiFS (sea-viewing wide field-of-view sensor) (1998–2007) and MODIS (moderate-resolution imaging spectroradiometer) (2003–2018)

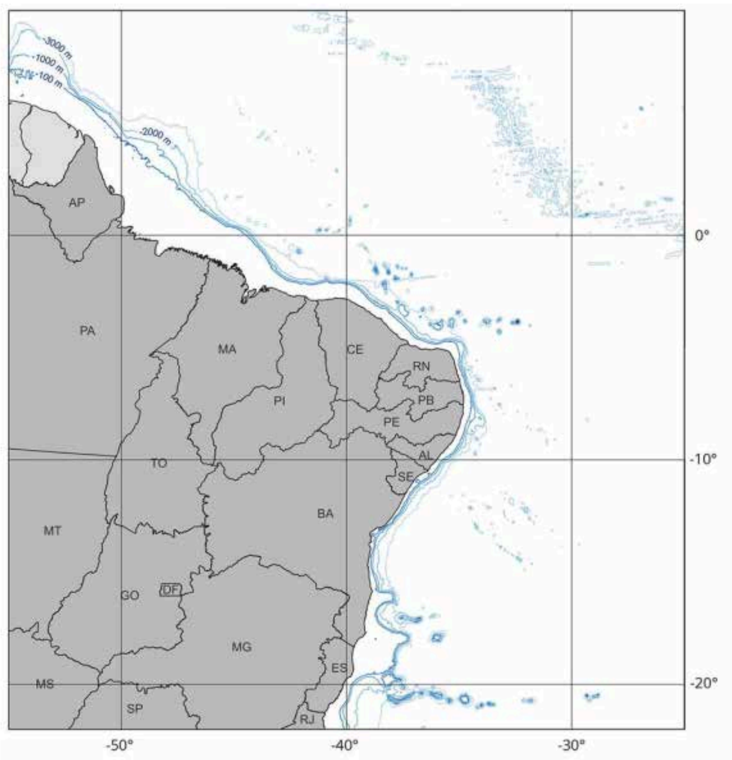
The tropical Atlantic: a diversity of ecosystems

The tropical Atlantic is small compared to the immense Pacific, yet it encompasses a variety of systems with diverse characteristics. The three systems considered in this chapter (northeast Brazil, the Cabo Verde archipelago and the Canary Current system) differ considerably in their characteristics and the levels of knowledge about them. The following provides some background information for each system that may help in understanding the other chapters in this handbook.

The northeast coast of Brazil

6 The northeast coast of Brazil, which extends from Bahia state to Maranhão state (fig. 3), is characterised by high SST (26–30°C, ASSUNÇÃO *et al.*, 2020) and low productivity, mainly due to the influence of oligotrophic tropical waters. It has fairly high diversity and endemism, although much lower than in the Caribbean region (TOSETTO *et al.*, 2022). The northeast coast of Brazil has a narrow continental shelf of 45–60 km dominated by a sandy and rocky bottom (VASCONCELLOS *et al.*, 2011; EDUARDO *et al.*, 2018). Coral reef formations are characteristic of this region, and fisheries in this area target reefs distributed along the continental shelf to the continental slope and on oceanic banks (FERREIRA *et al.*, 1998; FERREIRA and MAIDA, 2001; EDUARDO *et al.*, 2018). However, due to the impacts of global change, Brazilian reefs could experience a massive decline in coral cover in the next 50 years and may become extinct in less than a century (FRANCINI-FILHO *et al.*, 2008).

Figure 3. Bathymetry of the north and northeast coasts of Brazil



Brazilian states: AL: Alagoas; AP: Amapa; BA: Bahia; CE: Ceará; DF: Distrito Federal; ES: Espiritu Santo; GO: Goiás; MA: Maranhão; MG: Minas Gerais; MS: Mato Grosso do Sul; MT: Mato Grosso; PA: Pará; PB: Paraiba; PE: Pernambuco; PI: Piauí; RJ: Rio de Janeiro; RN: Rio Grande do Norte; SE: Sergipe; SP: São Paulo; TO: Tocantins.
The solid blue line shows the bathymetry at 100 m, 1000 m, 2000 m and 3000 m.
Source: A. Bertrand, M. Zimmer based on ETPOPO bathymetric data (https://sos.noaa.gov/catalog/datasets/etopo1-topography-and-bathymetry/)

7 Estuaries are key ecosystems on the Brazilian coast (LANA and BERNADINO, 2018). As economically important nursery and feeding areas for many coastal fish species, the livelihoods of many fishermen along the coast depend on them. Marine aquaculture activities are concentrated in Ceará and Rio Grande do Norte, accounting for almost 80% of total production in the Brazilian Nordeste. Further north, up to the mouth of the Amazon, the coasts and estuaries are often occupied by dense mangrove forests growing in muddy sediment. The mangrove forest south of the Amazon River is one of the two largest continuous mangrove habitats in the world: the above-ground biomass per unit area of these mangroves is higher than in most other regions of the tropical and subtropical Atlantic. Due to the high turbidity of the coastal waters, the shallow areas have little seagrass and few coral reefs.

8 The northeast is one of the most densely populated coastal regions in Brazil, with the state of Pernambuco standing out as the epicentre of this population concentration. In this region in recent decades, the household pollution and industrial activity associated with urbanisation has led to the degradation of coastal ecosystems such as mangroves, seagrass beds and coral reefs, most severely around the main urban centre, Recife. Human occupation and expansion have altered both water quality and aquatic biodiversity through the elimination of mangroves, changes in the trophic structure of the ecosystem, elimination of spawning and nursery sites, decreased biodiversity, pathogen infections, increased parasitic loads in commercially important species and mercury accumulation (VIANA *et al.*, 2010, 2012; LOPES *et al.*, 2019).

9 In Brazil, artisanal or small-scale fishing accounts for more than 90% of employment in the fisheries sector. In 2011, almost 600,000 fishermen were directly engaged in full-time fishing activities in fleets composed of vessels less than 12 m in length. Artisanal fishing is carried out along the northern and northeastern coasts, while most of the industrial fishing fleet is concentrated in southern Brazil (VASCONCELLOS *et al.*, 2011). Brazil has a poor record of fisheries management, with several stocks facing overexploitation and lack of systematic management (GASALLA *et al.*, 2017). Weak governance, erosion of traditional resource use systems, uncontrolled access to natural resources, poverty, lack of alternative employment and easy access to stocks with low investment and exploitation costs have encouraged overfishing and exacerbated climate-induced changes in artisanal fisheries (GASALLA *et al.*, 2017). The continued depletion of fisheries resources and environmental degradation of coastal areas particularly affect artisanal fishing. Current government strategies appear ineffective in overcoming the obstacles that hinder the sustainable development of artisanal fishing communities along the Brazilian coast.

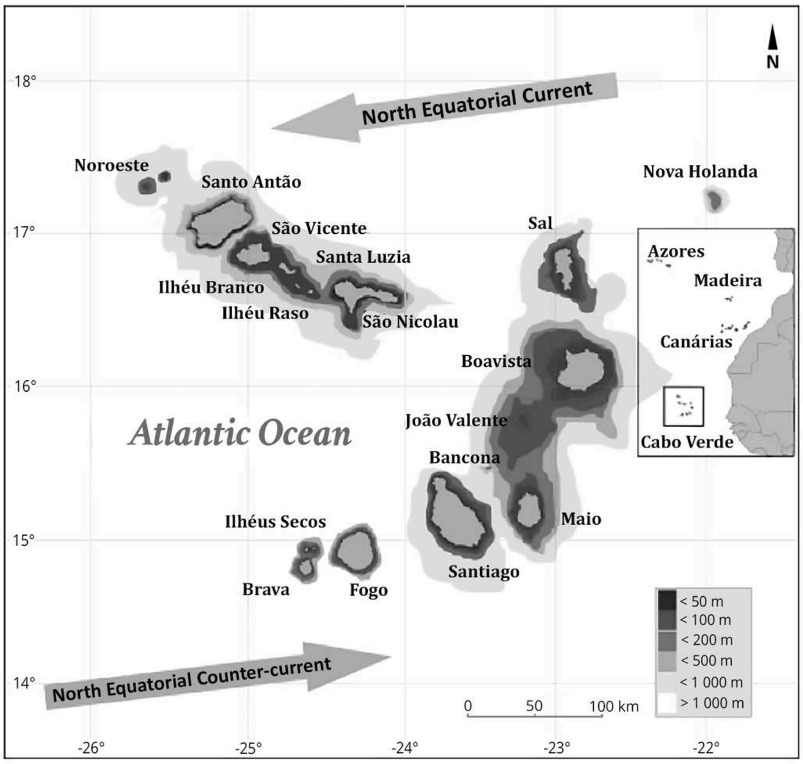
10 Marine extractive reserves represent the most significant government-supported effort to protect common property resources on which small-scale traditional fishermen depend. They are generally owned by the government, but rights of access and use, including extraction of natural resources, are allocated to local groups or communities. Marine extractive reserves benefit some 60,000 artisanal fishermen along the coast, although their effectiveness is hampered by weak law enforcement and anthropogenic and economic pressures, including tourism (SANTOS and SCHIAVETTI, 2014; BERTRAND *et al.*, 2018). In addition, Brazil is a data-poor region for fisheries. Brazilian fisheries statistics have not been reported since 2011 (2007 for detailed statistics), when the existing system was gradually dismantled and not replaced. The overall lack of information on these fisheries is a subsidiary problem that gives low political visibility to the sector

and thus contributes to perpetuating its status (VASCONCELLOS *et al.*, 2011). This is a serious obstacle to the development of effective marine spatial planning.

Cabo Verde

11 The Cabo Verde archipelago, together with the Azores, Madeira, Selvagens and Canary Islands, is part of Macaronesia, lying in the North Atlantic Ocean, close to the West African coast and the western Mediterranean region. The Cabo Verde archipelago extends over 58,000 km^2 of ocean and has about 1050 km of coastline. It consists of ten volcanic islands divided into two groups: (1) the Barlavento (windward) group, which includes the islands of Santo Antão, São Vicente, Santa Luzia, São Nicolau, Sal and Boa Vista, as well as the islets Raso and Branco; and (2) the Sotavento (leeward) group, to the south, which includes the islands of Maio, Santiago, Fogo and Brava and the three islets known as Rombos: Grande, Luís Carneiro, and Cima (Fig. 4).

Figure 4. Cabo Verde Archipelago



Source: MEDINA *et al.* (2007)

12 Oceanic islands trigger complex physical processes that increase primary production and concentrate high tropical levels. This mechanism, known as the island mass effect (DOTY and OGURI, 1956), creates a multiplicity of habitats with a rich array of fauna and flora. Nevertheless, biodiversity is restricted to the narrow geographical limits of the islands and is extremely vulnerable to disturbance by human activities (DUARTE and ROMEIRAS, 2009). Scientific studies are still ongoing and much remains to be discovered about the structure and functioning of Cabo Verde coastal ecosystems.

13 Fish is the main source of animal protein for the people of Cabo Verde. Although fishing contributes only about 5% of the gross national product (GNP), the sector

employs nearly 11,000 people and is important for the economy, especially in terms of exports, reaching a record 84% of national exports in 2014 (INE, 2018). Tuna is the most remunerative species caught in Cabo Verde, accounting for more than 80% of industrial catches until 1991. It is the most exported fish (43% of exports), followed by processed forms of mackerel (40%). The fishing sector can be divided into two distinct categories according to the market for the catch and the type of vessel: artisanal fishing, responsible for the decentralised supply of fish to local communities and islands, and industrial fishing, whose catch supplies the export market, the canned food market and the main urban centres of fish consumption at the national level.

14 Cabo Verde relies heavily on maritime traffic for the transport of goods and services between the islands, as well as within and outside the country. Bunkering (the supplying of fuel for ships) and shipyard activities, which have the potential to grow, may increase environmental and public health risks. Semi-industrial or industrial dredging in coastal areas is mainly related to the construction or expansion of ports (MONTEIRO and RAMOS, 2014). The few other dredging zones on the seabed are all located next to the coastline. As large sandbanks are present on many islands, the country's dredging zones are mainly located on beaches and the bottom of bodies of fresh water. Sand extraction activities were started along the coasts of the islands of Maio and Fogo, but this has been discontinued due to the threats it poses to marine biodiversity (CORREIA, 2012), a fact already reported by the European Commission in 2010.

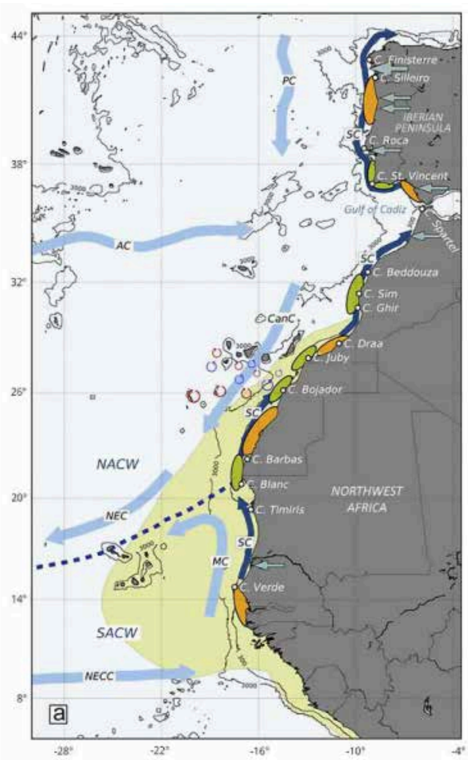
15 The World Bank considers tourism one of the most important investments for the future of Cabo Verde. If the country is to make tourism a major contributor to the gross domestic product (GDP), it will need to address key issues such as sanitation, waste management and illegal aggregate extraction. In 2000, the tourism sector accounted for only 6.4% of GDP. It then increased to 16% in 2010 and 22% in 2018 (BCV, 2018). This increase in tourism has put additional pressure on coastal and marine habitats. To address this reality, Pana II (Plano de Acção Nacional para o Ambiente, 2004) contains a series of planned programmes and studies aimed at enhancing and conserving Cabo Verde's biodiversity, which could be used to define a sustainable tourism strategy (e.g. REINA, 2015).

Upwelling system of the Canary Current

16 The Canary Current system is one of the major upwelling systems on the eastern edge of the world oceans (FRÉON *et al.*, 2009). The African part of the Canary Current system covers the exclusive economic zone (EEZ) of Morocco and Mauritania, and seasonally covers the area off Senegal, Gambia and Guinea-Bissau; it can exceptionally extend into Guinean waters (fig. 5). The width of the continental shelf varies from 50 to 150 km, with the largest parts located off Western Sahara/southern Morocco and south of Cabo Verde (fig. 5). Two large, quasi-permanent upwelling cells at Cape Ghir (~30° 38′ N) and Cape Blanc (~21° N) export surface water offshore. Between these two capes, other upwellings are commonly found at Cape Juby (~27° 56′ N), Cape Boujdor (~26° 12′ N) or in between (BARTON *et al.*, 1998). However, there are many cases where there is no upwelling activity in this region (ARÍSTEGUI *et al.*, 1994). Seasonal upwelling is also present off Cabo Verde (~14° 30′ N), when trade winds favour this in the area. The upwelling is seasonal in the northern part of the system (from northern Morocco to

~28° N), permanent in its central part (~21-28° N) and seasonal again in its southern part.

Figure 5. Schematic map of the Canary Basin showing the main currents (light blue: surface currents; dark blue: slope currents), the main headlands, freshwater (blue arrows) and dust inputs (> 10 g/m^2/year in yellow), retention (orange) and dispersion (green) zones on the shelf, the frontal zone between water masses (blue dashed lines) and mesoscale eddies (blue: cyclones; red: anticyclones) south of the Canary Islands.



AC: Azores Current; CanC: Canary Current; MC: Mauritanian Current; NACW: North Atlantic Central Water; NEC: North Equatorial Current; NECC: North Equatorial Counter Current; PC: Portuguese Current; SACW: South Atlantic Central Water; SC: Slope Current.
Source: ARÍSTEGUI ***ET AL.*** (2009).

17 The high biological productivity of the northwest African coast, due to the upwelling of nutrients that sustain large fish populations (FRÉON *et al.*, 2009), supports fisheries that play a crucial role for the economy and food security. The waters off northern Mauritania are among the most productive marine areas in the world and serve as important fishing grounds, while the waters off Senegal are reported to be of average productivity. Along the West African coast, the Sine-Saloum estuary in Senegal lies in the transition zone between a dry arid landscape and humid tropical coastal ecosystems bordered by mangroves and is an important nursery for fish. The shelf is wide and provides a fertile habitat and feeding ground for groundfish and small pelagic fish (SPF) important for coastal fisheries. The region's fisheries are the main source of animal protein for a population of over 225 million people, a third of whom are children (FAILLER, 2014). Today, the majority of stocks of long-lived species are depleted, and SPF have become the main species exploited, both for the global food industry (fish meal, TACON, 2004) and for human consumption (FAILLER, 2014). Pelagic fisheries north of Cabo Blanco are generally dominated by European sardine (*Sardina pilchardus*) and anchovy (*Engraulis encrasicolus*), while south of Cabo Blanco, sardinella (*Sardinella aurita*

and *S. maderensis*) generally dominate landings. Under current global warming conditions, the distribution of sardinella has been shifting northwards since the mid-1990s (SARRÉ *et al.*, 2018). Due to the Sahelian food crisis, demographic pressure on the coastal fringe has increased artisanal fishing activities (BINET *et al.*, 2013; FAILLER, 2014), adding to industrial fishing pressure. Overfishing of SPFs threatens the capacity of marine ecosystems to support fisheries (LAURANS *et al.*, 2004; PALA, 2013; THIAO *et al.*, 2012), amplifying the risk of collapse (MCOWEN *et al.*, 2015; ESSINGTON *et al.*, 2015). While there is comprehensive literature on the dynamics of SPFs in the northern upwelling zone, which is of particular interest to foreign fleets, our knowledge of biology, distribution, reproduction and exploitation status of inshore species in southern countries (from Senegal to Côte d'Ivoire) is severely lacking.

18 In central Senegal, the Sahelian drought of recent decades (PAGES and CITEAU, 1990) has led to the inversion of the Sine-Saloum estuary, leading to higher salinity inland than at the mouth of the river. Coupled with the fact that many arid regions are becoming drier as a result of climate change (IPCC, 2014b), the impacts of the estuary inversion on the function of the Sine-Saloum as a critical habitat and nursery area for local fish species are relatively unknown. Despite the near absence of sedentary fish species in a marine protected area in the delta, monitoring has revealed significant threats to fish biomass and diversity (BROCHIER *et al.*, 2011; ECOUTIN *et al.* 2014; SADIO *et al.*, 2017). Similarly, little is known about the hydrodynamics and tidal forcing within the spatially complex Sine-Saloum estuary with its many tributaries (locally called *bolongs*), the responses to environmental changes at the ecosystem level, and their contributions to human well-being. Local communities rely heavily on natural resources that come directly or indirectly from the mangroves that populate the banks of the estuary, such as fish, crustaceans and shellfish. These mangroves have also undergone drastic changes during the inversion of the estuary, and currently they do not grow further inland (eastwards) than the economically important town of Foundiougne. Despite recent changes in climatic conditions in the interior, the inversed salinity patterns of the estuary did not seem to reverse, but detailed studies and an understanding of the mechanisms are lacking. The sustainability of seafood extraction, mainly through artisanal fisheries, from the estuary and the corresponding coastal stretch is difficult to assess, as there is no data on landings or on fish or shellfish stocks in sufficient quantity or quality (BOUSSO, 2000; SIMIER *et al.*, 2004; ECOUTIN *et al.*, 2010).

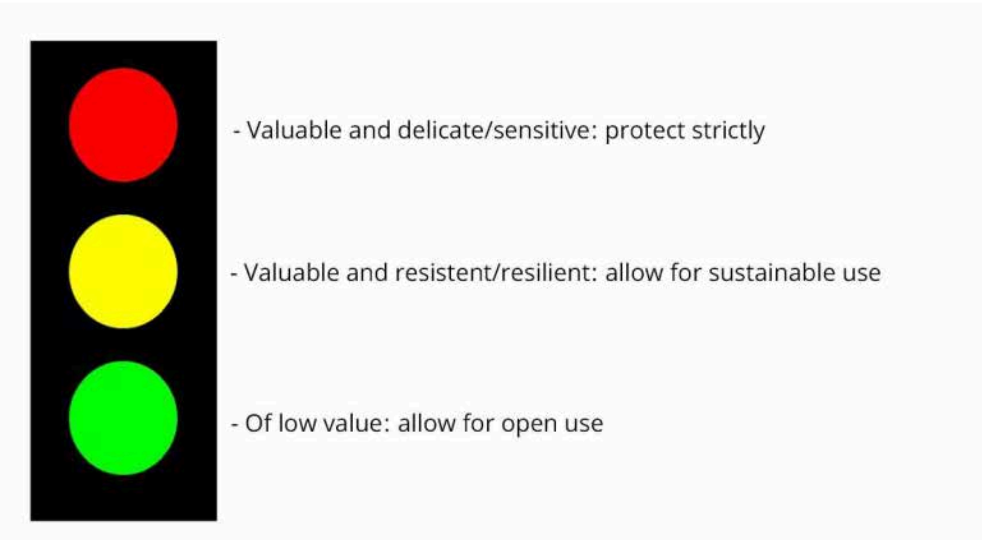
Conclusion

19 The tropical Atlantic is of global importance as an integral part of the global network of ocean currents and a matrix for the migration of marine species, many of which are of significant regional and international economic value. Its rich seafood stocks provide subsistence, food security and income for millions of coastal inhabitants and are exploited by neighbouring countries and beyond, including Europe. The sustainable management of these resources, their use and extraction, is essential on a global scale to ensure food security (local and international), human well-being and livelihoods, and help to prevent human migration due to poverty or disasters. This requires taking into account not only fisheries, but also competing activities and uses, as well as other contributions of the seas and coasts to human well-being. In order to avoid – or at least minimise – conflicts between human use/exploitation of natural resources and

environmental protection, maritime spatial planning must take into account in its priorities the demands of local/regional societies and the need to protect coastal and marine ecosystems from abuse and overexploitation. The aim should be a spatially explicit distribution of land and sea use that seeks a trade-off, optimising human benefits while minimising environmental damage.

20 One potential approach to provide such recommendations for policy- and decision-makers is the "traffic light concept" (HELFER and ZIMMER, 2018; fig. 6). This takes into account the stability, resistance or resilience of the ecosystem as well as its value to local, regional and global stakeholders. Ecosystems are classified as red, yellow or green (like a traffic light) based on field observations and measurements, as well as predictive models of ecosystem change under different scenarios of current and future environmental conditions and land and resource use change. To make the result user-friendly for stakeholders as well as policymakers, the categories are limited to a maximum of three and take into account that full protection of a given area is only possible and acceptable to local communities if neighbouring areas can be used. An area classified as red is "important and sensitive" and must be protected completely from human use. An area classified as yellow is "important and stable/resilient", permitting (sustainable) use. An area classified as green is "degraded or of little value in the future" and can be used according to local or regional needs, e.g. for infrastructure development, agriculture or aquaculture. These "green light" zones would limit the necessary and unavoidable use of space in areas of low ecological value, sparing areas of high ecological value from destruction or degradation.

Figure 6. Traffic light concept for spatial prioritisation of ecosystem protection and use



Source: HELFER and ZIMMER (2018)

21 Such approaches require a robust understanding of coastal systems informed by multidisciplinary knowledge, including ecology, socio-economics, sociology, law, as well as governance and public policy. The case studies of selected regions on the edges of the western Atlantic (Brazil) and eastern Atlantic (Cabo Verde and Senegal) presented in this chapter reveal our limited knowledge on many aspects necessary for effective MSP. Assuming that the same is true for the many coastal regions of the tropical Atlantic that are not covered in this chapter, more detailed studies of tropical

coastal and marine ecosystems, their processes and functions, their use and exploitation, and how resource use affects these ecosystems, are essential.

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NOTES

1. Prediction and Research Moored Array in the Tropical Atlantic: www.pmel.noaa.gov/gtmba/pmel-theme/atlantic-ocean-pirata
2. The Republic of Cape Verde changed its official name in all languages to the Republic of Cabo Verde on 24 October 2013 in a request submitted to the Secretary-General by the country's Permanent Representative to the United Nations. In accordance with this request, only Cabo Verde will be referred to in this publication. In order to respect the titles of previously published works, references or printed sources mentioning "Cape Verde" (in French) or "Cape Verde" (in English) in their title have not been changed.

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Chapter 2. Pollution in a liquid world

Sources and impacts of pollution in Senegal and the implications for marine spatial planning

Éric Machu, Timothée Brochier, Xavier Capet, Siny Ndoya, Ibrahima Sidiki Ba and Luc Descroix

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Introduction

1 Historically, the ocean has been considered large enough to accommodate all kinds of waste produced by human societies without causing damage (GORMAN, 1993). This logic has been taken to extremes by industrial societies, which are only now becoming aware of the limits of this approach. The origin and nature of the waste discharged into the marine environment vary highly: waste from the operation of ships, civil and military nuclear activities, industrial and domestic wastewater, run-off from agricultural inputs, brine and contaminants from the desalination of seawater, discharge and leaks linked to the extraction of raw materials, etc. The ocean is also subject to accidental or unintentional pollution, often as a result of negligence: solid waste including macro and microplastics, oil spills, leaks of radioactive materials, etc.

2 Human disturbance of nature in general, including the ocean, is characterised by the introduction and diffusion of pollutants, i.e. agents of external origin: biological, physical or chemical. Above a certain threshold, and sometimes under certain conditions (potentiation), these pollutants cause negative impacts on all or part of an ecosystem. Human interest in marine pollution now mainly concerns the impacts it may have on exploited biomass, consumer health, occupation of the marine environment and conservation of biodiversity.

3 In Senegal, studies measuring pollution and its potential impacts are rare. Between 2000 and 2013, the Senegalese population increased by almost 40% (from 9.8 million in 2000 to 13.5 million in 2013, the date of the first census), an increase that is still accelerating, according to the 2013–2063 projection of the Senegalese National Agency

for Statistics and Demography (ANSD) (17.2 million in 2021), with the 30 million mark expected to be passed by 2040.[1] Combined with the rural exodus, this dynamic has increased the population of Dakar from 400,000 inhabitants in 1970 to 2.2 million in 2002 and 3.6 million in 2018. More generally, the number of those living in coastal areas is increasing; due to a combination of lack of awareness and inefficient waste collection systems, a growing amount of non-biodegradable waste is being dumped on beaches and in estuaries. The recent media coverage of the dumping of hospital waste on the beaches around Cape Manuel[2] is an example of this (fig. 1A).

Figure 1. Sedimentation of waste. A. Accumulation of hospital waste in strata on the beach of Cap Manuel

Source: Screenshot of the report "Medical waste on beaches: images of horror… a hospital caught in the act"

Figure 1. Sedimentation of waste. B. Erosion of the coastline on the Djiffer oceanfront reveals a dumping ground of domestic waste and monofilament fishing nets

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4 In this chapter, we present the main sources of marine pollution emitted in Senegalese territory. We then discuss the risks and challenges this poses to the marine ecosystem, and the main physical processes affecting the transport and distribution of pollutants along the Senegalese coast. Finally, we offer recommendations for spatial planning of the marine environment.

Sources of marine pollution

When plastics become political

5 Plastic pollution is one of the most visible types of pollution, and is therefore at the centre of citizens and political initiatives to curb environmental degradation. Since 2008, but especially from 2015 onwards, the Senegalese government has adopted laws and policies related to plastic waste (NGAIDO, 2020). However, laws on other sources of pollution are more general, limited and out of date: recent initiatives for better waste management seem to pay little attention to these other sources of pollution. Although plastics make up the majority of marine litter recorded[3] (THIELE *et al.*, 2021), they account for "only" 12% of the litter generated.[4] In reality, there is a large diversity of pollutants released into the sea, and soluble pollutants are both less visible and often more dangerous. They are responsible for an increasingly serious health crisis despite early diagnosis and alarm bells sounded in the 1990s by Senegalese researchers (DIAW, 1993). In this section, we review the sources of agricultural, domestic and industrial pollution in Senegal.

Agricultural pollution

6 Marine pollution from agriculture is caused by the leaching of cultivated land during rainfall, which carries pesticides, herbicides and fertilisers to waterways and ultimately to the ocean. Fertilisers can cause eutrophication of coastal waters, while pesticides and herbicides have toxic effects on the wider ecosystem.

7 Although Senegal is increasingly importing fertilisers,[5] the quantities used per hectare of arable land remain an order of magnitude lower than in Europe.[6] Pesticide use is only partially documented in the country, particularly in the Niayes region,[7] which is a prime area for market gardening along the coast between Dakar and Saint-Louis, and where the water table is shallow. However, according to the Centre of Ecological Monitoring (CSE, 2015), most of the pesticides used are banned, and the recommended dosages are not respected. The passage of pollutants from the coastal water table to the ocean therefore seems likely, especially during the rainy season. The Petite Côte and the Casamance are a priori free of agricultural pollution, as they are areas with essentially small traditional farms that use few chemical inputs. In the Casamance River delta, mangrove swamp rice is traditionally grown in small areas. Groundnut crops in the Sine-Saloum watershed are not considered using large amounts of chemicals, but are responsible for deforestation and thus for reducing the soil's capacity to store rainwater, which is one of the key factors in soil salinisation, particularly in the delta (FAYE *et al.*, 2019). On the banks of the Senegal River, there are large farms with relatively heavy soils (75–90% clay) that drain chemical-laden water into Lake Guiers, which supplies Dakar with drinking water. The river thus potentially carries the chemicals used for the intensive crops present in the valley (rice, sugar cane, market gardening) to the sea.

Domestic pollution

8 In 2016, the Senegalese government estimated the annual production of solid waste at about 2.4 million tonnes, for a population of 15.4 million (KAZA *et al.*, 2018). Collected wastewater was estimated at 25 million m^3 per year in 2000. The spatial distribution of discharge correlates with that of the population, which is highly concentrated on the Cabo Verde peninsula. The Sine-Saloum estuary is exposed to discharge from more than 1.6 million inhabitants. In the north, the Senegal River is under pressure from more than 1.5 million inhabitants (if the populations of the cities from Saint-Louis to Matam are taken into account). In the south, the regions of Ziguinchor, Sédhiou and Kolda also have nearly 1.5 million inhabitants, mostly spread along the estuary of the Casamance River.[8]

9 Solid waste in the country is composed of 58% "fermentable" waste (organic waste, leather, paper and cardboard), 26% "combustible" waste (textiles, plastics and wood) and 13% "inert" waste (metals, glass, fine particles, stone and ceramics): 3% of waste is not classified. In 2016, an estimated 1.08 million tonnes of solid waste was not collected. It is difficult to estimate how much of this waste ends up in the marine environment, but it is often seen on beaches and in lagoons and estuaries (fig. 1B). In addition to domestic waste from residential areas, the influx of bathers on the beaches during the summer generates local pollution mainly consisting of disposable plastic objects (cups, straws, bags, bottles, etc.). Debris from fishing gear (nylon nets, polystyrene floats, etc.)

is commonly found in the sea and on the Senegalese coast. Moreover, the presence of hospital waste (syringes, plastic bottles and bags, etc.) is regularly reported on certain beaches in the capital (fig. 1A).

10 Wastewater discharge is difficult to estimate given the unquantified existence of direct discharge not connected to the stormwater network into the natural environment (CSE, 2013). Some wastewater seeps into the ground, or flows into the stormwater network and ends up in the sea. The storm drains collect a large amount of wastewater that is continuously discharged into the sea, but with peaks of discharge during heavy rainfall events.

11 The entire Cabo Verde peninsula is urbanised, covered by Dakar and its suburbs, with a population of almost 4 million inhabitants in 2020, almost double the 2.2 million inhabitants in 2000. Domestic pollution has become a large-scale issue there, especially as this is combined with industrial pollution (see the following sections). The increase in pollution, together with population growth, economic development and lack of infrastructure, has led to an explosion in pollution levels. The wastewater collected was estimated at 25 million m^3 per year in 2000, almost all of it (23,6 millions m^3) in Dakar. Less than 25% of this water is treated in wastewater treatment plants before being discharged into the sea.[9] This discharge results in the significant presence of coliforms (*Escherichia coli*) and enterococci and, more rarely, salmonella (SONKO *et al.*, 2016). The sources of the main discharge to the sea are listed in Table 1. Although historically concentrated on the western corniche, this discharge is now distributed all around the peninsula. Particularly critical points of emissions and accumulation of pollutants are observed (apart from the industrial zone of the autonomous port of Dakar) in Hann Bay, the southern part of the western corniche (in particular the accumulation in the bay of Soumbédioune), the bay of Carpes in Ngor and on the site of Cambérère (Fig. 2C). In addition to these critical sites where bathing and fishing activities are made impossible, there are many sites subject to emissions of lower intensity, but with a worrying increase, such as the site visible near the beaches of Virage and Yoff. It is also likely that the Mbeubeuss landfill, located less than 1.5 km from the coast, is responsible for indirect emissions to the sea, via rainwater run-off and/or underwater resurgence of the polluted water table, a process that has been demonstrated in other regions (BURNETT *et al.*, 2003). The increase in sources of pollution is making the Dakar coastline increasingly unfit for use, both for seafarers and for residents looking for places to relax.

Table 1. Types and quantities of soluble pollutant discharge around the Cabo Verde peninsula

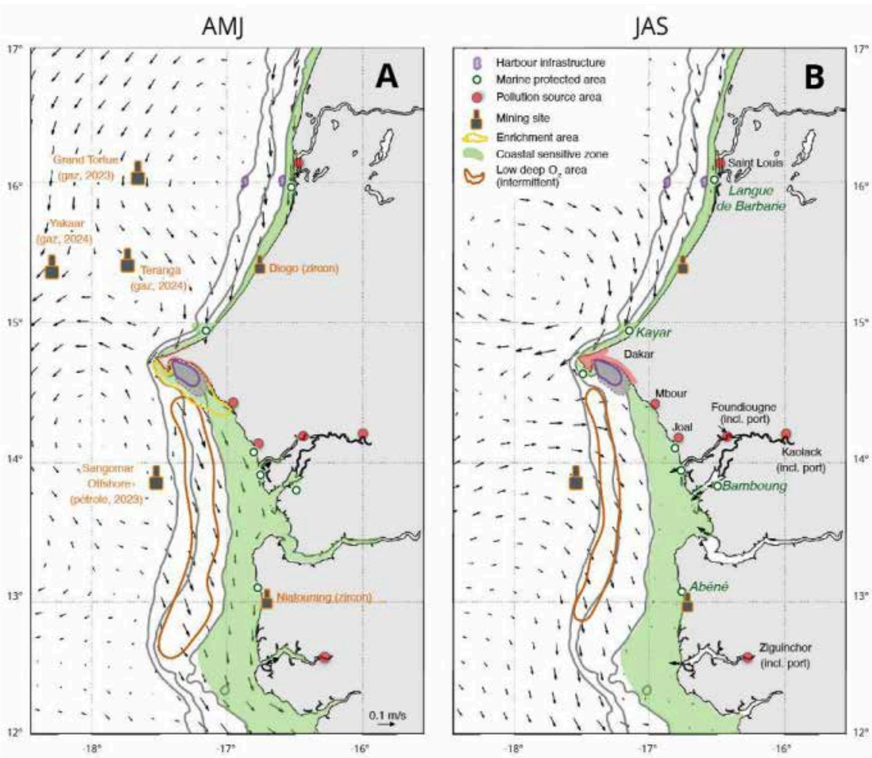
Origin of discharge at sea	**Quantity discharged into the marine environment (year $)^{-1}$**	**Date of the estimate***	**Main pollut identified**

Domestic wastewater from Dakar (of which less than 25% is treated before discharge)	24,000,000 m^3	2005 (ONAS)	Detergents, nutrients, microbes, plas parabens, nanoparticles (including plastics)
Domestic solid waste	~1,000,000 t**	2016 (DEEC)	Organic wa plastics, me glass, ceramics
Hann Bay industries	923,352 m^3	2013 (DEEC)	Hot wa chemical c hydrocarbons, solvents, an blood (slaughterhou organic ma and nutri (nitrogen phosphorus)
Diffusion via the water table under the Mbeubeuss landfill (especially in the rainy season)	No estimate	No estimate	Various he metals (espec iron, l cadmium aluminium)
Metal collection and sorting in the informal economy	Effluent mixed with domestic wastewater	No estimate known	Heavy me (lead, merc cadmium, e PCBs (polychlorinat biphenyls), aci
Dakar Port Authority	274,878 m^3	2000 (DEEC)	Hydrocarbons heavy me vegetable antifouling, phosphate, sulphur, attapulgite, c clinker, etc.

Mamelles desalination plant	50,405,000 m^3***	Max. discharge expected in 2035 (http://www.eau-assainissement.gouv.sn)	Brine (over-sa water) comb with t chemicals u for water treatment equipment protection (antifouling, e
Offshore oil and gas development	No estimate	No estimate known	Produced wa farm sludge, cargo

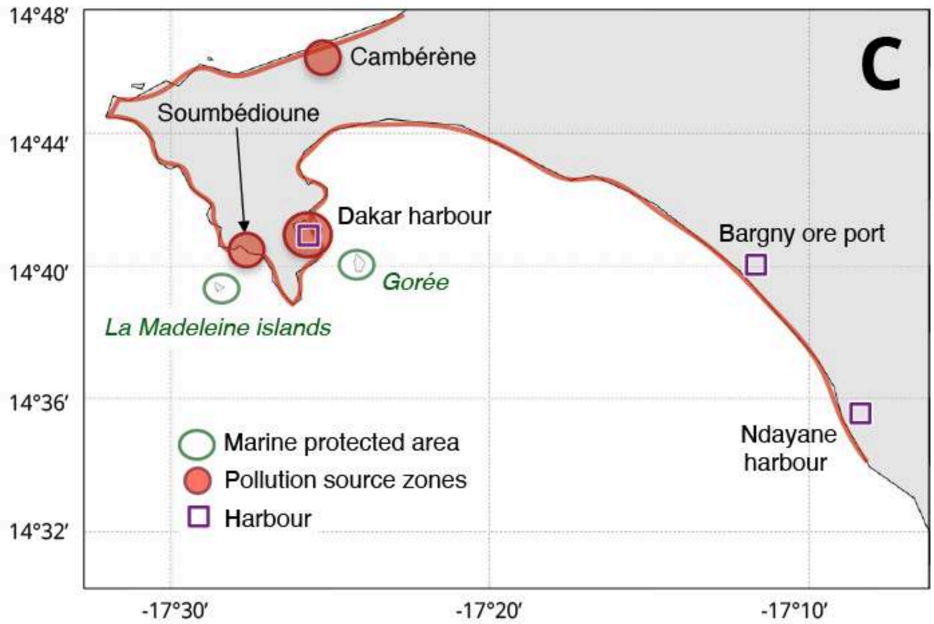
* Senegalese National Sanitation Office (ONAS)
Directorate for the Environment and Classified Establishments (DEEC)
** 1.08 million tonnes per year is not collected. Based on empirical observations, we estimate that the majority is disposed of in estuaries, lagoons or on beaches.
*** Assuming a recovery rate of 42%, which is the average rate for reverse osmosis on seawater.

Figure 2A and 2B. Main sources of pollution of coastal waters



Representation of elements relating to pollution and risks of damage to the Senegalese marine environment in two contrasting seasons: spring upwelling season (March–June; Map A) and monsoon period (July–September; Map B). The major specific point sources of pollution and the more diffuse pollution near Dakar are respectively indicated by red dots circled in brown and a red line along the coast.

Figure 2C. Main sources of pollution of coastal waters



Hann Bay and its vicinity (Map C) concentrate the impacts and risks due to the large amount of industrial and domestic pollution sources.
Source: E. Machu, T. Brochier, X. Capet, S. Ndoye, I. Sidiki Ba, L. Descroix

12 The ongoing construction of the multi-use port of Ndayane (which is intended to become the largest port in West Africa) and the mineral port of Bargny are expected to considerably expand the area of coastal ocean affected by port activities (figs. 2A and 2B, waiting area for ships, etc.; in purple with a solid line for the future situation and a dotted line for the current situation). Infrastructure is also under construction or planned at sea in connection with the exploitation of hydrocarbon deposits, such as off Saint-Louis. Maritime transport development projects also concern the Sine-Saloum estuaries (ports of Foundiougne and/or Kaolack) and the Casamance (port of Ziguinchor).

13 Rainwater runoff during the monsoon period washes out the soil and probably increases the amount of pollutants discharged into the sea (thicker red line, fig. 2B), but this seasonal variability is to our knowledge not documented (see LEE *et al.*, 2004 and CHOW *et al.*, 2005 for other regions).

14 The marine area near Dakar plays a key role in the marine ecosystem. It is an area that benefits from the upwelling of nutrient-rich deep waters during the upwelling period (fig. 2A) and a spawning and nursery area for several species of small pelagic fish (NDOYE *et al.*, 2018).

15 The 20, 50 and 100 m isobaths are represented by shaded lines (fig. 2). The 100 m isobath, located furthest offshore, is the outer shelf boundary. The 20 m isobath, located closest to the coast, is the inner shelf boundary, within which most artisanal fishing takes place. Several key small pelagic species are known to be associated with the inner shelf (flat sardinella) as well as the estuaries (ethmalosa).

16 Given the lack of knowledge, the proposed delineation of the sensitive coastal zone (green in figs. 2A and 2B) is subjective and does not include all the Important Bird Areas

(IBAs) identified by BirdLife. The area further offshore contains a particularly rich offshore ecosystem, the exploitation of which is an important source of both income and protein, and also contains areas considered to be IBAs. However, we posit that the pressures on this ecosystem and the associated risks are significantly lower compared to the coastal hotspot. The IBA identified in Senegal[10] is in the sector of the median/external plateau, which is subject to episodes of deoxygenation of the bottom layer, with consequences on the ecosystem that are not yet understood.

17 The mean surface currents from numerical simulations (NDOYE *et al.*, 2017) are indicated by black arrows for both seasons (fig. 2A and 2B). They reveal the complexity of current circulation, in particular in the vicinity of the Cabo Verde peninsula (Dakar), which is very different from the traditional pattern expected in the spring upwelling area (see also fig. 5). A direct connection via the mean currents exists in the model between the deep Sangomar offshore oil exploitation area and the South Senegalese continental shelf, especially during the monsoon period. This connection is intermittent due to the variability of the currents, which is due both to intrinsic/turbulence factors and forced by wind fluctuations (e.g. on synoptic and intraseasonal scales).

Industrial pollution

Hann Bay

18 This is the largest industrial zone in West Africa. In 2013, 42 industrial units generating discharge into Hann Bay were listed by the Directorate of the Environment and Classified Establishments (DEEC). These are mainly fish processing plants, chemical fertiliser manufacturing plants, tanning plants and oil refineries. Hot water, chemical dyes, hydrocarbons, solvents, blood (from slaughterhouses), organic matter and nutrients (nitrogen and phosphorus) are discharged from these sites into Hann Bay. Agri-food industries are responsible for the bulk of the emissions (approximately 1200 m^3/d, see details in the final environmental and social assessment report of the Hann Bay depollution project).[11]

19 In principle, these industries are monitored and pose a low risk of chemical pollution by heavy metals. However, the vast majority of the Senegalese economy is informal, which means that a large proportion of the waste is not recorded (e.g. illegal connections to pipes normally reserved for rainwater drainage). For example, there are informal battery recycling industries, which have been blamed for causing massive lead poisoning (WHO, 2008), as well as the very common practice of artisanal recycling of transformers, which may contain PCBs (polychlorinated biphenyls[12]). Generally speaking, all industrial waste containing a proportion of reusable metal is collected by scrap dealers, either small-scale or industrial, via informal economic circuits without any real monitoring of effluents or measures to prevent the release of heavy metals or other toxic products. The recycling of metals recovered in this way nevertheless takes place in factories classified for environmental protection (P. Tastevin, French National Centre for Scientific Research [CNRS], pers. comm.). Studies of metal pollution in the country are rare, but moderate levels of lead (48 mg/kg) and significant levels of cadmium (15 mg/kg) have been measured in the sediment of Hann beach (DIANKHA, 2012).

Fishing and shipping

20 Artisanal fishing canoes, industrial fishing vessels of various sizes, as well as cargo ships transit and anchor in Senegalese coastal waters. Industrial bottom-trawling vessels destroy benthic habitats and resuspend sediments, including any accumulated pollutants. Industrial fishing vessels frequently discard their bycatch, which decomposes in the water column and on beaches. Fishing gear debris (nets, traps, plastic drums and polystyrene floats) also constitutes a significant part of the waste observed at sea and on beaches.

21 The autonomous port of Dakar, the second largest industrial port in Africa, is located in the middle of the city. It adjoins Hann Bay, but its right of way for the mooring of industrial ships covers a vast maritime zone that encompasses the whole of Hann Bay, from Cap Manuel in Dakar to Cap Rouge in Yenne. The associated traffic was estimated at 20 million tonnes in 2019. Among the port's activities that cause marine pollution are ship repair, the grain terminal, and the loading and unloading of oil through oil tanker pipelines (underground and overhead) and oil traffic, the landing for import-export of solid industrial bulk such as sulphur, coal and clinker (a component of cement consisting of about 80% of limestone and 20% of aluminosilicate), and the shipping of phosphate and attapulgite. The most commonly observed pollution is from accidental sulphur spills, the continuous presence of urban effluent outfall in the port, the mixing of hydrocarbons and floating waste of undetermined origin (degassing/discharge by ship). There are many industrial ships moored in the port or in the maritime part of the port, which additionally generate constant noise pollution as the engines run continuously to provide power to the ship.

22 Lastly, over the past 20 years, the West African coast has seen the installation of some 60 fishmeal factories which, in addition to causing overfishing, the plundering of fish resources and the disappearance of the highly productive fish smoking sector, also causes pollution through the discharge of toxic products into mangrove wetlands and rice fields as well as into the ocean (GRAND and DIOP, 2018; DESCROIX and MARUT, 2015).[13]

Offshore oil and gas extraction

23 Exploration off Senegal in recent years has revealed the presence of hydrocarbon wells (gas in the north of the Cabo Verde peninsula, oil and gas in the south). Concessions cover a large part of the Senegalese exclusive economic zone, from coastal areas to about 200 km off the north and south coasts, and about 100 km from the Cabo Verde peninsula (Dakar), typically to a depth of 4000 m (fig. 2A; all concessions can be found on Map 2C in LE TIXERANT *et al.*, 2020). Offshore oil extraction activities started in 2019.

24 This type of activity generates daily pollution linked to tanker traffic, transhipment activities, and chronic discharge of drilling fluids (or "drilling muds") and produced water. Drilling muds are recovered solids from drilling operations impregnated with hydrocarbons, as well as drilling oils that are added to fluidify the extracted materials. For a given production site, this mud waste represents thousands of tonnes, hence the environmental concern. In addition, water from oil or gas production, also known as "produced water", is brought to the surface, often as an emulsion in the crude oil. This water is separated from the hydrocarbons. Three levels of standards govern the treatment of these by-products and the risks associated with exploitation: international standards, those adopted by operators, and those adopted by the countries concerned.

In Senegal, the signing of the Abidjan Convention authorises produced water to be discharged into the sea or reinjected, but requires drilling mud to be transported onshore.[14] The long-term effects of offshore exploration and development is therefore generally related to chronic low-level discharge of drilling fluids and produced water. Of course, there is also a risk of accidents and the massive release of hydrocarbons in the event of blowouts during extraction or from spills during transportation.

Mineral extraction

25 The West African coastline has also seen the emergence of other types of potentially polluting extractive or primary activities. The coastline itself (beaches and dunes) locally contains not inconsequent levels of zircon, ilmenite and rutile (titanium); this has been exploited since 2010 in Sanyang in the Gambia, and since 2014 in Diogo on the Senegalese Grand Coast (fig. 2A). In the latter case, any pollution is not necessarily likely to reach the ocean, as the extraction site is located 4 km inland. It should be noted that at least two extraction sites (Kartung in the Gambia and Varela-Sucujaque in Guinea-Bissau) have been closed at the request of the local population, who complained about the harmful impacts of this exploitation: toxic discharge on land, toxic discharge at sea, and undesirable turbidity of the sea and mangrove swamps. A project linked to a small dune containing a deposit with a very high heavy metal content (12% compared to 2% on the other sites mentioned) has been blocked in the north of the Casamance coast, following the fears of the population concerning the possible impacts on rice fields, mangroves and fisheries (DESCROIX and MARUT, 2015).

26 The Senegal, Gambia and Koliba/Corubal river basins have also been major gold mining sites for several years now, with large mines operated by South African or Brazilian multinationals, as well as more or less clandestine gold panning operations on land or in rivers. Is there not a risk that the waste from these activities, known to be highly toxic (including mercury, cyanide, etc.), will one day end up in the sea or in coastal mangrove forests?

Major coastal development projects

Desalination plant

27 The desalination plant project on the Mamelles site in Dakar plans an initial production of 50,000 m^3/d and eventually 100,000 m^3/d of drinking water. It will use reverse osmosis, which involves filtering water pumped from the sea at very high pressure through membranes: a very energy-intensive process. Local marine pollution, linked to the production of brine and the toxic chemicals used for water treatment and pipe cleaning (sulphuric acid, hydrochloric acid, caustic soda, citric acid, chlorine gas, etc.) is expected. Despite the validation of the environmental impact study by stakeholders, the pumping and discharge of treated water in the vicinity of the beaches and the artificial reef managed by the fishermen of Ouakam continues to raise various environmental concerns. For example, the lack of a baseline for the local ecosystem will make it difficult to assess the consequences of the alteration of the environment by brine discharge, or the impacts of the toxic chemicals used (the volumes of which were not quantified in the impact study). High salinity can cause a reduction in dissolved oxygen in the receiving waters, and ultimately have significant impacts on benthic organisms, which can have repercussions on the entire ecosystem. In addition, the

consequences of underwater noise pollution resulting from pumping installations are difficult to assess.

Industrial ports

28 Four new infrastructure projects are planned as part of the Plan for an Emerging Senegal (PSE[15]). In the mangrove ecosystems of the Sine-Saloum and Casamance, which are particularly sensitive to hydrocarbon pollution (DUKE, 2016), three hydrocarbon terminals (specialised landing stages, storage areas and loading/unloading systems: pipes, etc.) are to be built in Kaolack, Ndakhonga-Foundiougne (Sine-Saloum) and Ziguinchor (Casamance). The construction of this infrastructure would inevitably multiply the areas of potential pollution of the marine environment, both during their construction and throughout their operation. The risks of dispersing contaminants throughout these ecosystems are increased by the strong hydrological dynamics that characterise these regions, which are as yet largely unknown (see the section on the role of ocean dynamics in the trajectory of pollutants).

29 In the coastal region, the Bargny mineral and bulk port project and the Ndayane multipurpose port project, located in the extension of Hann Bay, could generate environmental damage comparable to that of the current port of Dakar. The relocation of existing industrial activities to these areas could reduce the sources of pollution in the current port of Dakar, but this could increase the vulnerability of mangrove ecosystems and the shallow continental shelf of the Petite Côte, which is a retention zone whose fragility and role in the reproduction of fisheries resources have been highlighted (e.g. TERASHIMA *et al.*, 2007; ECOUTIN *et al.*, 2010; MBAYE *et al.*, 2015; SADIO *et al.*, 2015; NDOYE *et al.*, 2017).

Ecosystem risks

30 The effects on a marine ecosystem resulting from exposure to a pollutant depend on the nature of the pollutant, the trajectory of the pollutant (in the environment and within the organism), the level of exposure and the organisms exposed. This section outlines the general principles of the consequences of exposure of marine organisms to pollutants, and presents examples of disturbance at different structural levels.

General principles

31 The response of organisms to pollution occurs at four levels of biological organisation: (1) biochemical and cellular; (2) the systemic physiological, biochemical and behavioural responses of the organism; (3) population, including changes in population dynamics; and (4) community, resulting in changes in community structure and dynamics (e.g. CAPUZZO, 1987)

32 Generally speaking, the first reactions of an organism to exposure to pollution consist of setting up mechanisms to resist or reduce the impact of toxic substances or stress. In the case of exposure to a toxic pollutant, for example, the response will be through the activation of toxic substance metabolism processes (at the biochemical level), or through the selection of toxic substance-resistant forms (at the population level). The biological effects of pollutants can manifest themselves at different levels before

disturbances are observed at the population level. Not all responses are harmful in nature and do not necessarily lead to degeneration at the next level of biological organisation. It is only when compensatory or adaptive mechanisms at one level begin to fail that deleterious effects manifest themselves at the next level (CAPUZZO, 1981). Adaptive processes are able to counteract disruptive processes until the system reaches a threshold of toxicity beyond which the adaptive potential is exceeded by the degeneration imposed on the system by the disturbance.

33 A pollutant can accumulate along a trophic chain, but it can also be resorbed by certain organisms, which thus mitigates this accumulation. Nevertheless, whatever the organism, the reactions caused by its exposure to pollution can disrupt its metabolism, modify its behaviour and induce energy costs that are often to the detriment of its maintenance, growth and/or reproduction. Differences in the adaptive capacity of different species can have significant consequences on the structure of communities.

Examples of disturbances and responses of organisms

34 In this section, we illustrate the responses of organisms at different levels of organisation using examples concerning species found in Senegal (or of close taxonomic rank) and of types of pollution affecting the region.

Biochemical disruption of cells: oysters and plastics

35 The presence of plastic debris in the ocean has been reported since the 1970s (CARPENTER and SMITH, 1972). Plastics are now ubiquitous and their presence in the waters of Senegal is reinforced by local pollution. Modern plastics are made up of a complex mixture of polymers, residual monomers and chemical additives. In the environment, the fragmentation of plastic debris by photo-oxidation, mechanical action or biodegradation generates small particles called microplastics (1 µm to 5 mm) or the even smaller nanoplastics (< 1 µm). This secondary waste represents between 97% and 99.9% of ocean contamination by plastics (TALLEC, 2019). The presence of nano-sized particles is important in an ecological context, as their small size allows them to cross biological barriers and penetrate cells. Several studies have highlighted the sensitivity of the early life stages of the oyster species *Crassostrea gigas* (the leading aquaculture species worldwide) to exposure to polystyrene nanospheres (SUSSARELLU *et al.*, 2016; TALLEC, 2019). TALLEC *et al.* (2020) found that 50 µm nanospheres induced acute toxicity on spermatozoa, oocytes, fertilisation and embryo-larval development of *C. gigas*. Given the absence of ingestion processes in oyster gametes and embryos, the toxicity of nanospheres is related to direct contact with the external barrier of these cells, i.e. their cell membrane. The latter is a complex and dynamic structure composed of two large families of macromolecules, the lipids forming the lipid bilayer, and the proteins inserted into this (transmembrane proteins) or attached to this (peripheral proteins). Transmembrane proteins play an essential role in homoeostasis (e.g. ion channels) and in communication with the intracellular environment. Their activity depends on their spatial configuration, which is directed by the state of the lipid bilayer (WEIL *et al.*, 2009). The WEIL *et al.* study shows that a modification of the physical properties of the membrane, linked to the adsorption of nanoplastics, can induce harmful effects in cell function.

Disturbance of organisms: marine birds, trace metals and oil

36 Early studies on the effects of pollutants on birds focused on direct mortality (BELLROSE, 1959), but later research has demonstrated a wide range of sublethal effects on the development, physiology and behaviour of individuals. Sublethal effects of pollutants on seabirds include reproductive deficits (AINLEY *et al.*, 1981), teratogenicity and embryotoxicity (HOFFMAN, 1990), eggshell thinning (RISEBROUGH, 1986), enzyme induction (FOSSI *et al.*, 1989; RONIS *et al.*, 1989), effects on endocrine function (PEAKALL *et al.*, 1973; PEAKALL, 1992) and behavioural abnormalities in adults and juveniles (BURGER and GOCHFELD, 1985, 2000; BURGER, 1990).

37 DIANKHA *et al.* (2019) studied the level of trace metal element (TME) and polycyclic aromatic hydrocarbon (PAH) contamination in four Senegalese seabird species (Caspian tern *Sterna caspia*, royal tern *Sterna maxima*, slender-billed gull *Larus genei*, and grey-headed gull *Chroicocephalus cirrocephalus*). Eggs of these species were collected in the national parks of the Langue de Barbarie and the Saloum Delta (fig. 2B), two breeding sites of these species with marine protected area status that are located close to future hydrocarbon exploitation sites. All species were found to be contaminated with PAHs and TMEs. Benzo(a)pyrene, one of the most toxic PAHs, was the compound most present in the eggs of three of the four species analysed. The concentrations of benzo(a)pyrene in the eggs of the royal tern and the grey-headed gull were above the median lethal concentration (causing the death of 50% of the individuals in a population) defined for species such as the mallard duck.[16]

38 Of the TMEs, lead was the metal with the highest concentration in the eggs of the species studied. Lead pollution comes mainly from industrial processes, leaded gasoline combustion, runoff, agricultural practices, eroded lead paint and, to some extent, natural processes such as erosion and volcanism. For three decades, lead contamination levels and effects in seabirds breeding in the New York-New Jersey area have been studied in the laboratory and in the field. This research has shown that lead affects a wide range of behaviours in chicks, including locomotion, balance, begging, feeding, growth and cognitive ability, which in turn affect survival in the wild (BURGER, 1990; BURGER *et al.*, 1994; BURGER and GOCHFELD, 1997).

Population disturbance: copepods, sardinella and warming

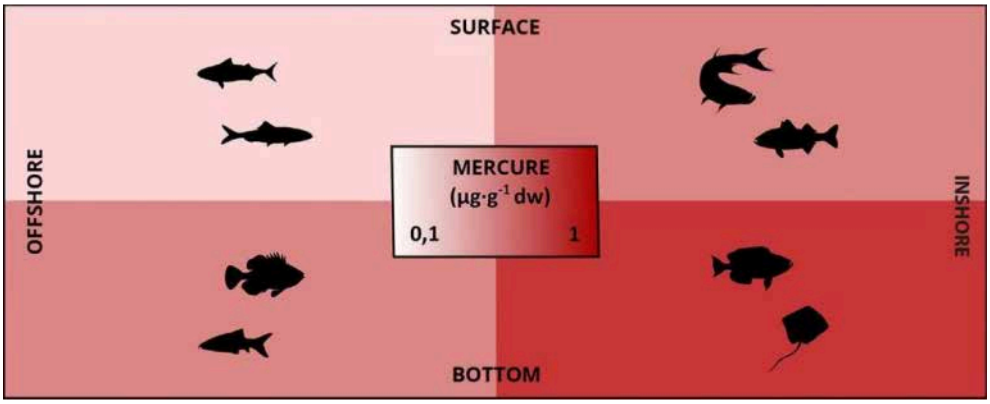
39 Studying the consequences of pollution at the population level of a species requires observation over a sufficiently long period of time. The number of documented examples of such impacts is therefore relatively limited. Using a zooplankton collection device installed on ships operating in the North Atlantic since the 1930s (continuous plankton recorder, WARNER and HAYS, [1994]), BEAUGRAND *et al.* (2002) were able to show that, in response to ocean warming, large-scale changes had occurred in the biogeography of calanoid copepod zooplankton organisms in the eastern North Atlantic Ocean and in the seas of the epicontinental shelf of Europe. Over a period of about 40 years (1960–1999), warm-water copepod species have moved up to 10° further north, an extension that has been associated with a decrease in the number of cold-water species. This type of shift is consistent with the general response observed and expected in response to climate change (HASTINGS *et al.*, 2020).

40 Several studies also suggest that the West African sardinella (*Sardinella aurita*) population is making increasingly northern migrations through the Canary Islands system (SARRÉ, 2017; KIFANI *et al.*, 2019). Using time series of independent observations, SARRÉ (2017) showed a northward shift in the distribution of *S. aurita* since 1995. These spatial changes observed over the last 20 years may be related to observed changes in surface temperatures, with warmer years associated with a more northerly population. However, KIFANI *et al.* (2018) point out that it is difficult to determine the relative contribution of climate change, natural variability and exploitation on the dynamics of this population over the last decades.

Community disturbance: fish and algae

41 For a TME such as mercury, for example, it has been shown that bioaccumulation can be highly variable in marine fish species found on the Senegalese shelf (LE CROIZIER *et al.*, 2019). The impact of trophic ecology and habitat on mercury accumulation was analysed through the total mercury concentration and stable carbon and nitrogen isotope ratios (which provide information on diet) in the muscle of fish belonging to 23 different species. Spatial occupation, both vertically and in terms of distance from the coast, seems to lead to differential mercury accumulation, with coastal and demersal fish being more contaminated than offshore and pelagic species (fig. 3). Proximity to the most anthropised urban sites is also a factor in amplifying the pollution of marine organisms (DIOP *et al.*, 2016, 2017). For individuals of the same species and from the same site, the variation in mercury content is mainly explained by the length of the fish, in line with the hypothesis that mercury bioaccumulates over time.

Figure 3. Mercury contamination of fish communities



Mercury contamination pattern for fish caught at sea during the AWA 2014 campaign. Vertical (i.e. distribution in the water column) and horizontal (i.e. distance from the coast) habitat resulted in differential mercury accumulation between species. Coastal and demersal fish were more contaminated than offshore and pelagic species.
Source: LE CROIZIER *et al.* (2019)

42 Data from laboratory and field studies support the hypothesis that mercury in the aquatic environment has a negative impact on the reproductive health of fish (CRUMP and TRUDEAU, 2009). In controlled feeding studies, consumption of diets containing mercury (e.g. methylmercury) at realistic concentrations resulted in a range of toxic effects in fish, including behavioural, neurochemical and hormonal changes (SCHEUHAMMER *et al.*, 2007). Some notable variations in response to mercury exposure

can be attributed to one or more of the following factors: species, life stage, gonadal developmental status, route of exposure, duration of exposure, mercury speciation and concentration. Although it is difficult to demonstrate these changes in the field, long-term exposure of fish to mercury is likely to affect the structure of fish communities.

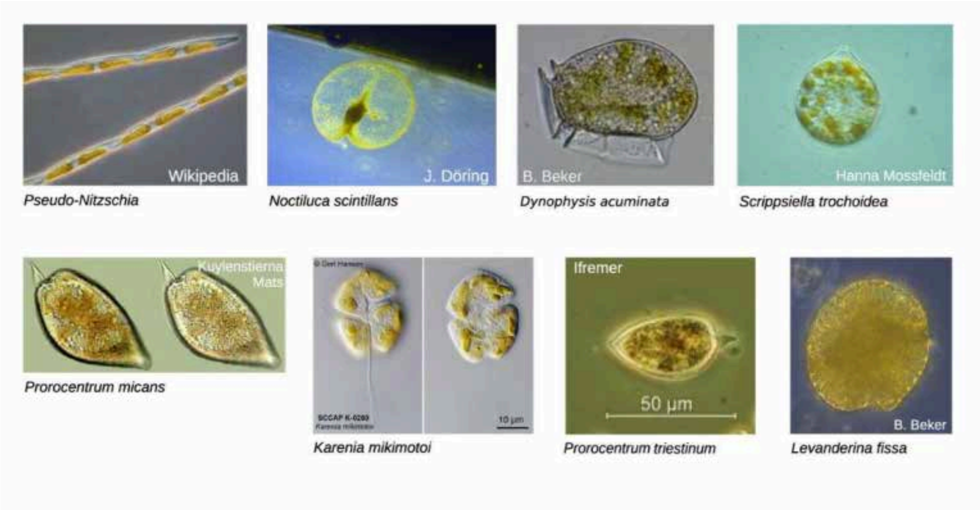
43 The consequences of anthropogenic disturbance on plankton communities have also been identified. Harmful algal blooms (HABs) are increasingly threatening the economic viability of fisheries and aquaculture, ecosystem health and diversity, and recreational activities in some areas. Among other things, these harmful algae can produce paralytic, diarrhoeal or amnesic toxins for humans who consume them indirectly through shellfish. Other toxins (e.g. ichthyotoxins, yessotoxins) can affect different components of marine ecosystems. These HABs can also have significant effects on ecosystems when the degradation of algae blooms leads to hypoxia or anoxia (COCKCROFT, 2001; GRANTHAM *et al.*, 2004; HERNÁNDEZ-MIRANDA *et al.*, 2010). In Senegal, hypoxic conditions are intermittently encountered in bottom waters along the middle and outer shelf (figs. 2A and 2B), likely related to the degradation of large blooms (MACHU *et al.*, 2019).

44 The eutrophication[17] of coastal areas is one of the mechanisms put forward to explain the increase in the number of HABs worldwide (e.g. HEISLER *et al.*, 2008; GLIBERT *et al.*, 2005). Beyond this eutrophication phenomenon, phytoplankton biodiversity is altered by merchant ships introducing exotic microorganisms into all ecosystems of the world (e.g. BAX *et al.*, 2003). Changing environmental conditions in response to climate change also affect the mechanisms of competition between species (EDWARDS *et al.*, 2006; HEISLER *et al.*, 2008; FU *et al.*, 2012). Climate change is expected to have significant effects on the frequency and abundance of HABs due to the complex factors that may change and the combined effects that these factors (temperature, acidification, salinity, sunlight, stratification) may have on HAB growth or habitat (FU *et al.*, 2012).

45 In addition to encouraging harmful algae, these changes are likely to alter planktonic assemblages. One study documented this type of potential change in the northern Arabian Sea, which has experienced a dramatic change in the composition of winter phytoplankton blooms. These previously consisted mainly of diatoms, but are now replaced by blooms of the large dinoflagellate *Noctiluca scintillans* (DO ROSÁRIO GOMES *et al.*, 2014). These *N. scintillans* blooms are facilitated by an unprecedented influx of oxygen-depleted waters and the extraordinary ability of its endosymbiont, *Pedinomonas noctilucae,* to fix carbon more efficiently than other phytoplankton in oxygen-depleted conditions. Such changes have the potential to disrupt the traditional food chain maintained by diatoms to the detriment of regional fisheries and the long-term health of an ecosystem supporting a coastal population of nearly 120 million people.

46 In recent years, nine of the 28 potentially toxic algal species found in the eastern upwelling ecosystems have been sampled off Senegal (Fig. 4). To our knowledge, no monitoring of these algae has yet been implemented in Senegal, either in the context of food security or health.

Figure 4. Potentially toxic algae of the 29 harmful algal species found in upwelling systems in coastal waters (TRAINER *et al.*, 2010)



Nine species have been identified by microscopy in samples collected since 2013 in Senegalese coastal waters.
Source: E. Machu, T. Brochier, X. Capet, S. Ndoye, I. Sidiki Ba, L. Descroix

The role of ocean dynamics in the trajectory of pollutants

47 Marine pollution has so far received relatively little attention, particularly where it does not lead to major damage to the coastline. Despite the fact that sources of pollution are mainly concentrated in certain nearshore and coastal areas, the dispersive properties of the marine environment generally tend to limit local accumulation in the water column (although not necessarily in marine sediments, MARTIN *et al.*, 2017; LUOMA, 2018). The ocean would therefore appear to be a giant landfill capable of rapidly diluting large quantities of water-miscible pollutants. However, in the case of debris or material floating on the ocean surface, accumulation effects are possible and pose specific problems. Dilution/dispersion/accumulation of liquid or solid pollutants can result from a large number of physical processes, mainly of a turbulent nature. Different processes act at different spatial scales with their own intensity depending on the environmental conditions and the type of pollutant considered.

48 Coastal environments subject to an upwelling wind pattern, as is the case off the West African coast, are considered to be unlikely to be affected by marine pollution due to the general characteristics of their circulation. In the simplified “2D vertical” view of a coastal upwelling, coast to offshore circulation is mainly forced by the wind and takes the form shown in figure 5. Due to the rotation of the Earth, the effect of wind friction drives surface water offshore. This is replaced by deep water that ascends at the coast. In this context, coastal sources of pollution can contaminate the upwelling water, but these are systematically transported away and the accumulation of pollutants is therefore, in theory, greatly reduced. This is consistent with the global simulations of micro-plastic drift presented by ONINK *et al.* (2019). The mixing by the mesoscale and

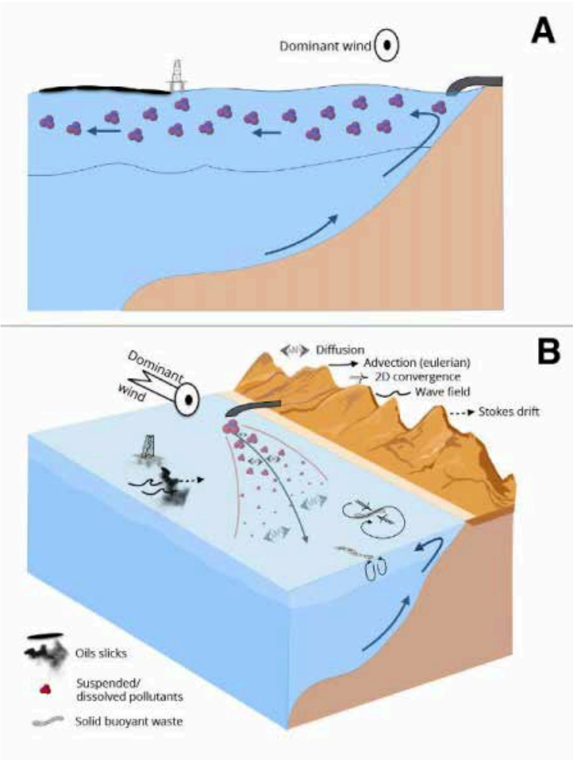
submesoscale eddies that accompanies the upwelling dynamics contributes to the rapid dilution of pollutants introduced into the environment.

49 The risk of oil spills reaching the coast is also considered limited due to circulation resulting from the wind. This, however, must be qualified. Oil slicks, which are frequently confined to the surface, and floating solid waste are transported separately from suspended or soluble waste in the water column. This is due to several factors:

- The prevailing dynamic balance between Coriolis force and wind friction on the ocean induces seaward (Ekman) velocity that is lower at the exact ocean surface than in the mixed layer maintained by the wind (typically 10 m to 30 m deep).
- Ocean wave fields are also responsible for the drift of substances and (micro-)objects trapped on the surface (Stokes drift, ARDHUIN *et al.*, 2009). Stokes drift can result in speeds of the same order of magnitude as Ekman velocity. Transport takes place in the direction of swell/wave propagation: generally towards the coast. Depending on the type of pollutant, a wind-borne effect (windage) can also contribute to its transport. In Senegal, the winds have a westerly component from February–March until October–November and also contribute to transport towards the coast.
- On horizontal scales of around a few tens of metres to ten kilometres, the convergence of surface currents is capable of aggregating pollutants trapped at the surface very efficiently along fronts that are clearly visible in calm weather (Langmuir cells, MCWILLIAMS *et al.*, 1997; sub-mesoscale circulation, CAPET *et al.*, 2008). The underlying processes are general, and their nature is turbulent. The partly random orientation of the fronts and their associated circulation can lead to the aggregation of polluting materials being moved closer to or further away from the coastline.

50 Beyond these general processes, the local specificities of certain coastal sectors subject to upwelling can lead to circulation patterns that differ significantly from the typical situation presented in figure 5. This is particularly the case in the vicinity of bays and capes where meanders and quasi-permanent recirculation frequently exist (LARGIER, 2020). Along the Senegalese coast, the geomorphological obstacle of the Cabo Verde peninsula strongly structures the circulation, both to the north and to the south. As a result, the mean surface currents in the area just below the cape are preferentially directed towards the coast (fig. 2). Contrary to what might be expected based on the general knowledge of the circulation in the upwelling zone, possible oil leakage from wells planned to come on stream in the next few years could, even in the upwelling period, affect the continental shelf area north and south of Dakar, and in particular the coastline of Hann Bay and the Petite Côte (fig. 6). During the rainy season (July to September/October), the weaker prevailing westerly winds lead to substantial changes in the circulation on the continental shelf, characterised by a relatively direct connection from the slope to the shelf south of Dakar via transport by surface currents, and a stagnant circulation on the inner part of the shelf, which is necessarily detrimental to the dispersion of pollutants (fig. 6)

Figure 5. Physical processes and trajectory of pollutants



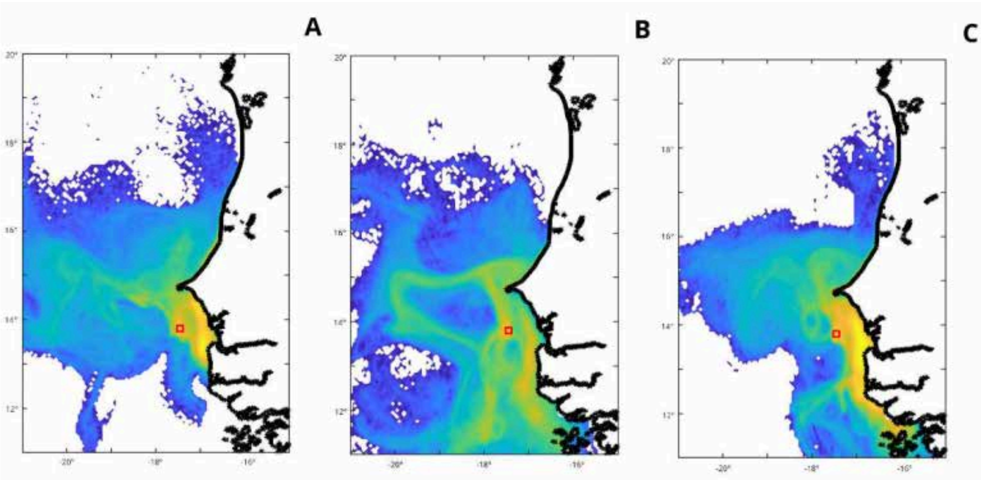
Representation of the typical circulation attributed to coastal areas subject to the upwelling process, under the action of a wind blowing parallel to the coast in the direction of the Equator for a coast oriented north-south

A. In the simplest setting, the cross-shore circulation consists of an Ekman cell that moves water from the open sea to the coast and transports surface water in the mixed layer to the open sea by the wind (Ekman transport). In this context, pollutants introduced to the ocean at the shore or at sea are carried offshore.

B. In a more realistic framework, seaward transport is accompanied by lateral dispersion/diffusion effects that affect all types of pollutants, as well as specific effects that affect pollutants confined to the surface (oil slicks, plastics, etc.). These effects are wave-driven drift (Stokes drift), which occurs in the direction of wave/swell propagation; horizontal convergence (2D) along fronts produced by meso/submeso-scale structures (MUNK *et al.*, 2000) or other forms of circulation involving vertical velocity (e.g. Langmuir cells, MCWILLIAMS *et al.*, 1997)

Source: E. Machu, T. Brochier, X. Capet, S. Ndoye, I. Sidiki Ba, L. Descroix

Figure 6. Oil spills



Simulation of the dispersion of hydrocarbons emitted continuously for 30 days (month of June) at the Sangomar offshore operation site (red rectangle)
Map A shows the average dispersion over the period 2001–2009. The interannual variability of the circulation, and thus of the dispersion, is illustrated by the maps for June 2004 (map B) and June 2005 (map C). These maps were generated based on Lagrangian transport of floating particles in the currents from a regional modelling experiment conducted with the ROMS model at a spatial resolution of 1/60.
Source: E. Machu, T. Brochier, X. Capet, S. Ndoye, I. Sidiki Ba, L. Descroix

51 Based on available knowledge of slope-shelf exchanges (NDOYE *et al.*, 2018), the dispersion study by MURAWSKI *et al.* (2019) and an ongoing study (fig. 6), Senegal's inner shelf is subject to significant pollution risks in the event of oil spills from Kayar, and especially the Sangomar offshore area (fig. 2) where deep oil exploitation is due to start in 2023. Potential long-range impacts were also identified as far north as the Banc d'Arguin marine protected area, and as far south as the Bijagos archipelago biodiversity sanctuary in Guinea-Bissau (fig. 6; figure 19.1.C in MURAWSKI *et al.*, 2019).

52 The typical circulation near and south of Dakar is also responsible for particularly favourable conditions for the reproduction of marine organisms with pelagic early life stages: upwelling water concentrated in Hann Bay (fig. 2; NDOYE *et al.*, 2018) and strong retention of upwelled water on the shelf. This allows the early life stages of many marine species to evolve in an enriched coastal environment (FRÉON, 1988; MBAYE *et al.*, 2015).[18]

53 All these inferences are made on the basis of simulations whose realism in terms of currentology needs to be assessed in more detail (but see NDOYE, 2016 and NDOYE *et al.*, 2017 for an encouraging general assessment of the model), which is not currently possible given the scarcity of existing current observations. Despite one-off measurements of varying duration since 2012 (CAPET *et al.*, 2017; MACHU *et al.*, 2019; TALL *et al.*, 2021), the reference circulation for the southern zone of the Senegalese continental shelf remains that of REBERT and PRIVÉ (1974), which has many limitations and probable bias, in particular due to the short duration of the stations and measurements (< 10 min per depth at each station) and the failure to take into account tidal currents, which we now know dominate the circulation perpendicular to the coast (CAPET *et al.*, 2017).

54 Modelling of oil dispersion clearly illustrates the importance of good in situ knowledge in the implementation of pollution risk management approaches in the coastal

environment and, more generally, in the spatial planning of marine areas. These remarks apply to the impact studies carried out recently with a view to oil exploitation (the Rufisque Offshore Profond block[19] and the AGC Profond block; cartographic atlas of marine environment law, Senegalese Oil and Gas Paddle), some of which were carried out using global circulation models, which are not very well suited to representing the dynamics of the continental shelf, and whose circulation on the Senegalese shelf differs markedly from that presented by REBERT and PRIVÉ (1974) or NDOYE *et al.* (2017).

55 The circulation in estuarine environments connected to the Senegalese plateau (Sine-Saloum, Casamance) and their fluid exchanges with it have been the subject of very few studies. Tidal currents here are intense and extraordinarily complex, and their residual (average over a complete cycle) is unknown. These estuaries are also evaporation basins for a large part of the year. This results in an additional component of estuarine (or gravitational) circulation similar in principle to that observed in the Mediterranean: inflow of water with relatively low salinity at the surface and outflow of dense/salty water at depth related to the existence of stratification despite the shallow depth (typically about 10 m, CAPET *et al.*, 2019). In view of this, oil intrusion as far as the southern Senegalese inner shelf (fig. 6) appears to be a risk that needs to be quantified (and, if necessary, prevented). The residence times of pollutants emitted within estuaries are also unknown, but are likely to be long (months to years). Recently initiated estuarine modelling work (B. NDOM and V. E CHEVIN, pers. comm.) will eventually provide valuable information to clarify these issues and guide possible prevention or remediation strategies.

Conclusion

56 The annual reviews written by the Emergency Response Division of the National Oceanic and Atmospheric Administration (NOAA) of the main publications that have studied the effects of pollution on marine organisms (e.g. MEARNS *et al.*, 2018, 2019, 2020) illustrate both the diversity of sources of pollution and the diversity of their effects depending on the organisms exposed to them. In Senegal, human activities generate various types of pollution, the composition of which is unknown and the volumes poorly quantified. These sources of pollution are added to the anthropogenic disturbances not described here that affect the entire globe, namely warming, acidification and deoxygenation of the oceans. Pollutants affect all levels of biological organisation, and Senegal is not spared from the many threats associated with this pollution. The effects of these pollutants can be significant and can act in concert. However, the combined effects on the species that make up the marine ecosystem remain unknown. Ocean circulation can also produce situations that are much more diverse than that generally envisaged in an area (i.e. through the dilution and rapid export of pollution to the open sea). For pollutants confined to the surface, there may be strong accumulation effects involving a combination of processes.

57 Figure 2 shows key areas for the ecosystem, either for vulnerable phases of the fish lifecycle (larvae, juveniles) and/or as biodiversity hotspots. The southern Senegalese inner shelf is generally an ecologically important area due to the physical conditions discussed in the section on the role of ocean dynamics in the trajectory of pollutants. From north to south, the estuaries of the Senegal River, the Sine-Saloum, the Gambia River and the Casamance also represent key sites for shellfish (see chapter 6) or certain

fish species (BAINBRIDGE, 1963; SIMIER *et al.*, 2004; ECOUTIN *et al.*, 2010; SLOTERDIJK *et al.*, 2017; DÖRING *et al.*, 2017). In terms of conservation, these estuarine areas are home to a high level of biodiversity (DIA, 2012), including some marine mammal species (VAN WAEREBEEK *et al.*, 1997; PERRIN and VAN WAEREBEEK, 2007; KEITH-DIAGNE *et al.*, 2021), and represent sensitive sites[20] for many bird species[21].

58 The key areas identified in figure 2 also concentrate a large number of human activities: small-scale fishing, tourism, and maritime transport linked to port infrastructure. They are also subject to local pollution, either because of the scale and chronicity of the sources of pollutants (Hann Bay and Petite Côte) or because of the length of residence time (estuaries). To this must be added the existence of delocalised risks, in particular linked to oil spills, which can affect the entire marine region and have a particularly significant impact in coastal areas. Figures 5 and 6 illustrate that circulation and dynamic processes connect areas of pollution to sensitive ecological areas and are therefore likely to pose risks to them. The seasonality of hydrodynamic conditions along the Senegalese coast is also an important element to take into account in the role that circulation can play in the transport and dispersion of pollutants (fig. 2).

59 From a marine spatial planning perspective, these different elements argue for the identification of sensitive areas on the basis of ecological criteria, risks linked to sources of pollution, and their socio-economic and cultural role. Given current knowledge, it seems legitimate to consider the entire inner shelf and estuaries as critical areas. In practice, these areas are places of conflicts of use between fishing, tourism and industrial activities. Numerous factors complicate the implementation of a spatial planning process for the marine environment (EHLER *et al.*, 2019), as many development projects show a strong tendency towards a top-down approach (e.g. the Ndayane multifunctional port project)[22] and are part of the weak regulation of polluting industries or artisanal fishing (unsatisfactory status of marine protected areas, CORMIER-SALEM, 2015). Failing that, and pending hypothetical conditions that are more favourable, the following recommendations can be made.

- *Prioritise work on pollution sources (upstream):* anticipate the risks linked to the installation of new infrastructure (desalination plant, port of Ndayane), ensure that a substantial budget and permanent human resources are allocated to monitoring and maintaining strict pollution prevention standards and implementing emergency responses. The project to clean up Hann Bay is one of the essential tools for reducing sources of pollution from the megalopolis of Dakar and is in line with this strategy.
- *Develop strategies and actions to mitigate pollution and its risks in concertation (co-construction):* marine spatial planning must resolve conflicts of use. It thus needs to be closely linked to a co-construction/co-development approach, which is essential whatever the level of aims. For example, the "What a Waste 2.0" project financed by the World Bank tackles the problem of plastic pollution by including local populations as well as government agencies and private stakeholders (see also the project *Ensemble Contre Les Ordures* [ECO] 'Together against rubbish').[23]
- *Advance scientific understanding:* given the rise in combined risks (local and global disturbance), it is urgent to better quantify pollution in Senegal, both in terms of the diversity and the quantity of pollutants entering the ocean. The consequences of this pollution also need to be anticipated. Understanding ocean circulation allows us to spatialise the risks linked to the different sources of pollution. The experimental study of the response

of every species in an ecosystem to disturbances, including the current and future variability to which they are/will be subjected, remains utopian. However, it is essential to identify the key species at risk, to understand their lifecycle in order to protect sensitive phases/areas, and to shed light on the mechanisms underlying all types of disturbance (DUPONT and PÖRTNER, 2013). It is difficult to assess the toxic effects of contaminants on populations with long life spans consisting of many overlapping generations. Establishing a causal link requires multiple steps, including both laboratory experiments and field observations.

60 Scientists and the rest of society must adopt a humbler attitude towards the relationship between humanity and our environment, as science is not advanced enough to anticipate all the consequences of global and local disturbances on the marine environment. In Senegal, as in many places around the world, the sources of environmental degradation seem to be accumulating faster than the state of knowledge is progressing. By advocating for marine protected areas or similar types of zones, marine spatial planning could reduce some, but not all, of the pressures on the environment. Yet an important unresolved question is whether it perpetuates a cultural relationship with life that may be at the root of human-induced ecological problems. This was highlighted at a recent symposium[24] that raised the question: "Is the protection of the marine environment part of the activities understood as 'uses' of the sea and its resources or should it be distinguished from them?" This reasoning is also found in the work of P. DESCOLA (2005) about the naturalism that characterises Western societies. Spatial planning, a tool for managing the marine environment, only attempts to organise the distribution of human activities at sea in order to optimise yields (for humans) and limit conflicts of use (between humans). That this results in areas where marine organisms can live relatively protected from human activities is only an unintended consequence. Is this enough to create truly sustainable conditions for coexistence between human societies and other species? The disproportionate share of human and financial resources invested in the forms of development that destroy nature rather than protect it, in Senegal as elsewhere in the world, unfortunately gives little cause for optimism.

Acknowledgements

61 The French National Research Agency (ANR) partially funded the research presented in this chapter ("Planktonic interactions, environmental factors and biological/geochemical consequences in the South Senegalese coastal laboratory" [SOLAB], project grant ANR-18-CE32-0009). The authors also received support from the international joint laboratory "Integrated climate and ocean studies in West Africa and responses to climate change in Senegal" (Éclairs). We are very grateful to Moussa N'Dienor from the Senegalese Institute for Agricultural Research (ISRA) for the documentation provided on fertilisers and pesticides, and to Alioune Kane from Cheikh Anta Diop University (UCAD, Senegal) for his constructive input.

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NOTES

1. See the figures of the National Agency of Statistics and Demography of the Republic of Senegal: https://www.ansd.sn/index.php?option=com_ansd&view=titrepublication&id=30
2. https://www.seneweb.com/news/Video/dechets-medicaux-sur-des-plages-les-imag_n_308080.html
3. According to several studies, between 60% and 80% of floating marine debris on beaches or on the seabed is plastic.
4. World Bank Infographic: *Waste, a global picture of household waste management to 2050*, Sept 2018: https://www.banquemondiale.org/fr/news/infographic/2018/09/20/what-a-waste-20-a-global-snapshot-of-solid-waste-management-to-2050
5. From about 40,000 t in 2010 to 150,000 t in 2016, according to the Senegalese Ministry of Agriculture.
6. In 2016, 16 kg/ha in Senegal vs 290 kg/ha in the Netherlands. https://donnees.banquemondiale.org/
7. The officially recorded use of these pesticides and herbicides varies between 700 and 800 t of active product per year (2012 to 2014, source: Plant Protection Directorate).
8. ANSD, 2013 Census.
9. See *the Yearbook on the Environment and Natural Resources of Senegal* 3rd edition (CSE).
10. IBAs can be consulted on a global scale at http://datazone.birdlife.org/site/mapsearch
11. https://www.onas.sn/sites/default/files/etudes/baiedehann_l3_volume_1_eies_v2_1.pdf
12. Organochlorine aromatic compounds are among the most ubiquitous and persistent toxic, ecotoxic and reprotoxic pollutants and are endocrine disruptors at low doses.
13. Informal report for DEEC, 2015.
14. Articles 10 to 13 of the Protocol to the Abidjan Convention ratified by Senegal.
15. https://www.un-page.org/files/public/plan_senegal_emergent.pdf
16. Species for which the experiment could be conducted.

17. Eutrophication of aquatic environments is an imbalance in the environment caused by an increase in the concentration of nitrogen and phosphorus.

18. For similar reasons, the Banc d'Arguin in Mauritania is another preferred spawning site for the *Sardinella aurita* population (CONAND, 1977; BOELY *et al.*, 1978, 1982; FRÉON, 1988).

19. A block in this context refers to a hydrocarbon exploration and production-sharing contract (BONNIN and LY, 2019).

20. *Important Bird Areas (IBAs) and biodiversity areas:* http://datazone.birdlife.org/site/ibacriteria

21. See all sensitive bird sites in Senegal: http://datazone.birdlife.org/site/mapsearch

22. http://www.big.gouv.sn/index.php/2019/05/09/le-port-de-ndayane-au-nom-de-la-competitivite

23. https://pfongue.org/Projet-Ensemble-Contre-les-Ordures.html

24. Colloquium "Conflicts of use at sea and European Union law", Aix-Marseille University, 19–20 November 2020. https://univ-droit.fr/actualites-de-la-recherche/appels/34550-conflits-d-usages-en-mer-et-droit-de-l-union-europeenne

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Chapter 3. How many fish in the sea and where?

Active acoustics to assess marine organisms

Anne Lebourges-Dhaussy

1 To establish balanced use between the users of a maritime space, the first step is to know this space: its abiotic characteristics and their dynamics; its biotic components, their distribution and dynamics; vulnerable areas and rich zones; mapping of fish habitats (LE PAPE *et al.*, 2014); the human and economic environments, etc. This initial diagnosis requires determining the distribution of living resources, exploited or not. For this purpose, the use of active acoustics was developed in the 1970s, and this method of assessing and observing the marine environment has since become commonplace in many countries around the world (in Europe, Australia, the United States, but also in Senegal, Morocco, Mauritania, Peru, Mexico, etc.). Its use has now been extended to the study of aquatic ecosystems as a whole, as fluctuations in fish populations cannot be explained without taking their environments into account. This non-intrusive and non-destructive method also has the advantage of being suitable for studying protected areas where biological sampling is not permitted.

The value of active acoustics

2 Acoustic data is a source of information for a range of components in a biocenosis and sometimes a biotope. The data is generally acquired continuously during oceanographic campaigns, from the surface to a depth of 1000 m or more. This provides a view of the ecosystem with a resolution unmatched by other approaches (on the order of a decimetre vertically and a few metres horizontally). By using several transmission frequencies, the different components of the ecosystem can be detected:

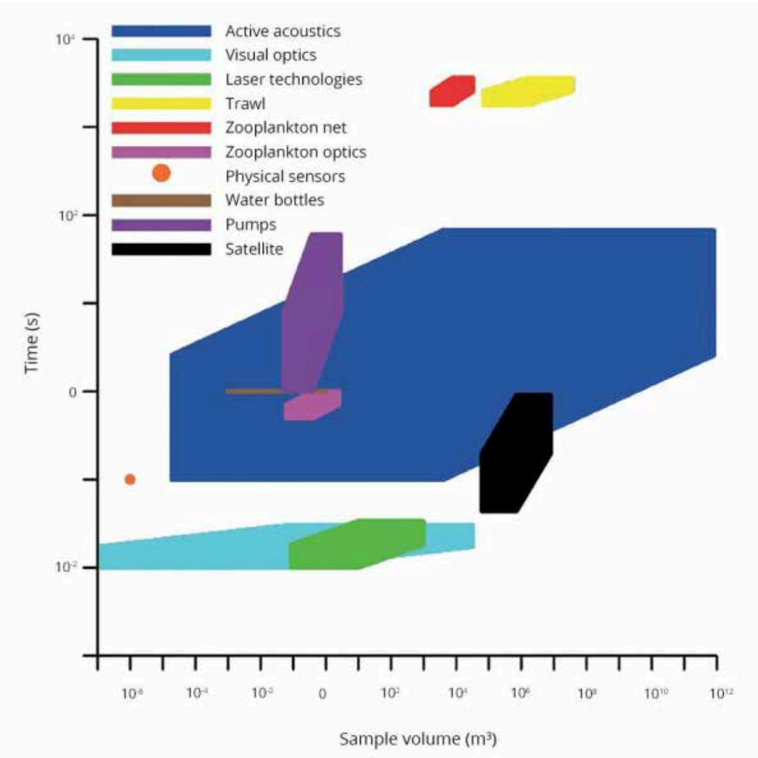
- strong physico-chemical gradients (of temperature, oxygen, density)
- the seabed and its geological composition
- zooplanktonic organisms (crustaceans and gelatinous organisms), in schools or in layers
- fish (from a few centimetres to several tens of centimetres), dispersed or aggregated

• top predators (e.g. tuna, marine mammals)

3 Acoustic data also provides information on the behaviour of organisms (vertical migrations, changes in the structure of organisms between day and night, movement in schools or dispersed, in layers, etc.). The information obtained is unique because of the spatial and temporal coverage it provides compared to other observation methods (fig. 1).

4 Acoustic data is thus essential to assess exploited and unexploited fish stocks and their trophic environment, to understand their nychthemeral, seasonal or interannual behaviour and predator/prey relationships, to define preferential habitats, etc., all of which is knowledge that can inform the choices necessary for marine spatial planning (MSP).

Figure 1. Spatio-temporal coverage of an observation unit for different in situ methods



The minimum resolution of the measurement is indicated by the lower left corner of each polygon and its maximum extension by the upper right corner.
Source: Trenkel et al. (2011)

Method

Principles

5 The physical principle of active acoustics is based on the propagation of acoustic waves in the water, which come into contact with the biotic components present in the marine environment. Propagation takes the form of a succession of compression-dilatations of the medium, which are supported by the particles that constitute it. An acoustic wave cannot propagate in a vacuum, it needs a particulate support. Each

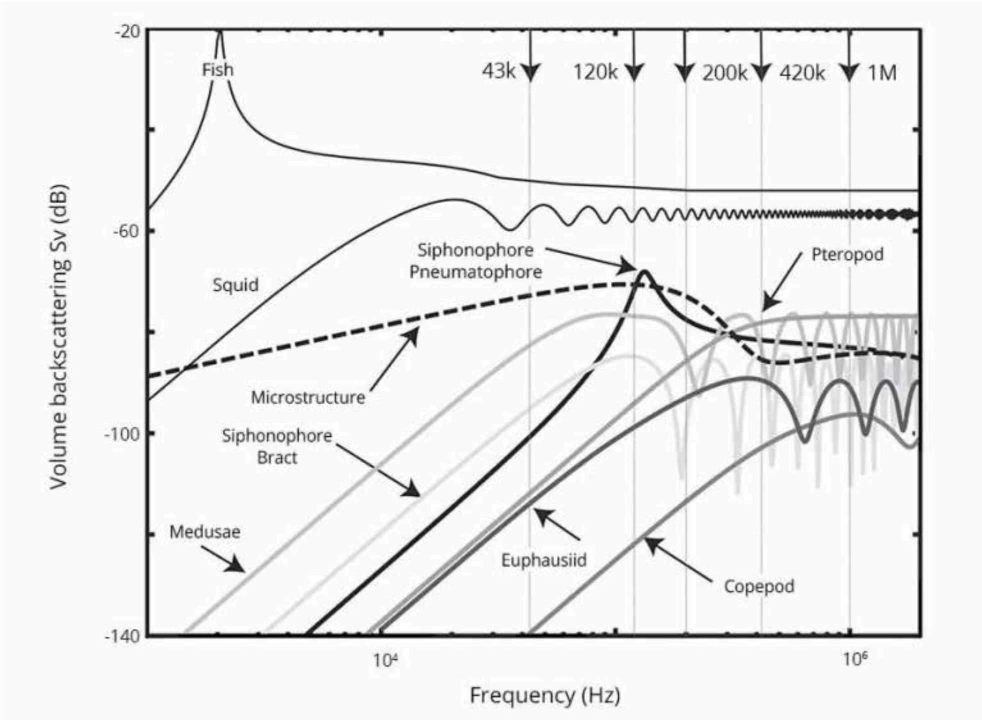
particle transmits a local pressure anomaly to its neighbour, which then propagates this to the next particle. When a change of density occurs in the medium, the obstacle presents more or less resistance to the movement of the particle, modifying the way in which the pressure anomaly is transmitted. Thus, part of the energy transmitted by the acoustic wave is reflected back to the source (as an echo) and the other part continues to propagate beyond the obstacle.

6 The ability of a target to reflect an acoustic wave is mainly determined by its density difference with the surrounding medium, in this case seawater or fresh water, and by the contrast in wave propagation speed between the medium and the target. Echoes will be strong whether they come from targets denser than water (rocks) or less dense (gas bubbles, water–air interface). Marine organisms containing a gaseous inclusion, such as some planktonic organisms (syphonophores to pneumatophores), or a gas swim bladder, such as many pelagic fish (sardines, anchovies, tuna, etc.), are very good reflectors.

7 The reflective properties of targets are a function of their density, size, shape and orientation with respect to the direction of the wave and its frequency. For a number of well-studied and documented fish species, equations quantify the relationship between the reflectivity index of a fish and its total length (SIMMONDS and MACLENNAN, 2005). For other species, such as triggerfish around Fernando de Noronha (Brazil), documentation does not exist; in this case, it is necessary to calculate these relationships from field data (SALVETAT *et al.*, 2022).

8 In the range of ultrasonic frequencies used, from about 18 to 400 kHz, organisms can have highly variable responses depending on the frequency (fig. 2). Multi-frequency systems are thus used to exploit the characteristics of the targets (fish, crustaceans, gelatinous animals, etc.) in order to better classify them. In this way, the fish, their predators and their prey can be observed simultaneously through the acoustic data.

Figure 2. **Echo levels as a function of frequency for the main biological groups, at a density of one organism/m³ of water**



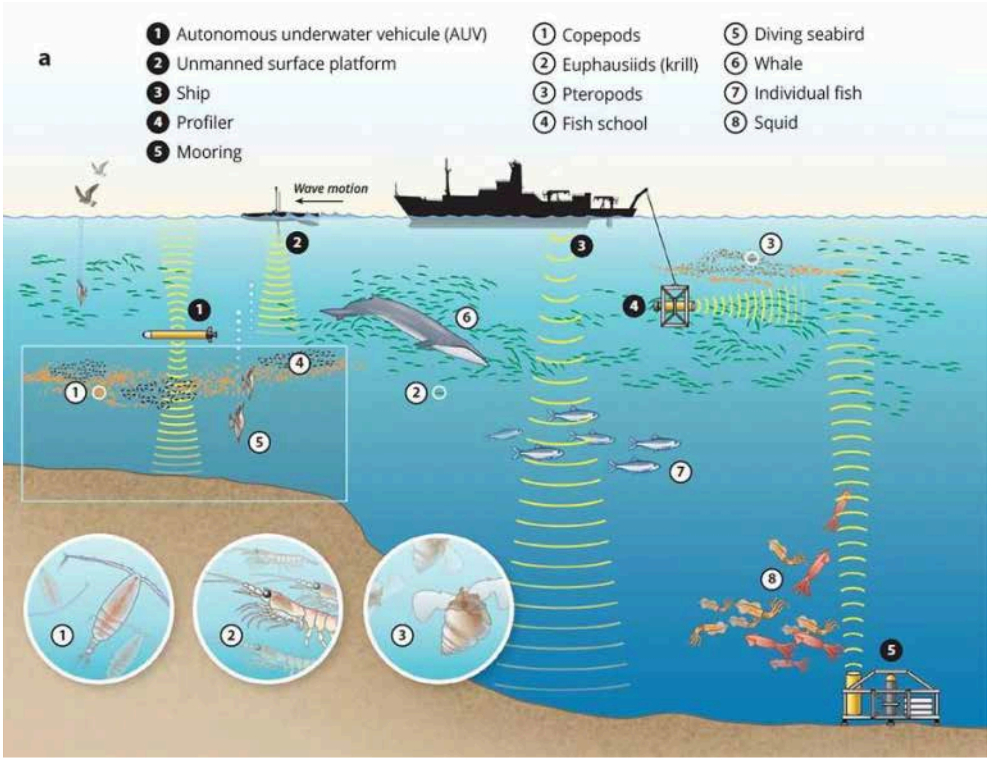
Microstructure: change in density of the medium; syphonophore and medusa: cnidarians; euphausiid and copepod: crustaceans; pteropod: molluscs.
Source: LAVERY *et al.* (2007)

Implementation

9 There is a wide variety of acoustic equipment. The most commonly used are mounted on the hull of research vessels. However, they provide data at the time of the field mission only and detect targets only from the surface. To detect deep targets (sometimes at several hundred metres), at distances where hull-mounted equipment does not provide sufficient resolution and/or provides data for which the signal-to-noise ratio becomes too low, there are autonomous sounders that can be directed close to the targets of interest in order to obtain better quality and much more spatially refined measurements. Other devices are designed to provide time series and are installed on moorings. Some very high frequency equipment, used as profilers, is dedicated to the detection of zooplankton (fig. 3).

10 A depth sounder (see black circle 3 in figure 3) is used continuously for the duration of a typical survey. Generally, it emits a wave into the water every second: at 10 knots, this corresponds to an emission every 5 m. The wave propagates to depths that are greater the lower the frequency used. Typically, at 38 kHz, it is possible to detect fish to a depth of about 1000 m. The vertical resolution is a few centimetres. The data is quasi-continuous both vertically and horizontally.

Figure 3. Acoustic devices used for ecosystem studies



Source: Benoit-bird and Lawson (2016)

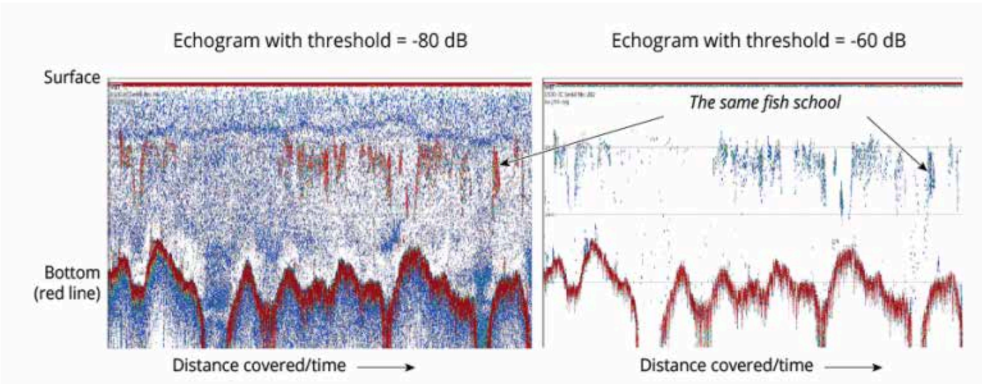
Assessing marine organisms

11 Active acoustics tools and methods were initially developed at the beginning of the 20th century to determine the depth of the ocean floor beneath a ship (the first echo sounder was marketed in 1925), particularly after the sinking of the Titanic (Juhel, 2005). The first mention of the use of a sounder to assess marine organisms dates from 1935 in an article in *Nature* on the detection of cod shoals in a Norwegian fjord with an echo sounder (Sund, 1935). Then as now, this is the only approach that makes it possible to "see", from the surface to the seabed, continuously along the ship's path, the reflective organisms present in the water column. As the reflectors are varied and of all sizes, depending on the frequency or frequencies used, it is possible to obtain a fairly exhaustive representation of the underwater "landscape". However, scientists have been primarily interested in fish, responding to the need to assess stocks of commercial interest in order to better manage them.

12 Stock assessments are based on the principle of echo integration, which is itself underpinned by a principle of linearity: for a given sampled volume, the reverberated acoustic energy results from the linear combination of the individual contributions of the organisms present in this volume. The higher the concentration of fish and/or the larger the fish, the higher the acoustic energy. "Echo integration" consists of summing the vertical samples of acoustic energy received in an integration cell, i.e. a given water height (e.g. the water column) for a given distance travelled (typically 1 nautical mile at sea).

13 In this integration cell, there may be a fish of several species, as well as zooplankton, gelatinous organisms, etc. So the first step is to select the share of fish in the total received acoustic energy. Applying a data analysis threshold of -60 dB (as in the example of figure 4) is sometimes sufficient to separate fish (acoustic energy above the threshold) from other organisms in the same trophic environment (acoustic energy below the threshold). In some cases, a classification algorithm based on the differentiated frequency responses of fish and other organisms can be used to better account for fish (MORENO *et al.*, 2007; FERNANDES, 2009; BALLÓN *et al.*, 2011; KORNELIUSSEN *et al.*, 2016; KORNELIUSSEN, 2018).

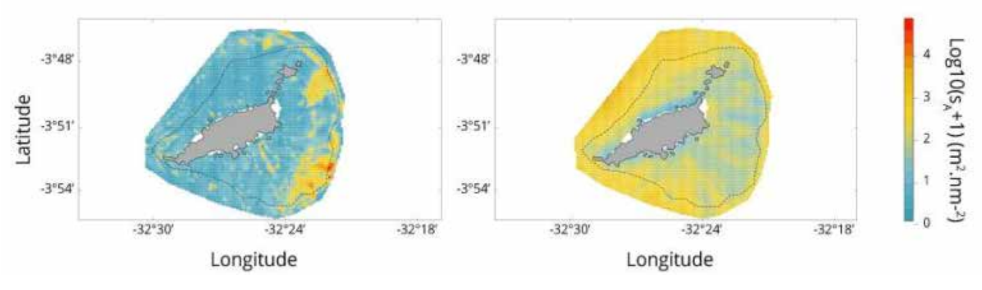
Figure 4. **Example of an echogram from the Farofa2 campaign ("Tropical Atlantic Interdisciplinary Joint Laboratory on physical, biogeochemical, ecological and human dynamics", LMI Tapioca) around Fernando de Noronha (Brazil) with two different thresholds (-80 dB on the left and -60 dB on the right).**



Source: A. Lebourges-Dhaussy

14 Once the proportion of acoustic energy related to fish has been identified, a map of their distribution can be made, as well as a map of the distribution of other types of organisms (fig. 5).

Figure 5. **Spatial distribution of fish (left) and other organisms (right) around the island of Fernando de Noronha (Brazil) by geostatistical interpolation of surface acoustic density s_A (see MCLENNAN *et al.*, 2002 for definition of acoustic quantities).**

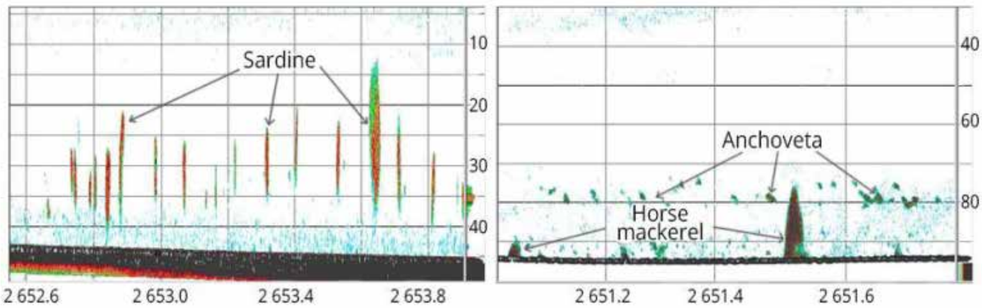


The 50 m isobath is indicated by the black dotted line.
Source: SALVETAT *et al.* (2022)

15 Stock assessment is ideally done by species. Within the share of energy returned by "fish" in the detection, this energy is divided according to the species present, some of which are exploited by fisheries, others not. Determining the distribution of energy between species is aided by identification trawls carried out using different types of

detection and the expertise of the scientific team on the pattern of detections by species in a given geographical area and season (fig. 6).

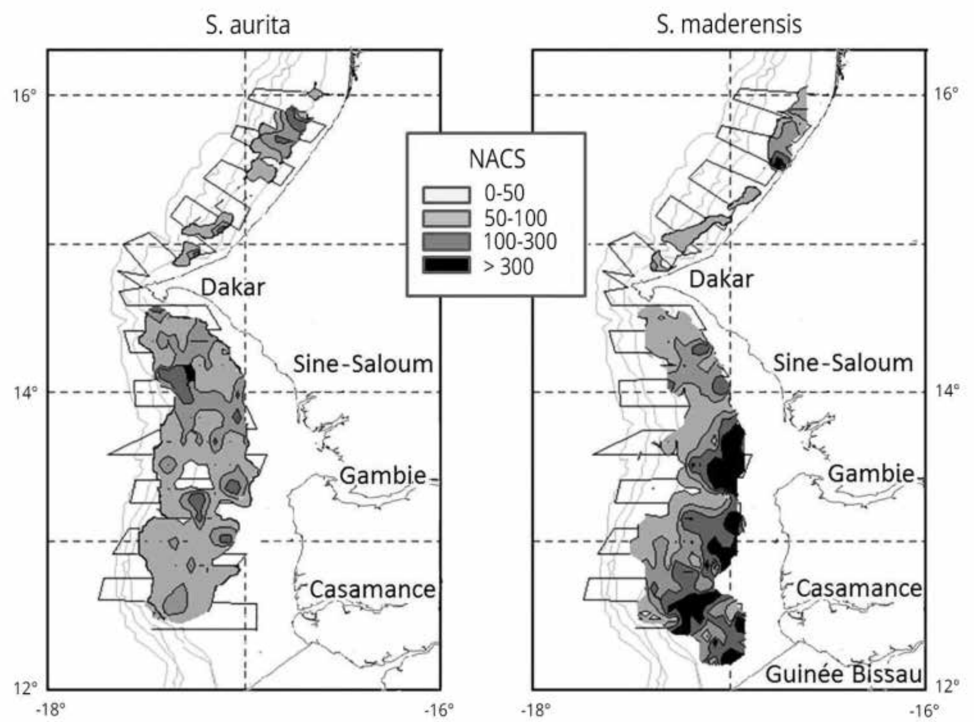
Figure 6. Detection of typical fish schools in the Bay of Biscay (France) in spring: sardines (left), anchovies and horse mackerel (right), confirmed by identification trawls. The acoustic energy of each school is calculated and assigned to the corresponding species.



Source: Noël Diner, pers. comm.

16 The distribution of each species is thus mapped in terms of surface acoustic density (SAD) (expressed in $m^2.nmi^{-2}$, MCLENNAN *et al.*, 2002) (fig. 7). Based on the size distribution from the trawls, the equations relating the individual echo of a fish to its size or to its size and mass make it possible to estimate the mass of the species per unit area. This mass, assigned to the distribution area of the species, ultimately provides an estimate of the total biomass of the species.

Figure 7. Acoustic density distribution (NASC, in $m^2.nmi^{-2}$) of two Senegalese sardinella species (*Sardinella aurita* and *S. maderensis*) obtained by the acoustic campaigns of the research vessel Itaf Deme 2005-2006-2007 (Senegal)



Source: SARRÉ *et al.* (2018)

17 There are a number of uncertainties associated with this assessment method (SIMMONDS and MACLENNAN, 2005). Weather plays an important role: bad weather (wind, swell) generates surface bubbles that attenuate the propagated signal to an extent that is difficult to quantify, and induces vessel movements that prevent the correct detection of echoes (if the orientation of the vessel changes between the time of transmission and reception). The classification of species based on acoustic detection is also a source of potential error: the assignment of detection to a given species (e.g. fig. 6) is done with an "expert eye" in an area and season for which the types of aggregation of species are known. Yet this assumes their stability, an assumption that may be challenged in the event of a strong wind event, for example.

18 In poorly documented, multi-species regions, trawling often identifies assemblages of species, and it is difficult to be more precise than the assemblage itself in the distribution of acoustic energy. The factor for converting acoustic density into a quantity and then mass of fish is not known for all species, particularly in tropical environments; equations from the literature are therefore used, which are not necessarily optimal for the environment studied. Fish behaviour is another important factor: the noise caused by vessels, depending on the depth of the organisms targeted and the frequency of use of the areas studied, may cause fish to avoid the vessel and no longer be detected by the vertical sounder. Devices such as omnidirectional sonars can detect schools of fish around the boat, but they do not allow for the quantitative analysis of observations, which is necessary for evaluation. They do, however, provide information on the presence of schools not detected by the vertical sounder under the boat. Despite these (studied and known) uncertainties and biases, the assessment of pelagic fish stocks with the acoustic approach is at least as good as – and probably better than – other existing methods (SIMMONDS and MACLENNAN, 2005). A combination of methods is, in any case, preferable.

Other applications of interest to MSP

Ecosystem approach

19 The ecosystem approach to resource management is currently considered the most relevant for achieving sustainable development, and is thus one of the key elements in marine spatial planning (ANSONG *et al.*, 2017).

20 In the case of active acoustics, moving from a fisheries approach to an ecosystem approach is a fairly simple choice. Indeed, as shown in figure 4, lowering the threshold for the visualisation and analysis of acoustic data allows the biotic environment of the fish to be taken into account. The latter, which is made up of planktonic layers, has a distribution that is much more constrained by the physical conditions of the environment (waves, stratification, currents, etc.) than the nekton, which is much more mobile, except when the environmental conditions include parameters that limit its survival. Acoustic observation of the distribution of organisms thus makes it possible to extract information on the hydrodynamic characteristics of the water column, provided that a low enough threshold is used. In the case of Peru, for example, the vertical distribution of anchovies (*Engraulis ringens*) is particularly constrained by oxygen availability. Acoustic detection of anchovy schools provides information on the depth of the oxycline (where the oxygen level drops rapidly relative to the surface

layer of the ocean), with the very fine resolution of the acoustic data (fig. 9A, BERTRAND *et al.*, 2010).

21 In addition to the data provided by acoustics on the distribution of fish and their biotic or even abiotic environment and its hydrodynamic structure, the ecosystem approach also takes into account primary production, currents, topography, etc., from other sensors (see Box 1 on biologging in marine megafauna) and aims to understand their interactions.

Box 1. How can megafauna biologging data be used for marine spatial planning?

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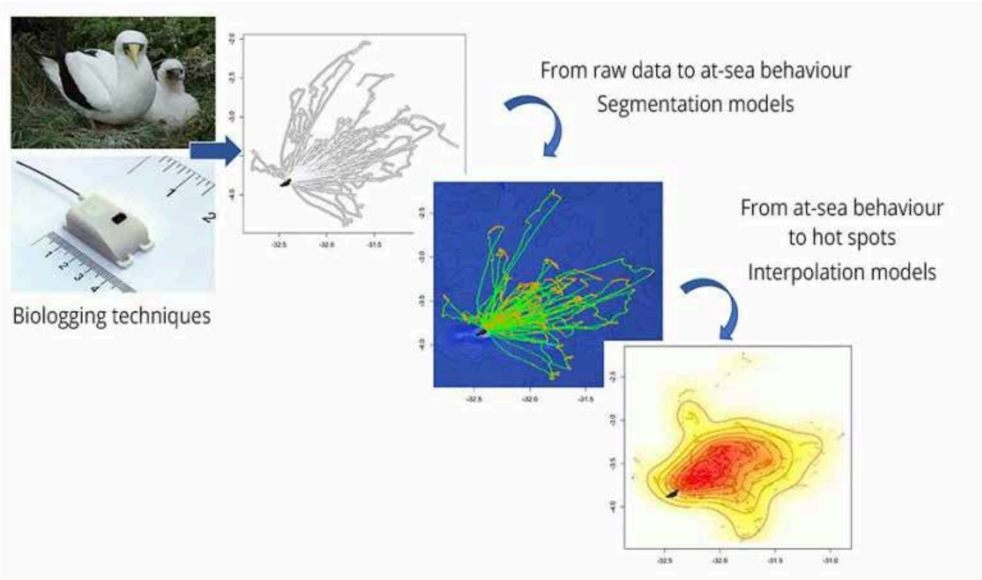
Marine systems have a number of attributes that make them particularly difficult to delineate for management purposes. They are inherently three-dimensional, opaque compared to terrestrial systems, and many systems (such as fronts and eddies) are dynamic in space and time. Fusion and scaling of oceanographic and ecological data are required to observe, dynamically manage and conserve species embedded in a dynamic mosaic of seascapes.

Marine megafauna (seabirds, marine mammals, large fish, etc.) are highly mobile animals that move over large areas of the sea to feed, breed, rest or migrate. Thus, a comprehensive understanding of the causes, patterns, mechanisms and consequences of megafaunal movements is essential to manage human activities in seascapes under multiple pressures: for example, through marine spatial planning. Yet measuring habitat use at sea and defining critical niches and corridors has long been a challenge.

In recent decades, considerable progress has been made with a range of recording technologies. Biologging refers to the use of miniaturised tags attached to animals to record and/or transmit data on an animal's movements, behaviour, physiology and/or environment. Today, ecologists have access to an arsenal of sensors (triaxial accelerometers, magnetometers, global positioning systems, cameras, diving sensors, etc.) that can continuously measure most aspects of an animal's condition (e.g. location, behaviour, caloric expenditure, interactions with other animals) and its external environment (e.g. temperature, salinity, depth). These technologies allow ecologists to obtain new answers about the physiological performance, energy, foraging, migration, habitat selection and sociality of wild animals, as well as to collect data about the environments in which they live. Combined with state-of-the-art statistical modelling in movement ecology, biologging technologies provide essential information on the dynamic ecological niches of megafauna species. This is a key step in delineating biodiversity hotspots and coldspots, which can help to better define conservation issues in a marine spatial planning framework (fig. 8).

Figure 8. Biologging data collected on seabirds (*Sula sula*) from the Fernando de Noronha archipelago (Brazil) in the framework of the Paddle project

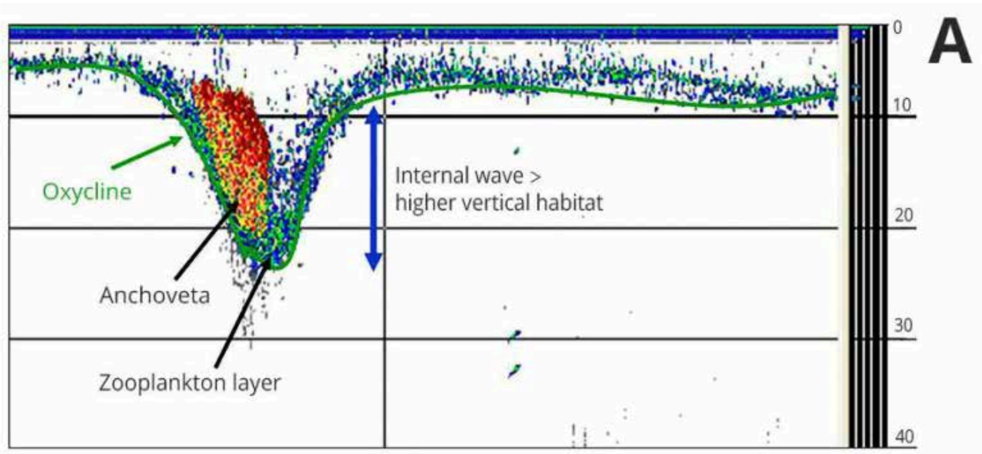


The raw GPS data was processed by different statistical models to identify feeding areas and deduce critical areas (hotspots) for this species.

Potential habitat and habitats to be preserved

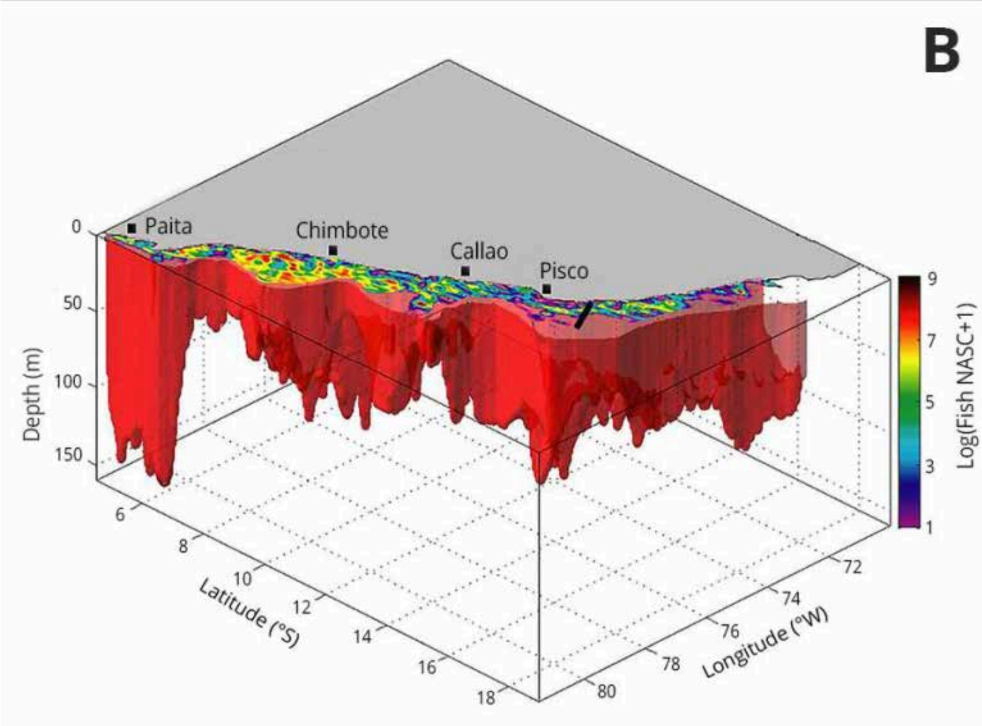
22 In the example of Peru, the resolution of the acoustic data allows the depth of the oxygen minimum zone to be mapped in three dimensions. From this, we can determine a volume of potential anchovy habitat, in which they have sufficient oxygen for their survival (fig. 9B, BERTRAND *et al.*, 2010).

Figure 9 A. Extract from an echogram showing a school of anchovies concentrated above a layer of plankton aggregated along the oxycline, at which the oxygen level drops sharply in relation to the surface layer of the ocean.



The presence of an internal wave in the water column causes the oxycline to sink and thus provides a higher volume of habitat for the anchovies. Example taken along the coast of Peru.
Source: BERTRAND *et al.* (2008)

Figure 9 B. **Potential anchovy habitat (in red) from the position of the oxycline provided by acoustic data from the small pelagic assessment campaign carried out by the Instituto del Mar del Perú (IMARPE) (Lima, Peru, February–April 2005)**



The acoustic abundance of anchovy is shown in a logarithmic scale above the volume of anchovy.
Source: BERTRAND *et al.* (2010)

23 Tropical offshore environments, which are essentially oligotrophic (poor in nutrients and resources), are still very poorly understood. However, in such areas, the presence of oceanic islands or seamounts locally modifies the flow of currents, forming more productive oases (MARSAC *et al.*, 2019). Large predators are present in these areas, such as tuna, dolphinfish, marine mammals, etc., which feed on organisms 2 to 20 cm in size (macrozooplankton and micronekton). These organisms are acoustically detectable (crustaceans, jellyfish, squid and other syphonophores in figure 2). Studying the distribution of organisms around certain topographical structures in offshore environments makes it possible to determine their interest as distribution areas for mammals or large fish and the prey of these large predators. Concentrations of organisms have been found on the flanks and tops of seamounts, particularly at night in the example of Cross Mountain in the central Pacific, a few hundred kilometres from the Hawaiian Islands (JOHNSTON *et al.,* 2008). Species may be associated with mountaintops or flanks, such as the potential prey of large predators associated with the summit and flanks of MAD-Ridge, south of Madagascar in the Indian Ocean (ANNASAWMY *et al.*, 2019; fig. 10 A and B). Combining active and passive acoustics (listening to the sounds of marine animals) can help link the presence of large predators and their prey concentrations (JOHNSTON *et al.*, 2008), and thus provide quantitative spatial observations that are critical to decisions on whether to protect an area.

24 The presence of strong vortex structures, such as exist in the Mozambique Channel, may have a greater enriching effect than topographic structures (ANNASAWMY *et al.*, 2020).

Figure 10A. Acoustic detections at the top of the MAD-Ridge seamount in southern Madagascar, at night

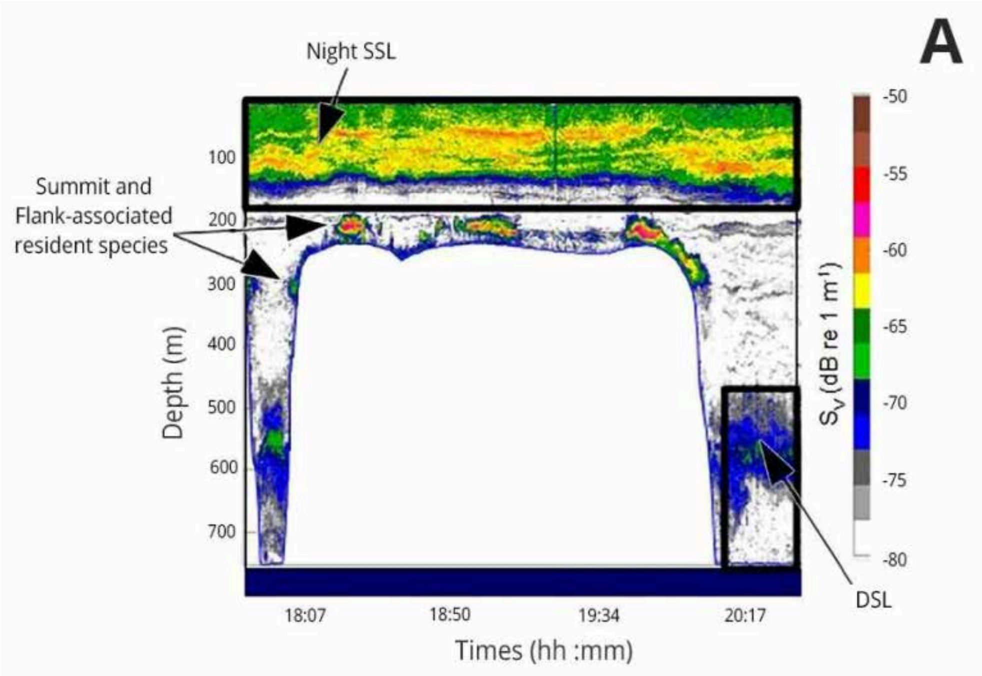
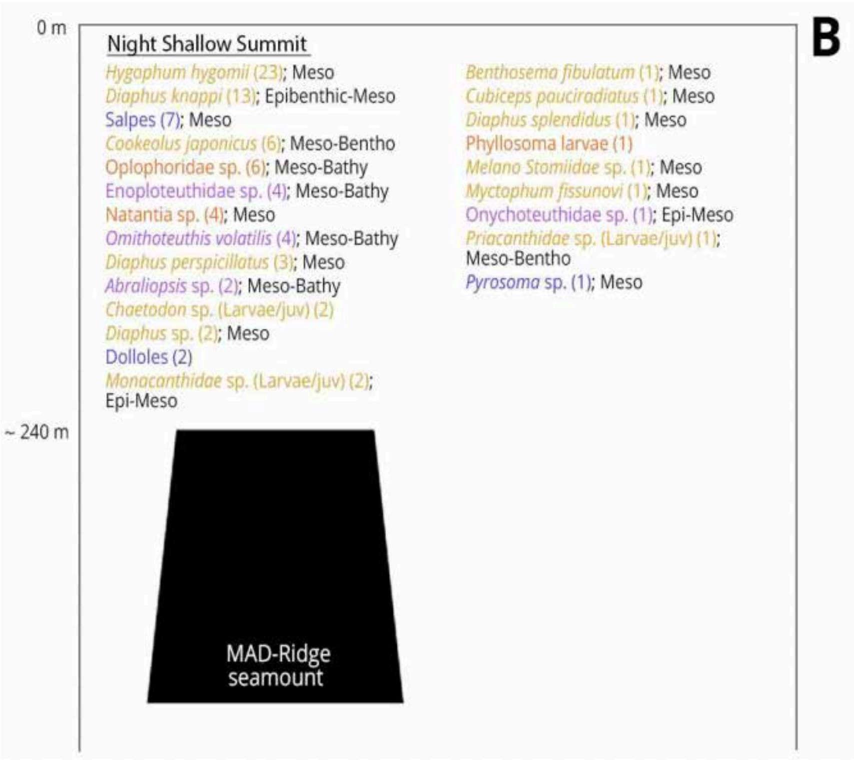


Figure 10B. Dominant species associated with the mountaintop according to trawls



Habitat categories: Epi: epipelagic; Meso: mesopelagic; Bentho: benthopelagic; Bathy: bathypelagic; epibenthic or the combination of several habitats
Source: ANNASAWMY *et al.* (2019)

25 At the scale of the exclusive economic zone (EEZ) around New Caledonia, for example, the pelagic zone has been fully integrated into the Coral Sea Natural Park since 2014; strict reserves were established in 2018 around some remote reefs, but the protected areas remain limited. A series of surveys covering the EEZ provided acoustic density and its horizontal and vertical distribution. Statistical models to study this set of densities in relation to environmental parameters and to the distribution of large predators may help to delimit other areas of priority interest to be preserved, for the conservation of species or the ecosystem in general (RECEVEUR *et al*., 2020, 2021).

Long-term observations in shallow environments

26 Taking stock of an ecosystem at a given time provides initial synoptic knowledge. However, the effects of new uses or of the implementation of conservation measures must be assessed through medium- or long-term monitoring. In the case of marine protected areas (MPAs), monitoring is carried out and experimental sampling provides information on changes in species diversity, size, age at first maturity, trophic levels, etc. The study carried out in the Bamboung MPA in Senegal in the Sine-Saloum estuary (ECOUTIN, 2013) is an example. Determining the density of organisms by vertical acoustics here is difficult due to the very shallow depth of the environment. Indeed, the operation of the equipment does not allow the first two metres below the surface to be exploited. Moreover, the echo off the bottom is much stronger than that of the biological organisms, which can only be detected if they are about 50 cm above the

bottom. However, this method provides additional insight (BÉHAGLE *et al.,* 2018), and without the bias of the selectivity of experimental nets. In the case of the study in Senegal, the variability of the environment, the small size of the MPA and practical difficulties in ensuring a perfectly regular protocol over the time series made it difficult to clearly summarise the results, highlighting the need for another methodology based on fixed stations over relevant periods (nychthemeral, seasonal, tidal, annual cycles) to monitor the dynamics of the fish at strategic points in the study environment. Fixed stations were used in a study conducted in northern Brazil in the Bragança region, combining acoustic and biological sampling. The results describe the migration patterns of mangrove fish, according to their size, in relation to the tide. This study also points to the interest of combining data from sounders used vertically and horizontally (KRUMME and SAINT-PAUL, 2003) to better quantify passing fish when the environment is vertically homogeneous and dominated by epibenthic species (KRUMME, 2004).

27 In very shallow environments, as mentioned above, the possibilities of depth sounders are limited, even when used horizontally: as soon as the single detection beam (cone small aperture, typically ~7°, or elliptical 2° x10°) meets the surface or the bottom of the water, other weaker detections are masked. Acoustic cameras, which consist of a set of much finer beams in both directions and which work like medical ultrasound scanners, provide other possibilities in these environments: if part of the beam hits the bottom or the surface, the other beams, which are oriented differently, can detect the biological targets of lower levels. In addition, the image resolution provided by the use of very high frequencies and the visualisation of the swimming movement of the targets allow in some cases the recognition of target types. These characteristics make it well suited to assessing individual targets in shallow environments, particularly for monitoring fish migrations (fig. 11, MARTIGNAC *et al.*, 2013).

Figure 11 A. Schematic presentation of the beams of an acoustic camera (DIDSON)

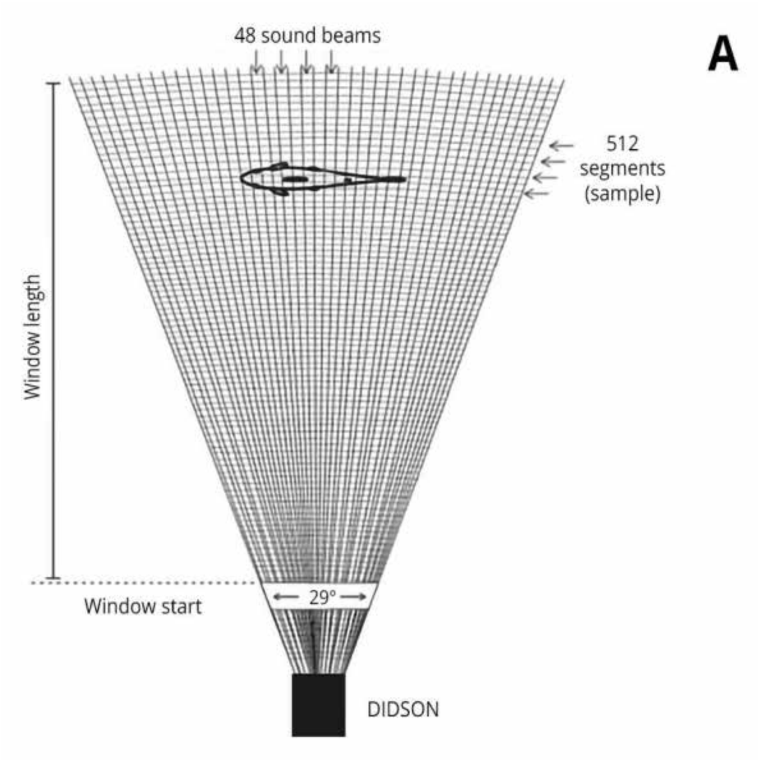
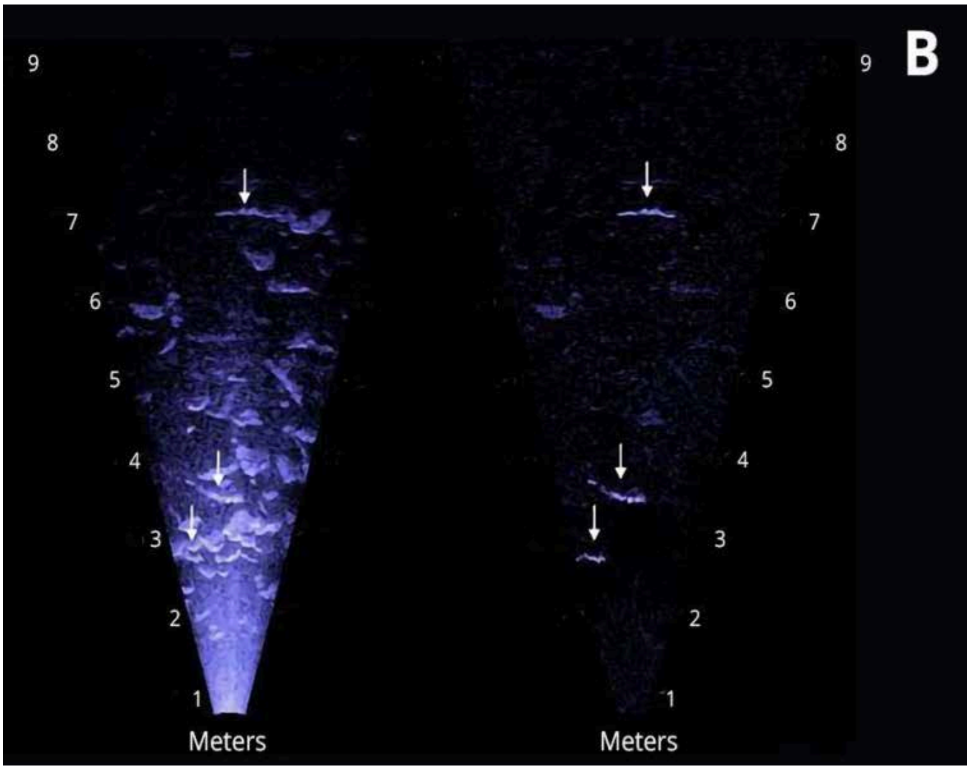


Figure 11 B. Detection of three fish (indicated by arrows) swimming over a rocky bottom (left) and the same fish after removal of the static bottom by post-processing (right) (MAXWELL and GOVE, 2004)



Source: MARTIGNAC *et al.* (2013)

Conclusion

28 This chapter presents an overview of the scope of information provided by active acoustics, as well as some of the applications for which this approach is essential. Stock assessment of exploited resources was one of the first concerns of its users, but its purposes have been greatly extended since the end of the 1990s with technological advances in the equipment. Today, acoustics has become a vital tool in an ecosystem approach: it provides quantitative and qualitative information on the various biotic components of an ecosystem, plankton and nekton, and sometimes on its physical structure. It is a preferred approach for studies in protected environments, as it is non-destructive and non-intrusive. The diversity of equipment available means that it can be used in turbid or obstructed environments, etc. or, conversely, in offshore environments where it is the only method that provides a cross-section of the water column from the surface to the bottom. The spatialized ecological knowledge obtained with high-resolution acoustic data is valuable for planning in liquid environments.

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Chapter 4. Local communities, global resources

Yellowfin tuna (Thunnus albacares) in Cabo Verde

Pericles Silva, Ivanice Monteiro, Vito Ramos and Marie Bonnin

1 Fishery resources are one of the few natural resources in Cabo Verde. Although the archipelago is located close to an important area of primary productivity and has a large exclusive economic zone (EEZ) of 734,265 km^2, its potential in fishery resources is low. The archipelago's small continental shelf extension, its volcanic origin, the scarcity of local upwelling systems, the hydrological and oceanographic regimes of its marine waters, the absence of rivers, and the scarcity of rainfall are all factors explaining this relatively modest potential.

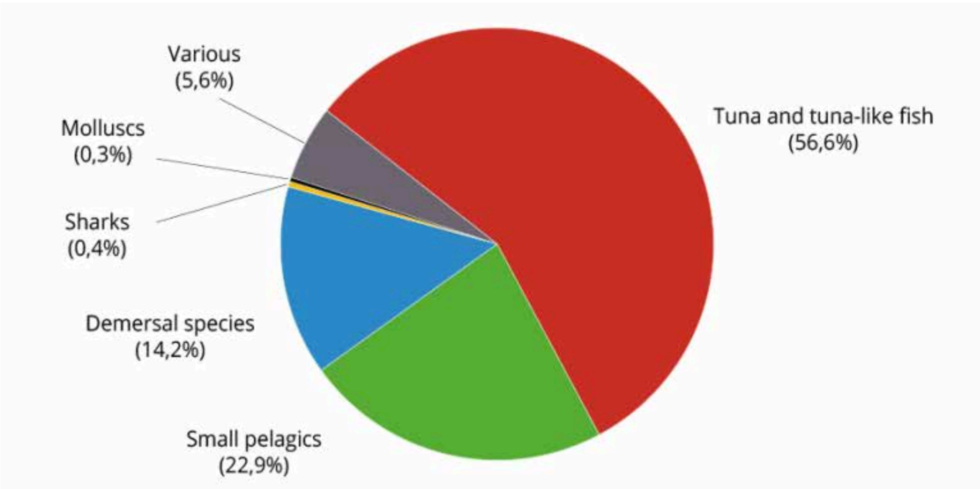
2 Cabo Verde shows the characteristic marine biodiversity of other tropical island systems, with a wide variety of species, yet the populations of certain species are small with relatively low abundance. The main fishery resources are large pelagic fish, small pelagic fish, demersal fish, surface sharks, deep-sea fish, lobsters and other gastropods. Large oceanic pelagic species include yellowfin tuna (*Thunnus albacares*), skipjack tuna (*Katsuwonus pelamis*), bigeye tuna (*Thunnus obesus*), little tunny (*Euthynnus alletteratus*), frigate tuna (*Auxis thazard*) and wahoo (*Acanthocybium solandri*). This group also includes mahi-mahi (*Coryphaena hippurus*) and beaked species (Istiophoridae, Xiphiidae). These are all essentially oceanic migratory species that come to the waters of Cabo Verde seasonally, although some species have resident populations.

3 Tuna fishing is an important sector in Cabo Verde, accounting for 25% of the total fisheries catch (fig. 1). It is very important both for local artisanal fishing communities and for the fishing agreements that exist between Cabo Verde and foreign fleets. One of the most economically important species is yellowfin tuna, accounting for about 55% of the artisanal catch and 24% of the national catch of tuna in Cabo Verde (INDP, 2019). This tropical and subtropical species is distributed mainly in the epipelagic oceanic waters of the Atlantic, Pacific and Indian Oceans (ARRIZABALAGA *et al.*, 2015). In the Atlantic, yellowfin tuna migrates seasonally, avoiding areas with the lowest sea surface temperatures (SSTs). Catches of yellowfin tuna are high in the waters surrounding Cabo

Verde, especially during the second, third and fourth quarters of the year. During the first two quarters, yellowfin tuna is mainly concentrated in the equatorial Atlantic and extends its range into the Gulf of Guinea. Juvenile yellowfin tuna extend their habitat into the western subtropical Atlantic to the Gulf of Maine (FONTENEAU and SOUBRIER, 1995). Exploited sizes range from 30 cm to over 170 cm; the species' size at maturity is about 100 cm. In an analysis of the habitat requirements of tuna worldwide, ARRIZABALAGA *et al.* (2015) show that yellowfin tuna have very specific habitat requirements, with a preference for warm surface waters (>24°C). The highest catch rates in the tropical Atlantic are associated with water temperatures of 24–25°C (LAN *et al.*, 2013).

4 This chapter focuses on this species central to international negotiations and to the daily life of local artisanal fishermen, which is illustrated by a photo report of a fishing day in São Pedro.

Figure 1. Average percentage (%) of landings by species group over the period 2014–2018



Source: Annual national fisheries statistics published by the Cabo Verde National Institute for Fisheries Development (INDP)

Yellowfin tuna fishing in Cabo Verde

5 As in several other West African countries, the fisheries sector in Cabo Verde is a multifunctional activity of major economic, social and environmental importance. Fish and fishery products are the staple food and the main source of animal protein for a large part of the Cabo Verdean population. Fishing is integral to the country's cultural heritage and also promotes tourism (recreational fishing). Exports of fishery products are crucial to the balance of payments, accounting for more than 80% of the value of the country's goods exports. Although its primary contribution to national wealth is modest, the fisheries sector is of great strategic importance to the economic and social development of Cabo Verde in general. This sector is subject to regulation both nationally and internationally through contracts.

Yellowfin tuna, an essential national resource

6 The yellowfin tuna fishery is regulated at the national level by a Fisheries Resource Management Plan adopted in 2020.[1] The current plan sets out the broad guidelines for fishery policy for the period 2020–2024. It is supplemented by biannual executive plans for the management of fisheries resources. The major innovation of this new fisheries management plan is the introduction of a system of individual quotas for several species. Yellowfin tuna fishing is not covered by the quota system, but the plan specifies that it be organised in strict compliance with the rules laid down by the International Commission for the Conservation of Atlantic Tunas (ICCAT). It also states that the licensing system will be revised to grant separate licences for each species of tuna. A specific plan for the different species fished is established annually: the plan for the yellowfin tuna fishery emphasises the importance for industrial fishing vessels to provide catch statistics. It is also innovative in requiring socio-economic studies on the fishery.

7 The Cabo Verde Fisheries Resource Management Plan divides the fleet into three categories: artisanal, industrial and semi-industrial. In practice, the boundary between the artisanal and (semi-) industrial fishing sub-sectors is not clear. There are interactions and complementarities in terms of personnel, with fishermen moving from one sector to the other to take advantage of the possibility of larger catches and higher incomes. Furthermore, it is important to take into account existing synergies in terms of exchange of experience, know-how and joint use of certain infrastructure.

Limited semi-industrial and industrial fishing

8 Industrial and semi-industrial fishing, which targets small pelagic fish, tuna, sharks, crustaceans, etc., is carried out by 13 communities, with 119 vessels of an average length of 12 m. Table 1 shows the species of tuna fished. The 2011 census shows that the largest vessels are located on the Barlavento Islands, where the maximum size observed is 26 m (on São Vicente Island). Santiago Island hosts the largest number of vessels (47%), followed by São Vicente and Sal with 27% and 10% respectively. Santo Antão, Maio and São Nicolau, and Brava, represent only 6%, 4% and 1% of the fleet respectively (INDP, 2019). The industrial and semi-industrial fleet is old, consisting of vessels ranging from 4 to 28 years of age (average 17 years), internal engine power of 25 to 500 horsepower (HP), gross register tonnage (GRT) between 2.5 to 121, and an average of ten crew members per vessel.

Table 1. Total catch (in tonnes) for tuna species over the period 2013–2018 (including flagged vessels)

Species	2013	2014	2015	2016	2017	2018	Total
SKJ	16,444	16,615	17,600	10,925	7823	1154	70,561
YFT	7596	4763	7866	6990	2837	1572	31,623
FRI	2717	5686	3556	2324	1795	4773	20,850
BET	1378	2368	2764	1680	1107	1418	10,714

WAH	445	445	445	490	228	298	2352
LTA	570	310	131	218	113	104	1445
Total	**29,149**	**30,188**	**32,364**	**22,625**	**13,902**	**9,319**	**137 547**

BET: bigeye tuna (*Thunnus obesus*); FRI: frigate tuna (*Auxis thazard*); LTA: little tunny (*Euthynnus alletteratus*); SKJ: skipjack tuna (*Katsuwonus pelamis*); WHA: wahoo (*Acanthocybium solandri*); YFT: yellowfin tuna (*Thunnus albacares*)
Source: INDP

Artisanal fishery

9 Cabo Verdean legislation defines artisanal fishing as fishing by vessels that do not have a deck and use only ice or salt to preserve fishing products. Artisanal fishing is traditional on all the islands. It is an important source of employment and, on some islands, is one of the main productive activities and a focus for development. It employs about 2.1% of the total population and 5.2% of the Cabo Verdean workforce. It directly employs more than 5000 fishermen, who have an average age of 45 (INDP, 2019). The sale and distribution of fishery products is almost exclusively carried out by women. In the artisanal fishing sector, women mainly work as fish sellers and are on average 40 years old (INDP, 2011).

10 The artisanal fleet consists of 1239 boats, each manned by three or four fishermen and operating in the coastal zone up to 3 miles from land. These vessels are distributed in 80 landing ports. Artisanal fishing boats vary in length from 4 to 8 m long and in width from 1.5 to 2.5 m. They are mainly built of wood and have an average age of 8 years. The means of propulsion are outboard motors, sails and oars. The rate of motorisation was 72% in 2011 (INDP, 2011), although more recent, unofficial results from field surveys have shown values above 80% throughout the archipelago. The engine power varies between 5 and 25 HP and can be combined with oars or spark plugs. The most commonly used fishing device is the hook and line, with 99% of these devices used in artisanal fishing.

11 Artisanal catches take a wide variety of species, landing over 150 species each year (GONZÁLEZ and TARICHE, 2009). This multispecies fishery is related to variation in the number and type of gear used, and also to the fact that with a single type of gear it is possible to catch different species. Vessels fish for tuna, demersal species and small pelagic fish by line as well as by seine, gillnet and beach net. The principal method is handline (89%), followed by diving (5%), gillnet (3%), seine (1%) and beach net (1%) (INDP, 2011).

12 According to statistics from the Cabo Verde National Institute for Fisheries Development (INDP), from 2014 to 2018 the tuna group made up the largest landings over the years, followed by demersal species and then small pelagic species, except for 2018, when demersal species were the main group caught (INDP, 2019).

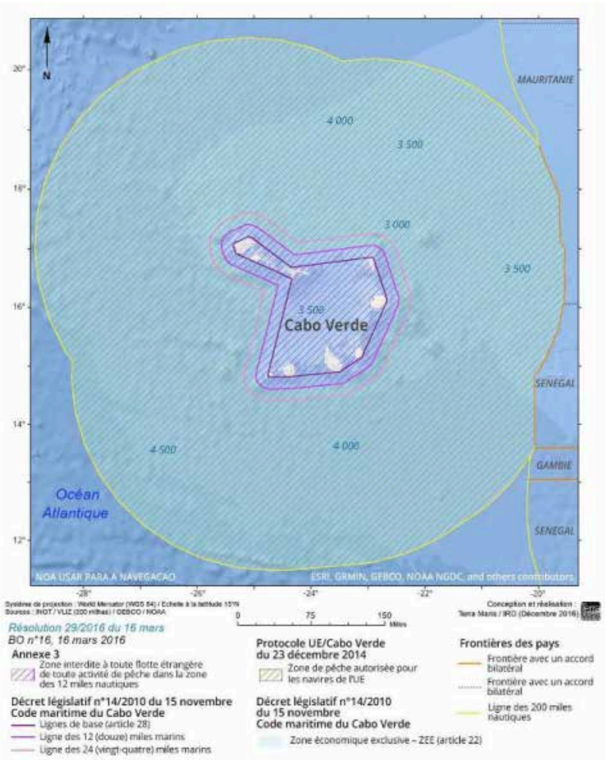
13 Yellowfin tuna (*Thunnus albacares*) represent 24% of the total artisanal and industrial tuna catch in Cabo Verde and 55% of the artisanal tuna fishery (INDP, 2019). This species is thus a resource with a significant impact on artisanal fishing communities in Cabo Verde.

Yellowfin tuna, a shared resource

14 Tuna fishing in Cabo Verde is carried out by both national and foreign fleets. The foreign fleets include European, Chinese, Japanese and Senegalese vessels that operate in the national waters of States linked by a bilateral fishing agreement. In recent decades, Cabo Verde has signed fisheries agreements and contracts with several countries/regions, including Senegal, China and Japan, as well as with the European Union (EU). These authorise these countries to fish in the Cabo Verde EEZ according to the rules set out in the Fisheries Management Plan, i.e. beyond a 12-mile zone from the baseline (fig. 2).

15 The Fisheries Partnership Agreement (FPA) between the EU and the Republic of Cabo Verde, signed on 24 July 1990, is one of the oldest. Since then, six protocols have been implemented, three under the FPA, which came into force on 1 September 2007.

Figure 2. Map of the management plan for fishing by foreign fleets in the Cabo Verde EEZ



Source: IRD/Terra Maris

EU Sustainable Fisheries Partnership Agreements (SFPAs)

16 The European Economic Community concluded its first bilateral fisheries agreements in the late 1970s. More than 30 other bilateral agreements have been concluded to date, mainly with developing countries in Africa and the Pacific. The negotiation of bilateral fisheries agreements multiplied after the adoption of the United Nations Convention on the Law of the Sea (UNCLOS) in 1982. This international convention establishes legal sovereignty over living marine resources in maritime areas of coastal states within 200 nautical miles of the baseline (i.e. the EEZ). Consequently, bilateral agreements with third countries have been necessary to allow EU fleets access to surplus fish stocks not

used by the local fleets of coastal states. Each Sustainable Fisheries Partnership Agreement (SFPA) is an exclusive agreement: once concluded, EU vessels can only fish under that SFPA, and they are not allowed to enter into private agreements with that partner country.

17 The SFPA defines the scope and basic principles of cooperation. It is supplemented by a protocol that allows access for European vessels and specifies fishing opportunities, quantities, payment methods, cooperation arrangements, etc.

18 SFPAs with third countries are negotiated and concluded by the European Commission (EC) on behalf of the EU. They allow EU vessels to fish for surplus stocks in the country's EEZ in a legally regulated environment. These agreements also include resource conservation and environmental sustainability, ensuring that all EU vessels are subject to the same rules of checks and transparency. A human rights clause has also been included in all protocols of these fisheries agreements.

19 Nonetheless, these agreements have been repeatedly criticised for failing to adequately address the ecological and, to a lesser extent, socio-economic sustainability of the European fishing industry. Critics of the international dimension of the policy are additionally concerned about the moral propriety of a rich and powerful region buying up the fisheries resources of poor and vulnerable countries (KACZYNSKI and FLUHARTY, 2002; BARTELS, 2007; SSNC, 2009 in CARNEIRO, 2012).

20 With respect to the ecological sustainability of the agreements, there are concerns about the low level of knowledge of the status of many negotiated stocks, and the generally inadequate levels of monitoring and verification of EC fishing activities. In general, EC fisheries agreements have been and continue to be implemented in contexts of insufficient information and checks, and the case of Cabo Verde is no exception.

The current EU-Cabo Verde protocol

21 The EU fishing protocol currently in force with Cabo Verde was adopted on 20 May 2019. This fishing agreement allows European vessels from Spain, Portugal and France to fish in Cabo Verdean waters and is part of the tuna network fisheries agreements in West Africa.

22 The fishing opportunities for EU vessels under Article 5 of the agreement are:

- freezer purse seiners for tuna: 28 vessels
- pole-and-line vessels for tuna: 14 vessels
- surface longliners: 27 vessels.

23 Article 4(2) specifies the annual amount of financial compensation paid by the EU referred to in Article 7 of the agreement, which amounts to €750,000, broken down as follows:

- an annual amount of €400,000 per year as financial compensation for access to resources, equivalent to a reference tonnage of 8000 tonnes per year
- a specific amount of €350,000 per year to support the implementation of the Cabo Verde sectoral fisheries policy.

24 In addition, the fees payable by European shipowners for fishing authorisations issued under Articles 5 and 6 of the agreement and in accordance with the procedures laid down in Chapter II, Section 2 of the annex to this protocol amount to €600,000 per year.

25 This financial contribution is supplemented by an obligation of scientific cooperation detailed in Article 6. During the period covered by the protocol, the EU and the Cabo Verde authorities must monitor the trend of catches, fishing effort and the state of fisheries resources in the Cabo Verde fishing zone for all the species covered by the protocol, including yellowfin tuna.

26 Specific measures apply to tuna vessels. Pole-and-line fishing is authorised in an area beyond 12 nautical miles from the baseline, and seine and surface longline fishing beyond 18 nautical miles from the baseline.

27 During the 2014–2018 agreement, 38 fishing licences were granted to vessels in 2015, 42 in 2016, and 45 in 2017, with an average utilisation rate of 59.1%. The country with the highest utilisation of fishing opportunities was Spain, with 26 licences granted in 2015, 28 in 2016, and 34 in 2017, with a maximum utilisation rate of 37% in 2015 and 39% in 2016. The country with the next highest utilisation rate was France, with 14% in 2015 and 15% in 2016. It should be noted that Portuguese vessels in this period made the least demand for fishing licences, with about 4% (ALMADA, 2018).

28 Table 2 shows the annual utilisation rate by vessel type in 2015, 2016 and 2017.

Table 2. Annual utilisation rate by type of vessel

	Utilisation rate (%)		
	2015	**2016**	**2017**
Seiners	75	75	75
Surface longliners	75	40	53
Pole and line	61.5	69	62

Source: INDP (2018)

29 According to ALMADA (2018), the ex-post evaluation of the current protocol indicates that the utilisation of the negotiated fishing opportunities by EU vessels is acceptable if one takes into account the efficiency of these vessels in terms of quantities caught during the period 2015–2017. The average annual catch under the agreement was 6181 tonnes, with an estimated overall value of €4.2 million per year for the EU countries and Cabo Verde (profits for operators, salaries for EU and Cabo Verde crews, and some profits for the downstream processing of catches in canneries in Côte d'Ivoire, Spain and France).

The importance of yellowfin tuna for local communities: the case of São Pedro

30 Fishing plays an important socio-economic role in the fishing communities of Cabo Verde. It is their main economic activity, sometimes complemented by other activities such as livestock, trade and, more recently, tourism. Fishing both provides income to the communities and is the largest employer of local people, including women.

31 Cabo Verde has about 83 fishing communities, which are almost all organised in associations. The typical profile of an artisanal fisherman is an individual with generally low income. Many households have an average of between five and seven members. Despite compulsory primary education, the level of education remains low, with a predominance of dropouts around the fourth year of primary education (compulsory education in Cabo Verde includes six years of primary education and two years of secondary education). This reduces the opportunity to engage in alternative economic activities and means those working in the fisheries sector are among the workers most likely to be poor (for initiatives to address this, see Box 1).

Box 1. A priority on training and capacity building
Osvaldina SILVA, President of the Cabo Verde INDP

The Cabo Verde government is committed to supporting training and research to ensure the effective implementation of marine spatial planning (MSP). The country's MSP process began with the political decision to transition from a maritime economy to a blue economy, with the adoption as early as 2015 of the Charter to Promote Blue Growth, reinforced by the Political Charter for the Blue Economy in Cabo Verde (Resolution 172/2020). In this context, the São Vicente Special Maritime Economic Zone (SVMEEZ) was created with the objective of using the geographical location and marine resources of Cabo Verde to develop an integrated maritime economy, thus promoting a value chain of industries and services related to the sea (Law 94/IX/2020). To implement this approach, it is imperative to invest in human resource capacity building, which requires the active participation of several sectors: education, training (technical and vocational) and research (academic and applied). To this end, the government of Cabo Verde has established the Campus do Mar, under the Ministry of the Sea and the Ministry of Education, as a training and research platform to support the MSP process.

The aim of the platform is to develop innovative programmes and strategic partnerships related to the ocean, fisheries, maritime transport technology and climate change (Legislative Decree 1/2020, Article 6). The Campus do Mar is an integrated structure with three poles: the School of the Sea (Emar), the Institute of the Sea (Imar) and the Atlantic Technical University (UTA).

- Emar is a public institution that aims to develop and implement basic modular vocational training in the ocean, the maritime economy and related fields (Legislative Decree 2/2020, Article 1).
- Imar aims to promote and coordinate applied scientific research in fisheries, oceanography, marine biology, aquaculture, the technological development of fisheries and fisheries statistics (Legislative Decree 40/2019, Article 4).
- The UTA aims to promote high-level training – ethical, cultural, scientific, artistic, technical and professional – through a diversified educational offer, conducting research, transferring and exchanging knowledge, providing continuing education and supporting development and entrepreneurship. This will contribute to the social and economic development of the country and the region and to the protection and dissemination of Cabo Verde's natural and cultural heritage, as well as provide services to the community (Legislative Decree 53/2019, Article 2). The UTA's teaching and research units are the Institute of

Engineering and Marine Sciences on the island of São Vicente, the Institute of Aeronautics and Tourism on the island of Sal, the Institute of Agricultural Science and Technology on the island of Santo Antão and the Institute of Arts, Technology and Culture on the island of São Vicente (Legislative Decree 53/2019, Article 78).
The UTA has set up a Master's degree on climate change and marine sciences in partnership with the West African Science Service Centre on Climate Change and Adapted Land Use (WASCAL), and a Master's degree and doctoral programme in oceanography and marine resources management in partnership with the University of Vigo in Spain. The UTA conducts multidisciplinary and interdisciplinary research and aims to inform policymaking at regional, national and international levels. In addition to the traditional disciplines, issues related to marine spatial governance are addressed.
These three complementary institutes will build capacity and skills for the implementation of marine spatial planning in Cabo Verde.

32 São Pedro is a fishing village on the island of São Vicente in the Cabo Verde archipelago (fig. 3). It is one of the country's fishing communities where the main target species are tuna and small pelagic species; yellowfin tuna is among the most caught species. The following case study presents the yellowfin tuna fishery in the community of São Pedro.

Figure 3. Artisanal fishing boats in Sao Pedro

© S. Hervé

33 The village is located 7 km southwest of the city of Mindelo, the capital of the island. To the northeast of the village is the airport that serves the island. The landscape is arid, but has a sheltered bay enjoyed by international visitors with its good conditions for

water sports such as diving and windsurfing. Ecotourism based on sea turtle watching is also developing, but lacks regulation and technical monitoring (INDP, 2019).

34 The population of São Pedro is estimated to be 991 inhabitants (513 males and 478 females) distributed in 203 households (INE, 2010), with 435 active residents aged 15 years and over. Two of the community's social organisations are the Association for Community Development and the Association of New Generation Fishermen of São Pedro. The latter was created in 2002 with the aim of defending the interests of the fishermen and, indirectly, of the community itself, whose families depend on fishing activity. Fishing thus plays an important role in the local socio-economic dynamics of the community, with more than half of the population living on the income from this activity. The main species caught are small pelagic species, tuna and buzio-cabra (a gastropod mollusc), which are mostly sold at the Mindelo fish market.

35 According to the Directorate General of Marine Resources, in 2018 the community of São Pedro had 36 artisanal boats (fig. 4), of which two were inactive, representing an inactivity rate of 6%. The motorisation rate is 100%, slightly higher than the 96% rate for the rest of the island. The community of São Pedro accounts for 31% of all boats on the island of São Vicente.

36 As in most Cabo Verde fishing communities, the handline is the most common fishing gear used for tuna fishing, with single circle or J hooks (fig. 4). All the gear is prepared the day before and each boat uses four to six lines with bait.

Figure 4. Fisherman preparing lines and hooks

© P. Silva, 2019

37 Mackerel scad (*Decapterus macarellus*), bigeye scad (*Selar crumenophthalmus*) and herring (*Sardinella maderensis*) are the main bait used. Other small pelagic species or additional small species can be used as bait. If fishermen are unable to catch live bait, they use dead bait.

38 Tuna fishing activity starts early in the morning with the first team of two boats leaving a few hours before the rest of the fishermen. This team concentrates on finding bait, and later the other fishing boats join them to share it. They surround the school to keep the bait alive until the other boats come to collect it (fig. 5).

Figure 5. Boats surrounding the bait

© Silva, 2019

39 Each boat has its own small tank on board where bait is stored and kept alive to the extent possible until the end of the fishing activity. The baitfish are kept oxygenated by a fisherman who feeds the tanks with seawater collected with a bucket. Each tank has small holes in the bottom to drain off excess water (fig. 6).

Figure 6. Distribution of bait to boats prior to fishing activity

© Silva, 2019

40 Another way to capture bait is by trolling with small hooks dangling artificial lures to catch small tuna species, including *Auxis thazard* and *Euthynnus alletteratus*, which is later used as bait for yellowfin tuna.

41 There are two ways the artisanal fishermen fish for yellowfin tuna: by anchoring (or drifting) or by trolling. When anchoring or drifting, the fisherman places the bait on the surface or at different depths depending on the behaviour of the tuna. The other method is trolling, which involves hooking the bait by the head and then dragging it behind the boat to lure the large tuna (fig. 7).

Figure 7. Tuna trolling from a boat

On the horizon, some boats also fishing for tuna are at anchor.
© Silva, 2019

42 After hooking a tuna, the fisherman catches it by hand and lands the larger specimens with a gaff after knocking them out with a large stick (fig. 8).

Figure 8. Fisherman holding a captured tuna with a gaff

© Silva, 2019

43 The landings are made on the beach of São Pedro. A small part of the catch is sold locally, and the majority is transported to be sold at the fish market in Mindelo.

Conclusion

44 Artisanal fishing is a very important sub-sector in Cabo Verde from a socio-economic point of view. It employs many people (more than 5000 fishermen and about 1000 women fish sellers) and is an important source of animal protein for the local population. According to recent INDP statistics, tuna species make up the largest catch by weight for artisanal fishing. Yellowfin tuna (*T. albacares*) represent 24% of the total tuna catch in Cabo Verde and 55% of the artisanal fishery (INDP, 2019). As this species is an important social and economic resource for artisanal fishing communities in Cabo Verde, the yellowfin tuna fishery should be given special attention in future marine spatial planning for Cabo Verde.

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Chapter 5. Cultivating the sea

Shellfish aquaculture issues in marine spatial planning

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Introduction

1 Global aquaculture activity has expanded considerably over the past decades. According to the 2020 *State of World Fisheries and Aquaculture* (SOFIA) report published by the United Nations Food and Agriculture Organization (FAO), total global aquaculture production was 82.1 million tonnes (Mt) in 2018, of which 30.8 Mt was from mariculture and coastal aquaculture (FAO, 2020). Marine farmed products, ranging from salmon and trout to shrimp, oysters and mussels, are traded globally. They also represent a key resource for coastal populations, providing both food and local economic development (BÉNÉ *et al.*, 2015; FAO, 2020). However, aquaculture practices are not without impact on the sustainability of ecosystems, leading, among other things, to diseases in the case of high stocking density, or the introduction of invasive species during the movement of stock. Aquaculture can also lead to pollution caused by the misuse of chemicals and antibiotics, increased waste, especially plastic, and loss of biodiversity due to the conversion of coastal areas (BOSTOCK *et al.*, 2010; BUSH *et al.*, 2013). Shellfish farming and coastal aquaculture are themselves under threat, due to increasing competition for space and pollution from other sectors, such as tourism, fishing, shipping and coastal infrastructure (SANCHEZ-JEREZ *et al.*, 2016). Managing these complex issues is a real challenge that requires a better understanding of the spatio-temporal characteristics of mariculture and coastal aquaculture: which species are cultivated in which locations, under which socio-economic systems, with what seasonality, and generating what environmental impacts? Increasing our knowledge of these questions will contribute to improving coastal governance, minimising the negative environmental impacts of shellfish farming and improving the livelihoods and social resilience of coastal communities (SANCHEZ-JEREZ *et al.*, 2016; NUNES *et al.*, 2011).

2 In this perspective, marine spatial planning (MSP) is a promising tool (LESTER *et al.*, 2018). According to EHLER and DOUVERE (2011), MSP can be defined as a political process with the aim of analysing and distributing human activities in time and (marine) space. MSP has a clear spatial orientation: it addresses issues of coexistence and conflict between different uses of marine and coastal spaces, including impacts on the environment and ecosystems, and aims to map locations, colocations and displacements. In this way, MSP contributes to spatially (re)organising marine and coastal areas. The MSP process depends, however, on the availability and reliability of information about all the human activities involved in a given space. In terms of aquaculture, there are significant gaps in the data, as highlighted in the 2020 SOFIA report: "The lack of reporting from 35–40% of producing countries, coupled with insufficient quality and completeness of reported data, hampers the FAO's efforts to present an accurate and more detailed picture of the status and trends in global aquaculture development" (FAO, 2020).

3 This chapter presents the expectations and concerns about shellfish farming activities (for which little data is available) in relation to MSP by exploring the case of shellfish farming along the coast of the Nordeste region in Brazil. This coastal area, which is characterised by numerous estuaries and mangrove forests, is a textbook case. In this region, shellfish farming (oysters, cockles, mussels) is largely an informal and undeclared activity that does not provide a main source of income, but which remains vital for coastal communities. MSP offers the potential to integrate shellfish farming into a maritime space shared with other activities, and thus contribute to reducing its environmental impacts and increasing its socio-economic benefits. However, the characteristics of shellfish farming must first be clear in order to explore: (1) the extent to which shellfish farming affects and is affected by environmental conditions and their dynamics, as well as (2) how it influences and is influenced by other activities. Secondly, it is important to study the challenges of shellfish farming in a specific context, in our case northeast Brazil. This chapter will look at these questions, and conclude with a discussion on the potential of MSP to contribute to a better organisation of shellfish farming practices in the tropics.

Shellfish farming

4 Marine bivalves, such as oysters, clams and mussels, have been cultivated in coastal areas for centuries in many areas of the world. They are recognised as a sustainable resource that captures food from the environment without the need for artificial feed. They are generally farmed in extensive aquaculture contexts that provide sustainable food production (SMAAL *et al.*, 2019). Bivalves are essential to the development, functioning and sustainability of coastal environments, human and non-human.

Biological and ecological characteristics of bivalves

5 Bivalves have long been exploited and cultivated for their meat, their shells or both. Their first known use and exploitation dates back to the Neolithic period. They are present in all marine habitats and are essential to the maintenance of food webs. They occupy extremely varied ecological niches, from intertidal zones to hydrothermal vents of the deep ocean, from the equator to the poles.

6 Bivalves are one of the classes of molluscs often found on our tables. The exploited species of bivalves can be divided into two subgroups: epigean species living on the surface of the substrate and endogean species living buried in the substrate. Epigean species include oysters, scallops and mussels. The endogean bivalves (or burrowers) include cockles, clams, razor clams, donax clams and tellin clams.

7 Bivalves are filter feeders. Capture of food particles and respiration are carried out by the same organ, the gills. The gills create water movement that allows the animal to draw in dissolved oxygen for respiration and to capture food particles (bacteria, plankton) naturally present in the surrounding water. The particles are trapped by the gill cilia and transported to the mouth. The digestive system is very simple and more or less straight: a mouth, a stomach, an intestine and an anus. Reproduction of bivalves is generally external. The male and female gametes are released into the water where fertilisation takes place and where the pelagic (swimming in seawater) larvae form and then settle on a substrate after a few days.

Ecosystem services: providers of environmental quality and habitats

8 The goods and services provided by shellfish farming are particularly relevant to take into account by MSP decision-makers and policy advisors. In addition to human nutrition, marine bivalves provide habitats for a wide range of species, regulate water quality, and sequester carbon and nitrogen. As eco-engineers, bivalves are used for the protection and conservation of coastlines. These functions can be defined as ecological goods and services.

9 Through their filtering capacity, they remove particles from the water and, under certain conditions, when inorganic nutrients are not a limiting factor, they increase phytoplankton production by improving light penetration. The water filtering and clearing capacity of natural and cultivated bivalves also play a major ecological role in controlling phytoplankton biomass. Bivalve farming can thus provide ecosystem services by depleting suspended particles in eutrophicated coastal areas (CRANFORD, 2019; LINDAHL, 2011). In this way, marine bivalves transform particulate organic matter (especially phytoplankton) into bivalve tissue or faeces that are transferred to the benthos.

10 These qualities mean that marine bivalves are receiving increased attention for their contribution to the extraction of nutrients from the coastal environment, thereby limiting the negative effects of excess nutrients caused by anthropogenic activities such as agriculture and sewage discharge (PETERSEN *et al.*, 2019). Nutrient removal occurs via two pathways: (i) harvesting/disposal of bivalves to return nutrients to the land or (ii) increased denitrification (the conversion of nitrate to nitrogen gas) in the vicinity of dense aggregations of bivalves, resulting in nitrogen transfer to the atmosphere.

11 Many bivalve species form clumps or aggregations that can in some areas cover a large part of the seabed (CRAEYMEERSCH and JANSEN, 2019). These bivalve aggregations or reefs occur naturally in many subtidal and intertidal areas around the world, but are sometimes widely exploited as they consist of valuable species such as mussels and oysters. These bivalve beds or reefs form a complex habitat for many other species and are valuable areas of biodiversity. The physical structure provided by the shells, enriched by bio-deposits produced by filtration, attract a high density of macroinvertebrate prey. The beds or reefs also provide shelter and habitats for many

species of bivalves, crustaceans and juvenile fish (HANCOCK and ERMGASSEN, 2019), which are observed in significantly greater density around bivalve reefs, particularly oyster reefs.

A source of food for humans

12 Total production from aquaculture and bivalve fisheries steadily increased from 5 to 16 Mt per year over the period 1995–2015, representing about 14% of total marine production worldwide (FAO, 2020). Most marine bivalve production (89%) comes from aquaculture, with only 11% coming from fisheries (WIJSMAN *et al.*, 2019). While marine bivalves do not receive the same media attention as fish for their health benefits, they are valued by consumers for their nutritional benefits and taste.

13 Marine bivalves are considered to be nutritious foods, low in calories yet filling, rich in quality proteins, vitamins (A and D) and minerals (iodine, selenium, calcium). The excellent nutritional quality of marine molluscs is provided both by the quality of their proteins and by their high content of long-chain polyunsaturated fatty acids (the famous omega 3), mainly 20:5n-3 and 22:6n-3, which are associated with the prevention of many human diseases (SARGENT and TACON, 1999).

14 Another advantage is that unlike fish farming, shellfish farming relies on phytoplankton naturally present in the water and does not require any external input (feed, antibiotics, etc.). However, the harvesting and production of bivalves for food must be balanced against the carrying capacity of the environment (the food available in the form of phytoplankton) and the implications of shellfish aquaculture for other services, including the maintenance of water quality and habitat structure.

Crafts, decoration and jewellery

15 Bivalve shells are also used for decorative purposes and crafts. The shape and general morphology of these shells vary according to the species' lifestyle and/or habitat. They come in a wide variety of sizes, shapes, patterns and colours, which allow them to be identified and classified. They can be used to decorate walls or steps; they are sometimes stacked and glued together to make ornaments or embellish certain crafts. They can also be strung or pierced to create jewellery.

16 Bivalve pearls are formed by the secretion of nacre from the epidermal cells of the mantle tissue of molluscs. Used throughout human history, pearls have been prized by many cultures. Like other precious stones, they can be used as ornaments signifying status and material wealth: for instance, in monarchs' crowns they are symbols of elegance and nobility. Pearls and shells can also be collectors' items (ZHU *et al.*, 2019).

Problems associated with shellfish farming

17 The environmental effects of shellfish farming are generally considered positive (CRANFORD *et al.*, 2012), contributing to the quality of the ecosystem (SMAAL and VAN DUREN, 2019). Nonetheless, shellfish aquaculture is associated with certain problems, such as conflicts of use for marine space, competition with other filter feeders, overstocking, accumulation of bio-deposits on the substrate, introduction of invasive species (both animal and plant) during bivalve transplants, and their associated

diseases. The accumulation of biotoxins or human pathogens by shellfish and the resulting health consequences for consumers are also a major problem (WIJSMAN *et al.*, 2019).

Toxic and harmful microalgae

18 Shellfish growing areas are regularly subjected to toxic phytoplankton blooms that are increasing in intensity and geographical distribution (HALLEGRAEFF, 1993; GLIBERT and BURKHOLDER, 2018). These toxic microalgae blooms are known to have major effects on the ecology of marine coastal areas (BURKHOLDER, 1998). A toxic phytoplankton bloom can alter the physiology or biology (mortality, susceptibility to disease, parasites, toxin accumulation, etc.) of key species or communities including bivalves, but also the food chain they support, leading to changes in marine ecosystems (HARVELL *et al.*, 1999). The accumulation of phycotoxins (produced by toxic microalgae) can cause health problems by contaminating higher trophic levels, including humans, through the consumption of bivalves. Phycotoxins are classified according to their effects and symptoms in humans following their ingestion: paralytic shellfish poisoning (PSP), amnesic shellfish poisoning (ASP), diarrhetic shellfish poisoning (DSP) and neurological toxins or ciguatoxins, responsible for ciguatera and its associated itching.

Human pathogens

19 Consumption of shellfish, particularly bivalves, can cause infectious diseases in humans, due to microbial pathogens naturally filtered by bivalves and then accumulated in their tissue (Table 1). These pathogens can be bacteria naturally present in the water (e.g. genus *Vibrio*), or viruses and bacteria from effluent and wastewater that can contaminate coastal waters. These include faecal coliforms (*Escherichia coli*), salmonella, hepatitis A virus, norovirus, etc., and bacteria such as *Vibrio vulnificus* or *V. parahaemolyticus*, whose content in water increases with temperature and which can cause problems of nausea, diarrhoea and vomiting in summer.

Table 1. Main microbiological indicators and pathogenic microorganisms found in bivalve molluscs

Bacteria	**Viruses**
Indicators: *Escherichia coli, Clostridium perfringens, Salmonella* spp.	Indicators: bacteriophages (anti-MalE, *Bacteroides fragilis*)
Main pathogens	**Main pathogens**
Vibrio cholerae O1 and O139 *Vibrio parahaemolyticus*	Hepatitis A (ssRNA); Norovirus (ssRNA)
	Secondary pathogens
Vibrio vulnificus	Rotavirus (dsDNA), Adenovirus (dsDNA)

Clostridium botulinum	Astrovirus (ssRNA), Poliovirus (ssDNA)
Secondary pathogens	
Campylobacter jejuni, Shigella spp., *Aeromonas hydrophila, Edwardsiella tarda, Plesiomonas shigelloides, Listeria monocytogenes Yersinia enterocolitica, E. coli* O157:H7, *S. aureus*	

Source: CHINA *et al.* (2003)

Shellfish diseases

20 Bivalve populations themselves can be affected by epizootics that decimate or weaken exploited stocks, limiting aquaculture harvests (BARBOSA SOLOMIEU *et al.*, 2015). Global trade contributes to the introduction of exotic species and, consequently, to the occurrence and spread of infectious diseases (ANDREWS, 1980; RENAULT, 1996). These diseases are caused by various infectious agents (ZANNELLA *et al.*, 2017), mainly viruses (ARZUL *et al.*, 2017), bacteria (TRAVERS *et al.,* 2015) and protozoa (ROBLEDO *et al.*, 2014).

21 Among the most serious bivalve diseases is that caused by a virus of the Herpesviridae family, ostreid herpesvirus 1 (OsHV-1), which has caused very high summer mortality in *Crassostrea gigas* oysters in France since the early 1990s. From 2008 onwards, severe mortality of 60–100% of juvenile *C. gigas* has been reported during the summer in France, resulting in severe economic losses. These events were associated with the emergence of a new variant, OsHV-1 µVar (SEGARRA *et al.,* 2010). This variant has a wide geographical distribution, its presence detected in several countries (ARZUL *et al.*, 2017). In Brazil, OsHV-1 has recently been reported in the cultivated oyster *C. gigas* and the native oyster *C. gasar* in the south of the country, which could represent a risk of excess mortality (MELLO *et al.,* 2018).

22 The most pathogenic bacteria often belong to the *Vibrio* genus. Vibriosis is a major disease of bivalves and is a serious concern in oyster hatcheries and farms, causing damage to larvae and/or spat depending on the species. The most pathogenic vibrios belong to the clades *splendidus* and *harveyi* or the species *V. aestuarianus, V. tubiashii, V. coralliilyticus* and *V. tapetis* (TRAVERS *et al.*, 2015).

23 Protozoan parasites of the genus *Marteilia* sp., *Bonamia* sp. and *Perkinsus* sp. can also have a major impact on the production of many bivalve species. Among the most widespread are parasites of the genus *Perkinsus*, which are known to cause mass mortality in farmed or fished populations worldwide. More specifically, *P. marinus* and *P. olseni* are identified as notifiable causative agents by the World Organisation for Animal Health (OIE). They regularly cause mass mortality in American oyster *C. virginica* populations in the United States (east coast and Gulf of Mexico) and in clam populations in Asia and Europe, impacting associated economic activities.

24 Lastly, a more recently observed disease is disseminated neoplasia (similar to cancer). It affects bivalves worldwide, including many commercial species (CARBALLAL *et al.*, 2015), and can result in mass mortality. Disseminated neoplasia is characterised by the excessive proliferation of anaplastic and hypertrophic cells in the circulatory system

and other organs (BARBER, 2004; CARBALLAL *et al.*, 2015). It has been associated with severe disease states in bivalves worldwide, leading to death (BARBER, 2004; CARBALLAL *et al.*, 2015; DÍAZ *et al.*, 2016), probably due to the replacement of haemocytes by neoplastic cells; vital functions, including defence systems, are thus no longer ensured.

Chemical contaminants

25 In many coastal areas, chemical contamination remains a major problem (OSPAR, 2010), affecting the water quality of marine environments. The unavoidable presence of chemical contaminants such as mercury and persistent organic pollutants (POPs) can lead to their bioaccumulation by bivalves and become a health risk for consumers.

Shellfish farming in Brazil's Nordeste region

26 Shellfish farming has developed mainly in the south of Brazil. The state of Santa Catarina is the largest national producer of bivalves. In 2019, this state alone accounted for 2760 t of *Crassostrea gigas*, 12,294 t of *Perna perna* mussels and 5.2 t of *Nodipecten subnodosus* scallops. *Crassostrea gigas* was first introduced to Brazil (in Rio de Janeiro) in 1974 from the UK (POLI *et al.*, 1990; POLI, 2004).

27 It the 1970s, in the state of São Paulo, studies began on the cultivation of native oyster species, *Crassostrea rhizophorae* and *C. brasiliana* (= *gasar*) (WAKAMATSU, 1973; AKABOSH and PEREIRA, 1981). Production of these two species is expanding and is now concentrated in the northern and northeastern states. In Nordeste, wild mussels of the genus *Mytella* are also extracted for consumption and sale. The presence of numerous estuaries in Nordeste makes its coastal region particularly favourable for shellfish farming.

Shellfish cultivation and tonnage

28 The Nordeste region has many estuarine and mangrove areas, which are rich in nutrients and serve as marine life nurseries. Two species of native oysters are cultivated here, *Crassostrea rhizophorae* and *C. gasar*. The latter is known as the "black oyster" due to its shell colour, which is darker than *C. rhizophorae* (SCARDUA *et al.*, 2017). *Crassostrea gasar* lives mainly on the beds of estuarine waterbodies and has better zootechnical characteristics than *C. rhizophorae* from a commercial point of view, due to faster growth and larger size (up to 100 mm).

29 In the estuaries, oyster production is carried out from the river mouth to relatively far upstream (8–13 km). Estuaries with large areas of mangroves offer the best conditions for oyster farming. The *C. gasar* oyster is generally found in areas of low salinity, while *C. rhizophorae* prefers areas of higher salinity. Oyster spat is collected in two ways, directly from the natural environment or from artificial collectors (fig. 1A) placed in locations that are generally chosen empirically depending on the species sought. The production system adopted by Nordeste producers consists of suspended structures made of wooden planks and stakes (mangrove wood) or plastic pipes (PVC) filled with concrete and fixed to the bottom of the estuary in sheltered areas (fig. 1C and 1D). Oyster bags can be laid directly on or suspended from the pillars of this structure (fig. 1B).

Figure 1

(A) Artificial collectors for spat collection
(B) *C. gasar* oysters inside the oyster bags
(C and D) Different aquaculture structures made of wood and PVC, allowing oysters to grow in estuaries in Nordeste, Brazil

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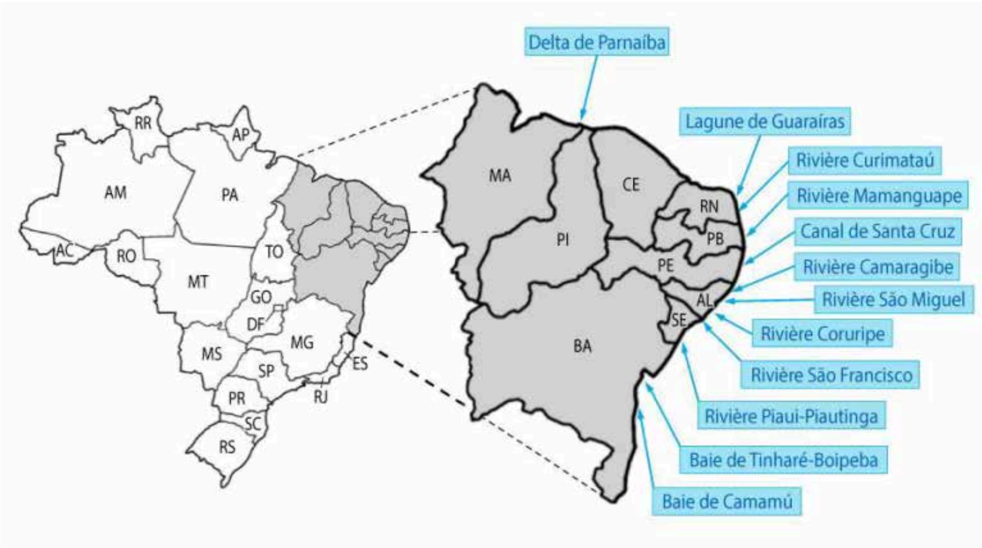
30 Tides vary between 2.5 and 5.6 m depending on the latitude of the estuaries. This allows the installation and maintenance of cultivation systems. Each estuary has its own characteristics that influence the performance of oyster farming: these include the supply of sediment and nutrients, the presence of predators, and the development of fouling organisms. The choice of cultivation area is mostly empirical as there is a lack of technical assistance and available data. Cultivators test locations until they achieve good growth and survival performance. However, the lack of oversight over the collection of natural spat or even adults appears to have already reduced natural oyster stocks, jeopardising the sustainability of oyster farming in the region. Hatchery spat production has been possible since 2013.[1] Currently, the hatchery has the capacity to produce 6 million spat per year (March to May). However, production costs are very high and demand for hatchery spat remains low, as shellfish farming is still in its infancy and producers rely mainly on wild collection.

31 In Nordeste estuaries, shellfish farming is rarely the main source of income. For most producers, it provides additional income on top of that obtained from harvesting other natural resources in the estuary, such as crabs and fish. Oyster producers are organised in collectives or work alone. The largest producers are currently found in the estuaries of the Guaraíras Lagoon, the Curimataú River in the state of Rio Grande do Norte (RN), and the São Miguel-Lagoa do Roteiro River in the state of Alagoas (AL). Small collective and individual initiatives also exist in the estuaries of the Mamanguape River (Paraíba state, PB), the Camarajibe and Coruripe Rivers (AL), São Francisco and Piauí-Piautinga Rivers in the state of Sergipe (SE), Camamú Bay and Tinharé-Boipeba (Bahia state, BA), Parnaíba delta (Piauí state, PI, and Maranhão state, MA) and in the Santa Cruz channel (Pernambuco state, PE) (fig. 2). Some species, such as *Anomalocardia brasiliana*, *Phacoides pectinatus* (known as “lambreta”) and the mangrove mussels *Mytella falcata* and *M. guyanensis*, are also used by local people as both a food resource and a source of income. The production of molluscs, including oysters, in the Nordeste was estimated at 133 t in 2018. But this is believed to be an underestimation of the actual amount produced. The

highest production in the Nordeste comes from RN, with 100 t per year. The two main obstacles to large-scale oyster farming in the Nordeste region are the lack of a constant supply of spat and the lack of health status monitoring of the oysters produced.

Figure 2. Map of shellfish aquaculture sites in the Nordeste region (Brazil)



Insertion of activity in coastal areas

32 The Nordeste has strong potential for the development of oyster farming of the *C. gasar* oyster (high primary productivity, favourable climate and geography). To date, oyster farming there relies on the collection of spat from natural populations and their growth in estuarine areas, but without real monitoring of growth, survival, health (the presence of diseases, in particular) or nutritional quality.

33 If shellfish farming is to be taken into account by MSP, it is essential to identify the gaps, threats and relevant resilience indicators for this economic activity. In the framework of the project “Planning in a liquid world with tropical stakes” (Paddle), knowledge and data were collected on this activity in order to develop models on the dynamics of these ecosystems and to identify the key factors allowing the sustainable development of shellfish farming in Brazil.

Present and future problems associated with shellfish aquaculture

34 Most of the phycotoxins implicated in human food poisoning worldwide are also present in Brazil. They come from species belonging to the genera *Alexandrium*, *Dinophysis*, *Gambierdiscus*, *Ostreopsis*, etc., which are responsible for PSP, DSP, ciguatoxin syndromes, etc. However, at present, there is no systematic monitoring of these blooms or of the contamination of bivalves by these toxins in Nordeste, where shellfish aquaculture is currently emerging. It is imperative to improve our understanding of the geographical distribution and consequences of these blooms on shellfish aquaculture in Brazil in terms of both human and shellfish health. Considering the spreading capacity of these toxic microalgae, it is strongly recommended to set up

regular monitoring of oyster farming areas and of toxin accumulation in bivalve populations cultivated along the northeast coast of Brazil. Such monitoring already exists in the southern part of the country, where the largest producers are located.

35 Shellfish aquaculture may also face biological threats such as microorganism- induced diseases. The most serious diseases recorded in Brazilian oysters are perkinsosis, caused by a protozoan parasite, and disseminated neoplasia. The study of perkinsosis in Brazilian oysters started in 2008, with a survey on the presence of *Perkinsus* spp. in two oyster species: *Crassostrea rhizophorae* from natural beds on the coast of the state of Ceará (CE) in the northeast and Santa Catarina (SC) in the south, and *C. gigas* from farms in SC. *Perkinsus beihaiensis* has been identified in oysters from CE (SABRY *et al.*, 2009, 2013). The first occurrences of *P. marinus* were recently recorded in SC in *C. gasar* and *C. gigas* oysters, and of *P. beihaiensis* in *C. gasar* oysters (LUZ CUNHA *et al.*, 2019). *Perkinsus chesapeaki* was also detected in 2012 in *C. rhizophorae* from CE (NETO *et al.*, 2016). In subsequent years, other studies were conducted, mainly on the coast of the Nordeste states, on natural and cultivated populations of native oysters (*C. rhizophorae* and *C. gasar*). In 2010, *P. marinus* and *P. olseni* were detected in *C. gasar* oysters from natural and cultivated populations in the state of Sergipe (DA SILVA *et al.*, 2014). The following year, samples of oysters (*C. rhizophorae*) collected in 2011 from the Paraíba do Norte estuary (PB) revealed up to 100% prevalence and very high intensity of *P. marinus* (DA SILVA *et al.*, 2013), which led to the first report in Brazil of a notifiable parasite to the OIE. At the time, an order was issued to restrict the movement of PB oysters. Although the infection dynamics of parasites belonging to *Perkinsus* spp. in northeast Brazil are still poorly studied, it seems that the lower salinity and lower temperature during the wet season in the region (winter in the southern hemisphere) are unfavourable for the proliferation of the parasite (DA SILVA *et al.*, 2014). The presence of *P. marinus* in tropical regions has not been associated so far with the mortality of the native host species, the oysters *C. rhizophorae* and *C. gasar* (DA SILVA *et al.*, 2016; SCARDUA *et al.*, 2017).

36 Histological monitoring of *C. gasar* populations in the Mamanguape estuary (PB) has also revealed the presence of disseminated neoplasia (DA SILVA *et al.*, 2018). Despite a low prevalence of the disease in oysters, neoplastic cells were found in oyster tissue and organs with varying levels of intensity. For the time being, this disease does not affect local oyster production.

37 The lack of knowledge about perkinsosis and disseminated neoplasia within the oyster populations cultivated in the different regions of Brazil makes it difficult to assess these diseases’ real impact, which may be underestimated. It would be advisable to set up permanent monitoring of oyster mortality rates and to contact the national reference laboratory for molluscs in the event of high excess mortality, in order to assess the health status of the population. Today, neither perkinsosis nor disseminated neoplasia seem to be a threat to oyster farming in Brazil. However, intensification of cultivation could change this balance. As a preventive measure, it is recommended not to transfer oysters from one farming area to another to avoid disseminating this parasite to healthy areas. In parallel, it is important to better characterise the geographical distribution, infection and prevalence levels of these diseases to monitor their impact on wild and farmed populations of *C. gasar* oysters.

Why integrate shellfish aquaculture in MSP?

38 In general, aquaculture activities are seen as highly dependent on MSP. Indeed, these activities lie at the intersection of natural dynamics and economic activities and are subject to a range of public policies, including the authorisation to use marine space. As shellfish farming continues to gain importance for the global food supply and future blue growth (FAO, 2020; BRUGÈRE *et al.*, 2019), there is a need to address current and future conflicts over space and to prevent the introduction of harmful or pathogenic species.

39 Adopting a holistic approach to environmental governance, i.e. taking into account the environmental, economic and social impacts of short- and long-term development of coastal aquaculture, requires considering the goods and services that shellfish farming can provide. Shellfish farming has positive effects on the functioning of ecosystems by helping to maintain their continuity, supporting functional and structural biodiversity, and reducing the effects of eutrophication (linked to urbanisation and intensive farming). In addition, in tropical areas such as northeast Brazil, informal and small-scale shellfish farming practices help communities by generating additional income for the households involved, thus reducing poverty. Shellfish farming thus represents an economic opportunity, supporting the livelihoods and social cohesion of coastal and rural areas (SHUMWAY *et al.*, 2003). The development of shellfish farming can also preserve and strengthen the cultural identity of coastal (typically fishing) communities, as it closely links local knowledge and skills to specific coastal locations and marine spaces (MURRAY and D'ANNA, 2015). Because of its marine nature, coastal shellfish farming is sometimes presented as a professional alternative to fishermen, although the opportunities (and constraints) need to be carefully assessed (WEEKS, 1992).

40 For all these reasons, MSP must take into account both aquaculture's effects on the environment and on other economic activities, and how it is affected by them. In the case of Nordeste, shellfish farming is more affected by other activities than it has effects on them. While the colocation of shellfish aquaculture with other activities (such as wind power generation) is becoming a reality in some parts of the world (e.g. with offshore wind farms; CHRISTIE *et al.*, 2014), there are no plans yet to develop shellfish aquaculture in Nordeste. The shellfish farming that does exist is potentially affected by other uses of marine and coastal space. For example, pollution from shipping and coastal tourism can be a major source of conflict, as it leads to health and biosecurity risks, and ultimately to financial and legal risks for all stakeholders involved in bivalve aquaculture. Risk assessment (e.g. oil spills, see SANTOS *et al.*, 2013) must therefore be integrated into aquaculture planning to ensure that the socio-economic benefits of this activity are optimal.

41 Regulatory stability is an essential prerequisite for accessing markets at regional, national and international levels. By establishing a policy framework for shellfish farming, MSP could contribute to providing this regulatory stability and to developing market opportunities. It could also help develop certification schemes, which offer promising avenues for aquaculture sustainability. Examples include the Aquaculture Stewardship Council (ASC) Bivalve Standard (ASC, 2019) and the Global Aquaculture Alliance (GAA) Best Aquaculture Practices (BAP) Standard for Bivalves (mussels) (GAA, 2016). These standards take into account multiple aspects of sustainability, such as land

and water use, water pollution, effects on the marine benthos, effects on biodiversity, and relations with workers and local communities (BOYD *et al.*, 2005; BUSH *et al.*, 2013). These certification systems thus help MSP to strengthen the sustainability of shellfish farming. This is one of the recommendations of Portugal's Maritime Spatial Plan for Aquaculture (*Plano de ordenamento do espaço marítimo*) cited by SANTOS *et al.* (2014), which refers to "the valorisation of fisheries and aquaculture products through certification schemes (including certification of seafood and sustainable fisheries)".

42 Yet it is important not to be too ambitious or optimistic about the contributions of MSP to aquaculture development; local realities need to be taken rigorously into account. In the case of Nordeste in Brazil, shellfish farming is a long way from achieving ASC or BAP certification. And although MSP can improve the (often difficult) access of shellfish products to regional markets, as shellfish farming is sometimes an accessory activity, the contribution MSP could make to local livelihoods and community development must be real enough for local stakeholders to invest time and effort in such a process (NUTTERS and DA SILVA, 2012). This makes it particularly essential to involve local stakeholders, as MSP requires both species-specific and site-specific information regarding aquaculture production. Engaging in an MSP process involves sharing local ecological knowledge, including information on informal and unreported or even illegal activities, so for the process to be successful it is crucial that it is designed to benefit local communities (FLANNERY and CINNEIDE, 2008).

Conclusion

43 Shellfish farming can play an important role in the global challenge of ensuring food security for a growing human population. A recent report by the consortium Science Advice for Policy by European Academies (SAPEA, 2017) indicates that it is essential to shift to seafood products with a lower trophic level than the average diet today. Increasing shellfish production from the current 18 Mt to 100 Mt in the next 20 years is one of the options SAPEA proposes.

44 In addition to contributing to future food needs, shellfish aquaculture fulfils several ecological functions. Due to their feeding behaviour (filter feeding), bivalves regulate water quality, primary production and nutrient dynamics. This makes them particularly useful in mitigating eutrophication, sewage discharge and fish farming impacts and in contributing to carbon dioxide sequestration. Their ability to form structures and reefs also modifies the physical environment and can be used to enhance coastal protection and promote the development of other communities using the reef for shelter.

45 To increase shellfish production in any location, it is important to find a space where the carrying capacity can be exploited in a sustainable way and where this production is socially accepted in the area concerned. The development of marine shellfish aquaculture must thus be based on comprehensive and long-term socio-economic data that allows an objective assessment of the best trade-offs between different development options. This would avoid its expansion at the expense of fisheries and other marine ecosystem goods and services (agriculture, shipping and tourism) and jeopardising the livelihoods of local populations. An MSP approach could help to overcome current limitations to shellfish aquaculture development, which include water quality requirements, episodic mortality, invasive species and interactions with

wild stocks. Such an approach must involve local stakeholders and ensure that the benefits from shellfish aquaculture systems are not diverted away from local communities for the sole benefit of parties operating in the global market.

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NOTES

1. From the company Primar Aquacultura: https://www.primarorganica.com.br

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Chapter 6. Artisanal fisheries, climate change and scientific challenges for marine spatial planning

Yoann Thomas and Malick Diouf

Introduction

1 The direct effects of fishing on the distribution, demographics and stock structure of exploited species, combined with changes in productivity and community composition as a result of climate change, are likely to limit the ability of fisheries to function in their current form and to adapt to future changes (BRANDER, 2007; JOHNSON and WELCH, 2009). In this context, artisanal fisheries, which are defined in the United Nations Food and Agriculture Organization (FAO) glossary as "traditional fisheries involving fishing households (as opposed to commercial companies), using relatively small amounts of capital and energy, relatively small fishing vessels (if any), making short fishing trips, close to shore, and mainly for local consumption", appear to be very vulnerable, particularly in the intertropical zone. This area is more exposed to the consequences of climate change than the rest of the world, and the populations involved in artisanal fishing have a high level of dependence on the exploited resource and limited capacity to adapt due to a fragile socio-economic context. Despite this known vulnerability of artisanal fisheries, few studies at the local level have addressed how climate variability and change affect the lives and livelihoods of the "tropical majority" of small-scale fishers, who make up more than 90% of the world's fishers and fish traders (see BADJECK *et al.* 2010). Policy options to reduce the vulnerability of fisheries need to be considered at local, national and international scales, and to address short-, medium- and long-term risks (CINNER *et al.*, 2012). As a first step, reducing the vulnerability of artisanal fisheries requires a better understanding of the processes involved at these different scales in order to be able to assess their degree of exposure and their capacity to adapt

to the consequences of climate change. Improving knowledge of these processes and the dynamics of marine ecosystems should make it possible to implement marine spatial planning (MSP) that is consistent with all uses.

2 This chapter summarises the impacts of climate change on fisheries in general and then focuses on the vulnerability associated with the particular case of artisanal fisheries, presenting a case study of the shellfish fishery in the Sine-Saloum delta in Senegal. It also discusses the scientific challenges to be overcome to support the implementation of MSP adapted to the problems of artisanal fisheries.

Impacts of climate change on fisheries

3 The warming of the climate is unequivocal and has many consequences for the oceans (IPCC, 2019). These include:

- rising average temperatures and increasing frequency of extreme heatwaves
- acidification associated with the absorption of atmospheric CO_2 into the water column
- decreasing oxygen levels in the water and an increase in the number of hypoxic "dead zones"
- rising average sea levels and increased risk of coastal erosion
- modification of soil inputs to coastal waters by changes in the rainfall regime.

4 These consequences of climate change on the oceans have direct and indirect impacts on the distribution and productivity of natural resources. They directly modify the physiological performance and behaviour of species, affecting their growth, reproductive success, fitness and phenology (i.e. seasonality), disrupting their migrations and potentially impacting their survival by increasing their vulnerability to pathogens (BEAUGRAND and KIRBY, 2018; BURGE *et al.*, 2014; DONEY *et al.*, 2012). Climate change also acts indirectly, at the population and ecosystem levels, by generating habitat loss, altering food webs by changing the productivity of food sources, and modifying interactions between species by modulating the abundance of competitors, predators and pathogens (ALBOUY *et al.*, 2014; DONEY *et al.*, 2012).

5 The consequences of fisheries are multiple (Table 1). Variability in environmental conditions determines the distribution, migration, abundance and size of species caught. This redistributes catch potential on a global scale, modifies species composition locally and changes the average size of exploited species (BRANDER, 2007). In addition to the consequences for resources, fishing operations and infrastructure are also directly affected. Rising sea levels and increased occurrence of extreme weather events (storms, cyclones) are weakening port structures. Fishing effort is also impacted through the reduction of opportunities to go to sea and the need for fishermen to adapt their fishing strategies and gear.

6 However, the consequences of climate change are not homogeneous on a global scale. A projection of the redistribution of catch potential by 2050–60 in the RCP 8.5 "business as usual" scenario (CHEUNG *et al.*, 2009) explicitly shows that the intertropical zone will be much more affected than the rest of the world, with catch decreases of between 40% and 60%, while high-latitude regions could see their potential increase by 30% to 70% (fig. 1). This is fundamental to the concept of vulnerability, which, according to the third assessment report of the Intergovernmental Panel on Climate Change (IPCC, 2001), is the extent to which climate change can damage or harm a system and depends

not only on the sensitivity of a system but on its ability to adapt to new climatic conditions. In the context of the artisanal fisheries studied here, this refers to a socio-ecological system, which is defined as "a system that comprises mutually interacting societal (human) and ecological (biophysical) subsystems" (GALLOPIN *et al.*, 1989). Considering the impacts of climate change on marine resources and the level of vulnerability of artisanal fisheries in developing countries in the tropics, the latter appear to be between a rock and a hard place, with higher exposure and lower adaptive capacity (ALLISON *et al.*, 2019).

Table 1. Examples of climate impact pathways on fisheries

Types of change	**Climatic variables**	**Impacts**	**Potential consequences for fisheries**
Physical environment	Ocean acidification	Effects on calcifying organisms, e.g. molluscs, crustaceans, corals, echinoderms and some phytoplankton	Potential decrease in the production of marine resources
	Warming of the surface layers	Cold water species replaced by warm-water species	Shift in the distribution of plankton, invertebrates, fish, birds, towards the North or South Poles, reduction in species diversity in tropical waters
		Modification of phytoplankton bloom periods	Potential mismatch between prey (plankton) and predators (fish populations) and decline in production and biodiversity
		Changes in zooplankton community composition	

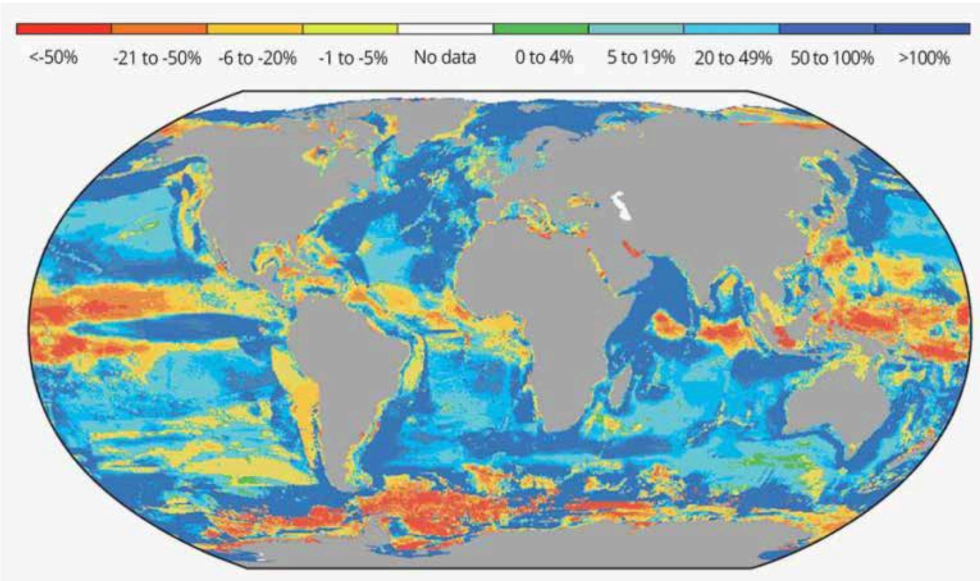
	Rising sea levels	Loss of habitats, e.g. nursery areas, mangroves, coral reefs	Reduction in inshore fisheries production
Stocks	Higher temperatures Changes in ocean currents	Changes in the sex ratio Changes in egg-laying periods Changes in migration periods Changes in peak abundance periods	Possible impacts on timing and productivity levels in marine and freshwater systems
		Increase in invasive species, diseases and toxic algal blooms	Reduced production of target species in marine and freshwater systems
		Reduction in recruitment success	Impact on the abundance of juvenile fish and therefore on marine and freshwater production
Ecosystems	Reduced flows and increased droughts	Changes in lake levels Change in low water periods	Reduced river productivity
	Increase in El Niño–Southern Oscillation (ENSO) events	Changes in the period and amplitude of upwellings Coral bleaching and loss	Changes in the distribution of pelagic fisheries Reduced productivity of coral reef fisheries

Coastal infrastructure and fishing operations	Rising water levels	Change in coastal profile, loss of harbours and settlements Increased exposure of coastal areas to storms	Adaptation costs make fishing less profitable, risk of storm damage increases insurance and/or reconstruction costs and increases vulnerability of coastal households
	Increased frequency of storms	More days at sea lost due to bad weather, increased risk of accidents Aquaculture facilities (coastal ponds, sea cages) more likely to be damaged or destroyed	Increased risks to fishing and coastal fish farming, which become less viable livelihoods for the poor Declining profitability of large-scale enterprises Increase in insurance premiums
Inland fisheries operations and livelihoods	Change of precipitation level	Reduced opportunities for agriculture, fisheries and aquaculture	Reduced diversity of rural livelihoods Increased risks to agriculture Increased dependence on non-farm income
	More droughts and floods	Damage to productive assets (fish ponds, dams, rice fields, etc.) and housing	Increased vulnerability of riverside and floodplain communities and households

	Less predictable rainy/dry seasons	Decreased ability to plan livelihood activities e.g. seasonality of farming and fishing	

Source: FAO (2007b); see ALLISON *et al.* (2005) for a summary

Figure 1. Projection of the global redistribution of the maximum catch potential of about 1000 exploited species of marine fish and invertebrates



The projections compare decadal averages for 2001–2010 and 2051–2060 using ocean conditions based on a single climate model in a moderate to high warming scenario, without analysis of the potential impacts of overfishing or ocean acidification.
Source: CHEUNG *et al.* (2009); from IPCC (2014)

7 The impact of climate change must also be assessed in the context of other anthropogenic and/or natural pressures, which often have significant and more immediate effects (BRANDER, 2010). In particular, fish species will be more sensitive to the effects of climate change if their habitat is degraded. Destructive fishing practices that deplete stocks, reduce biodiversity through bycatch mortality and damage the structure of the seabed reduce habitat complexity and thus undermine the resilience of fisheries to climate change (JOHNSON and WELCH, 2009). In addition, the decadal variability of regional climate conditions, characterised by climate indices such as the North Atlantic Oscillation (NAO), El Niño–Southern Oscillation (ENSO) or Pacific Decadal Oscillation (PDO), also puts pressure on fisheries resources related to, for example, wind conditions leading to variable intensity of coastal upwelling, or river run-off leading to contrasting coastal eutrophication, in combination with the effects of climate change (LEHODEY *et al.*, 2006).

8 As a result, two major effects of climate change have been identified, which are likely to have a significant impact on fishing activity, and in particular on small-scale fisheries: a

decrease in species productivity and the geographic displacement of species. These are multifactorial processes that are governed by variables occurring on multiple temporal and spatial scales. To better assess the consequences of climate change on small-scale fisheries, it is necessary to specify the processes behind these effects. This should help guide the implementation of ecosystem observation systems and support the development of appropriate management measures.

Decrease in productivity

9 In ecology, productivity refers to the production of biomass in an ecosystem. In the case of a fisheries resource, this productivity depends on several processes:

- reproduction and recruitment, which determine the arrival of new individuals in a population
- individual development and growth, which increases the overall biomass of a population and allows animals to reach the reproductive adult stage
- mortality, which regulates the number of individuals, and can be associated with predation, disease, stress (thermal, hypoxia, pollution, etc.) or fishing
- migration, which can play a role in regulating local biomass when looking at a given geographical area.

10 There are many stressors associated with climate change that are involved in the decline in productivity of harvested species. These stressors occur at multiple spatial and temporal scales throughout the lifecycle of organisms.

11 Warming is one of the main stressors associated with climate change. Temperature is involved in the majority of metabolic processes and seasonal behaviour. It regulates the rate of processes associated with growth, reproduction and survival (PÖRTNER *et al.*, 2017). The implications for fisheries can be very significant. LYNE *et al.* (2003) estimate a 35% reduction in economic revenue from fisheries in Australia by 2070 as a result of climate change. Rising temperatures can also have indirect effects by degrading the habitats of species of interest. Coral bleaching associated with warmer water is a prime example (FRIELER *et al.*, 2013), with adverse consequences for artisanal fisheries in reef ecosystems (CINNER *et al.*, 2012). Temperature is likely to be associated with other stressors. In particular, it increases the risk of mortality, as in the case of the North Atlantic oyster. The susceptibility of oysters to diseases is increased by warming in the winter, which favours the development of pathogens and reduces the biological rest period of the oyster by prolonging the period of high metabolic activity, resulting in greater fragility (FLEURY *et al.*, 2020; THOMAS *et al.*, 2018). Finally, the modification of the seasonal temperature cycle is likely to cause a shift in the species' reproductive season (phenology), leading to a desynchronisation between the recruitment of predators and the presence of prey, what is known as a "trophic mismatch", which can penalise the productivity of the exploited species (EDWARDS and RICHARDSON, 2004; RÉGNIER *et al.*, 2019).

12 Changes in the physicochemical properties of the water body, such as water acidification due to the accumulation of atmospheric CO_2 or deoxygenation due to coastal eutrophication, also have an impact on marine resources by degrading the quality of marine habitats. There has been a marked increase in hypoxic "dead zones" in coastal areas as a result of climate change due to increased stratification, warming and greater nutrient discharges to coastal ecosystems (DIAZ and ROSENBERG, 2008). This deoxygenation affects the physiological performance of species and is likely to reduce

their productivity (AGUIRRE-VELARDE *et al.*, 2018; LAVAUD *et al.*, 2019; THOMAS *et al.*, 2019). Ocean acidification also strongly impacts species productivity, reducing the survival of larval calcifying organisms such as shellfish and lowering their recruitment potential (ANDERSEN *et al.*, 2013; BYRNE, 2012). Effects on fisheries resources may also be indirect, through changes in trophic interactions associated with reduced productivity of food sources (i.e. phytoplankton and zooplankton), leading to lower nutrient inputs for consumer growth and reproduction (BRANDER, 2010). All of these constraints are combined with anthropogenic pollution, the sources of which are multiplying, and among which plastic pollution is a major threat to marine resources of all species (WILCOX *et al.*, 2015). It has been shown that microplastic pollution can reduce by 40% the reproductive capacity of the cupped oyster (*Crassostrea gigas*), the main shellfish species exploited for aquaculture worldwide (SUSSARELLU *et al.*, 2016).

Geographic displacement of species

13 Different processes are responsible for the displacement of species: loss of habitat, modification of migration, or changes in the connectivity between habitats, in particular at the time of recruitment. This can lead to the displacement, contraction or extension of the species' distribution area. Each species has an ecological niche defined by (1) the range of physicochemical parameters in which it can develop and (2) the biotic interactions of the species (i.e. prey, predators, etc.). If these optimal conditions are altered in a habitat, the species may not be able to maintain itself, in which case it will become locally displaced or extinct, thus changing its distribution.

14 The thermal limits of a species are one of the main variables determining its geographic distribution (PÖRTNER, 2002). CHEUNG *et al.* (2009) used modelling to forecast the future of 1066 species of marine fish and invertebrates exploited under a global warming scenario (A1B "business as usual" scenario). They predicted many local extinctions in sub-polar regions, the tropics and semi-enclosed seas by 2050. Species tend to move to high latitudes and deep waters to maintain favourable thermal conditions. Thus, some fisheries located in high latitudes are likely to benefit from warmer water, to the detriment of temperate and tropical areas. This is, for example, the case for the cod fishery in the Northeast Atlantic (SCHRANK, 2007). Each species is likely to react differently to stress. Climate change will modify the structure of communities and the interactions between species, such as the prey/predator relationship, trophic competition or competition for space, leading to changes in local density (POLOCZANSKA *et al.*, 2008).

15 Furthermore, this geographic displacement of species subject to the constraints of climate change is compounded by the increase in international trade – in particular maritime transport – leading to a rise in the number and severity of invasions of non-native species on a global scale, with significant impacts on marine ecosystems, habitats and fisheries resources (RIUS *et al.*, 2014; RUIZ *et al.*, 1997). Ocean warming has been shown to facilitate these species invasions (STACHOWICZ *et al.*, 2002). This has been demonstrated, for example, with the introduction of the Pacific oyster in northern Europe in the 20th century: this species tends to increase its local productivity and expand its range northwards as a result of global warming (KING *et al.*, 2021; THOMAS *et al.*, 2016).

16 Many species, such as shellfish and crustaceans, have a lifecycle with a pelagic larval phase. Recruitment thus depends on the dispersion of larvae by the current and the swimming behaviour of the larvae. This relies on connectivity (COWEN *et al.,* 2007), which defines the probability that an individual born in habitat A will be recruited in habitat B, which is more or less distant. Climate-related disturbances not only alter larval dispersal pathways by reducing export from affected areas and altering hydrodynamics, they can also lead to changes in several processes involved in connectivity (see, for example, COWEN and SPONAUGLE, 2009) such as:

- the phenology of reproduction (earlier laying by adults)
- larval transport (shorter duration of the pelagic larval phase)
- larval mortality (exposure to lethal temperatures and shorter larval lifespan)
- behaviour (increased swimming speed of the larvae).

17 Population connectivity plays a key role in population and community dynamics, genetic diversity and the resilience of marine populations to human exploitation (FOGARTY and BOTSFORD, 2007). In this context and for marine-use planning purposes, knowledge of dispersal patterns and their variability is particularly important. This information can help guide the establishment of marine protected areas, in order to optimise recruitment potential (KRUECK *et al.*, 2017; MAGRIS *et al.*, 2014).

18 Changes in the range of exploited species associated with climate change are already being observed throughout the oceans (JOHNSON and WELCH, 2009). The consequences for fisheries are manifold and will alter catch potential on a global scale. In particular, a shift in stocks may raise governance issues, involving transboundary management of fisheries. According to PINSKY *et al.* (2018), almost all of the world's exclusive economic zones will be affected by this issue by 2100 if no measures to reduce CO_2 emissions are taken.

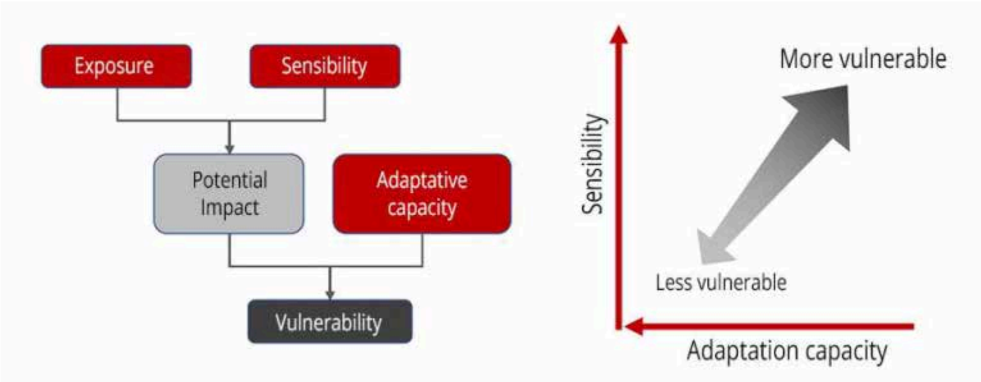
Vulnerability of artisanal fisheries

19 Vulnerability is generally considered to be the degree of change that a system is likely to experience as a result of the adverse effects of a chronic or stochastic disturbance and that it will not be able to cope with (ADGER, 2006). Several research frameworks have been developed to examine the vulnerability of societies to environmental change. This research generally measures three key dimensions of vulnerability (ADGER, 2006; CINNER *et al.*, 2012; fig. 2a):

- **Exposure** refers to the magnitude, frequency and duration to which a system is exposed to a climatic or environmental disturbance.
- **Sensitivity** is the degree to which a system is modified or affected by disturbance. Sensitivity can be strongly influenced by the degree of dependence on a resource that may be disturbed (e.g. a fish stock).
- **Adaptive capacity** is the ability of a system to adapt to changing risks or conditions, and to expand the range of variability it can cope with.

20 The more sensitive a process, activity or community, the lower its adaptive capacity and the more vulnerable it is (fig. 2). This vulnerability is exacerbated by a high level of exposure.

Figure 2. Representation of the vulnerability of coastal communities according to their exposure, sensitivity and adaptive capacity



Source: CINNER *et al.* (2012)

21 As JOHNSON and WELCH (2009) argue, "the marine fisheries most at risk from climate change are those whose fish stocks will experience the greatest ecological impacts due to their high exposure and sensitivity to changes in ocean climate, whose resilience is compromised by other pressures (such as overexploitation), and whose adaptive capacity is limited by resource dependence and weak economies". In this context, "resilience" is understood as the capacity of the socio-ecological system to absorb shocks while maintaining its function, and to reorganise itself after a disturbance (WALKER *et al.*, 2004). On a global scale, the vulnerability of fisheries to climate change is very heterogeneous (ALLISON *et al.*, 2009). It is clear that the poorest countries are the most vulnerable, particularly in the intertropical zone. These countries have high exposure to climate change, high dependence on fisheries resources and low adaptive capacity. African nations are particularly vulnerable and have a high level of sensitivity, due to (1) their nutritional dependence on fisheries resources: fisheries provide employment for 10 million people and are a vital source of protein for 200 million people in Africa, (2) their semi-arid climate, which increases their exposure to warming, precipitation and coastal flooding, and (3) their low capacity to adapt to change due to low economic and development indices (FAO, 2007a; JOHNSON and WELCH, 2009; LAM *et al.*, 2012).

22 This vulnerability is exacerbated in the case of artisanal fisheries (BELHABIB *et al.*, 2016). This activity is practised intensively in tropical geographical areas that are highly exposed to climate change (CHEUNG *et al.*, 2009; IPCC, 2019) and are also highly dependent on the resource. Artisanal fisheries are worth US$5–7 billion per year and employ more than 12 million people globally, compared to US$25–27 billion and 0.5 million jobs for industrial fisheries (JACQUET and PAULY, 2008). The sensitivity of artisanal fisheries to climate change is significant, particularly because of the low capital available, which does not allow for large fluctuations in income. The capacity to adapt is limited by the small scale of the activity, as fishing grounds are often located close to residential areas due to small-scale equipment (boats, engines). Artisanal fisheries are also threatened by the fact that they are focused on a limited number of species, with few alternative opportunities for reasons linked to culture, food habits and available markets (BELHABIB *et al.*, 2016; COULTHARD, 2008). This phenomenon, which encourages fishermen to "follow the fish", is likely to increase the vulnerability of the

activity by forcing them to increase their fishing effort and expand their fishing area, or even migrate to other, more productive areas (BELHABIB *et al.*, 2016).

23 Climate change thus represents an additional burden for artisanal fisheries in countries with unfavourable socio-economic conditions, particularly in the intertropical zone. These constraints are combined with other sources of vulnerability related to climate risks (e.g. submersion, salinisation, flooding, drought), which will undermine food security, reduce alternative livelihoods and increase health risks for the poorest populations (ALLISON *et al.*, 2009).

The artisanal shellfish fishery in Senegal: a case in point

24 The exploitation of shellfish by humans in coastal ecosystems dates back several tens of thousands of years (KLEIN and BIRD, 2016). This is particularly the case in West Africa, where shell middens dating back thousands of years as a result of accumulation from exploitation are found on the coast (HARDY *et al.*, 2016; KLEIN and BIRD, 2016).

25 The Sine-Saloum delta, located in the centre of the west coast of Senegal, 150 km south of Dakar, is home to a large artisanal shellfish fishing activity. The delta has been classified as a biosphere reserve (Saloum Delta Biosphere Reserve, SDBR) since 1981, and has been listed as a UN World Heritage Site since 2011, which allows the development of conservation measures, development actions and logistical support for the populations. The Sine-Saloum delta is a mosaic of terrestrial, lacustrine and palustrine wetland environments that are open to the ocean. From an ecological point of view, this interface zone contains various geomorphological units: mangrove mudflats, tidal flats, sandy strips and shellfish beds.

26 The delta is the centre of human activity developed around fishing and agriculture. The exploitation of shellfish, in particular the bloody cockle *Senilia senilis*, is very old (nearly 5000 years, HARDY *et al.*, 2016), and is an integral part of local culture and traditions, especially those of women's communities, as women typically carry out shellfish harvesting, processing and marketing (fig. 3). This artisanal fishery is highly vulnerable to climate change, in all three key dimensions of vulnerability.

27 It has **high exposure** to the impacts of climate change. The area has been subject to significant aridification over the past few decades (DESCROIX *et al.*, 2020); freshwater inflows into the delta have reduced and the hydro-biological properties of the water have been modified. The Sine-Saloum delta is a natural inverse estuary, which only receives freshwater during the monsoon season and contains hyperhaline water the rest of the year due to evaporation. As the delta is located north of the West African monsoon development zone, this ecosystem is very sensitive to the monsoon regime associated with the dynamics of the Intertropical Convergence Zone (ITCZ) and associated rainfall maxima (SULTAN and JANICOT, 2003). In conjunction with this, sea level rise is causing marked coastal erosion, which led to the development of a rift in the 1980s and significantly altered the morphology of the delta (DIEYE *et al.*, 2013). Agricultural land is becoming salinised as a result of sea level rise, reducing agricultural production and requiring the diversification of activities.

28 The area has **high sensitivity** to disturbance: a large majority of women in coastal villages are involved in shellfish collection and are directly dependent on this activity

for their subsistence and that of their families. Furthermore, a shift from food to commercial activity has led to the overexploitation of stocks, which are therefore more sensitive to the effects of climate change. The number of species exploited is also limited, and tonnages are mainly linked to a single species, which increases the degree of dependence.

29 There is **limited adaptive capacity**. The surface area of the available fishing grounds (sandbanks that are uncovered at low tide) is limited, as is the women's ability to travel: many women go to the fishing grounds on foot. Scientific lack of knowledge regarding the functioning of the ecosystem and the biology of the species exploited (e.g. ecological niche, biological cycle, population dynamics) also weakens the ability to support management measures in a context of environmental stress.

30 Measures to increase the adaptive capacity of local women's communities have been put in place. The women are supported by various partners at national and international levels, seeking to promote their traditional know-how and to modernise the processing cycle to improve the quality of the products. This positions them as a model of artisanal fishing in the West African region. In partnership with researchers and managers, the women have also implemented management practices to combat the overexploitation of resources, such as allowing a period of biological rest during the winter season, rotation of exploited sites, and the establishment of a minimum size for shellfish harvesting (DIOUF *et al*., 2014; DIOUF and SARR, 2014). Actions to restock mudflats and mangrove reforestation have also made it possible to increase the availability of stocks and improve catches, contributing to the long-term food security for the women and their families by providing them with resources while improving their income. The women supplement artisanal shellfish harvesting with many other activities, such as the processing of natural resources like fish, shrimp, forest fruits or cereals. This diversification offers women many levers for action, enabling them to manage marine resources sustainably and thus limit their vulnerability.

31 Despite the significant involvement of local communities, in particular of women shellfish collectors, knowledge about ecosystem functioning and the response of marine species to stressors remains limited. Supporting the sustainable development of fisheries will require a better understanding of the response of populations of exploited species to biotic and abiotic factors in the environment. This would enable the anticipation, implementation and evaluation of appropriate management measures. These approaches must involve stakeholders, particularly in order to establish an observation system capable of providing information on ecosystem dynamics. The implementation of participatory and outreach approaches contributes to raising awareness of environmental issues among local communities as well as strengthening their capacity to adapt to climate change.

Figure 3. Artisanal shellfish harvesting by women in the Sine-Saloum delta (Senegal)

A. Collection of *Senilia senilis* clams at low tide
B. Collection of clams
C. Shell cluster from the village of Falia, made up of clam shells that may date back several thousand years

Challenges for MSP involving artisanal fisheries

32 To best guide management measures, it is imperative that policymakers, researchers and stakeholders jointly consider the pressures associated with fishing and climate change in order to support fishing communities and increase their adaptive capacity. As proposed by CINNER *et al.* (2018), pathways for improving the adaptive capacity of artisanal fishing communities to climate change can be identified in five highly interconnected areas (*sensu* CINNER *et al.*, 2018):

- *assets*: the resources available to people, such as financial resources (e.g. savings or credit), technology (e.g. fishing gear) and services (e.g. healthcare)
- *flexibility*: the ability to grasp the diverse potential adaptation options available (e.g. changing fishing strategy, fishing location or even occupational sector)
- *social organisation*: the formal and informal relationships between individuals, communities and organisations, which provide social support and access to knowledge and resources (e.g. strengthening networks, creating arenas for interaction)
- *learning*: the ability to generate, appropriate and process new information about climate change, adaptation options and ways of living with and managing uncertainty (e.g. knowing about new fishing grounds, new gear, new weather patterns, new technologies, new species)

- *action*: the ability of people – individually or collectively – to have free choice to respond to environmental change (e.g. taking into account local knowledge, local skills and local management in both science and policy and increasing participatory processes).

33 Given this conceptual framework and the multiple pathways through which climate change impacts artisanal fisheries, reducing vulnerability begins with reducing exposure to climate change-related stress. The main – and perhaps only – lever for communities is to avoid overfishing, which leads to species fragility and increases the consequences of environmental stress (BRANDER, 2007; PERRY *et al.*, 2010). Such a pathway requires increased knowledge to better assess species production at local, regional and global scales. Improving our ability to model local-scale processes by integrating interannual, decadal (regional) variability and global climate change will be essential to provide relevant information for fisheries management and adaptive planning. This will involve improving observational capacity to provide information on current status and short- and medium-term trends. This is fundamental to assessing progress towards management objectives (WEIGEL *et al.*, 2018). Observational systems also provide measures to validate and assess the sensitivity of predictive models and to adjust the structure of existing models. Strengthening these observational systems should be considered from the perspective of community ownership and knowledge sharing. In this context, open science and low-cost development approaches are fundamental elements in constructing these dynamics.

34 To better understand the interactions between ecological processes and uses, it is also essential to take an interdisciplinary approach, combining natural and human sciences. This requires the integration of local Indigenous knowledge and the involvement of stakeholders in the development and implementation of monitoring and management plans. Communities that show a strong capacity for self-organisation reduce their vulnerability to climate change, as is the case in some villages in the Sine-Saloum delta through modernisation, diversification of activities and resource management; this has also been shown in other examples of artisanal fisheries around the world (KALIKOSKI *et al.*, 2010). However, this self-organisation seems difficult to generalise due to the specificities of local communities.

35 A key element in reducing the vulnerability of artisanal fisheries is the establishment of public policy and institutions for resource governance to enhance adaptive capacity (KALIKOSKI *et al.*, 2010). Management measures, as well as research in support of such management, need to be adapted to the diverse spatial and temporal scales at which the combined effects of climate change and natural resource exploitation occur. The impacts of climate change are likely to exacerbate existing variability in weather conditions, both in terms of frequency and magnitude, and thus increase uncertainty, which will require greater flexibility in management measures to support fisheries. Finally, vulnerability analysis needs to move from a global to a more local scale, incorporating the range of income and/or poverty levels of national populations in order to propose appropriate adaptive planning at national and local scales (ALLISON *et al.*, 2009). In the face of the challenges posed by climate change, added to the challenges of marine-use planning, it is essential that artisanal fisheries are properly taken into account in MSP in their diversity and in their specificities (COHEN *et al.*, 2019).

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Part II. Marine spatial planning in the tropical Atlantic. Local, national and international issues

Chapter 7. Legal tools for coastal zone management in Brazil

A basis for national marine spatial planning?

Katiuscia Da Silva Leite Noury and Florence Galletti

1 Marine spatial planning (MSP) is a recent process in Brazil. The administrative management of spaces at the intersection of the continental territory and the ocean has historically been addressed from two angles. The federal government has made use of (1) the international law of the sea for the largest maritime environments located away from the coast, and (2) environmental law, or "coastal law", which focuses on spaces restricted to a strip of land adjacent to the shoreline termed *costeira* (coastal) in the legislation. This strip penetrates inland to varying distances (up to 50 km) following the administrative boundaries of the coastal municipalities. A third space – which is not treated as a continuum or as a whole – would be the geographic coastal zone located between this strip of land and the marine areas distant from the coast. Only a portion of the marine waters of this coastal zone is of interest to public authorities: that which is legally known as the "maritime strip", with a width that does not exceed "territorial sea".

2 Since 2013, there has been a willingness on the part of government policymakers and agencies to move towards MSP for the area from the shoreline to the outer limit of the waters under jurisdiction (i.e. the boundary of the exclusive economic zone, EEZ). But MSP is not yet legislatively approved, and the text that mentions it is therefore not applicable. If it does become applicable, questions regarding the technical, scientific and legal modalities of MSP will arise; it will also be necessary to determine whether the legal instruments of current coastal zone management in Brazil can serve as a basis for MSP.

3 This chapter outlines the existing legal framework that gives rise to the predominance of land and shoreline planning. In Brazil, legal governance of the coast focuses on the land rather than coastal waters. The current system of coastal management is relatively cumbersome due to the multiple institutions involved at different scales, the complex distribution of responsibilities (at least tripartite), and the entrenched practice of land-based planning. Even the zoning of marine protected areas – the

premise of MSP – has not managed to counterbalance this tendency. To take into account the importance of Brazilian waters and the seabed, what they contain, and the ecological and economic services they provide, spatial planning on a much wider, non-partial, more systemic "maritime zone" would be required.[1] As for its feasibility, linking this MSP to coastal land management is possible. The second part of the chapter presents the conditions necessary for this, keeping in mind that (1) a shift towards the maritime area also means a change in the agencies overseeing that area and (2) if MSP takes an ecological orientation – in order to maintain the tropical ecosystems present and their ecological functions – this inevitably must compete with other options for national maritime planning. It should be noted that the territorial planning system described is not set in stone and can evolve. This chapter aims to offer practical insights to the administrators of future MSP.

Legal management of the coast: a focus on coastal land

4 Brazil's global importance is often linked to its forest cover, but it also has an equally impressive coastal strip of about 10,800 km (this estimate may vary depending on the calculation method)[2]. While 40% of Brazil's land area is below 200 m in elevation, coastal development and artificialisation are increasing as a result of soaring demography: the country's population has grown from 60 to 200 million in sixty years.

5 The coastal zone (*costeira*) represents less than 4.1% of the national land area (8,5 millions km^2), but an estimated 24.6% of the population[3] (190,732,694 inhabitants according to the last census in 2010) is concentrated there, with urbanisation increasing from 45% to 85% between 1960 and 2010[4]. Although the coastal zone has received much public attention, can we identify any real public policy concerning this space in decision-making, accompanied by a legislative and regulatory arsenal capable of planning how it is used by humans and for which activities?

6 The demarcation between maritime and coastal land areas was enacted as early as the country's independence. Planning policy has focused more on the shoreline and inland strip more than on marine waters, with the former subject to a succession of different coastal planning tools. However, legislative planning is constrained by the complex division of coastal authority between institutions.

7 Nevertheless, lessons can be learned from the experiences of managing vulnerable or protected ecosystems and species in the coastal zone, in particular through the consolidation of environmental law and legal regulations for ecosystems present on the coast or in shallow or nearshore waters. This management has been oriented primarily towards natural resources, and offers guidelines and tools that may benefit future MSP.

8 The scale of governance is considerable: Brazil's *zona costeira* encompasses one of the longest coastal strips on the continent. It contains diverse tropical ecosystems (coastal mangroves, sandbanks, dunes, estuaries and coral reefs, among others) with 92% of the area in the intertropical zone. It is made up of 17 coastal states, from Amapá in the north to Rio Grande Do Sul in the south, is the location of 13 of Brazil's 27 capitals, and includes more than 400 municipalities. A large part of the population resides there annually or periodically, working in both formal and informal activities considered to support national or local development (commercial ports, coastal and offshore

industries, artisanal and industrial fisheries, beach tourism, coastal real estate). To protect the coastal and marine environment from overexploitation of natural resources and risks of degradation, since the 1980s the Brazilian Federal Constitution, in Chapter VI (Art. 225), has provided that "all have the right to an ecologically balanced environment", the corollary being the duty to protect the environment; paragraph 4 of Article 225 also cites the *zona costeira* as a "national heritage" (5 October 1988)[5]. Brazilian legislation has been modified several times by laws, decrees and policies to regulate the coastal space.

A series of coastal planning measures

9 The administration of the coastline (territorial space) is enshrined in Law No. 7661 of 16 May 1988[6], which established the National Plan for Coastal Management (PNGC), which is an integral part of two long-standing policies: the National Environmental Policy (PNMA) enshrined in Law No. 6938 of 1981[7], and the National Policy for Marine Resources (PNRM)[8] enshrined in a decree of 12 May 1980. The law of 16 May 1988 specifies that the PNGC must be set out in detail in a specific document under the aegis of the Interministerial Commission on Sea Resources (CIRM) and must guide (1) the methods of managing resources in the coastal zone in a rational manner, (2) the means of protecting the environment and (3) authority over the management of this zone which is no longer considered as an ordinary space. The PNGC concerns inshore coastal areas much more than offshore.

10 A first version of the PNGC (PNGC I) was presented in November 1990, and the second (PNGC II) was approved in 1997, in the form of CIRM Resolution 005 of 3 December 1997, following approval at the 48th ordinary meeting of the National Environmental Council (CONAMA). This new version, PNGC II, which is still in force, was published in Decree No. 5300 of 7 December 2004[9] which, according to the official terminology used in Brazil, "regulates" Law No. 7661 of 16 May 1988 on coastal management. This important 2004 decree establishes rules for the use and occupation of the coastal zone and sets criteria for coastal management. It has provided the country with nine types of policy instruments, four of which are termed "plans":

- The National Plan for Coastal Management (PNGC) encompasses the set of guidelines applicable to different levels of government and scales of action, guiding the implementation of policies for the sustainable development of the coastal zone.
- The Federal Action Plan for the Coastal Zone (PAF) integrates public policies affecting the coastal zone and identifies shared responsibilities for action.
- The State Plan for Coastal Management (PEGC) implements state policy for coastal zone management, defining the responsibilities and institutional procedures for its implementation based on the PNGC.
- The Municipal Plan for Coastal Management (PMGC) implements municipal coastal zone management, defining the responsibilities and institutional procedures for its implementation based on the PNGC and the PEGC, and also takes into account other land use and occupancy plans at municipal level.

11 With regard to the planning process (in the sense of drafting planned actions), a decision by the Coastal Management Integration Group (GI-Gerco) resulted in a Federal Action Plan for the Coastal Zone (PAF-ZC). This is periodically revised and is one of the instruments in the PNGC.

12 The 4th Federal Action Plan for the Coastal Zone (PAF-ZC, 2017–2019)[10] is currently underway; it was approved by CIRM Resolution No. 02/2017, at the 58th session of the GI-Gerco on 18 October 2017. It includes 17 concrete actions, which have been under discussion since 2017 (Box 1).

Box 1. The 17 actions of the Federal Action Plan for the Coastal Zone

- A1. Brazilian action plan to combat marine litter
- A2. Macro-diagnosis of the Brazilian coastal zone
- A3. Development of a methodology for the integration of land and sea altimetry – Action: national coastal management meeting
- A4. National coastal conservation programme: design, formalisation and dissemination
- A5. Socio-environmental monitoring of Brazilian ports
- A6. Development of a methodology for evaluating the integrated management plans of the Secretária de Patrimônio da União
- A7. Promotion of training courses focusing on the coastal area
- A8. Integration of the *Orla* project with municipal master plans
- A9. Increase in the number of states with PEGCs
- A10. Identification and dissemination of good practices developed by the G17 (sub-group on the integration of coastal states) and municipalities related to the management of river, coastal, marine and estuarine zones
- A11. Identification of states that have not established coastal ecological and economic zoning, and monitoring of the preparation and implementation of this, aimed at strengthening the PNGC
- A12. Evaluation of effective actions of waterfront committees and integrated management plans, taking into account the recent changes in Law 13 240/2015
- A13. Regulation of motorised vehicle and vessel traffic on beaches
- A14. Contribution to the implementation of the UN Sustainable Development Goal “Life Below Water” (SDG 14) in Brazil
- A15. Contribution to the approval and implementation of the actions contained in draft law 6 969/2013
- A16. Development of a regional case study on integrated coastal–marine governance for the Babitonga ecosystem (Santa Catarina state)
- A17. Promotion of dissemination actions and implementation of Law 12 340/15 and its regulation on the transfer of beach management to cities and municipalities

13 These 17 actions include both frameworks and methodological instruments. Some actions are more advanced than others; all are subject to multiple divisions of authority.

A complex planning exercise

14 There are three levels of jurisdictions overseeing policymaking in Brazil, which is a federal state with a tripartite system. At the very least, authority is shared between the federal government (national level), the states and the municipalities. Article 21 of the Federal Constitution gives the federal government the legislative authority to draw up

national and regional plans for the national territory. The planning instruments available may thus have different origins:

- federal (the PNGC)
- state (the PEGC)
- municipal (the PMGC).

15 Another example is the Integrated Coastal Management Plan (PGI). For the specific territorial space known as the "*orla*" (equivalent to the shoreline or even the foreshore), the drafting of this plan involves officials from all three levels of governance, assisted by representatives of civil society. The PGIs, which aim to improve beach management, cover the territory of the municipality and are a strategic plan for the local level.

16 For a given topic, material authority for planning is assigned either exclusively to one institution or to several. Thus, the federal government may have exclusive authority, joint or suppletive authority, or concurrent authority (articles 22, 23 and 24 of the Federal Constitution of 1988[11]). The drafting of acts such as the PGI is an illustration of the interaction of these authorities.

17 Because of this complex division of authority and capabilities, Brazil's legal framework is sometimes considered an institutional and normative limitation to effective planning for the *zona costeira* or the maritime strip. The challenge linked to this is perhaps smaller during the design phase of measures. It is much larger during the phase of identifying damage to ecosystems, or identifying urban constructions causing partial or total degradation of the coast. Proof of degradation of biological and physical environments gives rise to conflicts between authorities that are so intertwined or numerous that the regulations created to sanction the degradation can no longer be applied by these same authorities[12] and it is no longer possible to identify which authorities have been harmed by these actions, nor how to enable them to take legal action to combat them. This results in a problem of recognition of the "interest to act" of the injured institution (victim of environmental destruction). Law 9605 of 1998[13] is clear on criminal and administrative sanctions, but it is difficult to apply if the institution is itself involved in the decision to authorise the activities and land uses that cause the degradation of the coastline[14]. Sometimes authorities are involved in environmentally damaging developments, such as those required to host the 2016 Olympic Games.

18 In the maritime area, the division of authority is unambiguous. This is under the jurisdiction of federal maritime authorities, which are concerned with defence, navigation and exploitation. In legal terms, in Brazil, the maritime zone is almost opposed to the coastal zone. While the continuity of these marine areas, from rivers and deltas to the high seas, can be demonstrated by the natural sciences, it is not, or very poorly, considered in law. According to Article 22 of the Constitution, it is exclusively up to the federal government to legislate on maritime law and criminal law: two aspects that are essential for the legal management and future of a geographic coastal area whose ecological integrity is threatened.

Management of coastal environments: lessons learned

19 The heritage status of the coastal zone is accompanied by a legal arsenal intended to prevent the degradation of the coastal and marine biome. The federal government is a

signatory to international conventions – universal or specialised – relating to the law of the sea, the protection of coastal and marine environments, or marine or migratory species.

20 In addition to management directed solely at the coastal space, there is also public policy that takes into consideration the species and ecosystems present in this zone. Even when it deals solely with protected natural environments, this policy reveals three trends that we will develop below: (1) the fragmentation of the management of coastal and maritime areas, (2) the desire to restore certain very attractive natural sites with a high economic value, including by technical and artificial means, and (3) the use of "zoning within zoning": for example, for the management of coastal mangroves.

Fragmented management of coastal and marine environments

21 The management of coastal and marine environments and natural sites suffers from the fragmentation of institutional and normative resources dedicated to protected natural environments. The PNGC must be implemented with the participation of the federal government, the states, the municipalities and the districts. The institutional and territorial organisation of environmental issues must be respected, as well as the National Environmental Policy, which was created in 1981 and supplemented by a decree in 1990 and by the creation of the Ministry of the Environment (MMA) in 1992 (with attributions established in 2003). The application of the PNGC is carried out through entities that integrate the National Environment System (SISNAMA). The National Environment Council (CONAMA) also coordinates the different public agencies.

22 According to OLIVEIRA and COELHO (2015), "coastal zone management issues, whose impact is hardly limited to the local scope, and which take on regional or national proportions, are of interest to the Brazilian Institute of the Environment and Renewable Natural Resources (IBAMA), in the federal autarkic mode, as it implements the National Environment System (SISNAMA)". According to Law 6938 of 31 August 1981 on the National Environmental Policy, which since 2003 has been centred on the tasks of the Ministry of the Environment, there are, in addition to the administrative policymaking bodies, several recognised implementing institutions – IBAMA and the Chico Mendes Institute for Biodiversity Conservation (ICMBio) – which are enlisted according to the action to be carried out[15]. One of ICMBio's missions is to organise and manage the protected areas established by the federal government (DELELIS *et al.*, 2010). The term "protected areas" is used here in a general sense (the different types of protected areas in Brazil are detailed later in this chapter). Specific implementation bodies dedicated to environmental protection also exist, from state level (State Environmental Agency, *Agência estadual de meio ambiente*) to municipal councils. This mainly concerns land and coastal areas, and more rarely extends to marine areas.

23 As for the maritime area of the *zona costeira,* and other national marine waters (territorial sea and all waters under the national jurisdiction), they are managed by the Maritime Authority in charge of constructions that may be carried out in these areas and their impacts. Its main objective among other provisions is to ensure safety according to Law No. 9966 of 28 April 2000 on the prevention, monitoring and surveillance of pollution caused by the discharge of hydrocarbons and other dangerous or harmful substances in waters under national jurisdiction. Jurisdiction is exercised

directly by the Commander of the Navy (*Marinha do Brasil*)[16]. Often, in a form of zoning, so-called "provisional prevention of gas and hydrocarbon exploitation" zones are drawn along the coast.

24 OLIVEIRA and COELHO (2015) highlight that this fragmentation of institutional authority is a limitation to the planned management of impacts on the natural environment: "Because of the joint authority of the central government, the states and the municipalities, potential conflicts arise in determining the relevant body for the environmental authorisation of an activity in coastal areas. These conflicts have arisen due to a lack of clarity on the delimitation of the authority of each federal entity, a point partially clarified by a complementary law (no. 140 of 8 December 2011), mainly on the random use of criteria to define the authority of each entity."

25 The authorisation to occupy and exploit the coastal zone (in its maritime space) is an instructive example. Law No. 140 of 8 December 2011[17] provides for three situations:

- Article 7 provides that the federal government has the exclusive authority to grant permits for constructions and activities located or developed concurrently in the land and sea areas of the coastal zone. Thus, if the location of the enterprise concerns both, a land and a sea strip, the authorisation falls within the jurisdiction of the federal government, but only in cases corresponding to a typology established by an act of executive power. This typology is established by a proposal from the National Tripartite Commission, with the participation of a member of the National Environmental Council (CONAMA), considering the criteria of size, the possible pollution generated and the nature of the activity.
- Article 8 states that the states may "issue environmental permits for activities or constructions that use natural resources, that are actually or potentially polluting, or that are in any way likely to cause environmental degradation, except in the cases provided for in Articles 7 and 9".
- Article 9 deals with municipal authority for "the administrative acts of the municipalities, which, observing the attributions of the other federated entities provided for in this law, aim to issue environmental permits for activities or constructions that have or could have a local impact on the environment, according to a typology defined by the environmental council of the different states, taking into account the size, the potential pollution generated and the nature of the activity".

26 Two points should be noted here: (1) this separation between administrative bodies for the land on one hand and for the sea and maritime and river navigation on the other undermines the ecological continuity between coastal and maritime areas and ecosystems in its day-to-day application; and (2) it is no simpler to identify the relevant institution and environmental authorisations for protected coastal areas than for ordinary coastal areas.

The role of public institutions concerning beaches

27 Seafront constructions and their impacts on beaches are often described by the term *orla marítima* (DE FREITAS, 2011); these constructions must obtain authorisation from the municipality and are used as residences or commercial premises. The result of this development is the replacement of open beach systems and a natural coastal landscape with lines of concrete. In this case, municipalities play a dual role, both in causing degradation and in restoration efforts (DA SILVA LOUREIRO FILHO, 2014). This transformation is often backed by law: according to DE FREITAS (2011), "among the most

frequently encountered problems in the coastal zone, one of the most worrying is the invasion of the beach and even of the dunes and *restingas* [coastal sand forests] with the construction of diverse structures or activities without clear rules governing them. These are irregular occupations, mainly due to the fact that these lands are public and, therefore, their use by individuals is subject to authorisation by the public authority. Buildings on Brazilian beaches are increasingly common, where bars, kiosks and hotels disfigure the natural beauty. As a rule, these constructions are irregular or authorised by the municipalities based on Article 30-subparagraph of the Federal Constitution, i.e. the subject is treated as being of local interest, although in some cases it is understood that the federal government has the authority if the beach is a property of its domain." In this context, measures dedicated to beach management have multiplied, including those of coastal management, such as the 'Orla project' (SILVA and FARIAS FILHO, 2015), incentives to sign the maritime beach management adherence clause (TAGP[18]), and the dissemination of technical manuals by laboratories specialised in coastal studies, regularly revised according to new standards (SPU *et al*., 2018; LAGECI *et al.*, 2020, etc.)

"Zoning within zoning": development and conservation of coastal mangroves

28 Legislation concerning the *zona costeira* deals with the planning, institutional authority and management of this area. It includes the National System of Protected Areas (SNUC) arising from the environmental law, which is based on Law 9985/00 on SNUC and Federal Decree 4 340/2002, which regulates it. The protected areas under SNUC apply to the national territory, including coastal areas, so also coastal mangrove areas, and waters under national jurisdiction further afield. Brazil's coastal mangrove areas are considerable (BRADAO, 2011). They are part of the legally protected "Atlantic Forest" biome and have irreplaceable importance for the flora and fauna of this land–sea interface as ecological corridors, and are also sources of food, revenue and enrichment for formal and informal mangrove farmers. This ecosystem extends from Oiapoque (Amapá state) in the north to the city of Laguna (Santa Catarina state) in the south.

29 The legal treatment of mangroves and the management of the coastal zone are carried out in different ways (DA SILVA LEITE NOURY, 2014; DA SILVA LEITE NOURY and GALLETTI, 2022). Mangrove law is part of an evolution of Brazilian environmental law, influenced by international law on wetlands and forests. In this context, SNUC aims not only to conserve biodiversity, but also to protect watersheds, water resources and landscapes, as well as recreational uses (including ecotourism), historical, archaeological and cultural sites, etc. (CABRAL and DE SOUZA, 2005).

30 This system of zoning, to create "permanent conservation zones" in rural or urban areas – protected spaces in the public or private domain that have been given a special character by the Constitution – is of particular importance for the protection of coastal mangrove areas (DA SILVA LEITE NOURY and GALLETTI, 2022). The legal status of this zoning (in particular Chapter II, Section 2, of Law No. 12,651 of 25 May 2012 and No. 12,727 of 17 October 2012 revising the Forestry Code) sometimes applies to coastal mangroves and other areas essential to them, such as dune-fixing or mangrove-stabilising sandbanks. The owner, possessor or occupier of a SNUC area has obligations to maintain the vegetation and restore it if it has been destroyed, except for exceptional uses or clearings authorised by law.

31 In addition, SNUC provides two kinds of legal protection for mangroves: full conservation or sustainable use conservation. These two types of protected areas have different levels of protection and can themselves be divided into different categories; they are administered by federal, state and municipal bodies. Each protected area should have a management structure and a management plan to monitor zoning and protection.

32 While the law allows for legal protection of mangroves, paradoxically it also allows for their clearance. The destruction of mangroves in a permanent urban conservation zone is possible, but only in cases of public utility or social interest, or if it has a low impact on the environment. It must then be explained and described in an administrative procedure (CONAMA resolution 369/2006). Any clearance requires the authorisation of the relevant environmental council, provided that the municipality concerned has a decision-making (authorised to decide) and advisory (authorised to issue an opinion) environmental council and a master plan: "They must be published in the Official Gazette and be available in a place of easy access from the public list and the list containing the data related to applications and permits for vegetation removal, as provided for in Law 10 650/2003" (MEDEIROS and ROCHA, 2011). Some planning instruments thus provide legal justification for mangrove degradation.

33 In addition to the law on protected species, mangrove areas are subject to many other legal areas such as water law or forestry law; mangroves are covered by the 2012 Forestry Code. Coastal management plans must therefore integrate and harmonise many sectoral topics (in this case forestry or health) that are *a priori* distinct, even though Article 3 of Law No. 7661 of 16 May 1988 on the National Plan for Coastal Management states that priority must be given to the conservation of certain natural elements, including mangroves.

MSP in Brazil: some unresolved questions

34 The bill PL 6969-2013[19], instituting the National Policy for the Conservation and Sustainable Use of the Brazilian Marine Biome (PNCMar), known as the "Law of the Sea", has the objective of promoting the equitable, efficient, shared and sustainable use of marine resources and ecosystems and ensuring the conservation of marine diversity and marine protected areas for sustainable development. Article 3 § 14, PL 6969-2013 cites the use of marine spatial planning to this end.

35 However, the bill PL 6969-2013 was still not approved in 2022, preventing its implementation. Indeed, this initiative is not unanimously supported and has been criticised, likely due to the changes the law would necessitate if approved. At the heart of the debate are which methods to use to conduct relevant, effective MSP. How to engage in planning of the marine space itself, beyond the small strip of shoreline and the foreshore?

36 This section explores two possible options: (1) MSP based on public policy inspired by scientific expertise, and (2) MSP that could cover the entire national maritime area.

MSP inspired by scientific expertise

37 The use of scientific expertise in national, regional and local sustainable development planning is part of the discourse accompanying MSP projects. The inclusion of ecological and toxicological expertise – which would play a leading role and guide proposals by decision-makers – in such new planning for natural areas is desirable, but it can only be achieved within a well-defined framework. Moreover, any such initiative must be carried out in the understanding that there are knowledge gaps, heterogeneous data and uncertainty, as illustrated by the case of marine protected areas.

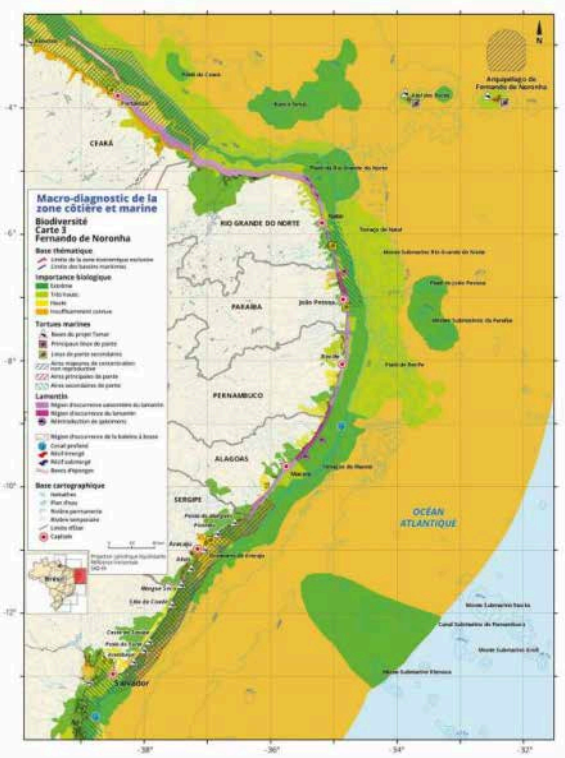
Frameworks for MSP based on scientific expertise

38 The role of scientific expertise is important in Brazilian environmental law. Public decision-making is supposed to be able to rely on the appropriate scientific council. Article 3 of Law No. 7661 of 16 May 1988 on the PNGC specifies that coastal management must provide for the zoning of uses by "prioritising" the conservation and protection of, among other things, natural resources, both renewable and non-renewable, reefs, seaweed beds, coastal and oceanic islands, marine caves, other natural permanent conservation areas and monuments that make up natural and landscape heritage. The law thus presupposes a scientific apparatus to document these elements of the marine and estuarine ecosystem.

39 Since 2004, Decree No. 5300/2004, Article 7, has provided tools for the management of the coastal zone, including:

- the Coastal Zone Management Information System (SIGERCO), a component of the National Environmental Information System, which integrates geo-referenced information on the coastal zone. It goes beyond GIS and brings together literary and technical information.
- the Coastal Zone Environmental Monitoring System (SMA), an operational structure for the continuous collection of data to monitor the dynamics of the use and occupation of the coastal zone and the assessment of socio-environmental quality objectives
- the Report on the Environmental Quality of Coastal Areas (RQA-ZC), which periodically consolidates the results obtained by environmental monitoring and evaluates the efficiency and effectiveness of management measures
- Coastal Economic Ecological Zoning (CEEZ), which guides the spatial planning process to achieve the conditions for the sustainable development of the coastal zone in accordance with the guidelines for economic ecological zoning of the national territory, as a support mechanism for monitoring, licensing, and management programmes
- the macro-diagnosis of the coastal zone to gather information on a national scale on the physical–natural and socio-economic characteristics of the coastal zone, in order to guide actions for the protection, conservation, regulation and monitoring of natural and cultural heritage (fig. 1).

Figure 1. Macro-diagnosis of the coastal zone in Northeast Brazil: example of a biodiversity map



Source: Ministério do Meio Ambiente (2008)

40 An MSP exercise applied in the open marine environment (characterised by the free circulation of biological and physical elements in the water) will be useful, better than what has been done inland by administrators who have not taken environmental continuity into account. However, such an exercise does not guarantee the perennial installation of research structures, or the improvement of the ecological governance of the mapped areas even if these objectives are made explicit in draft texts.

41 The emphasis on conservation and sustainability concerns in MSP, rather than other concerns (economic, cultural, security, etc.) is made explicit in the draft law PL 6969 of 2013 (PNCMar). While this bill was still in the evaluation phase at the time of writing, the intent of the legislation is clear. Article 3 proposes a very ambitious definition, stating that "marine spatial planning is the process of comprehensive, adaptive, integrated and ecosystem-based spatial planning, transparent, participatory and based on scientific knowledge aimed at assessing and distributing human activities in space and time in the marine biome, in order to identify the most appropriate areas for the different types of activities, to reduce environmental impacts and conflicts between uses, to promote compatible uses and to preserve ecosystem services, achieving environmental, economic and social objectives".

Planning in a context of uncertainty: the example of marine protected areas

42 It is prudent to consider MSP as an exercise that takes into account what already exists, and therefore knowledge gaps, the heterogeneity of data usable by decision-makers and uncertainty. Among the range of possible topics – from the port sector to marine pollution – we focus here on marine protected areas.

Coastal protected areas

43 Protected areas in Brazil exist up to the limits of territorial sea, but may cover marine areas up to waters under jurisdiction, according to Law No. 985 of 18 July 2000 on the SNUC. There are different kinds of protected areas.

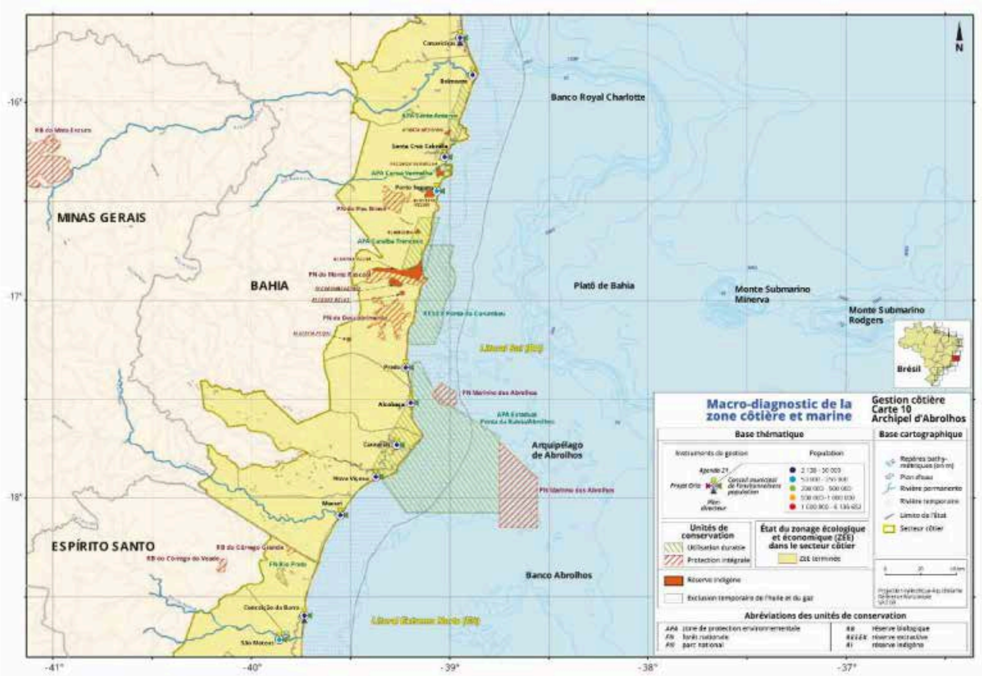
44 In areas with integral protection *(proteçao integral),* only the indirect use of natural resources is allowed; included in this category are ecological stations, biological reserves, national parks, natural monuments and refuges of forest life.

45 In areas of sustainable use (*uso sustentável*), the conservation of environmental goods is reconciled with the sustainable use and valorisation of part of the natural resource. The names and modalities of this conservation allowing for controlled use are environmental protection zones/areas, zones/areas of ecological interest, national forests, extractive reserves, wildlife reserves, sustainable development reserves and private natural heritage reserves. Areas defined on land or in a liquid environment fall either under the public domain or the private domain. Examples of public protected areas include ecological stations, biological reserves and national parks, and private protected areas include wildlife refuges, etc.

46 The ICMBio website showed, as of August 2021, an estimated 364,651,400 ha of marine biome and 851,600,000 ha of terrestrial biome in Brazil, within which there are 171,424,192 ha of ICMBio protected areas, of which 92,660,914 ha are marine protected areas.

47 Apart from an often-jagged coastline, with islets and shallows, Brazil has few remote oceanic islands, except for the Fernando de Noronha Archipelago, 350 km off the northeast coast, opposite the city of Nata, and a few famous islets, including the Abrolhos Archipelago (Bahia state, fig. 2). Legally, the Abrolhos Archipelago is a marine national park (*Parque Nacional Marinho dos Abrolhos*, Decree No. 88,218 of 6 April 1983) and covers 913 km^2. Atoll das Rocas (7.5 km^2), part of the state of Rio Grande Do Norte, is a biological reserve that was the first marine conservation unit created by the Brazilian government in 1979. This atoll was declared a UNESCO World Heritage Site in 2001. The São Pedro e São Paulo archipelago has been put forward for consideration as an Environmental Protection Area (APA) and a Marine Natural Monument (MONA) with the request under review in 2018 (FRANCINI-FILHO *et al.*, 2018). Other protected areas include Rebes do Parazihno off the state of Amapá, the Marine Park do Parcel de Manuel Luis opposite the state of Maranhão, the Marinha do Arvoredo Biological Reserve off the state of Santa Catarina, etc. This non-exhaustive list is difficult to establish because of the succession of different statutes applied to micro-portions of the protected area over time.

Figure 2. Macro-diagnosis of the coastal zone (Bahia): coastal management map of the Abrolhos archipelago



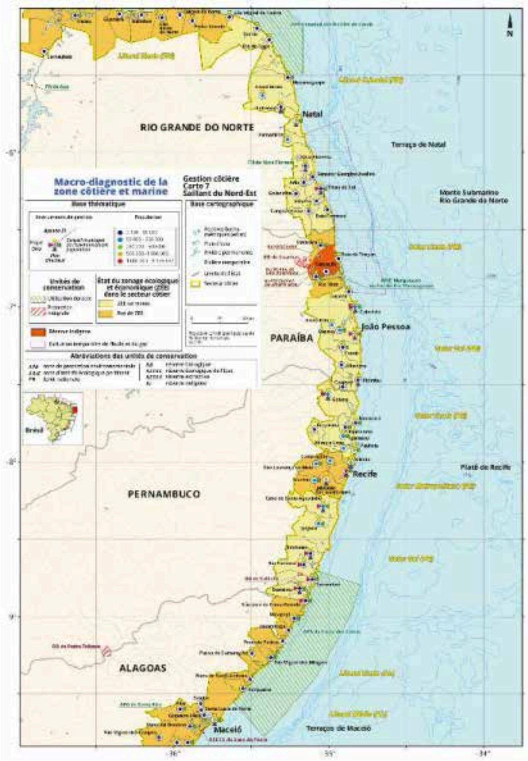
Source: Ministério Do Meio Ambiente (2008)

The case of the state of Pernambuco

48 The Pernambuco coast is long (187 km), attractive (white sands), and strategic for development. It extends from the municipality of Goiana in the northeast to Sao José da Coroa Grande in the south, and includes 21 municipalities. The high concentration of anthropisation, visible in industrial, commercial and residential buildings, etc., generates coastal pollution, especially from wastewater. The state seeks to manage the coastal zone, as it has been given this authority by law. To this end, it has established the State Policy for Coastal Management in Pernambuco through State Law No. 14,258/2010. This state law takes into account: (1) problems arising in its estuaries, which, although protected by Law No. 9931/86, are not free from uses related to public or private activities, (2) the *orla,* and the legal protection of its coastal mangroves.

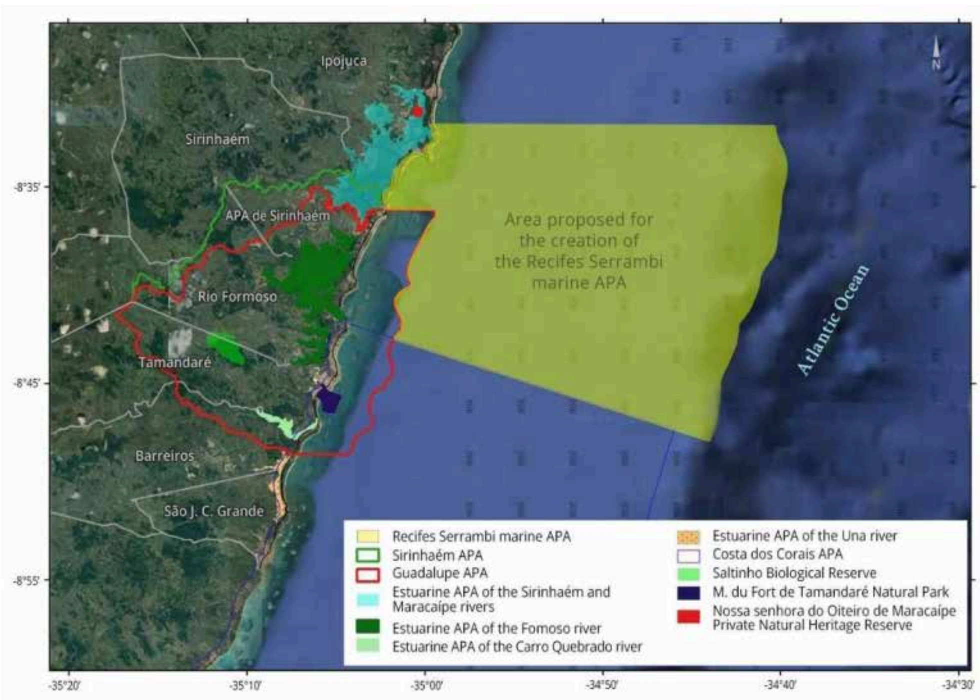
49 Concerned about the use of natural resources and the depletion of productive environments, Pernambuco's State Department of the Environment and Sustainability (SEMAS) and the State Environmental Agency (CPRH) presented, through a public consultation, the proposal to create the state's first exclusively marine environmental protection area (*area de proteçao ambiental*, APA) Marinha Recife Serrambi (fig. 4 and 5). This is adjacent to the ten other existing zoned areas (fig. 4) and is added to the landscape map previously represented in 2008 (fig. 3).

Figure 3. Macro-diagnosis of the coastal zone (2008): coastal management map



EEZ: ecological and economic zoning
Source: Ministério Do Meio Ambiente (2008)

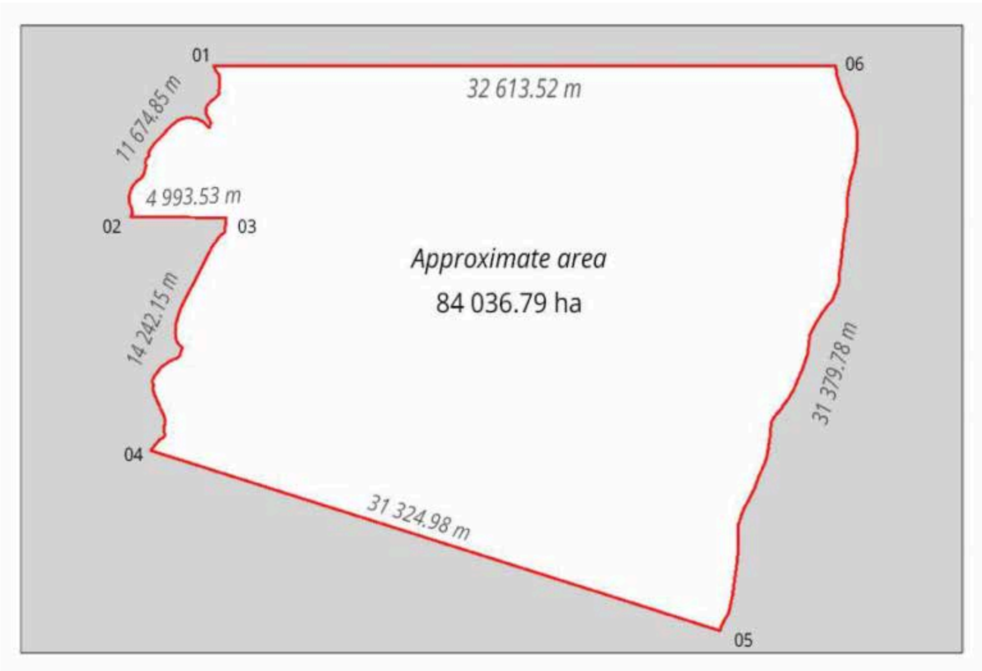
Figure 4. Map of the Recife Serrambi Marine Environmental Protection Area (APA)



Source: CPRH (2017)

50 This APA proposed by the SEMAS/CPRH technical group (2017, p. 11) aims "to integrate and organise the multiple marine uses on 84,036.79 ha of the southern coastline of the state of Pernambuco, involving the municipalities of Ipojuca, Sirinhaém, Rio Formoso and Tamandaré, and in harmony with the conservation of coastal ecosystems" (see Box 2). The APA defined in 2018[20] starts south of Ipojuca (fig. 5).

Figure 5. Recife Serrambi Marine Environmental Protection Area (APA) perimeter



Source: Map and Decree No. 46,052 published on 23 May 2018

Box 2. The objectives of the Recife Serrambi Marine Environmental Protection Area

As stated in Decree No. 46,052 of 23 May 2018 (art. 2), the objectives of the Recife Serrambi Marine Environmental Protection Area are to:

(1) Protect biodiversity in coastal and marine environments, focusing on endemic, rare and threatened species, considering their characteristics and ecosystem dynamics.
(2) Ensure the conservation of the reef environment, with its fauna, flora, geological formation and ecosystem functions.
(3) Ensure connectivity between different environments for the conservation of biodiversity, the recovery of fish stocks and the maintenance of environmental and ecosystem services.
(4) Reconcile and organise the various uses of coastal and marine environments, taking into account fishing, nautical activities, area management, tourism and other socio-economic activities, making them compatible with environmental conservation.
(5) Strengthen artisanal fisheries, encouraging sustainable management of natural resources.

(6) Strengthen sustainable tourism by promoting good practice in the implementation of tourism activities and community tourism.
(7) Support research, production and systematisation of knowledge on biodiversity, socio-environmental aspects, management of the area, etc. by capitalising on scientific and empirical knowledge.
(8) Encourage social participation through environmental education, sustainable practices and the development of conservation and protection strategies.
(9) Ensure the maintenance of the landscape of the coastal and marine environment.

51 The nine objectives for this APA are primarily ecological, but also include planning for the socio-economic future of the populations living near or from it. This is not always the case with marine protected areas and the functions assigned to them by decision-makers in emerging or developing countries (GALLETTI and CHABOUD, 2015). The creation phase of the marine protected area was collaborative and participatory, involving individual fishermen, presidents of fishermen's associations, lawyers, restaurant owners, agencies from all three spheres of governance, public officials, residents, etc. In 2020, this marine protected area still did not have a management plan, but negotiations were underway.

52 The decision to create an exclusively marine protected area (which adjoins another) is a step forward. It is interesting to note that this area allows for sustainable use rather than full protection. This could be used as an incentive for other states, some of which have begun the process of creating or have already created marine protected areas, such as the state of São Paulo's Laje de Santos Marine State Park (created in 1993).

53 Another interesting development is the emergence of joint protection efforts between Brazilian states. This is particularly the case along the Coral Coast (região da Costa dos Corais), which is making efforts to protect the marine manatee *Trichechus manatus* (the local name is *peixe-boi marinho*). Fifteen municipalities on the southern coast of the state of Pernambuco and the northern coast of the state of Alagoas are involved in this protection effort.

54 Another initiative is "mosaics of protected areas" (*mosaicos de áreas protegidas)*, initially envisaged in a forest context, but now used in coastal sites. This is the case for the maritime area of the northern coast of São Paulo (Ilhas do Litoral Norte de São Paulo) created by the São Paulo state Decree No. 53-525 of 8 October 2008. The creation of mosaics of protected areas has been tested since 2010 (DELELIS *et al.*, 2010). It is a tool for establishing a "mosaic" of protected areas recognised by an order of the Ministry of the Environment or by the states. It operates with an essentially consultative council which, in addition to representatives of the protected areas, includes members of civil society and other public institutions or figures. This council defines the area of the mosaic, with the ambitious aim of developing reconnections between individual protected sites, action plans and strategic planning, to form a kind of marine ecological corridor or network (GALLETTI, 2014) capable of enhancing biological and landscape diversity for regional sustainable development.

55 In 2018, the launch year of the Brazilian Blue Initiative and its financial extension (MARETTI *et al.*, 2019; ICMBIO, 2018; VILLELA MARRONI, 2014), the sites of São Pedro and São Paulo, and Trindade and Martim Vaz, integrated two ocean mosaics: (1) the Arquipélago mosaic of Trindade e Martim Vaz and Monte Columbia (APA of 471,532 km^2

with a surrounding EEZ of 402,377 km^2 and a natural monument of 69,155 km^2) and (2) the Arquipélago São Pedro–São Paulo mosaic (APA of 454,315 km^2 with a surrounding EEZ of 407,052 km^2 and a natural monument of 47,263 km^2). These could serve as examples to study questions around the establishment of management plans and their effectiveness. These collaborations around conservation actions allow hope for the harmonisation of provisions in future MSP approaches.

Towards MSP for the whole maritime area?

56 Spatial planning seeks modernised, informed and responsible planning of land space, now extended to the marine space. Another goal of MSP is to contribute to SDG 14 "Life Below Water: conserving and sustainably using the oceans, seas and marine resources", a goal that is not, or poorly, articulated, either in the law of the sea or with estuarine and marine natural sciences alone (GALLETTI and DA SILVA LEITE NOURY, 2022). While MSP is certainly an additional tool to public policy put in place by coastal and marine agencies, beyond the method, MSP ultimately leads to decisions concerning national marine use planning. This remains a question of marine public policy, which is situated high in the hierarchy in Brazil and has particular features. The maritime territory concerned is sizeable. In addition to the risks generated by development projects carried out, there may be other risks, real or feared, resulting from future MSP.

The "lead" institution of an MSP

57 At the institutional level, since 2019, MSP in Brazil has been promoted by the CIRM (coordinator at the federal level), which is composed of 15 parties: the Presidency of the Republic; Brazilian Navy; Ministry of Foreign Affairs; Ministry of Economy; Ministry of Regional Development; Ministry of Tourism; Ministry of Mines and Energy; Ministry of Citizenship; Ministry of Environment; Ministry of Science, Technology, Innovations and Communications; Ministry of Defence; Ministry of Agriculture, Livestock and Food Supply; Ministry of Education; Ministry of Infrastructure; and the Ministry of Health. The consideration of marine spaces to support development, coupled with the tradition of precedence of the Brazilian Navy in decision-making and control of these spaces, results in authoritarian and unilateral public decision-making and federal-level MSP that remains a strong expression of central and military power at sea.

58 The remit of the Brazilian Navy is reviewed quite regularly; for example, the recent short Decree No. 10,607 of 22 January 2021 aims to create a working group to review maritime policy. The Navy's activities and operational programmes, include – in addition to the National Coastal Management Plan[21] and the Survey of the Brazilian Continental Shelf[22] – the Sectoral Plan for Marine Resources[23], which includes 11 programmes that it sponsors or is associated with, such as the Brazilian Ocean Observation System[24] and the *Revizee* programme, among others, inspired by models for monitoring oceanic changes in the global ocean initiated by the Intergovernmental Oceanographic Commission (IOC). This institutional and legal structure that MSP can take does not exclude the involvement of naturalist scientific expertise in the process. There are necessarily cases of cooperation between the Ministry of Defence with the support of the Navy, ICMBio (for its technical expertise) and the National Council for Scientific and Technological Development[25] of the Ministry of Science, Technology, Innovation and Communication.

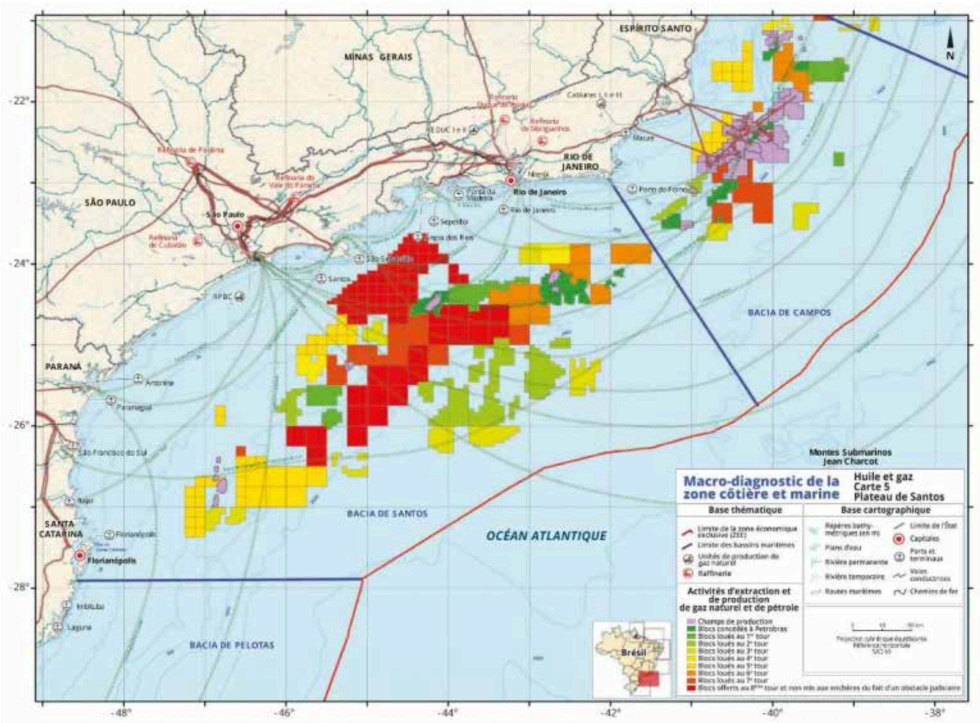
The maritime territory for MSP

59 In a maritime territory of 4.5 million km^2, expectations regarding MSP are high: it must bring about "better coordination of the actions of public authorities and private stakeholders in the marine sector", "in order to guarantee the best possible use of marine spaces and the economic development of the sector". There must be evidence of the public exercise, with maps, resources, allocated personnel and a dedicated budget, and go beyond the experience of managing only enclaves or the coastal strip.

60 The territory potentially concerned includes:

- Marine waters: Law 81617/93 recognises a territorial sea of 12 nautical miles in width along the entire coastline, a contiguous zone, and an EEZ of 200 nautical miles from the baseline. This baseline is drawn in the vicinity of the rather irregular coastline (low water line) and around the three island complexes that it encircles. This has the legal effect of extending the maritime zone eastwards, and in turn the following delineation of the EEZ.
- National continental shelf: Brazil has gradually increased (in 2004, 2006, 2015, 2017 and 2018) its definition of the outer limits of its extended continental shelf, which the Interministerial Commission on Marine Resources (CIRM) has termed the "*Amazônia Azul*" zone. This currently has a surface area of 4,451,766 km^2 if the EEZ and extended continental shelf are included, and 4,476,000 km^2 if territorial sea are included. This maritime area represents 52% of the national land territory. The marine spaces and uses have been identified politically and historically by the federal government. Its interventionism can be seen in the distribution of access to non-living resources (as in the case of opening up offshore areas to conventional and non-conventional oil and gas exploration) and the desire to control these. The same is true for living resources. For example, Brazil remains in control of its growing commercial fishing activities (exclusive fishing zone), despite the lack of continuity in catch and monitoring datasets and its membership in the Regional Tuna Fisheries Management Organisation since 1969 (Inter-American Tropical Tuna Commission, Northern Temperate Tuna Commission, Southern Temperate Tuna Commission, as well as commissions on other species).

Figure 6. Macro-diagnosis of the coastal zone: gas and hydrocarbon exploration/exploitation map



Source: Ministério Do Meio Ambiente (2008)

MSP and the risk of legal inconsistency

61 There are general risks if MSP is reduced to the mere mapping of areas and uses, or to the preferential allocation of use rights for particular activities. Marine planning that leads to the appropriation of ocean wealth ("ocean grabbing") is described in the scientific literature, either through privatisation of the ocean (ROS, 2019) or nationalisation; yet this is rarely mentioned in the conferences, public presentations and debates conducted by the public authorities mandated to initiate the process. The risk is reserving a particular volume of water and its contents, seabed or marine geological structures for the exclusive use of a single operator, or conversely, a natural resource conservation agency, with other activities being moved elsewhere. The other risk is granting majority use to one type of activity, with other activities being reduced without the possibility of challenging the decision. This is the case with the public policy supporting solid, liquid or gas mineral resource extraction (fig. 6), which makes other activities – fisheries or beach tourism, for example – residual, of lower quality, or risky.

62 In the case of productivist MSP, the risk of ecological impacts on the environment due to increased anthropic pressures (discharge, disturbance, extraction, overdensity, etc.) is proven, and ultimately leads to the degradation of these environments, the impoverishment of natural resources, or even to reaching a threshold of irreversibility in terms of ecological damage. Indeed, the risks of such MSP may be even greater in Brazil, a tropical zone, than elsewhere (QUEFFELEC *et al.*, 2021; FOTSO, 2018). For marine ecologists, this is due to the higher ecological stakes in these latitudes (Brazil lies between the latitudes of 5° North and 33° South, and between the longitudes of 34° and

73° West). For lawyers, the latitude (tropical or temperate) matters little, despite being reminded by environmental lawyers to be more open to the sciences (TELES DA SILVA, 2016). From a legal point of view, the risk is rather the quantitative importance of the area and resources affected and potentially degraded, and the size of national territory to be administered. The extent of any degradation that occurs in a marine area of this size would result in disproportionate public and private restoration efforts that would need to be carried out and financed.

63 Beyond MSP, the weakness of the legal rules enacted to regulate the increased activities of individuals or companies extracting resources from coastal and offshore sites needs to be given more attention, as does the lack of knowledge of the authorities of marine spaces regarding these spaces' productivity, vulnerability, interactions and monetary/non-monetary value. This lack of knowledge can lead to the allocation of exploitation rights in a process that is too rapid, uninformed or imprudent.

64 There are three key situations in which inadequate regulations have been problematic, and which MSP should try to remediate.

- Cases in which administrative authorities refrain from destroying structures (legal or illegal) that damage estuarine or coastal ecosystems, even though they have the ability to. For example, if the exploitation of mangroves for shrimp farming persists in a sustainable use zone, despite the proximity of mangroves located in a permanent conservation area that should be very strictly protected, without monitoring the consequences of the buildings or equipment, or without the appropriate collection, treatment and disposal of effluents and waste, or without ensuring the quality of the water and soil (these degradations can be exported to the permanent protected area without reaction by public authorities).
- Cases in which authorities fail to comply with jurisprudence recommendations or insufficiently take these into account: a recent example is the Foz do Amazonas area in the state of Amapá. The Federal Public Prosecutor's Office issued a recommendation on 19 April 2018 against the granting of an environmental authorisation to the French oil company Total, a permit that would have allowed oil exploration activities to begin on certain areas acquired in 2013 off the mouth of the Amazon. The prosecutor's recommendation was based on the recent discovery of the "Amazon coral reef" (about 56,000 km^2) and the inadequacy of the environmental impact assessment provided. The Brazilian Institute of the Environment and Renewable Natural Resources (IBAMA), to whom this recommendation was addressed, had to make a decision, and in 2019, new concession areas were made available for drilling under the sea on or near the reef.
- The case of the Brazilian paradox: although the country legally controls 3,661,000 km^2 of marine waters, these are less productive than those of other Latin American countries. The result is that Brazil is facing overfishing, overexploitation of stocks and species collapse, and has not managed to establish sufficient marine protected areas in its EEZ, despite the fact that these would ultimately support fishing (only 1.5% of the EEZ is reported to contain marine protected areas compared to 23.4% in territorial sea [FRANCINI-FILHO *et al.*, 2018]).

Conclusion

65 In Brazil, coastal planning law mainly concerns the land bordering the ocean, with a division of environmental assets and authority between the federal, state and municipal spheres. The *zona costeira*, delimited according to various plans, includes the coastal strip, merges with the boundaries of coastal municipalities, and makes some

incursions into territorial sea. Territorial management deals with the issues of land use and proximity to natural areas according to certain priorities (e.g. health).

66 Mapping of the shore, estuaries, seafloors and subsoils of territorial sea (maps that were not made in the framework of planning) show considerable areas currently under use – uses granted by the public authorities – in the Atlantic. In addition to the few perimeters of reef and coastal protected areas (within 12 nautical miles or beyond), there are many areas reserved for uses such as oil, gas and mineral exploration or exploitation. These areas are clearly visible off the states of Paraná (south) and Espirito Santo (north), allocated in the basins of Santos (*bacia de Santos*), Campos (*bacia de Campos*), and Espirito Santo (*bacia de Espirito Santo*), for example (fig. 6).

67 In a perspective of MSP, solutions must be identified for the over-anthropisation of space by activities, mainly with fixed or moveable rights of way. Such zoning is based on industrial – not natural – planning or development to multiply or intensify activities, such as aquaculture or hydrocarbons in offshore pre-salt hydrocarbon deposits. As a result, safety and public health issues will arise in territorial sea as well as in waters under jurisdiction (MUXAGATO and LE PRIOUX, 2011).

68 Shifting the focus of planners from simply the shoreline strip to coastal sites and beyond will be facilitated if coastal and ocean sciences can show why actions in remote marine areas help to maintain coastal benefits and services.

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NOTES

1. The coastal zone is included in the territorial sea according to Law No. 7661 of 6 May 1988.
2. This estimate is taken from studies on the representativeness of coastal ecosystems conducted by the National System of Protected Areas (SNUC) and includes the natural contours of the Brazilian coast (PRATES *et al.*, 2012, p. 11.).
3. According to Brazil's National Institute of Geography and Statistics, http://www.mma.gov.Br/gestao-territorial/gerenciamento-costeiro (consulted in 2021), and based on the demographic census (*Censo Demográfico*) it conducted in 2010–2011.
4. From the Brazilian Ministry of the Environment website: http://www.mma.gov.br/gestao-territorial/gerenciamento-costeiro%20consulté%20le%2010/07/2019
5. Art. 225 § 4: "The Brazilian Amazon Forest, the Atlantic Coastal Forest, the Serra do Mar, the Pantanal of Mato Grosso and the Coastal Zone constitute a national heritage; their use shall be in accordance with the law and under conditions guaranteeing the preservation of the environment, including the use of natural resources." Brazilian Federal Constitution (5 October 1988). https://wipolex.wipo.int/fr/text/218254
6. Lei nº 7.661, de 16 de Maio de 1988 institui o Plano Nacional de Gerenciamento Costeiro e dá outras providências. http://www.planalto.gov.br/ccivil_03/leis/L7661.htm
7. Lei nº 6.938/81 Politica Nacional do Meio Ambiente: http://www.planalto.gov.br/ccivil_03/leis/l6938.htm
8. https://www.mma.gov.br/gestao-territoral/gerenciamento-costeiro, see base-legal-gerco
9. Decreto nº 5.300 de 7 de dezembro de 2004, Regulamenta a Lei no 7.661, de 16 de maio de 1988, que institui o Plano Nacional de Gerenciamento Costeiro - PNGC, dispõe sobre regras de uso e ocupação da zona costeira e estabelece critérios de gestão da orla marítima, e dá outras providências.
10. IV Plano de Ação Federal para a Zona Costeira 2017–2019 (PAF-ZC).
11. In the Federal Constitution of 1988, according to Article 21, the federal government has the authority to: IX - draw up and implement national and regional plans for regional planning and economic and social development. According to Article 22, the federal government has exclusive authority to legislate on: I - civil, commercial, criminal, procedural, electoral, agrarian, maritime, aeronautical, space and labour law. However, according to Article 23, the federal government, states, districts and municipalities have joint authority: VI - to protect the environment and to

combat pollution in all its forms; VII - to preserve forests, fauna and flora. According to Article 24, the federal government, states and districts have the authority to legislate concurrently on: VI - forests, hunting, fishing, wildlife, nature conservation, defence of the soil and natural resources, environmental protection and pollution control; VII - liability for damage to the environment, consumers, property and rights of artistic, aesthetic, historical, tourist or landscape value. Constitution available at: https://wipolex.wipo.int/fr/text/218254

12. In the Federal Constitution of 1988, for example, it is stated in Article 24:

(1) "In the field of concurrent legislation, the federal government's authority is limited to enacting general standards."

(2) "The authority of the federal government to legislate on general standards does not exclude the suppletive authority of the states."

(3) "In the absence of a federal law on general standards, the states exercise full legislative authority in accordance with their specific features."

(4) "When a federal law on general standards arises, it suspends the effect of the sub-federal law insofar as the latter is contrary to the former."

13. Lei nº 9.605, de 12 de fevereiro de 1998 dispõe sobre as sanções penais e administrativas derivadas de condutas e atividades lesivas ao meio ambiente, e dá outras providências.

14. See next section on mangrove degradation.

15. Lei 6.938 de 31 de agosto de 1981, Art. 6, IV-Ógãos executores: o Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis - IBAMA e o Instituto Chico Mendes de Conservação da Biodiversidade - Instituto Chico Mendes http://www.planalto.gov.br/ccivil_03/leis/L6938.htm (accessed on 10/07/2019)

16. Lei 9.966/2000 de 28 de Abril de 2000 dispõe sobre a prevenção, o controle e a fiscalização da poluição causada por lançamento de óleo e outras substâncias nocivas ou perigosas em águas sob jurisdição nacional e dá outras providências, Art. 2, XXII-XXII - autoridade marítima http://www.planalto.gov.br/ccivil_03/Leis/L9966.htm

17. Lei Complementar 140, de 8 de Dezembro de 2011. http://www.planalto.gov.br/ccivil_03/leis/lcp/lcp140.htm

18. *Termo de Adesão à Gestão de Praias* (TAGP) or 'Beach Management Agreement'.

19. Draft law 6 969/2013 establishing the National Policy for the Conservation and Sustainable Use of the Brazilian Marine Biome (PNCMar) and other provisions, https://www.camara.leg.br/proposicoesweb/ficha de tra mitacao?IdProposicao=604557

20. Legislative Assembly of Pernambuco, 2018 (http://www2.cprh.pe.gov.br/wp-content/uploads/2021/01/lei_apa_mar_recife.pdf).

21. *Plano Nacional de Gerenciamento Costeiro.*

22. *Plano de levantamento da plataforma continental brasileira.*

23. *Plano setorial para os recursos do mar* (PSRM).

24. *Sistema brasileiro de observação dos oceanos.*

25. *Conselho nacional de desenvolvimento científico e tecnológico.*

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Chapter 8. Opportunities and challenges for marine spatial planning in Senegal

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1 In Senegal, access to and use of the ocean is a central element of the national and local economy. The fisheries sector, considered among the priority sectors of the national economy, occupies an important position due to its contribution to food security and to the creation of income and employment (ANSD, 2020). Thus, under Priority 1 of the Plan for an Emerging Senegal (PSE 2014–2035), fishing and aquaculture activities are intended to contribute to "the structural transformation of the economy in order to support a strong and sustainable growth dynamic". Between 2009 and 2013, the fisheries sector alone represented a source of income for more than 600,000 people in the country. The contribution of fisheries to national wealth is virtually stationary, fluctuating between 1.7% and 1.8% of gross domestic product (GDP)[1], showing the dynamism of this sector. The Sectoral Policy Letter for the Development of Fisheries and Aquaculture (LPSDPA 2016–2023) is in line with this goal of the PSE and defines the government's priorities for action in the field of fisheries and aquaculture.

2 While the ocean provides key services to the Senegalese economy, its condition is affected by increasing human activities on land and at sea. These include the development of port activities, maritime transport, industrial fishing and aquaculture, coastal tourism and underwater cabling. The disappearance of many natural habitats and the weakening of coastal ecosystems affect the quality and quantity of natural resources, which are both numerous and vital in this ecologically and biologically fragile area (LEFEBVRE, 2011) (see Box 1 on the importance of strengthening the collection of biological data in Senegal).

3 Marine spatial planning (MSP) aims to bring coherence to public policies that analyse and distribute human activities in marine areas over time and space in order to achieve ecological, economic and social objectives usually determined by political processes[2].

MSP is thus a priority issue for Senegal, although it also poses challenges. This chapter looks at the driving forces and obstacles to the implementation of MSP in Senegal. It first presents the strong regional incentive for the development of MSP in West Africa. It then discusses the challenges that must be taken into account and met at the national level for MSP to be both operational and in the interest of the Senegalese people.

Box 1. Scientific data: a necessary prerequisite for MSP
Malick DIOUF

The challenge of managing the marine and coastal environment in the face of climate change and anthropogenic activities calls for strategic and coordinated spatial planning. As EHLER and DOUVERE (2007) define it, this is a "public process for analysing and locating the spatial and temporal distribution of human activities taking into account ecological, economic and social objectives". In a country's exclusive economic zone (EEZ), this must include the political processes of the authorities in question. In international waters, planning may involve governments and UN organisations. The decision-making in management plans is based on a number of considerations; each government must have entities in charge of the maritime sector in order to be able to provide information on the main indicators that help decision-making and then to coordinate the implementation of marine and coastal management plans.

In terms of the state of knowledge, the structuring of research and the means committed to informing management policies, developing countries have a major challenge at all of these levels. In the coastal countries south of the Sahara, which are confronted with a range of problems, including food security and pollution, a good coverage of disciplinary fields is essential. In Senegal, after independence, research was oriented towards agriculture sensu stricto, and this field of research is well represented throughout the country.

The same cannot be said for the maritime sector. The Dakar-Thiaroye Oceanographic Research Centre (CRODT), created before independence, was long the only structure addressing ocean-related issues. The first universities were not created until 2003. However, years of drought have encouraged a renewed interest in marine activities, with the coast becoming a major economic issue. In 2021, artisanal maritime fishing, with 14,930 active pirogues, landed 83% of Senegal's fish production, representing a commercial value of US$156 billion (unpublished source, Ministry of Fisheries and the Maritime Economy). Added to this are other economic activities linked to the sea and its importance to human well-being. However, research does not currently have the capacity to meet policy expectations and allow sound planning decisions. Despite ongoing efforts to improve knowledge of Senegal's EEZ, the information is still insufficient due to:

- a significant shortage of staff
- inadequate research programmes
- a severe lack of funding.

As maritime waters are a national heritage, the development of research in an EEZ must be the responsibility of national agencies, with resources coming from the government to ensure sustainable activities. Decision-making bodies require scientific information provided by fundamental and applied research. For MSP and marine ecosystem management policies and to anticipate potential problems that could affect the health of the ocean, it is crucial to increase financial support for research in coastal countries south of the Sahara.

For more information

EHLER E., DOUVERE F., 2007

Visions for a sea change. Technical report of the International Workshop on Marine Spatial Planning, 8-10. Paris, International Oceanographic Commission/Unesco, Manual & Guides no. 46, folder 3.

A legal framework favourable to implementing MSP

4 While a regional or national agreement specific to MSP has not yet emerged in West Africa, the diversity of economic activities at sea has highlighted the need to consider the value of coordinated management. This has led at the regional level to the Abidjan Convention, which provides a framework and strategic direction for the development of MSP in West Africa. The formal regional planning instruments of the African Union (AU) could provide further support for its development.

The Abidjan Convention: a framework for MSP in West Africa

5 The Abidjan Convention on Cooperation for the Protection and Development of the Marine Environment and Coastal Areas, signed on 23 March 1981 in Abidjan (Côte d'Ivoire), was ratified by Senegal on 23 July 1982[3]. It entered into force on 5 August 1984. In total, more than 22 coastal countries in West, Central and Southern Africa are covered by the Convention, 19 of which have ratified it. Four additional protocols have been signed but not yet ratified[4].

6 Of these texts, the additional protocol on integrated coastal zone management aims to provide a framework for management and for strengthening regional cooperation to better protect and preserve the coasts of member states. Its objectives include the integrated planning and coordinated development of coastal zones, island zones and river basins, the maintenance of ecosystem resilience to human activities, natural hazards and climate change, including the adequate protection of sensitive areas, and the prevention and reduction of pollution from air, land and marine sources. The protocol on integrated coastal zone management is supplemented by seven thematic annexes[5]. The objectives of integrated coastal zone management (which are similar to those of MSP) aim to "ensure the sustainable use of natural resources and ecosystem services" and to "maintain ecosystem resilience to human activities"[6].

7 The additional protocol on the sustainable management of mangroves makes reference to the continuity between the land and the ocean. According to Article 2.ii of the protocol, "mangrove means any animal or plant species adapted to the salinity of coastal ecosystems in intertropical regions subject to exchanges between the land and the ocean". This definition of mangroves would make them subject to MSP insofar as it establishes a connection between the land and the ocean, and as mangroves themselves are a resource linking human activities at sea and in coastal areas. Indeed, mangrove ecosystems are the source of various income-generating activities, but above all of

shoreline protection. Article 7-2 and Article 8 of the protocol include provisions with the direct aim of protecting mangroves from human exploitation.

8 The principles of sustainable management of mangrove ecosystem resources listed in Article 4 of the protocol (e.g. the right to information, to participation and to access to justice, the ecosystem management approach) are also relevant to MSP processes. Additionally, the protocol contains annexes that are essential for MSP[7]. For example, Annex 2 categorises practices that may negatively impact mangroves, including the development of fishing ports, mineral ports and/or oil platforms.

9 The additional protocol concerning cooperation in the protection and development of the marine and coastal environment of the Western, Central and Southern African region against pollution from land-based sources and activities contains several provisions relevant to the establishment of MSP. The geographical area to which this protocol applies (hereafter referred to as the "protocol area") corresponds to that defined in Article 1 of the Abidjan Convention and includes the marine environment, coastal areas and inland waters under the sovereignty regime of State of the countries of the Western, Central and Southern African region, from Mauritania to South Africa. The protocol states that "Contracting Parties shall adopt and enforce national laws and regulations to facilitate, to the greatest extent possible, public access to relevant data and information on pollution and degradation caused in the protocol area by land-based sources and activities, on measures taken to prevent, reduce, mitigate and combat their adverse effects, and on the effectiveness of such measures, taking into account the provisions of international instruments concerning public access to environmental information"[8].

10 Article 6 also arguably highlights the need for coherent, dynamic measures between the marine and terrestrial environment: "Parties shall take all appropriate measures to prevent, reduce, combat and control pollution from offshore exploration and exploitation activities in the protocol area and shall, in particular, ensure that the best available techniques and best environmental practices, which are environmentally effective and economically appropriate, are implemented"[9].

11 Article 17.2 on reporting specifies that "reports [...] shall contain: (e) information on activities resulting in changes to the coastline, habitats along the coastline and related catchment areas". The requirements imposed by this provision thus provide the basis for a framework for joined-up action by the various stakeholders to combat pollution from land-based sources and activities.

12 These additional protocols of the Abidjan Convention contribute to the regional incentive to set up MSP systems. The African Union (AU) goes even further, with a continental maritime goal and strategy.

Towards regional MSP: the AU's goal

13 A significant 70% of the GDP of the African continent comes from the maritime economy, or "blue economy". This includes all water bodies and shorelines and involves a range of economic activities such as fishing, aquaculture, tourism, transport, shipbuilding, energy, bioprospecting and deep-sea mining sectors. In recognition of the importance of the blue economy in Africa, in 2012 the AU adopted the 2050 Africa Integrated Maritime Strategy (AIM 2050) (AU, 2012). This aims to foster the creation of

wealth from Africa's oceans and seas by developing a thriving, sustainable, safe and environmentally sound blue economy.

A Combined Exclusive Maritime Zone for Africa

14 Intra-African trade is at the heart of the AU's concerns as a means of reducing the continent's dependence on international trade[10]. Over a decade ago, the AU stated that the implementation of a common maritime zone would offer Africa significant "geostrategic, economic, political, social and security benefits, as it would generate collective efforts and reduce the risks of transnational threats, environmental damage, smuggling and arms trafficking" (AU, 2012). This goal is embodied in the proposed creation of a Combined Exclusive Maritime Zone for Africa (CEMZA).

15 The concept emerged from the AIM 2050 strategy and seeks to create "an African maritime space without barriers" whose objective is to "stimulate intra-African trade". The CEMZA would not create a new zone like the exclusive economic zone, but aims to eliminate or simplify administrative procedures in maritime transport within the AU, facilitating the internal market for intra-AU maritime trade and services. The AIM 2050 strategy is rather vague about the operationalisation of the CEMZA, simply calling for it to be "timely" (AU, 2012, p. 17). Similarly, its geographical boundaries are not clearly spelled out (VRANCKEN, 2020). However, it does provide for the establishment of a "strategic working group to prepare the technical proposal", which should include the geographical boundaries of the CEMZA.

16 To date, the AIM 2050 strategy is more a "solemn declaration" of intent to create a shared maritime space than a real action plan. The applicable legal framework, the operating rules, and the process for establishing this space have yet to be resolved.

CEMZA, a goal in line with MSP objectives?

17 The objective of MSP is to organise the spatial and temporal distribution of human activities taking place at sea, in order to promote the sustainable growth of maritime economies, the sustainable development of maritime spaces and the sustainable use of marine resources. A future CEMZA could constitute a common framework for the shared management of maritime space, and in several respects could be linked to a form of regional MSP.

18 The initiative to create a CEMZA coincides with many of the objectives of MSP. In addition to promoting economic and commercial interests, the CEMZA would include environmental protection aims and defend sectors that represent substantial sources of income for coastal populations, such as fishing and aquaculture (AIM 2050, AU, 2012). While the AIM 2050 strategy does not define the respective weight given to each cornerstone (i.e. economic, social and environmental) in the development and implementation of the CEMZA, there are similarities with MSP projects in other regions.

19 Establishing a CEMZA will require the joint initiative of African countries to regulate and manage the maritime space, and the distribution of authority. This is an issue that can be found at the national level in MSP, which also requires, albeit on a smaller scale, the coordination of various ministries and agencies relating to the marine environment and the activities that take place there. For a CEMZA to come into being, there will need

to be strong political will from African leaders, enhanced cooperation and effective coordination of all policies related to the marine domain. Since all AU member states will be involved in the establishment and operation of the CEMZA, the actors are not limited to coastal states. Other non- (or para-) governmental stakeholders will also be involved, such as local communities, specialist regional institutions and associations, the African maritime private sector, strategic development partners and the international community at large, including African organisations, the private sector and international development agencies.

National challenges to implementing MSP

20 While the supranational incentive for marine space planning is strong, implementing a continental-scale CEMZA is expected to take several decades. In the meantime, African states can implement MSP on a national scale. This will require overcoming a multitude of national challenges – for example, in Senegal, these include changes in environmental law and the sectoralisation of public policies. The Senegalese institutional framework would also need to be consolidated. In this respect, the emergence of land-use planning could be a basis for MSP.

Land-use planning, a reference for future MSP?

A recent law on land-use planning and sustainable development

21 The legal basis for spatial planning on land – and potentially maritime space – was recently passed in Senegal with the Framework Law for the Planning and Sustainable Development of Territories (LOADT)[11], which “has as its general objective the harmonious development of the national territory” (Art. 4, Law No. 2021-04 of 12 January 2021). Indeed, the maritime domain is considered an integral part of the national territory as a component of the domain of the state[12], whether it is qualified as natural[13] or artificial[14].

22 This law could thus be used as the basic text of a national system of marine and coastal planning. Its explanatory memorandum has several major innovations: in particular, it mentions “the creation of national and territorial planning and development bodies” and “the introduction of special provisions (…) for the planning of specific and priority areas due to their economic potential or ecological sensitivity”. The determination of these aspects is a key element of MSP, which aims to reconcile economic objectives with the conservation of marine biodiversity.

23 Despite the absence of an explicit reference to MSP in the text of the law, several related concepts are defined in Article 2, such as land-use planning[15], sustainable development[16], regional development, and the economic zone[17]. The fact that this law not only identifies the different areas concerned, but also determines the authorities responsible for managing them, demonstrates the legislation’s aim to create standards that balance conflicting economic interests and ecological imperatives. In terms of planning, the law provides for various instruments aimed at promoting the sustainable management of the environment and natural resources. One of these is a development plan (*schéma de cohérence territoriale*, SCOT) that sets the fundamental guidelines for the

development, protection and enhancement of a given area (for example, a coastline), which could be a fundamental tool for the implementation of MSP.

24 Public participation is also recognised as a fundamental principle in Article 3[18], as it is in the framework of MSP projects. The uses and users of the land or sea impacted by these plans are multiple and sometimes in conflict. In terms of fishing alone, traditional fishing accounts for nearly 80% of landings (ANSD, 2016). However, the fact that 95% of these jobs are recognised as informal (GOVERNMENT OF THE REPUBLIC OF SENEGAL, 2013) may complicate the participation of all stakeholders. If MSP is to provide balanced economic, environmental and social data in the process of allocating space, it is crucial to guarantee a place and a voice for each stakeholder. Currently, small-scale producers and informal workers are poorly represented in political processes. The challenge here is to avoid or minimise the phenomena of land or resource grabbing that can occur in certain African countries (NIASSE, 2011) and in the implementation of MSP throughout the world. True and broad public participation can help to counter this.

25 Article 28 of the LOADT also provides for reinforced and territorially differentiated development policies in priority development areas and sensitive urban areas. There is nothing to prevent policymakers from applying the principle of these priority areas to part of the maritime territory and using MSP to define their uses. The same applies to the special economic zones that can be created in certain areas by the government in conjunction with the local authorities to promote the creation of jobs and wealth (Art. 29).

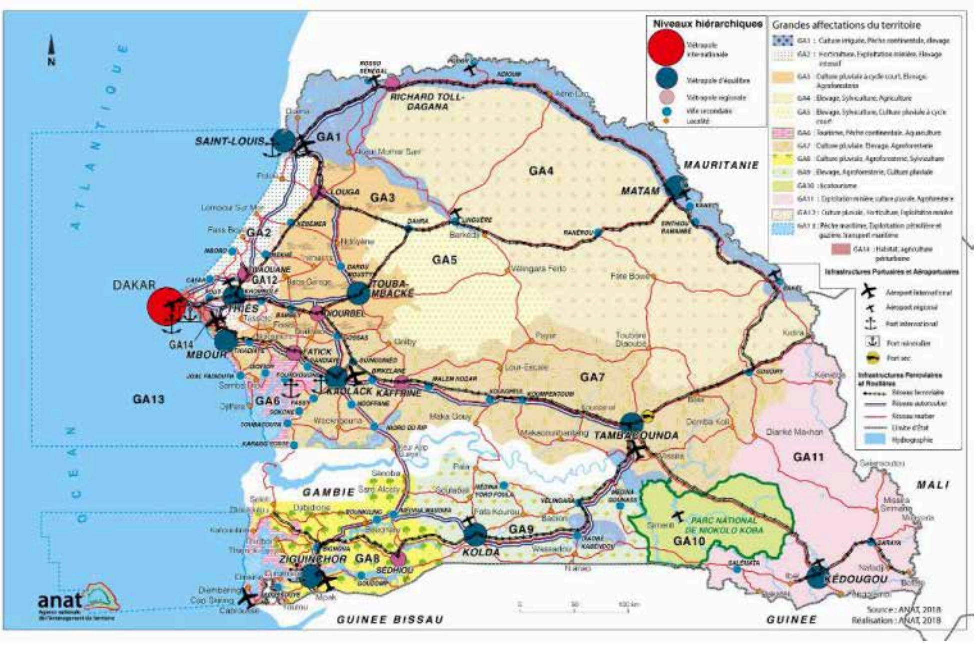
26 With regard to sectoralisation, the LOADT establishes an innovation with the creation of a National Territorial Observatory that “contributes to the monitoring and evaluation of planning and development policy and constitutes a decision-making tool for all territorial actors” (Art. 30, paragraph 3).

The National Spatial Planning and Development Plan and the marine space

27 The new National Spatial Planning and Development Plan (PNADT)[19] is an important document for MSP. In contrast to the previous National Spatial Development Plan (PNAT)[20], the PNADT has been adapted to the requirements of sustainable development and is of particular value for MSP. This plan aims to raise spatial planning to the level of a strategic instrument of public policy.

28 The PNADT lays the foundations for a division of uses of the marine and coastal environment. Figure 1 maps the activities that may overlap between potential stakeholders. The main objective of the PNADT is to take all stakeholders into account.

Figure 1. PNADT Map



Source: ANAT (2020)

29 This map could be the basis for MSP on a national scale. Any framework for MSP is based on the use of the sea. In addition to the various legal texts that apply, the maritime space can reflect rival interests of stakeholders. The aim of MSP is to take into account the various uses and users of the sea to ensure best practices in fishing, oil and gas exploitation, navigation, etc.

30 The Environmental Code[21] states that development plans and programmes must be subject to an environmental assessment. This of course includes urban planning strategies[22,23]. Poorly controlled urbanisation affects both land and sea and forces decision-makers to address the thorny issue of sustainability. The evaluation of public policy[24]. a new responsibility devolved to the National Assembly following the constitutional reform of 2016, can facilitate the implementation of planning in Senegal. This will necessarily involve a review of public policies relating to the marine space.

31 The process of MSP involves not just advising on the legal zoning of various marine areas, but recommends specific specialist institutions responsible for their management. In Senegal, these institutions exist, but are caught between sectoralisation and the need for cooperation.

An institutional framework between sectoralisation and cooperation

32 Despite recent developments taking a more integrated approach to the protection of the marine environment, the institutions in charge of the exploitation of the sea remain highly sectoralised in Senegal.

The need to adapt institutions to implement MSP

33 In Senegal as elsewhere, many institutions (ministries for urban planning, the environment, local authorities, fisheries, etc.) are involved in marine spatial planning.

They intervene in a sectoral manner and manage specific activities in the marine environment. Some are responsible for marine pollution, others for coastal erosion, others in the conservation of marine biodiversity or the exploitation of marine resources. Harmonisation of policies and legal texts is one of the main challenges in Senegal.

HASSMAR: an institution with general jurisdiction

34 The High Authority for the Coordination of Maritime Safety, Security and the Protection of the Marine Environment (HASSMAR) was created by Decree No. 2006-322 of 7 April 2006. Under the terms of Article 3, it "is invested with general responsibility for coordination in all areas relating to security, safety and environmental protection in maritime and river waters under Senegalese jurisdiction". This body was the first step towards taking the marine environment into account in Senegal. The powers devolved to it in terms of protection of the marine environment are diverse. One of its powers is to coordinate, in the event of an emergency, and with other authorities concerned, the National Marine Emergency Response Plan. This integrates within a single mechanism specialist plans relating to different fields of intervention, in particular those relating to search and rescue at sea, maritime security and environmental protection.

35 However, there is a limit to this progress towards greater integration, as HASSMAR's jurisdiction does not hinder the prerogatives conferred on other agencies and public services – such as the National Agency for Maritime Affairs (ANAM) – by legislative and regulatory texts[25].

ANAM: an institution with specific jurisdiction

36 The National Agency for Maritime Affairs was created by Decree No. 2009-583 of 18 June 2009. It is overseen by the Minister of the Merchant Navy. Its missions include: (i) prevention of pollution of the marine environment due to the discharge of hydrocarbons and harmful substances from ships, discharge due to the exploration or exploitation of the seabed or its subsoil, dumping of toxic waste, and incineration and discharge from land-based sources; (ii) research, recording and investigation of infractions.

Institutions with a variety of jurisdictions

37 Faced with the socio-economic challenges and vulnerability of the coastline, the Ministry of the Environment, and in particular the Directorate of the Environment and Classified Sites, set up the Coastal Management Division in December 2012[26]. The main missions of this division are to manage, prevent and combat all forms of coastal degradation, including coastal erosion, implement integrated coastal zone management and define appropriate action plans for sustainable coastal management[27].

38 In addition, the Directorate of Marine and Community Protected Areas[28] is responsible for setting up and managing a network of protected areas sufficiently representative of coastal, estuary and marine ecosystems. Its aim is to ensure the conservation of marine

and coastal biological diversity by consolidating and strengthening the network of marine protected areas.

39 To enable concerted management with all marine environment stakeholders, a national observatory for coastal protection is being set up by the West African Coastal Area Management Programme[29]. This national observatory is an integral part of the national coastal body that is also being established.

40 It is crucial that the institutional body responsible for MSP, while taking into account international requirements, respects, works with and adapts to these existing national structures in order to maximise its relevance and ownership.

41 Beyond this institutional complexity, the capacity of institutions to enforce legislation is also a challenge for MSP.

Better protection of the marine environment: the latest developments

42 Texts and institutions aimed at protecting the marine environment are very often dispersed (BONNIN *et al.*, 2016). Yet cooperation and institutional synergies are a prerequisite for MSP – and ideally also a product of the process. A law on the coastline that is currently being drafted could help to better achieve this in Senegal[30]. This draft policy has gone through several versions that have circulated for more than a decade. Initially, the aim of this first government initiative to legislate on the matter was to address shortcomings in the procedures for occupying, classifying and declassifying the coastline in order to amend the legal system in force. The option chosen by the government was not to revise Law 76-66 of 2 July 1976 on the State Domain Code or the 2002 Merchant Navy Code by making amendments and additions to these two laws (which would have been the most practical solution), but rather to draft a new law whose content and preparation give broad responsibilities to the Ministry of the Environment and also involve other sectoral ministerial departments (ministries in charge of the public domain, the maritime economy, town and country planning, tourism, local authorities). This draft law provides for the creation of a National Authority for Integrated Coastal Management attached to the Ministry of the Environment and bringing together the ministries responsible for the coast to coordinate the various institutions (Article 11).

43 The draft law on the coastline is still in the preparation phase; the current objectives of public authorities are to accelerate the study of the feasibility of the coastal management body (statutory aspects and institutional oversight) in order to aid the work of the commission drafting the law and its application decree. The adoption of the policy is dependent on the results of this study[31].

44 The adoption on 12 January 2021 of the Framework Law on the Planning and Sustainable Development of Territories (LOADT) introduces new challenges that the draft law on the coastline must take into account. The former includes a number of major legislative innovations, determining the fundamental principles of territorial planning and development policy, legally officialising the National Territorial Development Plan (PNAT), sectoral master plans and other spatial planning documents on a territorial scale, and creating national and territorial planning and development bodies. These institutions include a Presidential Council for Territorial Planning and Development (Article 13), a national commission for territorial planning and development (Article 14), and regional and municipal commissions for territorial

planning and development (Articles 15 and 16). The draft coastal law will need to take into account these new bodies, whose remit covers the entire national territory, although the coast has specific features that must also be considered.

45 Protected fishing areas (*zones de pêche protégées*, ZPPs) are another development in Senegal that are relevant to MSP. In some localities, these areas allow several activities aimed at the sustainable exploitation of resources. For Senegal's artisanal fisheries, the integrated management approach is favoured to build up coastal demersal stocks by promoting local co-management initiatives and implementing measures to restore degraded coastal marine ecosystems such as ZPPs and artificial reef zones (SSC, 2018, p. 128).

46 In the Hann ZPP[32], fishing activity is subject to authorisation. According to Article 4, paragraph 1 of the decree creating this ZPP, "fishing, in all its forms, is strictly forbidden within the zone delimited in Article 2. Only experimental fishing and underwater diving operations duly authorised by the Directorate of Maritime Fisheries for the purposes of scientific and technical research or monitoring and evaluation of the ZPP are permitted". Paragraph 2 of the Article specifies that "in the area defined in Article 3, only single-line fishing is permitted"[33]. Protected fishing areas require the cooperation of different stakeholders in planning the sustainable exploitation of resources. This integrated approach is one of the pillars of Senegal's local co-management model and seeks to reconcile the three-fold objective of rebuilding coastal demersal fisheries, rehabilitating marine ecosystems and habitats and improving the living conditions of fishing communities (SSC, 2018).

47 Another recent development is Decree 2020-1784 of 23 September 2020 on devolution. This decree will apply to all administrative districts (including the coastal regions and departments of Saint-Louis, Louga, Thiès, Dakar, Fatick and Ziguinchor). The devolution charter sets out the principles of the decentralisation of public policy, public services, and the pooling of devolved services. Any development of the coastline must take into account the rules defined by the charter.

48 In short, the process of finalising the coastal law must take into account a wide range of political and legal factors, and is a precondition to achieving coordinated and effective MSP.

Conclusion: a priority on development?

49 In 2014, Senegal adopted a new development strategy to accelerate its progress with the Plan for an Emerging Senegal (PSE). The PSE is the benchmark for economic and social policy in the medium and long term and the main reference framework for "governance policies aimed at leading Senegal towards development by 2035". The PSE specifically includes environmental goals through the promotion of a green economy, the prevention of the degradation of environmental resources and the depletion of biodiversity, the enhancement of natural resources and biodiversity, the strengthening of institutional and technical capacities, the improvement of environmental knowledge, and the mobilisation of financing for green jobs.

50 While MSP can be a key tool in achieving these goals, many challenges remain. One of these is legal. The production of atlases of marine environmental law in West Africa (BONNIN *et al.*, 2019) has shown that the various administrative bodies have little

knowledge of the rules outside their sector of activity (LE TIXERANT *et al.*, 2020). As knowledge of the law is a necessary prerequisite for the implementation of marine spatial planning, this will be an important challenge to overcome.

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NOTES

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2. From the definition of marine spatial planning by the United Nations in 2009.
3. Law no. 82-31 of 23 July 1982, Journal officiel de la République du Sénégal of 21 August 1982, p. 557.
4. The Abidjan Convention includes the Protocol for Combating Pollution in Cases of Emergency as well as four additional protocols: (1) the Protocol on Environmental Norms and Standards for Offshore Oil and Gas Activities, (2) the Protocol on Integrated Coastal Zone Management, (3) the Protocol on Cooperation in the Protection and Development of the Marine and Coastal Environment of the Western, Central and Southern African Region against Pollution from Land-based Sources and Activities, and (4) the Protocol on Sustainable Management of Mangroves. The 2nd Plenipotentiary Conference held in Abidjan on 2 and 3 July 2019 led to the signature of these protocols, opening the perspective of their ratification and implementation (see http://abidjanconvention.org/).
5. Annex 1 deals with integrated water resources management, Annex 2 with coastal zone protection, Annex 3 with specific coastal ecosystems, Annex 4 with recommendations for socio-economic activity, Annex 5 with risks that may affect the coastal zone, Annex 6 with coastal zone protection and water resources management works, and Annex 7 with environmental assessment of the coastal zone.

6. Article 5 Integrated Coastal Zone Management Protocol of the Abidjan Convention.
7. Annex 1: Indicators of the status and trends of the mangrove ecosystem; 2: Sustainable use of mangrove ecosystem resources; 3: Environmental impact assessment; 4: Guidelines for sustainable management of mangrove ecosystems.
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9. Article 6 of the Protocol on Pollution from Land-based Sources and Activities.
10. Theme of the 18th Assembly of the African Union Summit. The Assembly met in Addis Ababa, Ethiopia, in January 2012 and adopted a decision (Assembly/AU/Dec.394 [XVIII]) to establish a Pan-African Continental Free Trade Area (AfCFTA) by the indicative date of 2017.
11. JORS no. 7398 of 30 January 2021, p. 88.
12. Law No. 76-66 of 2 July 1976 on the State Property Code (CDE).
13. The natural public maritime domain comprises the covered and uncovered coast at the highest tide; navigable waterways up to the first obstacle to maritime navigation; a zone 100 m in width on each bank from the limits determined by the height of the water flowing full bore before overflowing.
14. The artificial public maritime domain includes sea and river ports with their immediate and necessary dependencies, dikes, piers, quays, medians, basins, locks, semaphores, lighting and beacons, lighthouses, buoys, canals and their dependencies.
15. Art. 2, § 1: "A set of voluntary measures and actions aiming, through the organisation of space, to use a territory rationally, according to its resources and potential and with the aim of satisfying the immediate and future needs of the whole population."
16. Art. 2, § 2: "A development model that reconciles economic efficiency, social equity and rational management of natural resources and the environment in order to ensure that the needs of present and future generations are met."
17. Art. 2, § 10: "An area designed to be an investment pole par excellence by offering a competitive business and investment environment."
18. Art. 3, § 4: "Any policy for the planning and sustainable development of territories must promote and guarantee effective participation of all stakeholders, at all relevant territorial levels, in its drafting."
19. Article 6 of Law No. 2021-04 of 12 January 2021 on the Framework Law for the Planning and Sustainable Development of Territories (LOADT).
20. Planning instrument adopted by the Interministerial Council for Spatial Planning in 1994.
21. Article 48 of the Environmental Code.
22. Book 1 of the Town Planning Code (Law No. 2008-43 of 20 August 2008) deals with the general provisions and rules of urban planning.
23. Article L 8 of the Environmental Code.
24. Public policy is defined as "the intervention of an authority invested with public power and governmental legitimacy in a specific area of society or territory" (BOUSSAGUET *et al.*, 2006).
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Chapter 9. Institutional, legal and governance frameworks for marine spatial planning

Case studies in the tropical Atlantic

José Guerreiro, Ana Carvalho and Daniela Casimiro

Introduction

1 The rise at the turn of the 21st century of new marine science and technology around the world, particularly in the most developed countries, has opened the way for new uses of the sea, ranging from renewable energy production to deep-sea mining and offshore aquaculture. These new uses are expanding the number of economic activities at sea, boosting growth but also increasing the potential for conflict over maritime space within a country's exclusive economic zone (EEZ). The "blue economy" and "blue growth", as defined by the European Union (EU) within the broader framework of its Integrated Maritime Policy (EUROPEAN COMMISSION, 2007; EUROPEAN UNION, 2011), have become a political priority, with expected growth in gross domestic product (GDP) and new jobs, particularly in the burgeoning fields of renewable energy, blue biotechnology, deep-sea mining, marine tourism and aquaculture.

2 These new uses of the sea and the intensification of economic activities require not only political economy measures, but regulatory instruments of two types: governing the use of maritime space and environmental safety. To this end, the EU has adopted two key directives: the Maritime Spatial Planning Directive and the Marine Strategy Framework Directive (EUROPEAN COMMISSION, 2014; EUROPEAN COMMISSION, 2008).

3 These directives make marine spatial planning (MSP) a key instrument for an integrated approach to address competing activities/uses of ocean resources and spaces. The Marine Strategy Framework Directive also aims to ensure the good environmental status of the sea, through more effective measures for sustainability and

the implementation of an ecosystem management approach in the marine environment.

4 This new approach to the maritime economy has spread rapidly around the world, leading many developing countries to seek to mobilise their own capacities and benefit from cooperation with more technologically advanced partners. In different continents and oceans, a number of coastal nations have started to develop their own "blue economy" strategies.

5 One policy impact of this priority on the blue economy has been the need to adjust or develop legal frameworks, as well as political and institutional marine governance models. This has quickly become evident within the EU and in other geopolitical contexts.

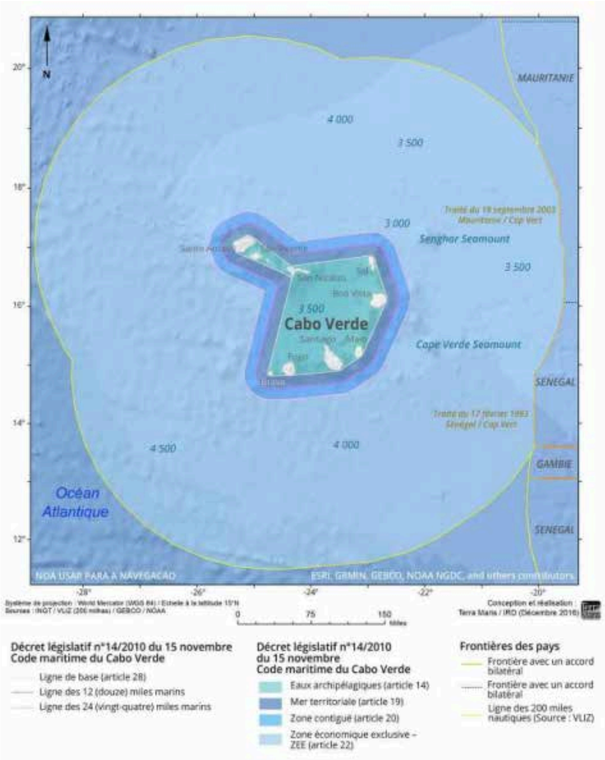
6 The nature of the oceans, a common good for humanity, has led to multilateral efforts over time to develop sound and harmonious ocean governance across maritime boundaries. The Atlantic Ocean, from Antarctica to Cape Town, and from the eastern coasts of the Americas to Cape Horn, is of major geopolitical importance to many regions, not least the EU.

7 One of the major objectives of the Paddle project ("Planning in a liquid world with tropical stakes") was to assess, in a North–South context, how the countries of the "Atlantic frontier" are including this trend towards MSP in their legal, institutional and policy frameworks and their strategies to promote the blue economy. A review of marine and coastal policies as well as legal, institutional and governmental frameworks was carried out to analyse the spatial planning initiatives of each country in order to obtain a true state of the art on MSP in this tropical area. In the three countries explored in this chapter – Brazil, Cabo Verde and Senegal – the results show that they are taking their first steps in MSP approaches. While the latter are at different stages of maturity, these countries have the basic institutional, legal and policy instruments that can pave the way for the development of MSP and are starting to put in place the pillars of a new blue economy.

Cabo Verde

8 The Republic of Cabo Verde is an archipelago of ten volcanic islands located in the central Atlantic Ocean, about 570 km off the coast of West Africa. The islands cover a total area of just over 4000 km^2. The capital, Praia, is located at 14° 55′ 0″ N, 23° 31′ 0″ W, on the island of Santiago (fig. 1). Traditionally, Cabo Verde's maritime economy was based on fishing and tourism; the latter has increased over the last three decades to become one of the main contributors to the economy, representing 22% of GDP (BANCO DE CABO VERDE, 2019). Recently, the government of Cabo Verde adopted a holistic policy approach to the blue economy and has taken significant steps to develop this: a new Ministry of Maritime Economy was created in 2018, as well as the Directorate General of Maritime Economy (DGEM). Resolution No. 112/2015 outlines the Charter for the Promotion of Blue Growth in Cabo Verde. On the international front, the "Mindelo Agreement" was signed in 2018 by the European Commission and the government of the Republic of Cabo Verde, with the aim of strengthening research and innovation in blue growth – a clear illustration of the EU's interest in reinforcing political and economic ties in the tropical Atlantic.

Figure 1. Cabo Verde archipelago and its Exclusive Economic Zone



Source: IRD/TERRA Maris, 2016

9 Table 1 summarises Cabo Verde's institutional, legal and policy frameworks for marine governance. Figures 2 and 3 show the main governmental and institutional links and mandates.

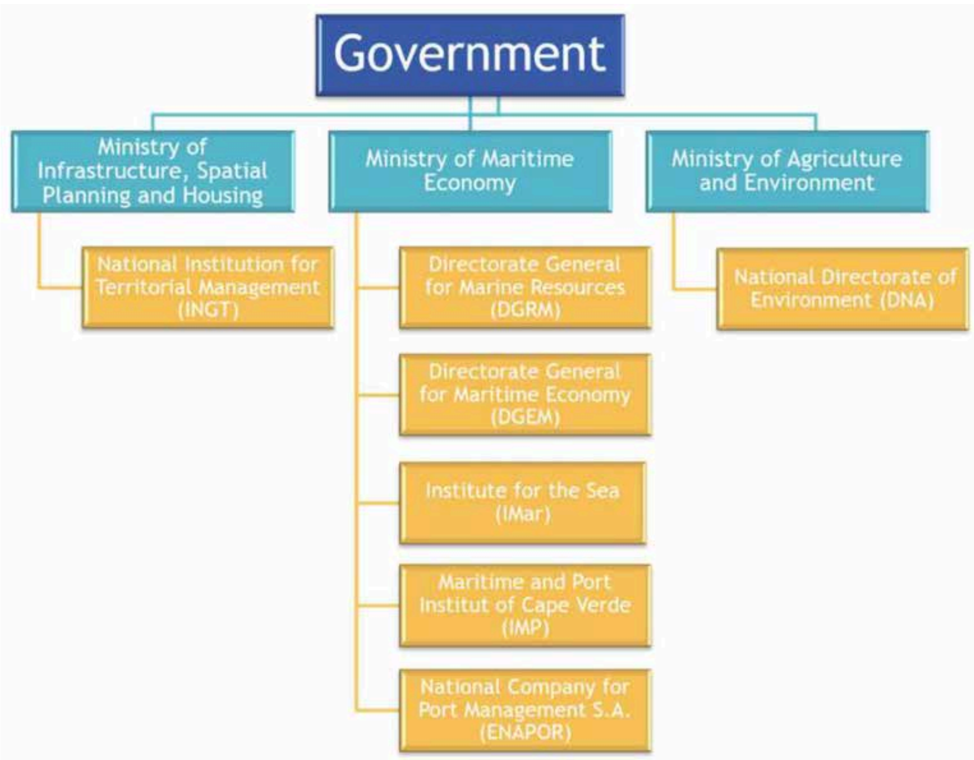
Table 1. Institutional, legal and policy frameworks supporting marine governance in Cabo Verde

Institutions	Mandates/Objectives
Ministry of Maritime Economy	Responsible for maritime policy, economy and industry, marine resources, fisheries, aquaculture, ports and navigation (Legislative Decree 27/2018).
Directorate General for Maritime Economy (DGME)	Responsible for the design, planning, implementation and evaluation of maritime economic policies. Develops and coordinates, together with the relevant entities, maritime and coastal spatial planning (Legislative Decree 27/2018).
Directorate General of Marine Resources (DGMR)	Responsible for carrying out activities to support the development of fisheries and aquaculture and the authorised exploitation of living marine resources (Legislative Decree 27/2018).
Institute of the Sea (Imar)	The national technical authority in the fields of oceanography, marine and fisheries biology, mariculture, fisheries technology development and statistics (Legislative Decree 40/2019).

Maritime and Ports Institute (IMP)	Contributes to the definition of the country's maritime and port policy; proposes the definition of maritime and port jurisdictional areas; ensures that port development plans take into account other spatial planning instruments (Decree-Law 38/2018).
Ministry of Infrastructure, Spatial Planning and Housing	Responsible for national spatial planning and housing policies (Legislative Decree 14/2018).
National Institute of Land Management (INGT)	Responsible for implementing spatial planning, land use and housing instruments and policies; manages Cabo Verde's spatial data infrastructure (Regulatory Decree 22/2014).
Ministry of Agriculture and Environment	Responsible for national policies on agriculture, forestry, livestock, agro-industry, food security, environment, water and sanitation (Decree-Law 14/2018).
National Environment Directorate (DNA)	The national environmental authority responsible for prevention of environmental harm, environmental impact assessment and nature conservation (Legislative Decree 49/2016).
Legal framework	
Law on urban and spatial planning	Legislative Decree No. 1/2006 of 13 February 2006 approves the Urban and Spatial Planning Act (amended by Legislative Decree No. 6/2010 of 21 June 2010); defines the national system of spatial planning and land use, which includes special spatial plans for coastal zones and protected areas (Legislative Decree 1/2006; Legislative Decree 6/2010).
National regulation of land use and urban planning	Decree-Law No. 43/2010 of 27 September 2010 regulates and defines land use, urban planning and land management (Decree-Law 43/2010).
Management plans for coastal areas and the adjacent sea	Decree-Law No. 14/2016 of 1 March 2016 regulates the management plans for coastal areas and the adjacent sea (POOCM) identifying both "onshore" and "adjacent sea" areas. These plans identify territorial areas, boundaries and areas of intervention, including special areas such as tourism areas, risk areas and protected areas (Legislative Decree 14/2016).
Management plans for protected areas	Decree-Law No. 3/2003 of 24 February 2003 (amended by Decree-Law No. 44/2006 of 28 August 2006) establishes the legal regime for the management of protected areas. The conservation objectives set out in the law can be materialised in a master plan (*plano diretor*) for protected areas (Decree-Law 3/2003; Decree-Law 44/2006).
Charter for the promotion of blue growth in Cabo Verde	Resolution No. 112/2015 is a charter that sets out the strategic options for blue growth in Cabo Verde (Resolution 112/2015).

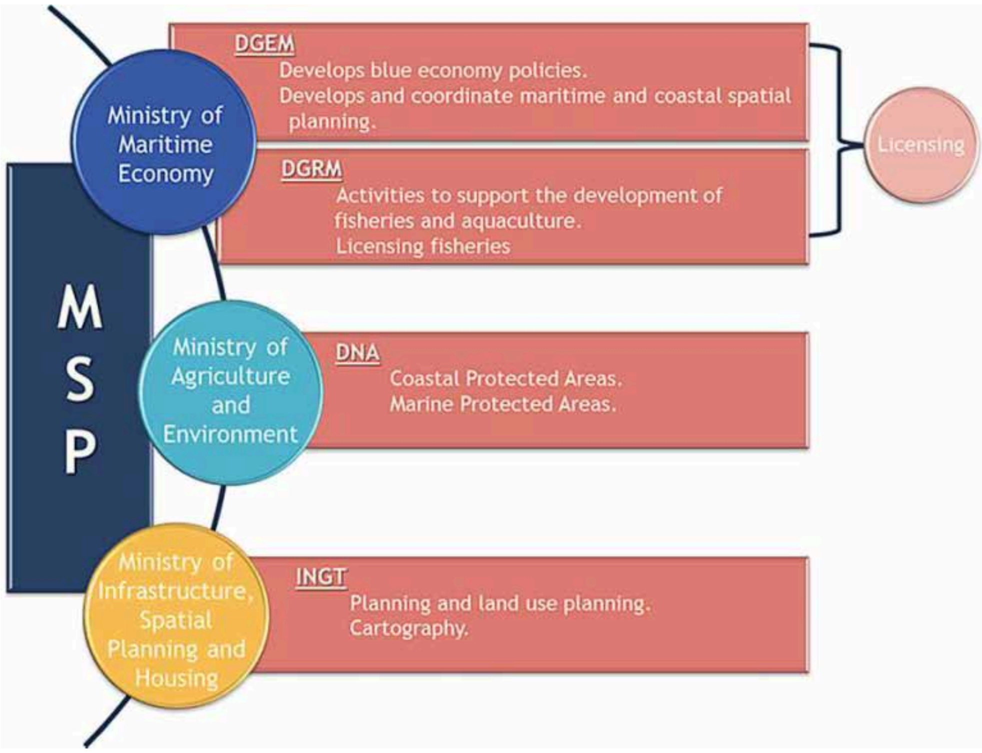
National investment plan for the blue economy and the blue economy promotion programme	United Nations Food and Agriculture Organization (FAO) assistance to Cabo Verde is defined by the Country Programming Framework 2018–2022. The main national processes and policies supported by the FAO in Cabo Verde include the establishment of the national investment plan for the blue economy (PNIEB) and the blue economy promotion programme (PROMEB) (FAO, 2019).
Mindelo Agreement	In 2018, the European Commission and the government of the Republic of Cabo Verde signed a new agreement on research and innovation cooperation. The so-called Mindelo Agreement aims to strengthen and improve research and innovation cooperation in the field of blue growth (EUROPEAN COMMISSION/GOVERNMENT OF THE REPUBLIC OF CABO VERDE, 2018).
Special Maritime Economic Zone of São Vicente	Resolution No. 26/2018 created an ad hoc organisation to accompany the planning process of the Special Maritime Economic Zone of São Vicente (ZEEM-SV) aiming to contribute to the development of an integrated maritime economy through the creation of a maritime and logistics platform in the Middle Atlantic (Resolution 26/2018).

Figure 2. Cabo Verde's institutional framework for marine governance



Source: J. Guerreiro, A. Carvalho, D. Casimiro

Figure 3. Cabo Verde agency mandates for MSP



Source: J. Guerreiro, A. Carvalho, D. Casimiro

10 The DGEM has a clear mandate to coordinate MSP, supported by the INGT (under the aegis of the Ministry of Infrastructure, Spatial Planning and Housing), which is responsible for spatial planning and management. These two agencies, together with the DGRM (marine resources management), the DNA (environmental protection agency, under the aegis of the Ministry of Agriculture and Environment) and the port authority (IMP), constitute the core institutions potentially involved in MSP. They have a clear mandate to develop MSP, backed by strong legislation on land use planning that includes integrated coastal zone management instruments of a special spatial nature (as they override municipal plans). In addition, a comprehensive network of marine protected areas, clear legal support for nature conservation, as well as sound impact assessment and water quality legislation, provide a solid foundation for working towards an MSP process that preserves an ecosystem approach.

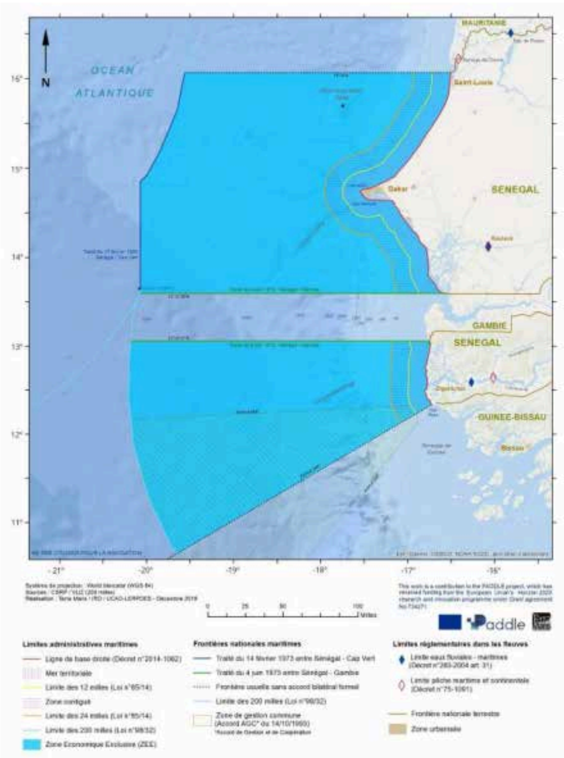
11 However, certain challenges have also been identified. The blue growth strategy is not supported by a law defining maritime spatial use and planning. Existing spatial planning legislation is mainly terrestrial and coastal in scope and does not cover the boundaries of the EEZ. In addition, coastal management plans, although foreseen in the legal instruments, have not yet been developed; only two are in the process of being completed. This delay is generally attributed to the pressure of coastal tourism as well as coastal urbanisation, two very strong economic sectors in Cabo Verde. It is expected that pressures from the tourism, construction, fishing and port sectors will threaten a sound MSP approach and the approval of a specific legal framework for this. In 2020, the Coastal Zone and Adjacent Seas Management Plan (POOCM) on Boa Vista Island was approved by Joint Order No. 41/2020 of 14 August, republished by Order No. 112/2020 of 10 September 2020, which is a step in the right direction.

12 While there are clear political and governmental commitments, including the creation of an agency dedicated to the development of the blue economy and the coordination of MSP, it is essential to develop a specific legal framework for MSP. This will be a crucial next step, as well as efforts to rethink the organisation of the jurisdictions and mandates of the national agencies, namely the DGEM, INGT and DNA, in order to avoid inter-agency conflicts and to facilitate an integrated approach to coastal zone management and marine conservation and promote sustainable blue growth.

Senegal

13 The Republic of Senegal is located on the west coast of Africa, between the latitudes of 12º 88' and 16° 41' N and the longitudes of 11° 21' and 17° 32' W, and has a total area of 196,720 km^2. It has land borders with Mali, Gambia, Guinea and Guinea-Bissau. In 1993, Senegal and Cabo Verde agreed the delineation of their maritime border by treaty[1].

Figure 4. Maritime boundaries and mapping of Senegal's marine environmental law

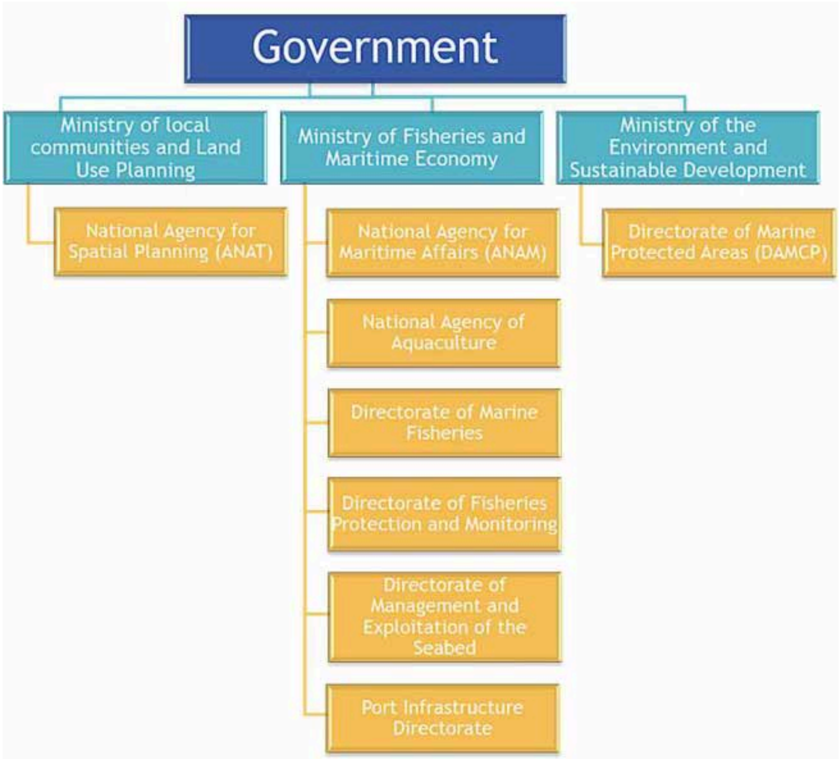


Source: IRD/Terra Maris, UCAD-LERPEDES, 2019

14 According to CORMIER-SALEM (2015) in BONNIN *et al.* (2015), the development of the maritime economy in Senegal over the last 50 years can be divided into three periods: (1) the 1970s saw the development of fisheries and related infrastructure; (2) the 1980s was a period of growth in coastal tourism, with both fisheries and tourism major contributors to GDP; (3) from the 2000s the exploitation of gas and oil has grown, which is increasingly contributing to GDP. According to the World Bank, Senegal was one of the ten fastest growing economies in 2018 (THE ATLAS, 2019). This diversification has led to a conceptual change in government structures, transforming the former Ministry of Fisheries into the Ministry of Fisheries and Maritime Economy, which reflects the trend

towards a more holistic approach to the blue economy. Currently, the blue economy in Senegal is based on five cornerstones: oil and gas, tourism, fisheries, aquaculture, shipping and ports.

Figure 5. Senegal's institutional framework for marine governance



Source: J. Guerreiro, A. Carvalho, D. Casimiro

15 The Senegalese government is rather large, with more than 30 ministries. Although the Ministry of Fisheries and Maritime Economy regulates navigation and ports, fisheries and aquaculture sectors, oil exploitation falls under the jurisdiction of another ministry, despite the regulatory mandate of the Directorate of Management and Exploitation of the Seabed (see table 2). The authority for navigational safety and protection against pollution is the High Authority for the Coordination of Maritime Safety, Security and Protection of the Marine Environment (HASSMAR), which is directly under the aegis of the Prime Minister.

16 Marine conservation is a clear policy concern, and the Ministry of Environment and Sustainable Development has a mandate to oversee this. It is supported by a specific agency, and there is a national strategy for marine protected areas (MPAs) and a comprehensive network of MPAs in place. The objective of the Directorate of Community Marine Protected Areas (DAMCP) is "the conservation of marine and coastal biological diversity, through the consolidation and strengthening of the network of marine protected areas; for better management of ecosystems and species, in particular for sustainable management of fisheries and fish stocks" (DAMCP, 2019). This network of institutions and policies highlights a priority on the sustainability of the marine environment, and in some ways serves as a "checks and balances" mechanism between agencies, but also holds the potential for inter-agency conflict.

Table 2. Institutional, legal and policy frameworks supporting marine governance in Senegal

Institutions	**Mandates/Objectives**
Ministry of Fisheries and Maritime Economy	Responsible for the development and implementation of policy on the fishing industry, seabed exploitation, aquaculture, port infrastructure and maritime transport (Decree 2019-789).
National Maritime Affairs Agency (ANAM)	Responsible for the implementation of maritime policy and the application of international maritime conventions, codes and regulations in force in Senegal. It is also the National Port Security Authority (Decree 2009-583).
National Aquaculture Agency	Responsible for the implementation of the national aquaculture policy (Decree 2011-486).
Directorate of Maritime Fisheries	Responsible for the implementation of the industrial and artisanal maritime fisheries policy (Ministerial Decree 2466 of 19 April 2006).
Fisheries Protection and Monitoring Directorate	Responsible for monitoring marine and inland fisheries (Ministerial Order 2467 of 19 April 2006).
Seabed Management and Exploitation Directorate	Responsible for the development of research, monitoring and exploitation of the seabed (Ministerial Order 2463 of 19 April 2006).
Port Infrastructure Directorate	Responsible for the management of port infrastructure in secondary ports and ports of call (Ministerial Decree 3825 of 29 July 2005).
Ministry of Local Authorities, Development and Land Use Planning	Responsible for land use planning and management policy (Decree 2019-791).
National Agency for Spatial Planning (ANAT)	Responsible for spatial planning and the implementation of national spatial planning policy (Decree 2009-1302).
Ministry of the Environment and Sustainable Development	Responsible for environmental policy and nature conservation (Decree 2019-794).
Directorate of Community Marine Protected Areas (DAMCP)	Responsible for the conservation of marine and coastal biological diversity, through the consolidation and strengthening of the network of marine protected areas for better management of ecosystems and species, in particular for sustainable management of fisheries and fish stocks (DAMCP, 2019).
High Authority for the Coordination of Maritime Safety, Security and Environmental Protection (HASSMAR)	Responsible for maritime safety, maritime security and protection of the marine environment with regard to the regulation, prevention and management of emergencies at sea (Decree 2006-322).
Legal framework	

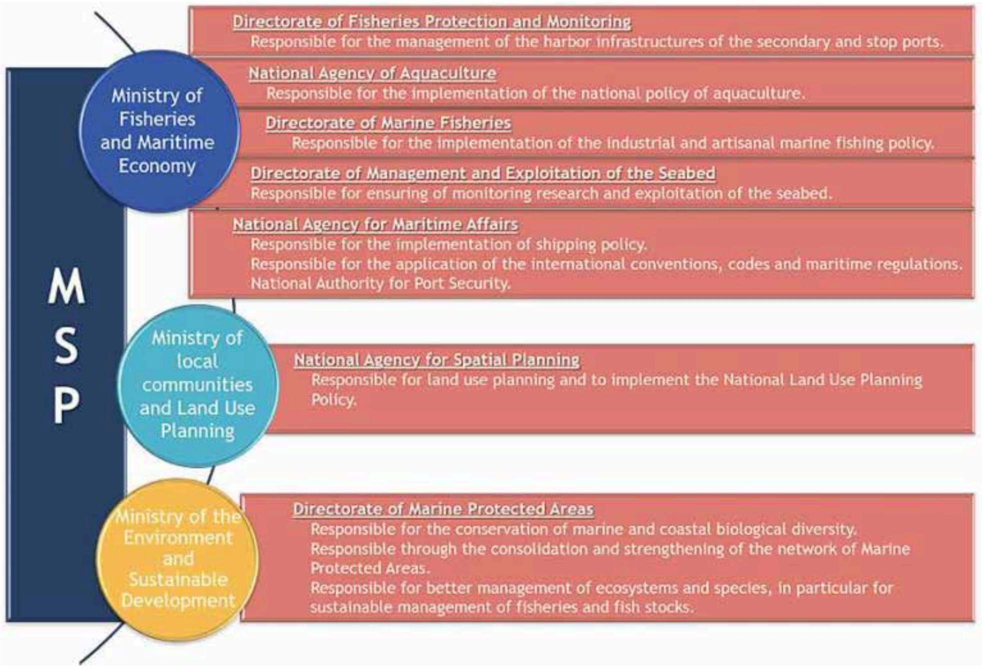
Urban planning code	Law No. 2008-43 of 20 August 2008 is the urban planning code, including the approval of regional master plans, municipal plans, detailed urban plans and special area plans for environmental protection (Law 2008-43).
Regulatory town planning code	Decree no. 2009-1450 of 30 December 2009 regulates and details the urban planning code (Decree 2009-1450).
Environmental code	The environmental code (Law 2001-01) sets out the basic rules for environmental protection (Law 2001-01).
National Strategy for Marine Protected Areas	The national strategy for marine protected areas aims to develop a coherent network of marine protected areas that are ecologically representative and effectively co-managed, ensuring the conservation of marine and coastal biodiversity, the sustainable management of fishing areas, the enhancement of cultural heritage and the sharing of socio-economic benefits for communities (REPUBLIC OF SENEGAL, 2013).

17 In Senegal, spatial planning is governed by a strict urban planning code (table 2 and fig. 6), with clear instruments for spatial planning, including special spatial plans for environmental protection, developed and managed by the National Agency for Spatial Planning (ANAT). However, the coastal zone, where spatial management has long been absent, is critically fragile. Successive governments have yet to approve a proposed law for the coastal zone, which has led to anarchic occupation of the coastline, insufficient delimitation of the public maritime domain and lax enforcement by the authorities, resulting in illegal development of the coastal zone (BONNIN *et al.*, 2015). In this context, MSP will be a challenge to develop, as economic pressures, mainly from tourism, fisheries, oil and gas, often outweigh sustainable spatial planning of the coastal zone and, consequently, the adjacent maritime space.

18 Currently, MSP in Senegal is not supported by a specific legal framework: there is no clear policy or mandate to develop it, and authority over this has not been assigned to any government agency. Yet the growth of the blue economy in Senegal and the obvious potential for user conflicts, as well as unsustainable pressure on the coastal zone, requires coordinated action on MSP. Several ministries are key players in this area and interact on policy, including the Ministry of Local Government, Development and Territorial Planning, the Ministry of the Environment and Sustainable Development, and the Ministry of Fisheries and the Maritime Economy, as well as the Ministry of Petroleum and Energy and the Ministry of Tourism.

19 This very complex governmental and institutional framework for marine governance suggests that it would be valuable to create a coordinating structure at the intergovernmental/inter-agency level, to develop a specific legal framework for MSP and an integrated approach to the management of coastal zones and, finally, to determine which national agency will be responsible for the implementation and oversight of MSP.

Figure 6. Mandates of Senegal's agencies for MSP



Source: J. Guerreiro, A. Carvalho, D. Casimiro

Brazil

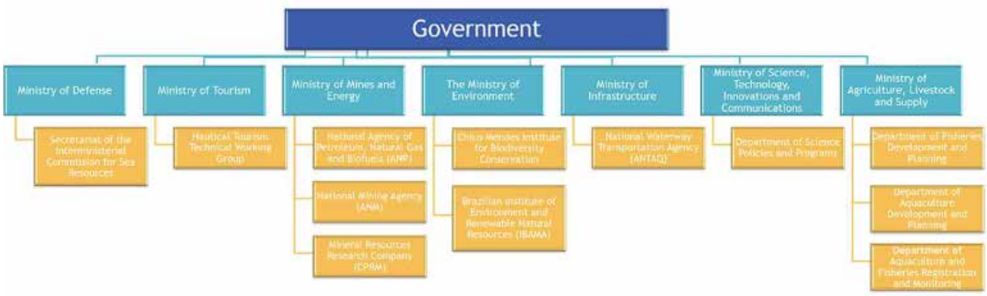
20 The Federal Republic of Brazil is the largest country in South America and the fifth largest country in the world, with a land area of 8,515,767,049 km^2. It extends north of the equator and south of the Tropic of Capricorn to 33°S, and has land borders with all South American countries, except Chile and Ecuador. The eastern border is the Atlantic Ocean, with a coastline of 7491 km^2; the marine area under Brazilian jurisdiction is 4,471,000 km^2, about 2.3% of the world's EEZs. The capital, Brasilia, is located at 15° 47' 56" S 47° 52' 00" W. Marine resources contribute strongly to the Brazilian economy, especially oil and gas exploitation, as well as coastal tourism and fishing.

Figure 7. Geographic borders of Brazil

Source: Instituto Brasileiro de Geografia e Estatística (2019)

21 The federal government has 15 ministries (in 2019), seven of which share responsibility for marine governance and resources (table 3 and figure 8). With shared authority over maritime resources and uses divided between these seven ministries as well as 12 agencies, Brazil has long opted for a coordinating structure for maritime affairs and resources, supported by the Brazilian Navy. This system dates back to 1974, and is a solution also adopted in some EU countries (CASIMIRO and GUERREIRO, 2019). The cornerstone of maritime affairs is undoubtedly the Interministerial Commission for Marine Resources (CIRM), which is under the aegis of the Ministry of Defence (fig. 9).

Figure 8. Brazil's institutional framework for marine governance



Source: J. Guerreiro, A. Carvalho, D. Casimiro

Table 3. Institutional, legal and policy frameworks supporting marine governance in Brazil

Institutions

Interministerial Commission for Marine Resources (CIRM)

Ministry Defence	
Ministry of Tourism	
Ministry of the Environment	

Brazilian Institute of Environment and Renewable Natural Resources (IBAMA)

Chico Mendes Institute for Biodiversity Conservation
Ministry of Infrastructure
National Agency for River Transport (ANTAQ)
Ministry of Mines and Energy

National Agency for Petroleum, Natural Gas and Biofuels (ANP)	
National Mining Agency (ANM)	

Mineral Resources Exploration Company (CPRM)	
Ministry of Science, Technology, Innovation and Communications	

Science Policy and Programmes Department

Ministry of Agriculture, Livestock and Food Supply
Fisheries Planning and Development Department

Aquaculture Planning and Development Department

Aquaculture and Fisheries Registration and Monitoring Department
Legal framework
National Maritime Policy
National Marine Resources Policy

Sector Plan for Marine Resources
National Coastal Development Plan
National Environmental Policy

Ecological Economic Zoning in Brazil	
National System of Protected Areas	

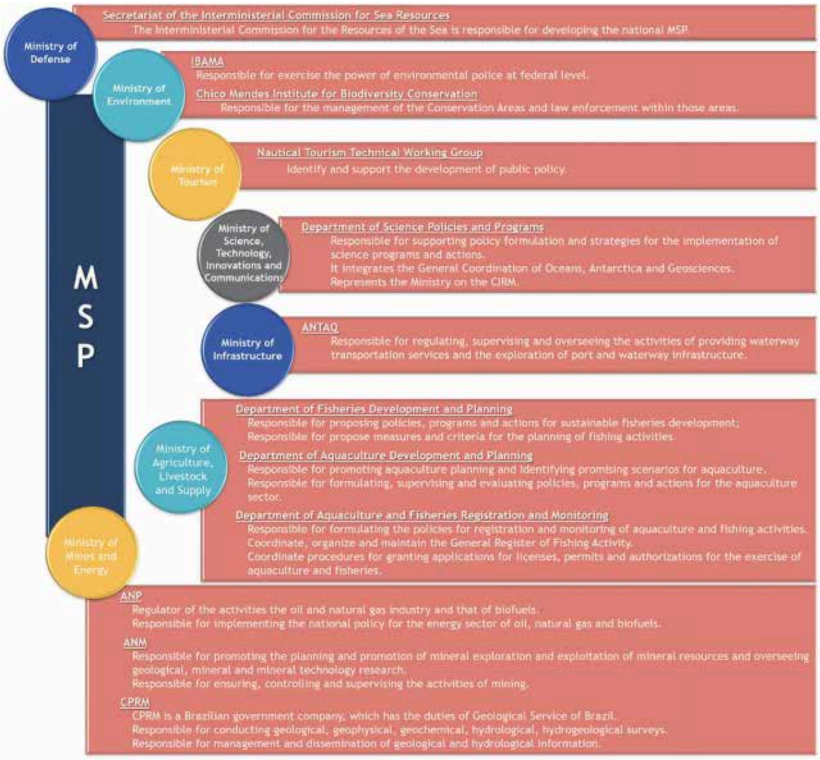
National Protected Areas Strategic Plan

Figure 9. Institutional composition of the Interministerial Commission for Marine Resources (CIRM)

Source: J. Guerreiro, A. Carvalho, D. Casimiro

22 Currently, the governmental structure and jurisdiction of the ministries are very similar to those described by SHINODA (2018), although some clarifications have been made, particularly with regard to fisheries and aquaculture policies, which have returned to the sphere of authority of the Ministry of Agriculture, Livestock and Food Supply. The Ministry of Environment clearly leads national conservation policies through IBAMA, while the Chico Mendes Institute is responsible for the overall management of protected areas. Other co-responsible entities are: (1) the Ministry of Science, Technology, Innovation and Communications, responsible for research policy in the oceans, Antarctica and geosciences; (2) the Ministry of Infrastructure, responsible for navigation and ports; (3) the Ministry of Mines and Energy, responsible for national oil and gas policy; and (4) the Ministry of Tourism, responsible for national tourism policy, and a Working Group on Water Tourism Policies.

Figure 10. Mandates of the Brazilian agencies for MSP



Source: J. Guerreiro, A. Carvalho, D. Casimiro

23 With a coastline of almost 8000 km that is intensively used, Brazil has long developed policies and instruments for integrated coastal zone management, dating back to the 1980s. The Federal Constitution of 1988 (PRESIDÊNCIA DA REPÚBLICA, 2016), Article 225, paragraph 4, defines the coastal zone as a "national heritage", highlighting it as a part of Brazilian territory that deserves special attention in public policy regarding its occupation, land use and natural resources, ensuring the conservation of the environment.

24 This commitment was expressed in a 1988 law that established the National Plan for Coastal Management (PNGC) as an integral part of the National Environmental Policy (PNMA) and the National Policy for Marine Resources (PNRM) (Law No. 7661 of 16 May 1988). This law also provided that the details of this plan should be established in a specific legal document within the framework of the Interministerial Commission for Marine Resources (CIRM), aimed at guiding the rational use of resources in the coastal zone. The first version of this document was presented in November 1990 by the CIRM. Subsequently, coastal spatial management plans were developed for the Brazilian coast (MINISTÉRIO DO MEIO AMBIENTE, 2019). In addition, a key policy instrument, the National Maritime Policy, was established in 1994 by Decree-Law No. 1256. In 2005, the National Policy for Marine Resources was approved.

25 Currently, IBAMA is the agency responsible for coastal management, although the coordination of agencies is carried out by CIRM, under the Coastal Management Integration Group. With regard to marine conservation, Brazil claimed, as of 2018, to have 26.3% of its maritime space covered by MPAs (about 940,000 km^2), with the

support of the Marine and Coastal Protected Areas (GEF Mar) project, under the aegis of the Ministry of Environment (FUNDO BRASILEIRO PARA A BIODIVERSIDADE, 2019).

26 Generally, we can consider that, for at least the last 30 years, Brazil's policies have taken marine and coastal governance seriously, with a clear coordinating role attributed to one institution: the Interministerial Commission for Marine Resources (CIRM). Today, Brazil's maritime policies are evolving to strengthen the blue economy, and several initiatives are underway, such as the Programme for the Evaluation of Mineral Potential by the Brazilian Continental Legal Platform (Replaceac), Blue Biotechnology (Biomar) and the Programme for Strengthening Aquaculture and Sustainable Fisheries (Aquipesca) (SECRETARIA DA COMISSÃO INTERMINISTERIAL PARA OS RECURSOS DO MAR, 2019). There are also several projects on renewable energy which, if added to existing uses of the sea, will call for the implementation of MSP to avoid conflicts of use.

27 In this context, the Brazilian government has given a clear mandate to CIRM to develop national MSP, which is reinforced by the existing legal framework based on the National Maritime Policy, the National Policy for Marine Resources (PNRM) and a Sectoral Plan for Marine Resources (PSRM IX) (Decree 1265 of 11 October 1994, Decree 5377 of 23 February 2005, Decree 8907 of 22 November 2016). Several key steps towards MSP have been taken in the last five years, following the creation in 2013 of the Working Group on Shared Uses of the Marine Environment (WG Ucam), under the aegis of CIRM, including:

- the establishment of the "Legislation" sub-group (LEG) and the "Marine Spatial Planning" sub-group (MSP) within the working group in 2014
- the approval of a work plan to establish a national maritime spatial planning process in 2017.
- the diagnostic mapping of the spatial distribution of uses (covering the territorial sea, the exclusive economic zone and the continental shelf) in 2018.

28 Recommendations on guidelines for the development and implementation of MSP are expected to be adopted in the early 2020s (CARVALHO, 2019). However, there remain a number of challenges to be addressed, including the development of specific legislation for MSP and how this legal framework will fit with the long-standing coastal management framework, as well as with specific management instruments for MPAs. In addition, the overall spatial planning and management framework will be affected, which is always a delicate exercise, as a comprehensive approach to the National Spatial Management Policy only dates back to 2003, although land management instruments have long been implemented.

29 Last but not least, pressures from several stakeholders with a strong economic impact, such as oil and gas, offshore mining and coastal tourism, will undoubtedly weigh in regarding environmental sustainability and nature conservation. This will be a challenge and a potential for conflict between the 12 agencies involved, requiring additional coordination effort by the CIRM and a strong public awareness and consultation mechanism. Nevertheless, the process is underway in Brazil to develop MSP, which may also provide an opportunity to update existing instruments on marine governance in the light of integrated maritime policy.

Conclusion

30 A strategy of blue growth, driven by new uses of the sea, makes it necessary to rethink the way marine space is planned and used. There will be a number of competing interests: offshore aquaculture, renewable energy, deep-sea mining, blue biotechnology, coastal tourism, maritime transport and oil and gas exploitation. Many coastal countries, in some ways inspired by the EU and a more holistic vision of maritime policy, have responded to this by developing different approaches to maritime spatial planning as well as specific instruments for this. These new planning instruments have both top-down and bottom-up implications. They will affect governmental, institutional and legal frameworks, which will have to adapt to the "new blue economy".

31 One of the questions that has arisen is whether these approaches only concern the Global North, and if not, how the Global South would approach MSP and how North/South oceanic transition zones would evolve. The Atlantic Ocean is a critical geopolitical area, stretching from the northern countries of the EU and North America to the Cape of Good Hope in Africa and Cape Horn in South America. The aim of the Paddle project was to analyse MSP trends in the crucial transition zone at the "border" between the North and South Atlantic, tracing a line from Senegal and Cabo Verde to Brazil. In Senegal and Cabo Verde, blue economy concepts are developing and there is pressure to implement MSP, a trend that is echoed in a number of states and regions, including the EU, as noted by KELLY *et al.* (2018). Both Senegal and Cabo Verde have adapted the governmental framework by introducing mandates and authority for the maritime economy, albeit with different solutions: a Ministry of Fisheries and Maritime Economy in Senegal and a specific Ministry for Maritime Economy in Cabo Verde. In contrast, Brazil has not changed its governmental structure to accommodate "blue economy" authority. These different approaches may indicate a more direct influence of the EU on Senegal and Cabo Verde, whose relationships are traditionally linked by several agreements.

32 Senegal has not yet given a mandate to a specific institution to develop MSP, and the concept is not yet integrated into the legal framework, as the management of the maritime space is attributed to sectoral agencies with no apparent coordinating structure. In contrast, Cabo Verde has created a specific agency to develop the maritime economy, which has the mandate to implement MSP, coordinating the process with other sectoral agencies; in particular, those with authority over spatial planning, maritime activities and the environment. For its part, Brazil has long had a coordinating structure for marine resources, which now has the mandate to develop MSP. This is the Interministerial Commission for Marine Resources (CIRM), which coordinates a complex institutional framework of seven different ministries and 12 agencies, which is a similar solution to the one used in some European countries, such as the UK or Norway (CASIMIRO and GUERREIRO, 2019). Whatever the institutional arrangements, there is a need for some form of coordination between the different agencies, which often represent opposing interests, leading to conflicts and tensions between agencies, as other authors have highlighted (ASCHENBRENNER and WINDER, 2019).

33 The most fragile element seems to be the legal framework, where no specific instrument to support MSP is yet in force in these countries, and the options are very different. Brazil has a long tradition in coastal management and a strong legal

framework, supported by the constitution, which puts it in a good position to move towards MSP; the development of a specific mandate for MSP is underway. Cabo Verde has also chosen to develop a specific legal framework for MSP, and the existing legal framework for spatial planning already includes coastal management instruments, although these are not yet in force.

34 In Senegal, on the other hand, the lack of coastal management and regulation and the tensions related to coastal occupation are a real challenge. Although coastal and maritime legal frameworks for spatial planning exist at different stages of maturity, the need to take into account coastal zones is a crucial issue. The experience of EU countries shows that MSP must correspond with integrated coastal zone management instruments (EHLER, 2008). In fact, it would be wise to avoid discontinuity or fragmentation between "land" and "sea" in spatial planning systems, avoiding territorial fragmentation in the coastal zone and promoting the efficient use of space. Examples could be drawn from certain EU countries (DOUVERE and EHLER, 2009).

35 A possible challenge to the development of MSP in these tropical areas is the temptation to put economics over sustainability, leading to "soft sustainability" (SANTOS *et al.*, 2014). This can be counteracted through efforts to implement MSP with an ecosystem approach. However, one of the intrinsic characteristics of MSP is freedom of choice in processes, which must be adapted to geopolitical and socio-economic realities (ANSONG *et al.*, 2019).

36 In the tropical Atlantic, MSP is a boat that is already sailing, carried by the winds of blue growth. Although the approach is still in its infancy and integrating institutional, legal and policy frameworks is a challenge, pooling academic and policy knowledge, different realities and experiences, should contribute to the more sustainable use and governance of our common Atlantic Ocean.

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NOTES

1. See https://www.marineregions.org/

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Chapter 10. The information challenges of marine spatial planning

Lessons learned from small-scale fisheries in Senegal

Brice Trouillet, Ndickou Gaye, Aïchetou Seck, Michel Desse, Awa Niang, Alexis Fossi, Thierry Guineberteau, Alioune Kane and Laurent Pourinet

Introduction

1 Marine spatial planning (MSP) requires the ability to "objectify" the distribution of activities at sea, which in turn requires information on multiple aspects. Geographic information is one of the central of these. However, from the construction of information to its dissemination (types, metrics, collection and processing methods, modes of representation, quality and reliability, tools and forms of dissemination, etc.), data is far from "objective" or neutral, and thus nor is the series of following choices (D'AQUINO *et al.*, 2002; ILIADIS and RUSSO, 2016; KITCHIN and LAURIAULT, 2018; NOUCHER *et al.*, 2019). BOWKER (2005) stated this in his assertion, later taken up by GITELMAN and JACKSON (2013), that "'Raw data' is both an oxymoron and a bad idea." Geographic information is no exception to this (BOUCQUEY *et al.*, 2019; CAMPBELL *et al.*, 2020; TROUILLET, 2019). This leads to an information issue that is little discussed, but lies at the heart of several problems raised by the scientific literature on MSP. Among these are the unequal distribution of the benefits of MSP, the predominance of the rationalist approach, the absence of real theoretical foundations, and the dominance of certain interests to the detriment of others (FLANNERY and ELLIS, 2016; FLANNERY *et al.*, 2018; JENTOFT, 2017; KIDD and ELLIS, 2012; TAFON, 2019; TROUILLET, 2018).

2 Two elements may further accentuate this information issue. Firstly, this problem is particularly acute when seeking to characterise spatially dispersed, mobile and variable activities, which are difficult to describe and represent. This challenge can be even greater in the case of activities at the margins of the market or in the informal sector,

for which observation systems may be inoperative. This is linked to another limitation of MSP that tacitly makes it an exercise of rationalising the use of space in a quest to maximise economic gains while taking into account marine ecosystems, but leaving aside other aspects associated with its use (cultural, social, identity, religious, territorial). In short, MSP is not only a question of defining what to observe, but knowing how to do so, i.e. with what variables. Fisheries, in particular small-scale, artisanal, subsistence fisheries, are often off the radar of observation systems (AGAPITO *et al.,* 2019; TROUILLET *et al.*, 2019), and therefore marginalised (PAULY, 2006). At best, they are summarised by reductionist bioeconomic metrics unable to capture their complexity and diversity (TOLVANEN *et al.*, 2019; SAID and TROUILLET, 2020), and as such can be at risk.

3 The second element that makes information an issue in MSP particularly affects developing countries and involves the greater scarcity of data (MILLS *et al.*, 2011) and informational dependence on foreign actors (e.g. foreign aid agencies, large international non-governmental organisations) (AVGEROU, 2008; WALSHAM and SAHAY, 2006). As a result, to date, very few marine plans have been developed in emerging countries (FRAZÃO SANTOS *et al.*, 2020; TROUILLET, 2020), with the exception of a few island micro-states and other sub-national approaches sometimes related to MSP, such as certain marine protected areas (MPAs)[1]. Yet this situation is starting to change as new uses of the sea arise and major projects become more numerous, in developing countries as elsewhere. This is the case in Senegal, where the evolving blue economy may lead the Senegalese authorities to embark on MSP in the near future, following in the footsteps of a growing number of countries around the world (ZAUCHA and GEE, 2019). A project promoting MSP in all the signatory countries of the Abidjan Convention (including Senegal) is currently underway[2].

4 This chapter aims to draw attention to the information challenges of MSP by exploiting the heuristic potential of the case of small-scale artisanal fisheries in Senegal. In particular, the chapter examines the role of geographic information and associated geo-technologies used in MSP to identify the main points of vigilance to be considered (see Box 1 on the risk of ocean grabbing, for example). An empirical approach was used, based on fieldwork, interviews with stakeholders in maritime and coastal development, and the analysis of a body of literature including reports and websites of the various stakeholders. The first part describes the changes taking place in Senegal's maritime space that may justify the implementation of MSP in the near future, and the importance of taking into account information issues in an MSP approach. This information issue is highlighted in our case study at two levels: fisheries at the national level and three more localised cases in Senegal. The chapter then discusses lessons to be learned regarding geographic information in the context of MSP in developing and emerging countries in the tropics.

Box 1. The threat of ocean grabbing
Alexis FOSSI

The term "ocean grabbing" originated in a 2012 report on fisheries by Olivier DE SCHUTTER (UN Special Rapporteur on the right to food) for the UN General Assembly. The report raised the alarm on the growing constraints faced by coastal communities and artisanal fishermen linked to the non-respect of "human rights" or "rights of access to resources". It stressed the importance of involving fishing communities at all stages when developing projects in coastal areas, as well as in the development and implementation of fisheries policy. Many of the report's recommendations were incorporated into the Voluntary Guidelines for Securing Sustainable Small-scale Fisheries (FAO, 2015), supported by the work of organisations such as the World Forum of Fisher Peoples (WFFP) and the International Collective in Support of Fishworkers (ICSF) in negotiations with the Committee on Fisheries of the Food and Agriculture Organisation of the United Nations (COFI).

In 2014, the issue of ocean grabbing was analysed in a study carried out jointly by three fisherfolk and farmer support organisations (TNI *et al.*, 2014) with the WFFP. The causes identified for this phenomenon are very diverse, but one of the most important is the complex process involved in defining fisheries policy and access rights in the form of quotas, from which artisanal fishing is often excluded. Other factors are the increasing number of projects linked to aquaculture or energy production (e.g. offshore wind farms), the creation of large marine protected areas associated with ecotourism projects, the expansion of the oil and gas extraction industry and the development of port infrastructure. These activities, grouped under the concept of the “blue economy”, very often involve a form of privatisation or restrictions on access to marine or coastal spaces and/or resources. Fishing communities, which depend on these areas and resources for their livelihoods, are typically not involved in the discussions and decision-making processes, which tend to be mainly oriented towards short-term economic benefits.

The Transnational Institute (TNI), a non-profit research and advocacy think tank, brought up this issue in a critical analysis of blue growth in 2018, in which it presented MSP as a tool for the privatisation of maritime space for the benefit of the most “profitable” industries, such as fossil fuel extraction and maritime transport.

For more information

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Marine spatial planning and geographic information

5 In this section, the emerging issues around sharing maritime and coastal space in Senegal are highlighted, with a focus on challenges around the information issue in the field of fisheries.

Changes in Senegal's maritime and coastal space

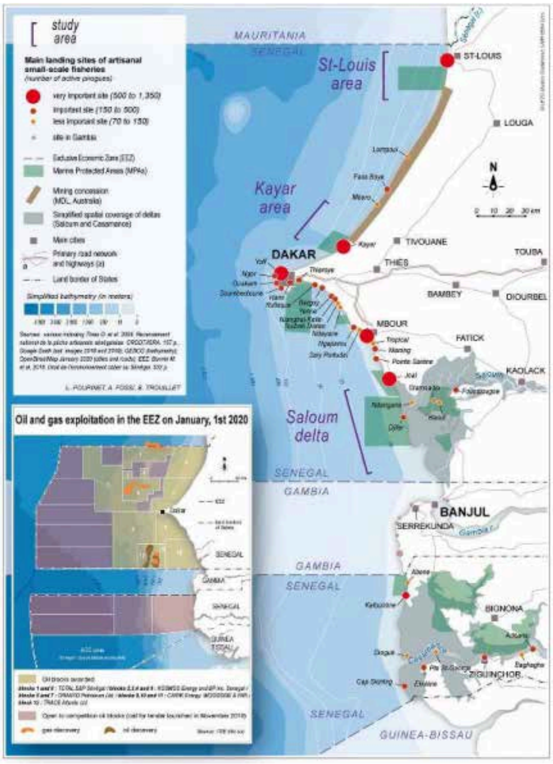
6 There have been multiple changes in Senegal's maritime space in recent years. These affect all coastal and maritime sectors in the country to varying degrees, and are often linked to global changes (climate, energy transition, etc.).

7 Following several initiatives to promote growth in different sectors, the Plan for an Emerging Senegal[3] (PSE) (REPUBLIC OF SENEGAL, 2014) puts forward an overall development strategy for 2035, focusing in particular on the diversification of activities. This has resulted in an ambitious Strategic Plan for the Development of Aquaculture (PSDA) adopted in December 2016. Its objective is to increase aquaculture production to 40,000 or 50,000 t in 2023 (BONNIN *et al.*, 2016), a 40- or 50-fold increase, in certain identified geographical areas, notably Casamance (Sédhiou department upstream from Adéane; fig. 1). Another priority in the PSE is tourism, which has been the subject of various previous initiatives: the National Agency for the Promotion of Tourism in 2004, the Society for the Development and Promotion of Senegal Coasts and Tourist Zones (SAPCO) in 1975, whose scope of action was extended beyond the Petite Côte from 2004, and a tourism development strategy defined in 2005. Although the development of tourism is aimed at the whole of Senegal, the expected effect will be particularly strong in the coastal areas, which include five of the six "integrated tourist areas"[4] of the PSE. The energy sector is a further priority, with the PSE expanding the orientations in the 2012 policy letter on the development of the energy sector. With regard to hydrocarbons, after the first discovery of deposits in 2014 in the current Block 10 (fig. 1), almost all of Senegal's maritime space has been opened up to offshore oil and gas exploration permits. In terms of mining activities, a sand extraction zone (rich in zircon and ilmenite) corresponding to a 4.5 km strip extending over 107 km was granted in 2007 until 2032 to the Australian company Mineral Deposits Limited (MDL) (BONNIN *et al.*, 2016) (fig. 1). Lastly, there is a development strategy for infrastructure, which is reflected in several projects to create new commercial ports. This includes a multifunctional port project at Ndayane on the Petite Côte (fig. 1), built by the UAE company Dubai Ports World. This would be one of the links in a large logistics hub integrating several port projects, including the bulk and mineral port currently under construction in Bargny, interconnected by planned road, motorway and rail networks. In Ndiago in Mauritania, just on the other side of the border with Senegal (15 km north of Saint-Louis, where a river–sea port project is in the works under the aegis of the city and the Organisation for the Development of the Senegal River), the multifunctional port of Ndiago is being constructed by the Chinese company Poly Technologies and is due to be completed soon. The Ndiago port is designed both to take advantage of the exploitation of the offshore deposit of Grand Tortue Ahmeyim on the Mauritania–Senegal border (partially in Block 2; fig. 1), and to land fish from Senegalese fishermen working in this area.

8 Despite the fact that they are spread along the Senegalese coastline, these rapid changes, which are sometimes profound, are having an impact on fishing activities, (fig. 1), which form the backbone of Senegal's coastal economy and on which many coastal communities depend. After several years of growth, fishing landings in Senegal are slowing, or even decreasing, depending on the species (MINISTRY OF FISHERIES AND MARITIME ECONOMY, 2016). This is due to a complex mix of fishing overcapacity, habitat degradation (MBAYE *et al.*, 2018) and the effects of climate change, which are redrawing the distribution patterns of species of interest. Moreover, these changes are taking place against a backdrop of geopolitical issues linked to fishing agreements with neighbouring countries (particularly Mauritania[5]) or regions further afield (Asia, Europe), or issues linked to illegal, unreported and unregulated (IUU) fishing, which represents an estimated loss of income of nearly US$300 million per year in Senegal (BELHABIB *et al.*, 2014).

9 Two other elements add to an already complex fisheries situation. Firstly, following sub-regional initiatives such as the Regional Partnership for Coastal and Marine Conservation (PRCM), the Regional Network of Marine Protected Areas in West Africa (RAMPAO), etc., Senegal has recently developed a national MPA strategy in line with international commitments (MINISTRY OF ENVIRONMENT AND SUSTAINABLE DEVELOPMENT, 2013). To date, Senegal has about 15 MPAs, four of which are relatively large (fig. 1). Secondly, strong urban pressure on the sea front (construction of hotels, urban port projects, etc.), combined with sometimes very rapid coastal erosion problems (Guet Ndar, Dakar, etc.), exposes fishing communities to the risk of exclusion and forced relocation.

Figure 1. Study areas and general context



Source: L. Pourinet, A. Fossi, B. Trouillet
High resolution map: Figure 01 HD

10 All of these changes are taking place at a time when the legislative foundations for coastal and maritime planning to regulate their effects are still unclear, both in land planning (problems of defining the public maritime domain) and in marine planning (absence of agreements on maritime borders with Cabo Verde, an unclear zone between Gambia and Cabo Verde, and a joint management zone between Senegal and Guinea-Bissau) (BONNIN *et al.*, 2016).

Geographic information: key to marine spatial planning

11 While MSP has its roots in experiments carried out as early as the 1960s and 1970s, it only really began to take hold in the mid-2000s. Of the many existing definitions, the most common is: “The public process of analysing and allocating the spatial and temporal distribution of human activities in marine areas to achieve ecological, economic and social objectives that are usually specified through a political process” (EHLER and DOUVERE, 2009). It can be tempting to adopt a unifying and universalist definition, but in reality practices encompass diverse rationales and pursue diverse goals (JONES *et al.*, 2016; TROUILLET, 2020), tipping the balance either to the side of systematic conservation planning (AGARDY *et al.*, 2011; KIRKMAN *et al.*, 2019) or to spatial planning in the broadest sense of the term (JAY, 2010a; OLSEN *et al.*, 2016).

12 Nonetheless, three constants can be identified, regardless of the position between the two typical cases mentioned above. Firstly, **geographic information is omnipresent throughout the MSP process**. It is used to describe the existing situation, to construct and represent different scenarios, and finally to translate these into spatial management measures. Geographic information technologies – in particular geographic information systems (GIS) – are thus enlisted to carry out multi-criteria spatial analyses that shed light on “(in)compatibilities” between uses, regulations, natural habitats, species and the physical environment (CALDOW *et al.*, 2015; PINARBAŞI *et al.*, 2017; STELZENMÜLLER *et al.*, 2013). In this, the input data (from which information is extracted) is fundamental, as to a large extent the final result and the very way of rendering it depends on this: “What data go into the data portals has profound impacts on what kinds of decision-making are possible and how the environment and communities are formatted” (CAMPBELL *et al.*, 2020).

13 This information issue is central to MSP, even more than in land-based planning, for two main reasons. One is that for most maritime stakeholders, and especially decision-makers, maritime space is an abstract space disconnected from experience (STEINBERG and PETERS, 2015). This means that there are fewer alternatives to qualitative – even sensitive – data on maritime space, and less critical distance from the data itself. The other is the multiple levels at which “what data goes into the data portals” plays out: the presence or absence of information, the context of information production, the metrics used, the types of processing carried out, the cartographic representations produced, the portal or dissemination infrastructure, and the nature and status of the information producers (BOUCQUEY *et al.*, 2019; ST. MARTIN and HALL-ARBER, 2008; STAMOULIS and DELEVAUX, 2015; TROUILLET, 2019; SAID and TROUILLET, 2020). At each of these levels, choices are made, whether conscious or unconscious, explicit or implicit, and none can be considered neutral. As MSP is now leaning towards a quantitative and rationalist model, unlike land-based planning (JAY, 2010b; KIDD and ELLIS, 2012), the information

issue is exacerbated and, paradoxically, remains little studied. The consideration of this is in line with the perspective of "a partial renewal of the methodological frameworks of critical cartography (...) [which] must allow for a deeper description of new ways of making maps, of the stages of their making (...) and of the power relations that accompany this making both in design and in use" (JOLIVEAU *et al.*, 2013).

14 The rationalist anchoring of MSP, confining itself to "evidence-based" or "data-driven" planning, seems to be linked to the dual aims of MSP of systematic conservation planning and spatial planning (understood here in the broad sense). So the second constant is that **the information issue delineates an epistemological fault line between conservation science and spatial planning science**. In the absence of the clarification and substantive theoretical debates taking place for over a century in land-based planning, this fault line raises the question of positivism in the field of MSP (TROUILLET, 2019). In land-based planning, DAVOUDI (2006) reminds us that facts and information are not in themselves evidence (it is more a matter of combinatorics), and that any evidence must include multiple forms of knowledge. It is therefore necessary to place this information issue, which is currently only indirectly addressed in the already limited theoretical debates regarding MSP, at the centre of our concerns. Failing this, and given a certain revival of (neo)positivism in the field, there will be an overinvestment in "how" to the detriment of "why", returning to the tired but endless debate between spatial and strategic planning.

15 The third constant is that **the question of information is also one of situated and relational power.** Information is strongly dependent on the socio-technical organisation – or network – of actors, as well as objects such as information, technology, discourse, etc., within which it is gathered and disseminated (AKRICH, 1989; CALLON, 1986; 2006; LATOUR, 2005). Each point in the network influences the others and thus contributes to shaping the power relationships between actors. To take an extreme example, a situation of data deluge, in which there is an abundance of data, differs from that of a lack of data, even if the abundance of data has no bearing on its quality and vice versa. In some ways, the situated and relational power in the information issue echoes the shift from an interest in maps as objects to maps as practices (CRAMPTON, 2009) or, by extension, geographic information as object to geographic information as practice. The capacity of geographic information to exert power over the dominated has long been pointed out (PICKLES, 1995; CHAMBERS, 2006; DUNN, 2007), but vigilance is particularly necessary in the West African context, as standards and references are usually defined exogenously (as is often the case with aid and data production), overlooking pluralism, local specificities and so-called "non-scientific" knowledge (D'AQUINO *et al.*, 2002). This observation has been at the origin of the development of participatory geographic information systems (CRAMPTON, 2010), and the emergence of certain currents of critical cartography, critical GIS, counter-mapping and even data activism. It is linked to questions of invisible power (LUKES, 2015), referring in part to what YOUNG (1990) defines as cultural imperialism, i.e. a process leading to the unconscious acceptance of the norms and references of the dominant power. In tropical maritime contexts, where geographic information is scarce, attention must be paid to intertwining top-down and bottom-up (especially participatory) approaches to information production, and the associated information issues, including the analysis of formal and informal information networks, powers and modalities of collection, and tools for knowledge integration (POMEROY *et al.*, 2014).

16 With these three constants in mind, it is of interest to apply a methodological framework explicitly attentive to power issues to the question of information and MSP in the case of small-scale fisheries in Senegal.

The information issue in Senegal's fisheries

17 This section gives a brief overview of Senegal's fisheries at a national level and the information systems related to this, and then looks at three case studies in the regions of Saint-Louis, Kayar and the Saloum delta.

Overview of Senegal's fisheries

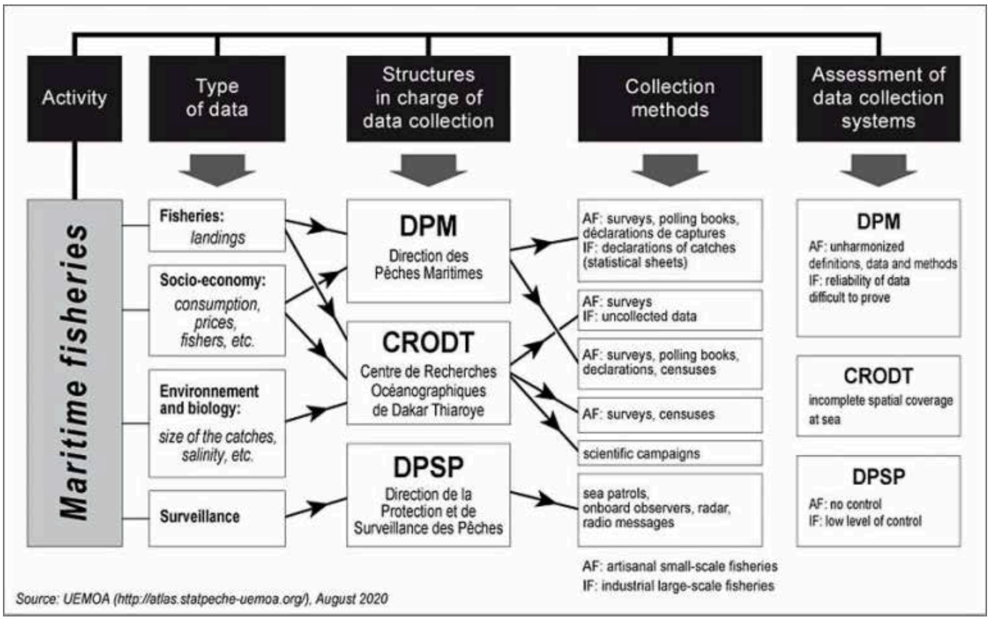
18 While there has long been pirogue fishing activity on the Senegal coast, at the turn of the 20th century, the French colonial power began to develop Senegalese maritime resources (CHAUVEAU and SAMBA, 1990). The initial colonial objective "was to supply food products to France at war and to the local European population cut off from exports"; over the subsequent decades, Senegal's fisheries would undergo many changes (CHAUVEAU and SAMBA, 1990).

19 Today, maritime fishing in Senegal is made up of two sectors with often competing rationales, with a marked dichotomy between industrial and artisanal fishing. Industrial fishing, based in Dakar, is mainly characterised by vessels equipped with inboard engines. The national fleet consists of an estimated 104 trawlers and eight tuna boats[6], not counting the presence of a foreign fleet. Landings are destined for export and, unlike artisanal fishing, industrial fishing plays a small role in the national economy. Artisanal or traditional fishing is often defined by (1) a household-based production unit, (2) the acquisition of knowledge and skills adapted to the local environment, based on local or traditional transmission, and (3) the use of relatively simple technologies (JENTOFT, 2006; WORLD BANK, 2008; 2012). In an attempt to capture the diversity and complexity of artisanal fisheries, various criteria are combined: technological (size of boat and type of fishing gear), spatial (area of exploitation, area of catch) and socio-economic (capital, labour, integration into local and national markets) (CHUENPAGDEE *et al.*, 2006; GARCIA *et al.*, 2010). In Senegal, artisanal fishing is increasing due to its flexible nature, which allows new actors to take up the activity or develop related industries and trade networks, but also because it is being promoted as a lever for development. The artisanal fleet is estimated at 19,000 pirogues, of which more than 90% are motorised[7]. These two different types of fishing pose challenges in terms of fisheries monitoring: the industrial fishing fleet is concentrated in the port of Dakar and consists of a small number of boats, while the artisanal fishing fleet is scattered along the coast, is very diversified and has a much larger number of boats.

20 It is important to note that fishing activity should not be reduced to its bioeconomic dimension alone: it constitutes the most visible form of maritimisation of coastal societies. Senegal's fishing area presents forms of exploitation and appropriation that policies have long sought to structure and organise. The Senegalese government's initiatives and strategies in terms of information collection in this sphere are essentially based on two objectives: the development of the fisheries sector and the management of the fisheries resource (FAO, 2008). The latter provides an overview of the existing information on fisheries throughout Senegal's maritime space. To ensure

the sustainability of its marine resources, Senegal has relied heavily on the institutional framework, particularly by strengthening the capacity and means of action of the fisheries agencies. At the national level, the collection and management of this information is the responsibility of the Directorate of Maritime Fisheries (DPM), the Directorate of Fisheries Protection and Monitoring (DPSP) and the Oceanographic Research Centre of Dakar Thiaroye (CRODT) (fig. 2). These institutions are supported by decentralised regional and departmental agencies, and locally by monitoring stations. An example of a classic monitoring system, this institutional framework aims to provide information for discussions on sectoral policies, particularly those aimed at fisheries management, regulatory and environmental frameworks, and the implementation of monitoring programmes for certain overexploited species (e.g. sharks and shrimp).

Figure 2. Collection and management of marine fisheries information at a national level



Source: WAEMU (http://atlas.stafpeche-uemoa.org/)

21 Information collection relating to the fisheries sector thus relies heavily on both central and decentralised agencies, as well as on national research institutes (notably CRODT). These structures are mainly oriented towards collecting information on resources (landings, size/weight, quality, origin, etc.), and the sprawling development of small-scale fishing poses a problem for monitoring. Fisheries agencies are understaffed, and cooperation at a local level with management agencies (particularly for checks at sea) is not operational. These rely on a small number of volunteers who lack official status and very often encounter resistance from small-scale fishermen. There is also an issue of the reliability of the collected data, which is often biased or even the result of extrapolations.

22 The system for monitoring foreign fishing vessels is also problematic. Satellite monitoring by a vessel monitoring system (VMS) was made compulsory by Ministerial Decree No. 009757 of 5 December 2005, theoretically making it possible to receive data on the position of vessels operating in Senegal's national waters and to verify their activities. In practice, surveillance is far from regular. Aerial patrols (flyovers,

photography and identification of vessels) are subject to the availability of the French armed forces in Senegal (EFS) (DIAGNE, 2014), while maritime patrols (especially on the high seas) require significant financial resources. These constraints prevent regular monitoring and leave an open door to illegal, unreported and unregulated (IUU) fishing.

23 Other entities are also involved in the collection/production of data alongside Senegal's fisheries agencies: other ministries (in particular the Ministry of the Environment via the Directorate of Community Marine Protected Areas), national organisations and federations (Association of Shipowners and Fishing Industrials in Senegal, Employers' Union of Wholesalers and Exporters of Senegal, Local Artisanal Fisheries Councils), foreign or regional supranational organisations (European Union, Sub-Regional Fisheries Commission), scientific institutes and non-governmental organisations (NGOs) through research programmes, etc. These various forms of cooperation provide more or less one-off additional information, either for routine monitoring or in areas not covered by observation systems.

24 The collection of data on the fisheries sector thus faces a variety of shortcomings (reliability, availability of human, technical and financial resources, etc.). Once collected, the information is processed by Senegalese authorities and disseminated through statistical reports that are sometimes accessible online. There is little or no geographic processing of the data collected, except through landing points. To date, there is no fisheries data infrastructure in Senegal (in open access).

The Saint-Louis region: multiuse and multiscale

25 The Saint-Louis region (fig. 1) is one of the most active and long-standing artisanal fishing areas in the country. Artisanal fishing is mainly carried out by the migrant fishermen of Guet Ndar, a coastal community that has participated in turning West African fishing into a market economy (SECK, 2014). Through its dynamism and by taking advantage of technological advances, the Guet Ndar community has extended its fishing area along the West African coastline to preferred zones such as Mauritania and Guinea-Bissau (DÈME *et al.*, 2012). The mobility of the production unit (the pirogue), its specialisation in relation to the resource, and the investment made for long migrations give the Guet Ndar of Saint-Louis a succession of fragmented fishing areas that extend beyond Senegal's national jurisdiction.

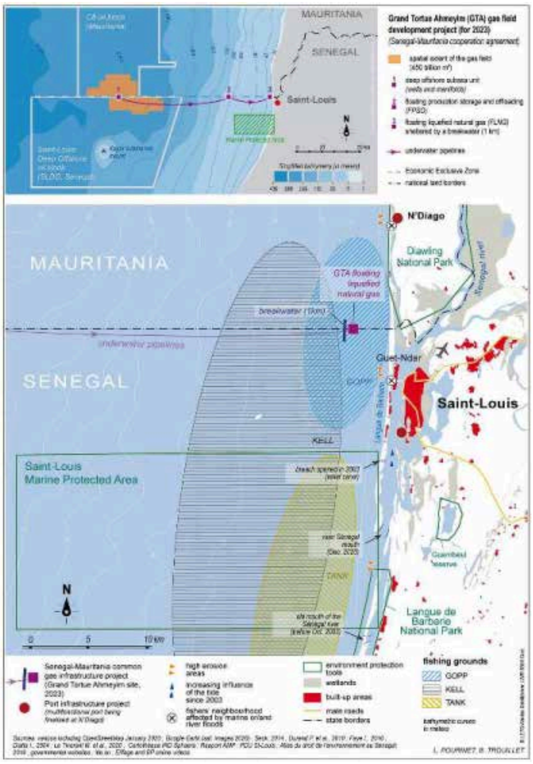
26 In the Saint-Louis region, the specific characteristics of fishing, in addition to the appearance of new maritime activities (MPAs, blocks for gas and oil extraction and future ports) have resulted in real MSP issues that involve methods of sharing maritime space, integrated management of the coastline and its resources, and environmental protection. These issues must be addressed on an appropriate scale, taking into account the functional borders which, in the case of the northern region, transcend the Mauritania–Senegal border, or even take shape on a sub-regional scale. The Saint-Louis fishing area is undergoing rapid and profound changes that require a reexamination of the dynamics of the activities involved. As early as 2004, the creation of an MPA covering an area of 496 km² upset the spatial perception of artisanal fishermen and raised the question of the capacity of local agencies to regulate, manage and monitor the marine area. When the Saint-Louis MPA, located between the relief canal opened on

the Langue de Barbarie in 2003 and the original river mouth (fig. 3) was defined, three considerations were taken into account to ensure that the MPA:

- encompasses an important spawning area for shrimp – resources necessary for the presence of demersal species (fishermen participated in its definition)
- avoids proximity to the fishermen's settlements and is therefore far from the Guet Ndar district, while not encroaching on the Louga area located further south
- covers a large area – an asset for artisanal fishermen to stop repeated incursions by trawlers into their fishing space (arbitrarily set by the government at 6 miles offshore).

27 However, the participatory process to delimit the MPA was quickly unanimously opposed by the community, which feared restrictions on the resource and sanctions. This led to numerous demands and even a denial of the conservation area by certain categories of users (those fishing with passive nets and purse seines). In addition, the lack of monitoring resources (equipment and personnel), the absence of markers, and the conflicts of authority between the Ministry of Maritime Fisheries and the Ministry of the Environment have all created obstacles to the proper functioning of the MPA. Today, the Saint-Louis MPA is recognised as a conservation area by fishermen; however, updating its perimeter will rely on the availability of information to enable managers to establish clear planning and mapping, which is currently lacking (fig. 3).

Figure 3. Spatial planning issues in the Saint-Louis region



Source: L. Pourinet, B. Trouillet
High resolution map: Figure 03 HD

28 In this already complex context, new challenges are emerging on the Saint-Louis coastline with the discovery of gas leading to exploration/extraction blocks and a renewal of river and maritime transports through port projects (the "Polish" port of Saint-Louis and the port of Ndiago). The potential for a hydrocarbon industry has been

discussed and researched since the 1990s, and in the 2000s the Senegalese government initiated exploration contracts with oil companies. Hydrocarbon exploration and production activities carried out in Senegal's sedimentary basin between 2014 and 2016 confirmed the presence of significant oil and gas reserves along the coastline, with the prospect of effective exploitation by 2022 (fig. 1).

29 In this context, the Grand Tortue Ahmeyim gas field on the Mauritania–Senegal border in the Saint-Louis area presents great opportunities (fig. 3). With reserves estimated at 450 billion m^3 according to British Petroleum [8], the gas field is located in rock formations under the seabed 125 km from the coast and covers a total area of 9463 km^2. A framework agreement was signed on 14 January 2016 between Société des Pétroles du Sénégal (Petrosen), Société Mauritanienne des Hydrocarbures et du Patrimoine Minier (SMHPM) and Kosmos Energy Ltd.[9] This agreement covers the delineation, evaluation, development and exploitation of the common hydrocarbon resources of the area. The area of activity is specified as:

- an offshore area approximately 125 km from the coast and at a water depth of 2700 m. It includes the gas field as well as the subsea wells and manifolds.
- a pipeline area linking the offshore and nearshore infrastructure. It will house a floating production, storage and offloading facility (FPSO) and a platform about 35–40 km offshore for gas pre-processing and liquid disposal.
- a nearshore area where a breakwater will protect the planned floating gas liquefaction plant. The breakwater is 1-km long and will be approximately 3–5 km from the coast where the depth is approximately 16–20 m.

30 There are high economic expectations for the Grand Tortue Ahmeyim project, with production intended for export as well as for the domestic market, but the project also raises questions about its potential impacts. A public consultation was conducted in 2017 between project stakeholders and local stakeholders in Saint-Louis (fishermen's organisations, women's groups involved in fish processing, fishmongers, Saint-Louis citizens, local authorities, NGOs, academics, etc.), but information that would allow the environmental and social impacts of gas exploitation to be identified is sorely lacking.

31 The fishermen of Guet Ndar fear that the future construction of the gas terminal will lead to a reduction in their fishing territory in an already tense context. They are concerned that a loss of territory would lead to a drop in landings and revenue, not to mention the risk of accidents, safety problems and pollution caused by the operation. For their part, conservation stakeholders (managers of the MPA and the Langue de Barbarie National Park) are very uncertain about the future of migration corridors for certain species (avifauna, marine turtles and cetaceans) due to the noise caused by seismic activities. The decentralised government services are powerless to anticipate the risks of pollution and degradation of the marine environment related to the project. The local authorities also have an urgent need for information to deal with issues linked to coastal erosion, a major problem on the north coast, an area in which two major port projects are underway. With the retreat of the coastline particularly marked on the Langue de Barbarie and the relocation of Guet Ndar populations to the interior (which is not always successful, especially when fishing communities are very resistant to these measures), risk management for vulnerable coastal communities will require planning that takes greater account of the need for observation data on coastal dynamics[10]. In this context, updating development and management plans on the basis of documented information is imperative in order to reassess the human and financial

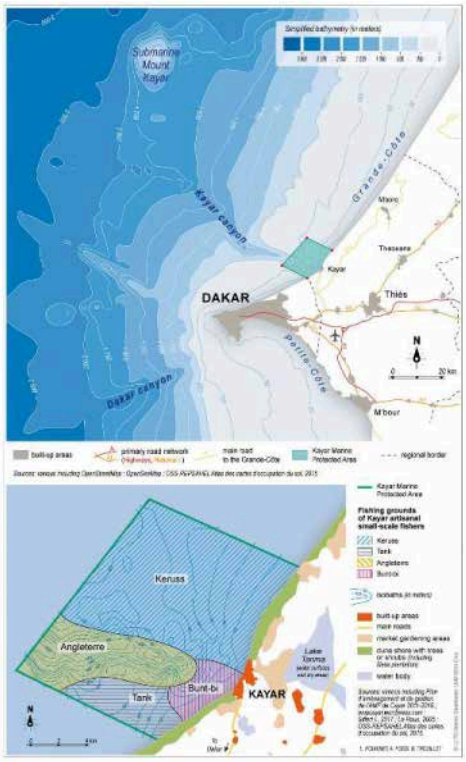
resources necessary in this new context, including for various monitoring activities – a question that currently remains without a clear answer.

Kayar MPA: mapping fishing grounds

32 The fishing areas of Senegal's artisanal fleets have expanded considerably over the last few decades. Although economically very important for the country, artisanal fishing is not yet officially and systematically geo-referenced, although a great deal of data exists. The example of the trollers of Kayar, a dynamic fishing centre, illustrates the potential that exists at a national level.

33 Located about 60 km north of Dakar (fig. 1), Kayar has long been considered one of the two main landing centres for artisanal fisheries on the north Senegalese coast along with Saint-Louis (CURY and ROY, 1987). The particular topography of the coast as well as the presence of a submarine canyon that cuts deeply into the continental shelf creates a discontinuity in the environment that strongly influences the distribution of fish in this area (CURY and ROY, 1987) (fig. 4). As early as the 1950s, artisanal fishing developed here with the construction of a paved road following the recommendations of the 1948 Dakar Maritime Fisheries Conference (CHABOU and KEBE, 1989). Subsequently, various projects have contributed to the development of the site: the Senegalese Cooperative for the Supply and Distribution of Seafood Products (Coopmer) with an industrial complex in 1950, followed by the Senegalese Artisanal Fishing Support Centres (Capas) and the Pirogue Motorisation Support Centres (Camp) in the 1970s[11]. In the early 2000s, with the support of Japanese cooperation, major developments took place to improve the marketing and processing of fishery products. In this context, the artisanal fishermen of Kayar developed an awareness early on of the uniqueness of their marine environment, which became their "fishing territory" (CHARLES-DOMINIQUE and MBAYE, 2000).

Figure 4. Kayar MPA: geographical context and fishing areas of Kayar artisanal fishermen



Source: L. Pourinet, A. Fossi, B. Trouillet
High resolution map: Figure 04 HD

34 This attachment to a “fishing territory” and the desire to preserve it, combined with strong local cohesion, have generated repeated and sometimes violent conflicts (1953, 1985, 2001, 2005) between the trollers of Kayar and the driftnetters of Guet Ndar and Fassboye (LE ROUX and NOËL, 2007; SIFFERT, 2017). The Kayar fishermen wanted to ban fishing with set nets, arguing, quite rightly, that the nets lost on the shelf edge “destroy” the trollers’ fishing grounds. However, according to some analyses, this “technical argument” was merely a catalyst for tensions between communities that existed for different reasons (CRODT, 1985). Thus, in the 1980s, the Kayar fishermen participated in the first structuring of the profession within the National Committee of Senegalese Fishermen (CNPS) and created a local Fisheries Committee. This level of organisation enabled, in 1994, a set of “management rules” to be accepted by the two main fishing communities present: the Kayar and the Guet Ndar of Saint-Louis. These “rules” made it possible to regulate the daily supply of fish in order to raise prices and compensate for the economic loss linked to the devaluation of the CFA franc (CHARLES-DOMINIQUE and MBAYE, 2000; DÈME, 2014).

35 From the end of the 1990s onwards, the possibility of acquiring a portable GPS – which can therefore be used onboard a pirogue – has had a major impact on the evolution of fishing strategies. It is interesting to note that the appropriation of GPS by Senegalese artisanal fishermen was very rapid and was not supported by any project. This new tool was an immediate success among the artisanal fleets, as in Kayar (fig. 5), facilitating the precision of the positioning of anchorage, which largely determines fishing success, particularly in the vicinity of the canyon.

Figure 5. Kayar troller looking for a position on his portable GPS

© A. Fossi, 2002

36 In 2004, the Senegalese government created four MPAs along the coast ex nihilo under pressure from a conservation NGO, without taking into account the knowledge of artisanal fishing communities. Only the Community Marine Protected Area of Bamboung was the subject of consultation with local communities before it was set up under another programme. In Kayar, it was not until the establishment of the MPA development and management plan in 2007 that community knowledge was taken into consideration (DÈME, 2014). The resulting MPA zoning map (fig. 4), based on toponymy and the knowledge of artisanal fishermen, shows precise zones determined by bathymetry, the different areas and uses, making it possible to precisely define fishing zones. The community mapping of fishing zones is very different from the arbitrary and rectangular delimitation of the MPA, but is limited to the perimeter of the MPA up to about 7 miles offshore. Thus, it does not cover all the fishing zones of the Kayar fleet, whose range has been estimated at between 10 miles and several dozen kilometres (CURY and ROY, 1987; CHARLES-DOMINIQUE and MBAYE, 2000). It is highly likely that the small-scale fishermen of Kayar have a vision of their "fishing territory" and the toponymy associated with fishing zones that extends well beyond the boundaries of the MPA towards the north, west and open sea.

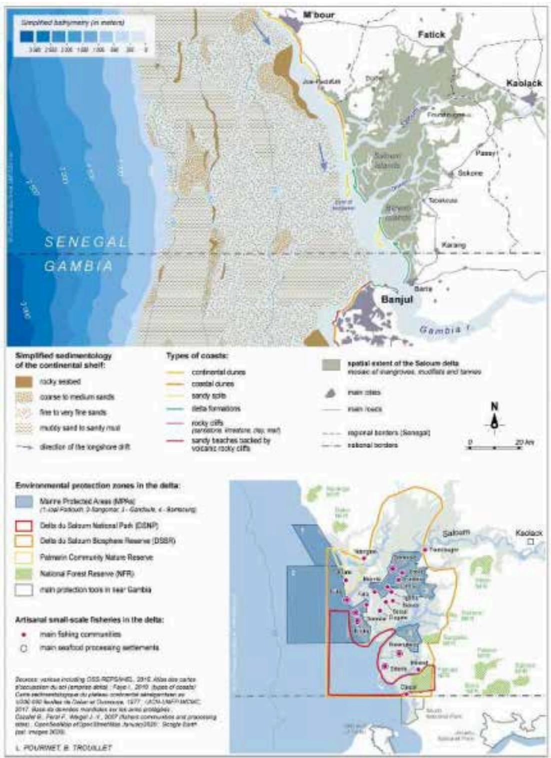
37 Within Senegal's artisanal fishing communities, there is now very detailed geographical knowledge of the zones and of artisanal fishing practices. Following the example of the work carried out in Kayar, capitalising on the knowledge of artisanal fishing communities, at least in the major fishing centres, would make it possible to draw up dynamic "maps based on the words of fishermen"[12], produced by and for artisanal fishermen, and to understand the occupation of maritime space by the artisanal fisheries sector in its entirety. Given the numerous issues that weigh on fishing in

Senegal today, producing geographic information by artisanal fishermen would contribute to envisaging a more just consideration of the fisheries sector in the framework of future MSP in Senegal.

The Saloum delta: finding a balance between traditional and new activities

38 The Saloum delta is located in the Fatick region (fig. 1), where populations living in this estuarine environment have structured the area through the exploitation of a variety of terrestrial and aquatic resources (CORMIER-SALEM, 1997). Although modest on the national scale, fishing activities in the Saloum delta are distinguished by the great diversity of resources due to the biodiversity reservoirs created by the alternation of “bolongs” (inlets colonised by extensive mangrove vegetation) and “tannes” (mangrove swamp interiors). This forms a mosaic of environments (fig. 6) that are favourable to the harvesting of various marine resources (fish, shrimp, shellfish) and other types of activity.

Figure 6. **The Saloum delta: geographical context of artisanal fisheries**



Source: L. Pourinet, B. Trouillet
High resolution map: Figure 06 HD

39 Until the 1970s, the exploitation of these resources was based on a balance between activities and seasons, with agriculture dominant (rice, maize, millet, groundnuts, sorghum, etc.), followed by artisanal fishing, oyster farming, livestock farming and the harvesting of sea products (molluscs, shellfish, etc.). However, a conjunction of factors has led more and more people to turn to fishing activities: the decline in agriculture due to the lack of rainfall since the 1970s, the fall in the price of agricultural raw

materials during the 1980s, free access to fishery resources, and insufficient regulation of the fishing effort. As a result, artisanal fishing has risen sharply in the Saloum delta: the number of pirogues increased by 38% between 2011 and 2014, accompanied by an increase in the size of pirogues and in engine power. In parallel, the number of annual trips to the sea, the technology for locating fish, and the fishing methods used have continued to develop (DÈME, 1991), leading fishermen to explore areas that were previously difficult to access by rowing or sailing over several days at the whim of the tides. These changes in the former ways of doing things have exacerbated the situation, and the increased pressure on fisheries resources is threatening the pre-existing balance to the point of raising doubt about the sustainability of fishing activities, weakening coastal communities (KÉBÉ, 2008).

40 In the Saloum delta, women traditionally do most of the fish processing and earn substantial income from this, contributing to the improvement of their families' living conditions. Yet the profound changes taking place mean they are now experiencing difficulties related to the supply of raw materials, as well as to a rise in the purchase price of fish, as they are in competition with fish traders who have much greater financial and material capacity. Despite the fundamental role local women play in the various segments of the sector (micro-trading, artisanal processing, marketing, etc.), they do not always master the methods for better commercialisation of their products. They are also subject to increased competition from foreigners (for example, from Guinea and Burkina Faso) who are increasingly entering the processing business.

41 Shellfish harvesting is another exclusively female activity. It has become the main source of local income, contributing significantly to the improvement of women's living conditions. Shellfish provide more than 90% of the animal protein consumed in the delta islands (DIOUF, 1996). Unlike fishing, where the resource is mobile, shellfish gathering is a localised activity that takes place in the mangrove channels and in the mudflats uncovered at low tide. The collection is organised by the women during the *mbissa*, i.e. the period of the month during which the low tides are diurnal. This generally lasts between 15 and 18 days per month (DESCAMPS, 1994) and is punctuated by a cycle of seven days of activity followed by four days of rest (DIOUF and SARR, 2009). Shellfish harvesting takes place during the dry season, from December to June, when it is easier to dry the products collected. Conversely, it is insignificant, or even non-existent, during the rainy season when agricultural activities mobilise almost the entire family.

42 Due to the diversity of ecosystems and landscapes as well as a rich cultural heritage, tourism is emerging in the Saloum delta, which is now the fifth largest tourist region in Senegal. There are many protected areas in this zone, but local populations were long excluded from the tourism industry. It was not until the 1990s that local populations became aware of the economic interest of tourism. Several types of tourism are now practised in the Saloum delta: fishing tourism, hunting tourism in leased areas of Niombato, and discovery tourism. Other types of tourism also exist, but are less developed (integrated rural, beach and cultural tourism). The Saloum Delta Biosphere Reserve became a UNESCO World Heritage Site in 2011, and the challenge today is to promote activities that encourage nature conservation. To this end, the policy defined by the Fatick Regional Council highlights the comparative advantages of ecotourism through the development of tourist infrastructure and the promotion of tourist products. The aim is to counter the model of large hotel complexes set up by foreign

companies with an alternative model in which the camps belong to the local population (FALL, 2006). Currently, tourism in the Saloum Delta Biosphere Reserve provides very little employment and income for the local population (DEHEUNYNCK *et al.*, 2004), as:

- almost all the camps and means of transport are owned by external investors
- most guides are not from the area
- local food and craft products are not sufficiently promoted
- the jobs reserved for villagers are often menial.

43 However, the creation of the Community Marine Protected Area of Bamboung in 2004 has been a promising development. Some tourism stakeholders believe that ecotourism is a serious avenue to explore that could have a significant impact on the future of the delta.

Some lessons on information issues in these case studies

44 These three examples highlight a fairly wide range of information issues that could affect MSP. The case of the Saint-Louis region illustrates the chronic lack of geographic information. It also shows the need to consider the spatial logic of various uses – and the interactions between these – on a range of scales (local, regional, or even global, including cross-border issues). In particular, there is a concerning lack of information on the foreseeable impacts of offshore oil and gas activity, which is likely to profoundly change the territory and coastal communities that have long been highly dependent on fishing for food and income.

45 The example of Kayar shows that, while it is necessary to document fishing practices and fleet areas in detail in order to take their specific issues into account, it is important to remember that the ways of documenting the practices (in this case, mapping them) can be diverse. Fishermen and communities can themselves be actors in the construction of information. Moreover, this active participation is probably the best guarantee of the effective appropriation of information by fisheries stakeholders (TROUILLET *et al.*, 2019).

46 Finally, the example of the Saloum delta highlights the importance of reconstructing the dynamics of human activities over a longer period of time to take these into account. There are limitations to seeing traditional activities such as fishing and shellfish harvesting solely as economic activities. Artisanal fisheries can be mainly subsistence activities, with dimensions that virtually always go beyond the framework of the market and touch on identity, culture, etc. This web of relationships is not easy to untangle, and the information that leads to decision-making must reflect this complexity. This requires a close examination of the way in which the diverse and complex reality of fisheries is coded, translated and transcribed into geographic information and not just reduced to simply market interests.

47 Taking a step back, it should be noted that these various information issues concern the entire information chain, from the production to the dissemination of data. In terms of geographic information production, the case studies clearly show that an approach of constructing information project by project, in fits and starts, has limitations, particularly when government information systems are deficient. This type of approach results in gathering information only where the attention of project sponsors

is focused, without necessarily having an overall strategy for producing this information, leading inevitably to data issues (problems of standardisation making comparisons difficult, fragmentation and gaps in data, loss of information, etc.). It is necessary to pay attention to how information is produced, for what purpose and by whom. This has opened up the field of "data sovereignty" at a time when powerful private operators (Tech Giants such as Google, Apple, Meta, etc.) have become leading data producers.

48 Gaps in knowledge can also result in the misuse of existing geographic information. Indeed, since information is often not available for MSP purposes, authorities logically resort to the "best available information", to quote a principle adopted by European authorities for MSP[13]. However, this approach has a downside, since information used for purposes other than those for which it was designed compromises its "external quality" (DEVILLERS and JEANSOULIN, 2006). From this point of view, within the framework of MSP, fisheries are a typical example of a field for which information is constructed (essentially bioeconomic information to characterise fishing effort and the monitoring of fishery dynamics), and then enlisted for want of a better way to illustrate the challenges of the fisheries sector as a whole. Given that this data only concerns the bioeconomic aspect of fisheries, it is erroneous to imagine that such information correctly reflects the issues of the sector as a whole, especially as regards small-scale or subsistence fisheries. However, this is only rarely discussed in the literature on past or current MSP processes (SAID and TROUILLET, 2020). This makes it essential to study more closely how pre-existing information or data created for MSP purposes is used. The same applies to the non-use of data. It is possible that key information exists but is not used, either through disinterest, to serve other interests or simply through ignorance. The example of fishermen's knowledge in the Kayar MPA provides a good illustration: information on fishing grounds beyond the boundaries of the MPA exists, but only that concerning the MPA is used.

49 Another challenge is the dissemination of information. In Senegal, based on the recognition of a threefold problem – the fragmentation of geographic data, the underfunding of the geographic information sector, and inconsistency between existing systems – the National Geomatics Plan (Decree No. 2009-799) has enabled the creation of a geographic data infrastructure called "GéoSénégal"[14]. However, the maritime and coastal space remains on the fringe of the priority application areas of this ambitious plan supported by the Canadian International Development Agency, the United States Agency for International Development (USAID) and the European Union (GICC, 2012)[15]. In addition to this plan, there are many other initiatives also supported by international agencies: for example, the West Africa Coastal Areas Management Programme (WACA)[16] and one of its offshoots (WACA-F), supported by a French public institution, which has set up a data portal to make available geo-referenced orthophotographs documenting coastal retreat on a regional scale[17]. If the information hosted in these portals is enlisted for MSP, it will be important to look closely at the data, as this type of infrastructure in general shapes the representation of issues (BOUCQUEY *et al.*, 2019), sometimes to the point of becoming a mode of governance in itself rather than a simple governance tool (CAMPBELL *et al.*, 2020).

50 A further issue concerns the transversal appropriation of information at three major phases: its production, its use and its dissemination. In terms of the appropriation of the construction of information, how can the various stakeholders in MSP contribute to

producing geographic information or alternative data that not only enriches knowledge, but makes the power relationships around geographic information used for spatial planning more explicit? Regarding the use of information, how is it possible to reduce or ideally eliminate the "black box" effect of many information processing tools to allow an understanding of the assumptions underlying data processing? Finally, concerning the appropriation of the tools and methods for disseminating information, how can alternative information that can contribute to a more diverse, complex vision, or a vision out of step with the dominant representations and narratives, be made visible?

51 These considerations on the issues around information at stake in MSP will resonate differently depending on the type of planning (spatial, strategic, communicative, prescriptive, integrating land/sea and the different levels of these) and the entity leading the approach (public agencies, NGOs, international institutions and the different combinations of these). Whatever the case, the stakes around geographic information in MSP call for redoubled attention, as this can be instrumentalised by the dominant powers, whether political or economic, particularly when MSP concerns populations that are more vulnerable to this risk of domination, such as coastal communities in developing or emerging countries.

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NOTES

1. In a census by the United Nations Educational, Scientific and Cultural Organisation (UNESCO), the Banc d'Arguin National Park (BANP) in Mauritania has oddly recently been listed as an MSP initiative, although the BANP has existed since 1976.
2. Mami Wata Project: https://mamiwataproject.org (accessed May 2020)
3. http://senegal-emergent.com/fr/ (accessed May 2020)
4. Saint-Louis, Dakar, Petite Côte, Fatick, Casamance (Kafountine and Ziguinchor) on the coast, and Tambacounda inland: http://senegal-emergent.com/fr/zones-touristiques-integrees-zti (accessed May 2020).
5. In the period between the end of the previous agreement and a new agreement signed in July 2018, the absence of a fisheries agreement for 2.5 years between Senegal and Mauritania was highly detrimental to Senegalese fishermen, particularly those from Saint-Louis. Between 1950 and 2010, 48% of landings in Senegal by Senegalese migrant fishermen came from Mauritanian waters (BELHABIB *et al.*, 2014).
6. www.spcsrp.org (accessed May 2020)
7. www.spcsrp.org (accessed May 2020)
8. https://www.jeuneafrique.com/742328/economie/senegal-mauritanie-eiffage-et-saipem-construiront-le-terminal-gazier-de-grand-tortue-ahmeyim/ (accessed May 2020)
9. Kosmos Energy Ltd subsequently sold the majority of its shares to British Petroleum, which became a shareholder in both countries.
10. www.international.gc.ca (accessed March 2020)

11. The Capas and Camp initiatives, financed with Canadian cooperation, were part of the first development projects for artisanal fishing in Senegal in the 1980s.
12. "Fishermen's maps" based on the toponymy of fishing areas could include "metadata" related to: (1) the determination of these areas (by who? why?), (2) the species present according to season, (3) the fleets and fishing strategies.
13. Directive 2014/89/EU Art. 10.
14. http://www.geosenegal.gouv.sn/ (accessed May 2020)
15. The plan's priority application areas are "land registration and the land sector in general, spatial planning in support of local governments, agriculture, water management, transport, democracy support, natural resource management [and] civil protection" (GICC, 2012, p. 34).
16. https://www.wacaprogram.org/ (accessed May 2020)
17. https://cerema.maps.arcgis.com/apps/MapJournal/index.html?appid=ff30db5d09dd42ec8f4b8145fd346a3c (accessed May 2020)

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Chapter 11. South "Atlanticism"

Ocean governance in a community of interest

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Introduction

1 Since the fall of the Berlin Wall in 1989, geopolitical developments have initiated a reorientation of the geopolitical centre of gravity southwards and eastwards, alongside a process of growth spurred by globalisation in emerging countries. Brazil has been one of the leading emerging countries in this period, as has South Africa, on the opposite edges of the South Atlantic basin. In parallel, in recent decades, Brazil has extended its jurisdictional rights over a vast maritime area with a potentially high level of natural resources. On both sides of the South Atlantic, expectations of economic development linked to maritime activities have risen. Brazil, South Africa and the Gulf of Guinea have begun to be configured as economic and political poles in a basin bordering a new continent – Antarctica – to be appropriated along with its waters.

2 In geopolitical terms, the tropical Atlantic presents a marked political and geographical asymmetry between the South American and African coasts. The former is characterised by the territorial domination of a single country, Brazil, with an expansive continental and maritime area. The southeast Atlantic, on the other hand, is bordered by a mosaic of relatively small countries, with the exception of Angola and Namibia. Another geopolitical characteristic of the tropical Atlantic is its islands, which include: (1) a block of microstates in the northwest (Caribbean islands); (2) Brazil's oceanic islands in the centre of the tropical basin; and (3) the presence of islands that are colonial remnants, which creates large jurisdictional zones around territories of non-coastal (former colonial) countries in the tropical belt.

3 The maritime economy has enormous potential for development, particularly in the field of energy resources (Brazil and the Gulf of Guinea), biological resources – traditionally exploited by exogenous fishing powers – and the construction of port infrastructure, currently of little relevance, but which is set to grow, particularly in

western Africa, in connection with the strong development potential of the Gulf of Guinea.

4 At present, ocean governance in the South Atlantic is conditioned and limited by the lack of institutional development of coastal states, especially in the southeastern Atlantic basin, which is still dominated by fragile states, and in the southwestern basin, with its high number of island micro-states with limited ocean management capacity. In this context, Brazil, the largest maritime state in the region and the one with the greatest technical and institutional capacity to develop ocean governance, has the highest potential for leadership.

5 The objective of this chapter is to analyse the extent to which the governance of the South Atlantic basin – where the expectations are high and the unknowns are many – could lead to the construction of a transatlantic community in the Southern Hemisphere, overcoming institutional structures with fragile transatlantic political, cultural and economic links. Although to date a strong network of common interests has not been built in the South Atlantic – unlike the Atlanticism in the North Atlantic – jurisdictional expansion requires coastal states to adopt maritime policies commensurate with the extent of territorial authority acquired. This chapter focuses on the maritime space that spans the two tropics, from the shores of Brazil to the coasts of the Gulf of Guinea. As in the case of the North Atlantic, the western edge is occupied by countries with a large geographical extent compared to the eastern edge, which is composed of mainly smaller countries, including the largest concentration of landlocked states in the world.

6 The first section provides a description and analysis of the geomorphology of the tropical Atlantic, and the second discusses the existing maritime policies on each edge of the South Atlantic basin. A particular focus is given to the importance of maritime development and the degree of cohesion that may be possible for maritime governance in this tropical basin.

The geopolitical seascape of the South Atlantic

7 Over the last 25 years, Brazil, other South American countries, and the Portuguese-speaking African countries (PALOPs) (Angola, Cabo Verde[1], São Tomé and Príncipe, Guinea-Bissau, Mozambique and Equatorial Guinea, which recently adopted the language) have forged closer horizontal relations, with the aim of increasing cooperation and reducing asymmetries in areas of strategic interest, such as the South Atlantic. These relations are even closer in the maritime sphere, due to the entry into force on 16 November 1994 of the United Nations Convention on the Law of the Sea (UNCLOS), which allows coastal states to acquire rights to use and protect living and non-living resources in their exclusive economic zone (EEZ) and extended continental shelf (ECS).

8 Many of the PALOPs are located near the Gulf of Guinea, an area characterised by the existence of hydrocarbon basins and other natural and mineral resources. At the same time, piracy and other transnational illicit activities, commonly referred to as "new threats", occur all along the West African coast. These factors make them susceptible to being controlled by states with greater systemic power (Marroni, Castro and Violante, 2018). Brazil is included in this geopolitical equation, as the West African coast is part

of Brazil's eastern maritime frontier and also involves almost 95% of Brazil's foreign trade conducted by sea (Brasil, 2020).

9 In sub-Saharan Africa, Brazil is focusing on economic and military rapprochements with South Africa, Nigeria and Namibia, as well as with the PALOP countries, through the Community of Portuguese-speaking Countries (CPLP). Brazil is also forging bilateral relations with South Africa within the Southern African Development Community and the India–Brazil–South Africa (IBAS) Forum established in 2004.

10 Brazil's presence in the CPLP can be analysed as having two advantages: (1) for Brazil, it can extend its interests abroad, while seeking to maximise all possible resources, including occupying larger spaces than other nations in this community; (2) for the other states, Brazilian foreign policy in conjunction with the CPLP can address global interests that would be impossible to achieve individually (Miyamoto, 2009).

Relations in the South Atlantic

11 The current interest in the resources and potential of the South Atlantic Ocean is not an isolated fact, and even less a global novelty. On the contrary, this interest is part of a system of expansionism by great powers, which globalises actions in the geopolitical, economic and environmental context. Historically, the Atlantic Ocean, now politically divided into North and South to justify the sharing of natural resources, sea routes and naval power, has had a significant impact on the international system. The geostrategic shift to the new oceanic sphere in the South has led to the expansion of the jurisdiction of the continental shelf and a sea-based economy, with new investments in job training and naval technology (MARRONI, 2013).

12 In this regard, Brazil, Angola, Cabo Verde, São Tomé and Príncipe and Guinea-Bissau – all members of the CPLP – as well as Nigeria, Namibia and South Africa, acquired greater potential relative power in the international system with the adoption of UNCLOS in 1994. Brazil and the coastal states of West Africa have shown that they possess privileged strategic positions, able to control large maritime expanses full of living and non-living resources.

13 Yet the increase in the sovereignty of these states has made them more susceptible to new threats, including piracy, drug trafficking, human trafficking and other international crimes, in addition to the constant threats from extra-regional powers. This new and evolving geopolitical context has led to proposals that the countries of the South Atlantic incorporate precepts related to their internal policies (internal sovereignty) and their external policies (external sovereignty) to safeguard defence and security. The South Atlantic Peace and Cooperation Zone (ZOPACAS) is a good example of how this area is projecting itself in world geopolitics through the formation of treaties and political integration between Africa and South America. This zone, created in 1986, has also established fruitful relations with Argentina (VIOLANTE, 2017).

14 In the 1990s, negotiations on a collective security pact along the lines of the North Atlantic Treaty Organisation (NATO) resurfaced in the South Atlantic basin, under the name of the South Atlantic Treaty Organisation (SATO), an idea that had been initially proposed in 1976 by the United States, Argentina and South Africa. In both periods, the Brazilian government of the time did not think that any external influence or

deepening of military alliances at the regional level would contribute to national strategic objectives.

15 In line with the development reality of emerging countries, according to HILL *et al.* (2011), multilateral cooperation in its various forms is on the agenda of large economic blocs in search of a new global governance – which would include ocean policy. However, from a conceptual point of view, the strategy of blocs or countries illustrates the same tension between efforts to strengthen effective multilateralism on the one hand, and efforts to establish privileged bilateral partnerships with various great powers on the other. Thus, in a globalised world, the United States and Russia, as well as Japan, China, Canada and India, are actual or potential strategic partners.

16 The term BRICS (Brazil, Russia, India, China and South Africa) was coined in 2001 to describe emerging powers seen as poised to achieve a considerable degree of stability and prosperity in the coming decades. These countries were and (in most cases) are undergoing a historical transition that is shifting the locus of the global economy, changing the world in order to reflect a greater diffusion of power with the emergence of new major powers. The G20, formed in 1999 to replace the G8, was an important political step in the changing hierarchy of global interests, which is beginning to rebalance the world order with the weight of BRICS plus other countries with growing power (e.g. Australia, South Korea, Indonesia and Turkey).

17 Today, Brazil is gaining visibility as a strategic player in the global energy sector. It is likely that non-renewable energy consuming countries will shift their interests to the fossil fuel resources of the South Atlantic. This would lead to a shift in the geographic axis from the oil-rich Middle East, troubled by various ethnic and political conflicts, to the South American continent. This may lead to a "flight to the South" of large industrialised countries of the Northern Hemisphere, a "course alteration" that may establish a "new Atlanticism" (MARRONI, 2014).

Maritime space: jurisdictions

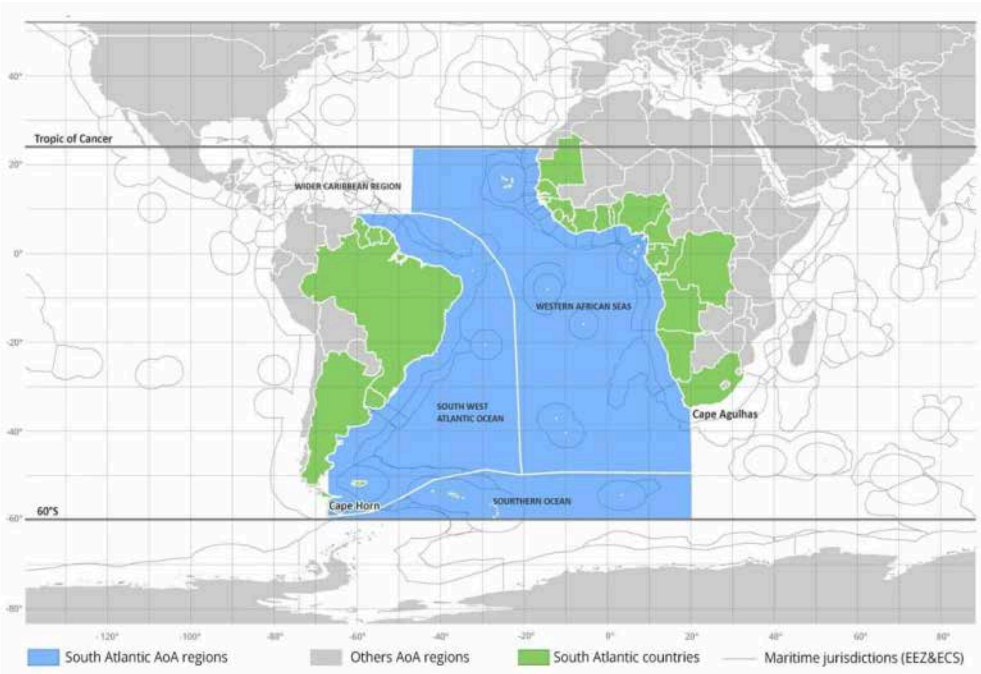
18 It is important to look at the jurisdictional structure of the South Atlantic maritime space to better understand its political and geographical organisation. The distribution of maritime space under national jurisdiction and beyond, as well as the zones of the coastal states and political blocs of the region, allow the characterisation of this maritime picture and its configuration as a political sphere, as well as its impacts on the governance of the South Atlantic.

19 Although the geographic delimitation of maritime regions may be based on purely objective elements (e.g. latitude), it is usually functionally defined by political factors. For example, the North Atlantic (including the so-called "Atlantis") is closely linked by a political alliance, of which 16 of the 29 members are not on the shores of that ocean and four are landlocked countries.

20 For our purposes here, the South Atlantic is defined as the maritime area south of the Tropic of Cancer, consisting of the southwest Atlantic and West African waters, i.e. excluding the Southern (Antarctic) Ocean and the Greater Caribbean (fig. 1). The context is a basin flanked by blocs or alliances, such as the Southern Common Market (Mercosur) (western Atlantic) and the African Union (eastern Atlantic)[2]. A total of 29 countries, with a population of approximately 1.1 billion (844 million in Africa and 258 million in South America), are unequally distributed around the two coasts

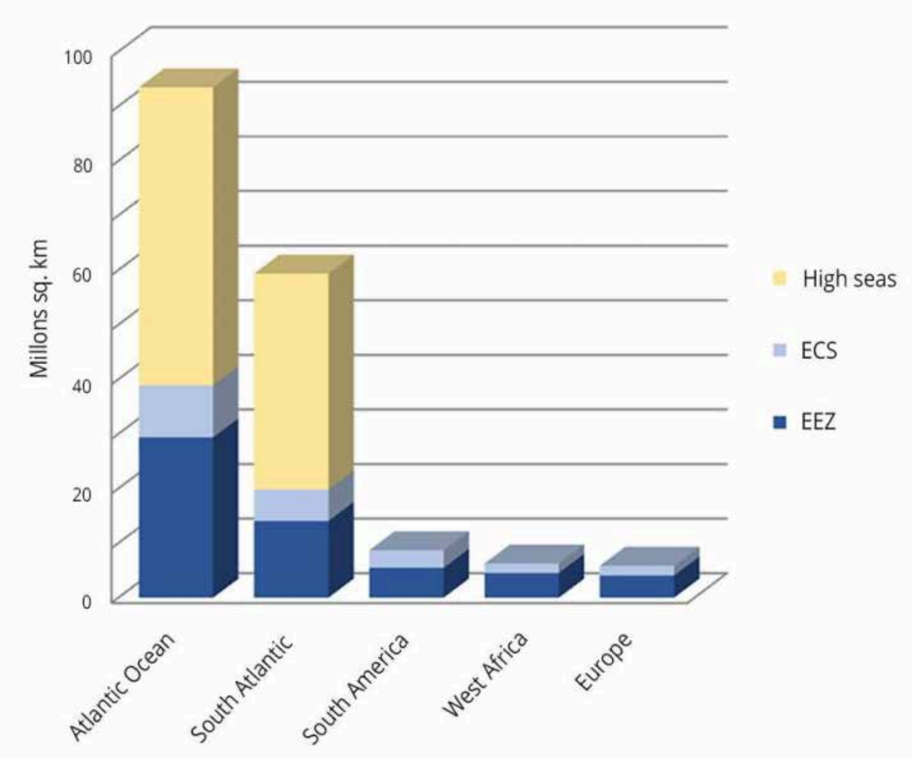
bordering this maritime area: 24 in Africa compared to 5 in South America. This asymmetry is also reflected in the distribution of waters under national jurisdiction (table 1): 7.8 million km^2 (South American coast) versus 6.1 million km^2 (African coast). In terms of jurisdictions, compared to the Atlantic basin as a whole, the South Atlantic has 26% of the basin's EEZs, 12% of the continental shelf beyond 200 miles and 74% of the high seas (table 2), which represents a greater presence in areas beyond national jurisdiction, i.e. the Southern Hemisphere commons (figure 2).

Figure 1. South Atlantic regions



Source: United Nations Division for Ocean Affairs and the Law of the Sea (Doalos, 2022)

Figure 2. Jurisdictions and marine regions



Source: Doalos, 2022

Table 1. Countries by region, maritime jurisdictions and populations

Country/Region	EEZ	ECS	Total	Population (thousands)
European Union (EU)	133,924	81,224	215,148	283
French Guiana	133,924	81,224	215,148	283
Europe (non-EU)	3,911,061	1,692,524	5,503,585	8
United Kingdom (overseas territories)	3,469,894	1,596,928	5,066,822	8
Norway (Bouvet Island)	441,167	95,596	536,763	
South America	5,465,511	3,194,700	7,805,585	258,357
Guyana	135,996	57,531	193,527	778
Suriname	128,349	82,834	211,183	563
Brazil	3,645,625	1,818,419	4,609,417	209,288
Argentina	1,423,176	1,145,796	2,568,971	44,271

Uruguay	132,365	90,120	222,485	3457
North Africa (Maghreb)	155,195		155,195	4420
Mauritania	155,195		155,195	4420
Central Africa	2,944,793	158,687	3,028,304	420,692
Cabo Verde	796,454		796,454	546
Equatorial Guinea	308,219		308,219	1268
Liberia	246,079	75,176	246,079	4732
Ghana	224,697	16,707	241,404	28,834
Gabon	193,120	38,537	231,658	2025
Côte d'Ivoire	174,232	20,267	194,499	24,295
Nigeria	181,600	8001	189,600	190,886
Sierra Leone	159,264		159,264	7557
Senegal	157,477		157,477	15,851
São Tomé and Príncipe	130,658		130,658	204
Guinea	108,967		108,967	12,717
Guinea-Bissau	105,728		105,728	1861
Republic of Congo	40,466		40,466	5261
Joint scheme	34,539		34,539	
Benin	30,025		30,025	11,176
Gambia	22,526		22,526	2101
Togo	15,378		15,378	7798
Cameroon	14,311		14,311	24,054
Democratic Republic of Congo	1050		1050	81,340
Southern Africa	1,434,666	1,526,162	2,960,828	89,035
Namibia	559,589	1,059,364	1,618,953	2534
Angola	500,597	365,222	865,819	29,784
South Africa	374,480	101,576	476,056	56,717

Total	14,045,150	6,653,298	19,768,645	772,95

Source: Doalos, 2022 and World Bank, 2021
* Data from the maritime jurisdictions of French Guiana are not included in the "South America" section.
EEZ: exclusive economic zone
ECS: extended continental shelf

Table 2. Overview: South Atlantic jurisdictions

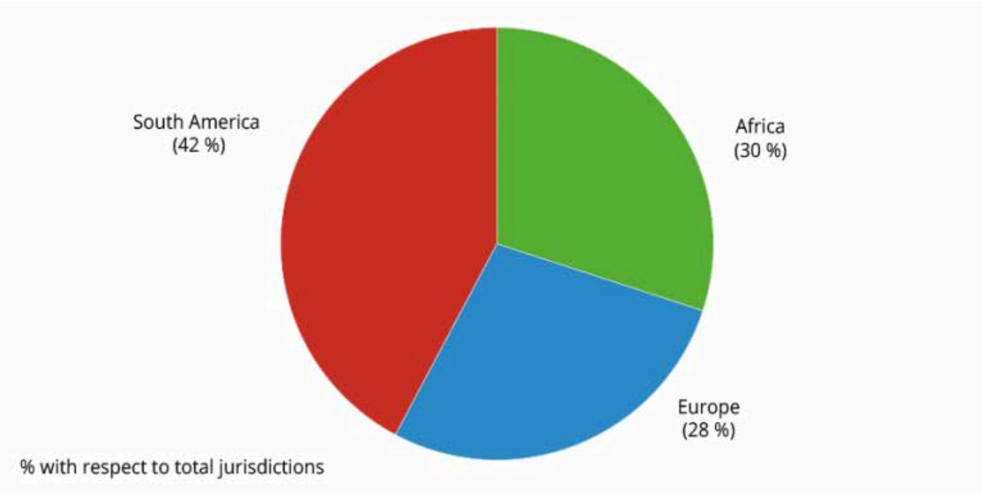
Jurisdictions (1)	Surface area	
	km²	% of the Atlantic basin
EEZ	14,045,150	26%
ECS	6,653,298	12%
High seas	39,541,087	74%

Source: Doalos, 2022
EEZ: exclusive economic zone
ECS: extended continental shelf

21 What really distinguishes the South Atlantic from the North Atlantic is the significant presence of the jurisdiction of European states over waters, which represents 28% of the jurisdictional space (fig. 3), predominantly by the United Kingdom, due to its island territories (Ascension, St Helena, Tristan da Cunha, Falklands, South Georgia, Sandwich Islands). The geopolitical distribution of jurisdictions divides the basin into three major zones (fig. 4): the two edges adjacent to the two continents and the central zone occupied by European island territories, favouring the integrity and political cohesion of the maritime basin.

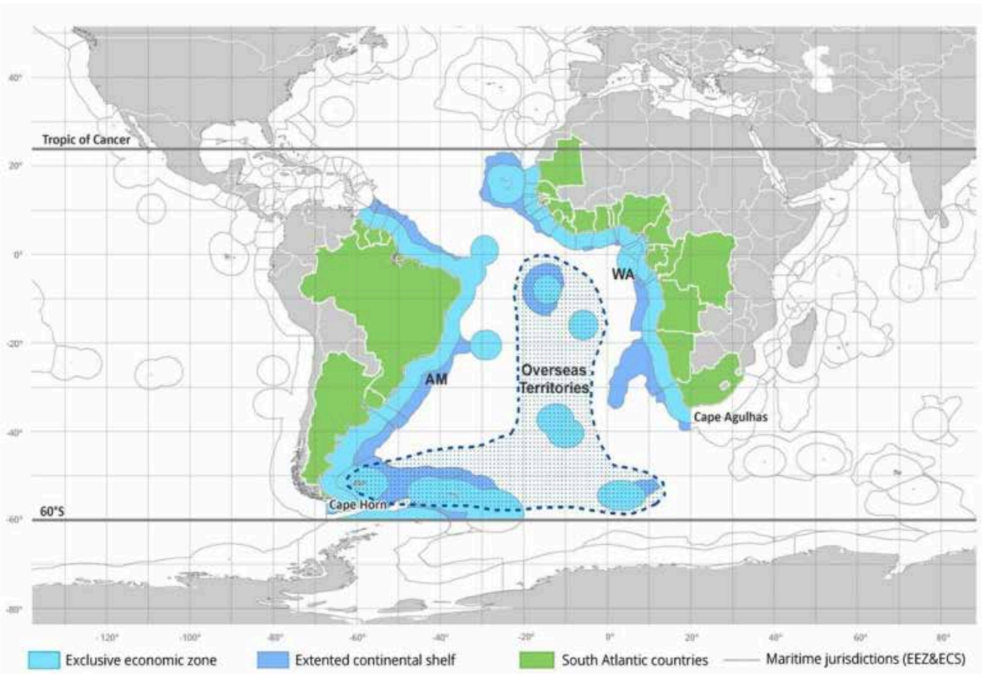
22 Although there is a certain regional balance – the South American coast, the central islands, the African coast – the asymmetry is very pronounced in terms of the number of countries in each zone, which introduces potential difficulties in the decision-making process, since national institutions have sovereignty in international and regional bodies, with distinct tasks related to ocean governance.

Figure 3. Distribution of maritime jurisdictions in the South Atlantic



Source: Doalos, 2022

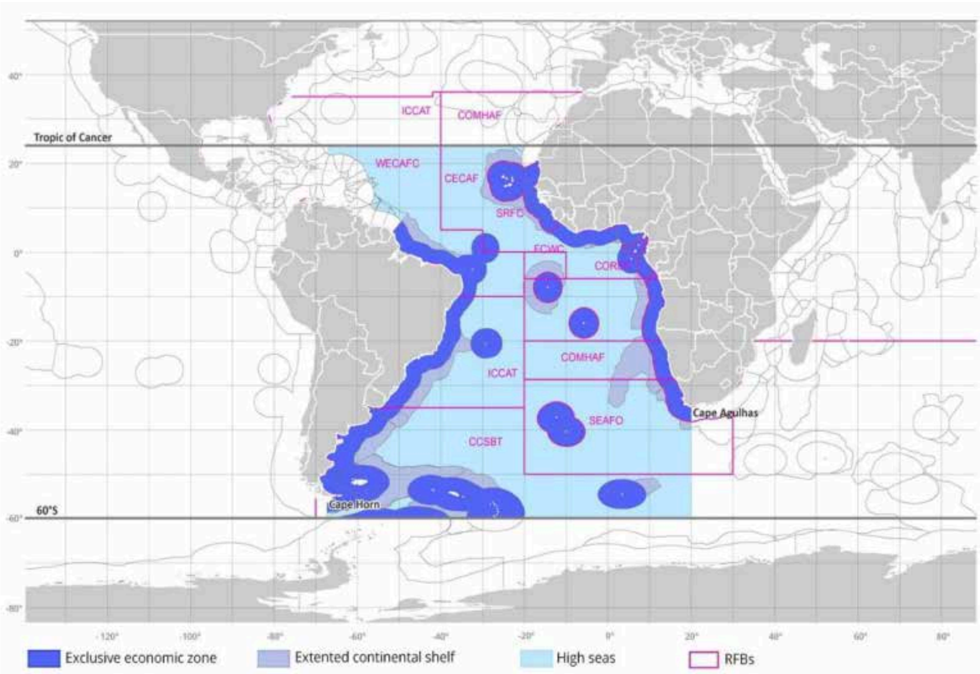
Figure 4. Overseas territories



Source: Doalos, 2022

23 Fishing activity is managed by organisations, notably by regional fisheries bodies (fig. 5).

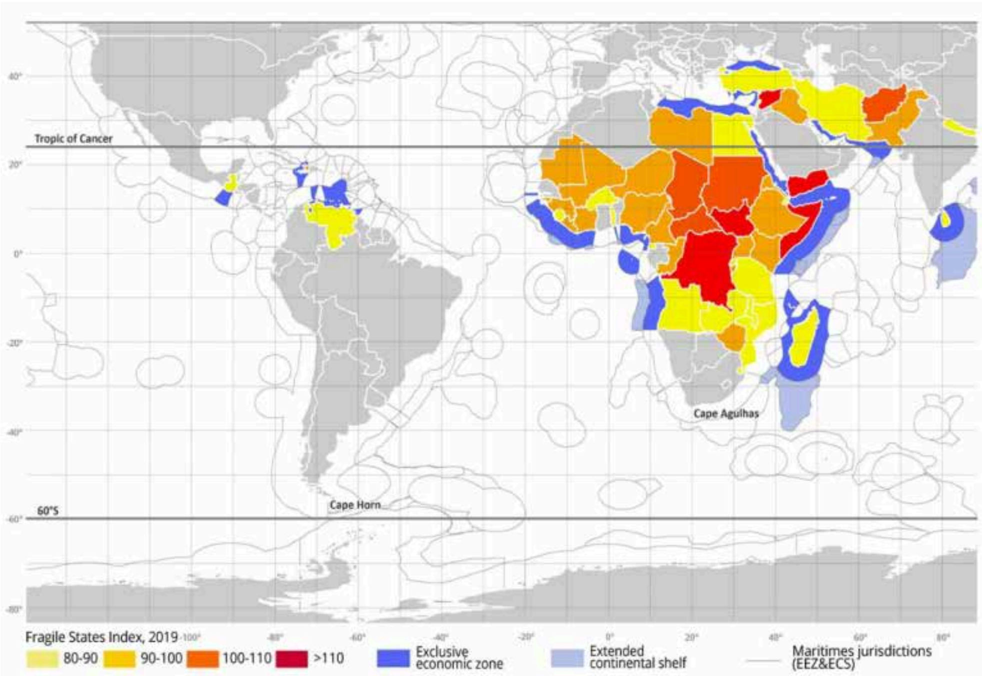
Figure 5. Regional fisheries bodies



ICCAT: International Commission for the Conservation of Atlantic Tunas
COMHAFAT: Regional Convention on Fisheries Cooperation between African States bordering the Atlantic Ocean
SRFC: Sub-Regional Fisheries Commission
FCWC: Fisheries Committee for the West Central Gulf of Guinea
COREP: Regional Fisheries Commission for the Gulf of Guinea
SEAFO: South East Atlantic Fisheries Organisation
CCSBT: Commission for the Conservation of Southern Bluefin Tuna
Source: Doalos, 2022

24 Regional fisheries bodies provide a framework for ocean governance, although national limitations and knowledge gaps may reduce their capacity to act. The Fragile States Index (FFP, 2019) (fig. 6) shows the location and relative position of the maritime spaces most exposed to political-institutional shortcomings, particularly in terms of territorial control. This highlights the asymmetry around the South Atlantic basin.

Figure 6. Fragile states



Source: Doalos

25 In summary, the maritime political space reveals three main points:

- *Uneven maritime authority*. In the South Atlantic basin, the surface area beyond national jurisdiction is twice that of the space subject to sovereignty and jurisdictional rights. The 29 coastal states exercise responsibility over nearly 20 million km^2, but with a very uneven and somewhat unique distribution: the country with the largest area of maritime space under national jurisdiction is actually located in the North Atlantic, the United Kingdom (5 millions km^2), followed by Brazil (table 1). The Democratic Republic of Congo has the smallest area (1,050 km^2), although it is the third largest country in terms of population (after Brazil and Nigeria).
- *Cohesion versus fragmentation of maritime authority*. South America shows a certain concentration of maritime territorial power, with five countries controlling 42% of the space under national jurisdiction, while in Africa 24 states control 32% of the maritime space subject to sovereignty and jurisdictional rights – a significantly more fragmented situation. This is of direct relevance to maritime safety (shipping lanes) and national security, as authority is distributed between a large number of countries with very different levels of institutional development.
- *Transoceanic integration*. A comparison of the northern and southern maritime hemispheres shows the different levels of integration between the eastern and western edges. While north of the equator a political, economic and cultural alliance has been consolidated (although not without criticism), the south still lacks sufficiently strong links between countries to build a similar alliance. In this context, the existence of a third maritime jurisdictional bloc with extra-regional authority may be relevant, although difficult to specify.

The blue economy

26 As regards the South Atlantic maritime economy, we must first choose how to define this. The term "blue economy" can have different meanings (SILVER *et al.,* 2015), as it can refer to a particular school of economic thought (the so-called "circular economy"), whose main representative is Gunter Pauli, but has also been adopted by the European Union (EU) in its strategy to develop the maritime economy (EUROPEAN COMMISSION, 2012, 2017, 2018). While for some specialists and organisations focused on the environment, the blue economy means the sustainable use of the sea and its resources in line with economic development, for others it is a broad concept, referring to all marine economic activities, whether sustainable or not. Here, we use the approach that the EU and other international organisations such as the Food and Agriculture Organisation of the United Nations (FAO) (Blue Growth Initiative) take in defining the maritime economy: considering all sectors in the maritime economy that can contribute to the creation of prosperity, jobs and the eradication of major social problems (poverty, unemployment, malnutrition, etc.)[3].

27 While not exhaustive, this section will examine the importance of the sea and its resources for the coastal states in the South Atlantic, assessing the potential of this marine environment for the creation of wealth and employment and its link with sustainable and environmentally sound development. It looks at both the role played by "traditional" economic activities (exploitation of living marine resources, offshore hydrocarbons, port activities, maritime industry, maritime transport, coastal tourism) as well as emerging or innovative activities (renewable energy, marine biotechnology, mining, desalination, environmental protection, defence and security, research and education).

28 Since the 1970s, the South Atlantic has been considered by its coastal states as a marine area of enormous economic potential. This has led to growing strategic and economic interest in this oceanic region, both because of the presence of certain major emerging powers (Brazil and South Africa) and for strictly economic factors (importance of maritime routes and marine resources, especially fishery resources and offshore hydrocarbons) (GREÑO VELASCO, 1976; BRAINARD and MARTÍNEZ-DÍAZ, 2009).

29 The "Shackleton Report", an economic survey of the Falkland Islands conducted by Britain in 1976, highlighted the significant potential for fisheries and hydrocarbons in the waters surrounding the archipelago – territory disputed by Argentina (GREÑO VELASCO, 1977). Subsequent studies have also highlighted the importance of fisheries in the southwest Atlantic and on the African Atlantic coast, as well as the existence of large, as yet untapped, hydrocarbon reserves on the Brazilian continental shelf. In terms of fisheries, catches in 2016 were around 1.5 million tonnes (1.7% of the world total) in the southwest Atlantic (FAO Major Fishing Area 41) and around 1.7 million tonnes (1.85% of the world total) in the southeast Atlantic (FAO Major Fishing Area 47) (FAO, 2018a).

30 Briefly, several important differences between the two sides of the South Atlantic can be highlighted.

31 The situation in South American countries is generally much more socio-economically developed. Maritime economy projects are emerging strongly in these countries: for example, in Argentina, where the blue economy is seen as important for the national

economy (BARUCH and DRUCAROFF, 2018), and includes innovative activities such as algaculture, deep-sea mining and renewable energy production (PAULI, 2017). In Brazil, marine economic activities account for about 19% of GDP and are seen as having a very promising economic and geopolitical future, given the country's intention to extend its continental shelf (this extension request is currently under review by the UN Commission on the Limits of the Continental Shelf) to take advantage of its significant resources. Uruguay is another country in the region with efficient (and growing) infrastructure and port traffic, while the Guianas cover a small territory heavily dependent on foreign trade and thus on maritime traffic.

32 Compared to the maritime economies of South American countries bordering the South Atlantic, those of the coastal states of Africa represent a more "critical" or at least contradictory situation. Most of these countries have much more fragile economies and face enormous social and demographic challenges, the consequences of which are difficult to manage in many cases. While these African countries can be considered relatively emerging states, they still suffer from important shortcomings: lack of adequate infrastructure, very low maritime traffic, limited or no development of innovative maritime activities, development of an extractive (hydrocarbon) sector that is subject to conflicts, and the low positive impact of economic activities on the general well-being of the population. Other disruptive factors include illegal fishing and trafficking, generating insecurity and piracy in the waters of some countries (leading to "failing seas"), for example. On a more positive note, the existence of underexploited marine resources is motivating the recent interest of many African countries to rethink the basis of their development. Different management strategies are therefore being put in place, making the blue economy a realistic possibility to fight hunger and poverty and creating a certain climate of optimism (UNITED NATIONS/ECONOMIC COMMISSION FOR AFRICA, 2016). Several African countries are turning to the blue economy and putting in place policies and institutions (ministries, agencies, etc.) to plan and diversify their economies in this sense, taking into account the untapped potential of the sea.

33 In short, the South Atlantic is a very diverse and uneven maritime area, with substantial differences between its two shores, but with significant economic potential. The possibility of offering an alternative maritime trade route to the Persian Gulf–Red Sea–Suez–Mediterranean route, the existence of a belt of hydrocarbon reserves off the coasts of Argentina and Brazil and in the Gulf of Guinea, as well as the exploitation of marine resources to obtain clean energy or biotechnology products all point to a future of blue growth, especially for countries willing to innovate and manage these marine areas rationally. The establishment of regional cooperation initiatives in and between Africa and Latin America in favour of blue growth could be a useful starting point to address these challenges.

Maritime policy and planning: Brazil and West Africa

Maritime development in Brazil

34 Despite its uneven economic and political evolution in recent years, Brazil's growth, geographic and demographic weight, and maritime expansion make it a key player in the southern hemisphere. Brazil occupies a central position both in South America and

in the South Atlantic basin, so any cooperation initiative between the western and eastern Atlantic will be conditioned by the circumstances of this country.

35 Since the early 1970s, maritime policy has represented a new face of Brazilian development, through a number of initiatives to formulate national policies for the sea. This takes considerable importance in the case of a large emerging power like Brazil. The strategic position of Brazil in the South Atlantic provides excellent conditions for an analysis of changing sea policy (MORRIS, 1979).

36 During the 2000s, Brazil experienced a phase of economic growth that translated into economic and social development, which in turn required government initiatives such as job creation, improvement of workers' income and social protection. The growth of the state was accompanied by opportunities for new investments in various sectors of the Brazilian economy, including an entire segment of marine-related businesses and jobs. Historically, Brazil has long had a coastline with significant navigational possibilities, and its waters have also been a source of fishing and natural resources valuable for the country's development. However, today oil exploration on the Brazilian continental shelf is the coveted target of investors, national or foreign (MARRONI, 2013).

37 The political regulation of the use of maritime resources and coastal spaces in Brazil became a growing concern in the 1970s, as did environmental planning at the federal level. International pressure to preserve the country's environmental heritage led Brazil to create, in 1973, the State Department of the Environment (SEMA), linked to the Ministry of the Interior, as a first step in integrated government planning aimed at the conservation of Brazilian biodiversity. One year later, by Decree No. 74,577 of 12 September 1974, the Interministerial Commission on Marine Resources (CIRM) was created with the aim of coordinating topics that would lead to a national policy for the Brazilian coastal region (MARRONI and ASMUS, 2005).

38 Since the passing of Decree No. 5377 of 23 February 2005, Brazil has had a specific public policy on marine issues. The first version of the National Policy for Marine Resources was produced in 1980. Following that came more than 25 years of continual revisions of the Sectoral Plans for Marine Resources (PSRM), alongside important changes in the national and international context related to seas, oceans and coastal or transitional areas. Since the 2005 decree, this policy has been updated through a series of instruments that guide the management of marine resources. Of these, the Multiannual Plan 2004–2007, also known as "A Brazil for All", served as the basis for marine policy in Brazil.

39 During the revisions of the PSRMs, discussions contributed to structuring political thinking regarding the sea and generated knowledge about the marine environment and the sustainable use of its resources, emphasising the socio-economic dimension. Within the framework of institutional cooperation, the governance of marine areas is based on the political, economic and environmental management of government activities in these areas. The understanding gained from an initial study of the coastal zone, in accordance with the strategic importance of the South Atlantic for Brazil, as well as Brazil's interest in maintaining a research base in the Antarctic, reaffirmed the country's commitment to the sea.

40 Currently, the tenth PSRM (2020–2023) (BRASIL, 2019) is in force, which aims to promote the training and resources for education professionals, community leaders and other

opinion makers to develop educational programmes on the role of the oceans for the economy, quality of life and health of all, in order to improve the capacity of future generations to contribute to the development of the blue economy.

Brazil's maritime expansion: leadership in the tropical Atlantic

41 Global governance of the oceans has become dependent on the internationalisation of knowledge about the sea and several expansionist actions derived from external political processes, through the agreement of international organisations that manage mechanisms to organise this space (such as the UN Commission on the Limits of the Continental Shelf). In the case of developing countries, the narrow boundaries of their maritime jurisdictions were typically inherited from the former colonial powers. Newly independent countries were not yet fully aware of the importance, especially economic, of the seas adjacent to their coasts. To a large extent, the industrialised countries tried to preserve the freedom of action of their military fleets, merchant ships, fishing vessels and scientific expeditions.

42 Until 1970, only Latin American countries, some African and Asian countries and Iceland had extended sovereign or jurisdictional rights over adjacent waters in one way or another. Latin America initiated the process of extending national maritime jurisdictions. Several Latin American countries were the forerunners in maritime expansion: Argentina in 1946, and Chile and Peru in 1947, setting the extension of adjacent waters at precisely 200 nautical miles and proclaiming sovereignty and jurisdiction over this territory (CASTRO, 1969; MARRONI, 2013).

43 In this context, the meetings prior to the UN Convention on the Law of the Sea (UNCLOS, adopted in 1982) and, in particular, the action of some Latin American countries, had two fundamental consequences on the content of the convention: (1) they limited the proposal of the two superpowers at the time (USA and USSR), in a conference with a limited agenda, where the pressure against the expansion of national maritime zones was particularly strong; (2) they removed the issue of the definition of coastal state jurisdiction from the specific scope of negotiations on the common heritage of humanity. The political/diplomatic picture this presented was worrying to Brazil, which was seriously considering the 200-nautical-mile option. On the one hand, developing countries would, in principle, have an interest in assigning broad geographical boundaries in international waters. On the other, the maritime powers were keen to prohibit measures – so far adopted by a minority of member states – to extend national jurisdictions over maritime waters. While there were political/diplomatic factors that would justify Brazil's decision to extend its maritime domain, there was the very real prospect that this move would provoke a strong negative reaction from traditional maritime powers, with which the country had friendly relations and a good understanding. Nevertheless, it was concluded that the political/diplomatic cost would be tolerable and absorbable.

44 This 200-nautical-mile zone did not only concern the issue of free transit over the seas, but also the possession of underwater mineral wealth. This area of territorial sea adopted by Brazil was the result of a set of factors or forces that prompted the government to assert its decision-making autonomy in national foreign policy within the framework of "Brazilian power" desired by the military. Leading up to this time (during the late 1960s and early 1970s), scientific research projects aimed at

discovering the potential of the sea were already being conducted. Politically and diplomatically, there was also an interest in uniting Brazil with Latin American countries to extend the 200-mile zone, a desire for recognition of Brazil as an emerging power, and a strategic objective of rapprochement with African countries. African solidarity with Brazil's unilateral decision to extend its maritime domain in the South Atlantic has been an important asset in multilateral forums (CASTRO, 1989; MARRONI, 2013).

45 In this way, Brazil and other countries have offered resistance to the hegemony of global powers, challenging this and increasing their bargaining power in the forums that shape the international system. Brazil, abandoning its diplomatically conservative position, adopted a more decisive stance to defend its rights over the natural resources adjacent to its coastal zone. It based its policy decision for a 200-nautical-mile territorial sea on Latin American precedents (as stipulated in Decree No. 28,840 of 8 November 1950). Among other reasons, the increase to 200 nautical miles was recommended as this would serve as an incentive to increase the size of the naval force according to the maritime area and thus Brazil's strategic position in the South Atlantic. The perception of international trends and national interests informed this unilateral claim over a large maritime area adjacent to the country's coast.

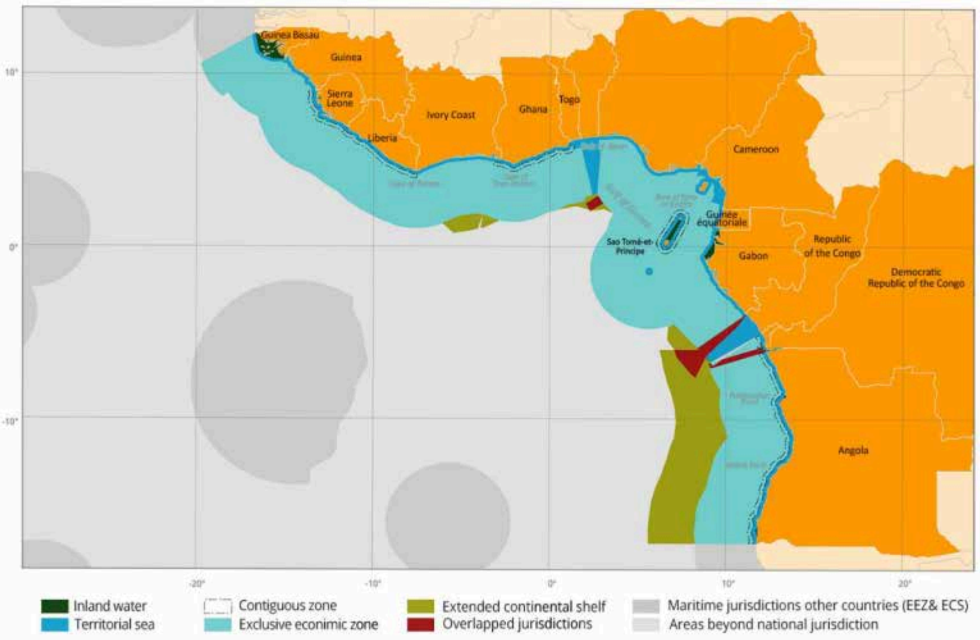
46 The extension of Brazil's territorial sea was welcomed by Latin American countries that had already extended their maritime jurisdictions, as Brazil's adherence to the 200-nautical-mile limit strengthened their international position. Solidarity with neighbouring countries was not the main reason Brazil extended its maritime domain; it followed the example of these countries in accordance with its own national interests. But once this decision was taken, Brazil's unilateral act could be justified as a political gesture of solidarity with the Third World.

Maritime planning in the Gulf of Guinea

47 The Gulf of Guinea is a maritime region of particular importance, concentrating economic and political elements that give this space a certain geopolitical cohesion and identification: a regional reference in the vast marine sphere of the South Atlantic. Together with Brazil, this is an emerging oceanic area, a new geopolitical reality in the vast marine basin between the Arctic and Antarctic.

48 The geographic area of the Gulf of Guinea can be defined as the vast region of the African continent stretching from Guinea-Bissau to Angola (fig. 7), totalling 16 coastal states, with a population of about 400 million inhabitants, 14,087 km of coastline, and a surface area of almost 6.7 million km^2. According to these boundaries, the marine space included in this region covers more than 9 million km^2, with a total surface area reaching 15.7 million km^2. Including the landlocked countries, this area would exceed 20.4 million km^2 and about 475 million inhabitants.

Figure 7. **Geography of the Gulf of Guinea**



Source: Doalos

49 Politically, the Gulf of Guinea benefits from institutions that give it cohesion as a marine region, and which are essential for the development of supranational policies on the maritime economy to combat piracy and illegal activities in its waters.

50 The African Union (established in 2001), heir to the former Organisation of African Unity (established in 1963), is Africa's largest political organisation. Its main objective is to accelerate the integration of the continent in order to meet the challenges of globalisation and promote Africa's role as an international actor. In recent decades, market expansion has emerged as a factor for regional integration. In the Gulf of Guinea region, organisations have been established such as the Economic and Monetary Community of Central Africa (CEMAC), the Economic Community of West African States (ECOWAS) and the West African Economic and Monetary Union (UEMOA). In 2001, the Gulf of Guinea Commission (GGC) was established in Libreville, Gabon, and started its activities in 2007. The GGC is composed of eight countries: Angola, Cameroon, Congo, Democratic Republic of Congo, Gabon, Equatorial Guinea, São Tomé and Príncipe and Nigeria. In the Gulf of Guinea, there are four Commonwealth states (table 7).

51 The weakness of political institutions in Africa south of the equator – particularly in coastal countries – inevitably transfers, and to an even greater degree, to the maritime space over which the sovereignty and jurisdictional rights of coastal states are extended. Territorial control, which is already weak on the continent, is even more difficult to exercise over a maritime territory of more than 2 million km^2, including 1.17 million km^2 of territorial sea of the nine coastal states on the Bight of Benin and the Bight of Biafra.

Table 7. Supranational institutions

Country	African Union	EU Neighbourhood Policy	Commonwealth	CEMAC	ECOWAS	CEEAC	OPEC	GGC	UEMOA
Angola	X	X				X	X		
Benin	X	X			X				X
Burkina Faso	X				X				X
Cameroon	X	X	X	X		X		X	
Côte d’Ivoire	X	X			X				
Gabon	X	X		X	X		X[1]	X	
Ghana	X	X	X			X			
Guinea	X	X			X				
Equatorial Guinea	X	X		X		X		X	
Guinea-Bissau		X			X				X
Liberia	X	X			X				
Mali	X				X				X
Niger	X				X				X
Nigeria	X	X	X		X		X	X	
Central African Republic				X		X			
Democratic Republic of the Congo	X	X				X		X	
Republic of Congo	X	X		X		X		X	
São Tomé and Príncipe	X	X		X		X		X	

Sierra Leone	X	X	X		X				
Chad	X			X		X		X	
Togo	X	X			X				X

CEMAC: Central African Economic and Monetary Community
ECOWAS: Economic Community of West African States
CEEAC: Economic Community of Central African States
OPEC: Organisation of Petroleum Exporting Countries
GGC: Gulf of Guinea Commission
UEMOA: West African Economic and Monetary Union

52 Maritime security is essential to secure the income of coastal states, as well as activities that contribute to the livelihoods of these economies, including fisheries, aquaculture, shipping (which also affects landlocked states), tourism and marine ecosystem services. In addition to national and regional impacts, maritime security has a clear international dimension related to oil and maritime trade, which affects the energy supply of other countries and regions, investment in the oil industry and the transport sector. The continent of Africa is attracting increasing interest from the international community. Since the 2010s (with the exception of the period of the COVID-19 health crisis), its growth rate has hovered around 5%. Africa is generally considered to be an area with high potential, which explains why it is subject to strong global competition (VEDRINE *et al.*, 2014). West Africa is considered a "rising geopolitical star", yet some studies have shown that although this region is considered more attractive than East Africa, it is less so than Southern Africa and is somewhat overlooked in the investments of large multinationals (DAMON and IGUÉ, 2003).

53 The European Union considers Africa an area of economic interest of great strategic value, including the Gulf of Guinea and its energy resources. As a result, EU policies address a wide range of issues relating to the continent, including development, but also governance, human rights, trade, regional integration, climate change, food security, migration and, in recent years, conflict management through participation in peace operations in various countries.

54 Since 2007, the EU's relationship with Africa has been built on the "partnership" outlined in the Joint Africa–EU Strategy (JAES) adopted at the Lisbon Summit in 2007. The JAES provides the overall framework for political relations between the two continents, although the EU has created other regional instruments. For example, all North African countries are part of the European Neighbourhood Policy (ENP), which includes a financial instrument (European Neighbourhood and Partnership Instrument, ENPI).

55 The West Africa–Gulf of Guinea region is part of a larger partnership between the EU and African, Caribbean and Pacific (ACP) countries under the Cotonou Agreement, which was revised for the second time in 2010. This instrument provides a legal framework for political dialogue and economic cooperation between the EU and ACP countries, for which the European Development Fund (EDF) exists. When the actions to be developed are of a local nature, only one financial instrument is available, the Instrument for Stability, which makes it possible to address situations of high strategic interest. This is applicable to the issue of piracy in certain areas, such as the Gulf of

Guinea. This instrument has been in force since 2007 and is used in complement with other regional instruments. The Instrument for Stability is useful when transnational regional instruments cannot be applied and is mainly aimed at security-related situations (and the link between internal and external security), although its drawback is its small financial package (ROY, 2012).

Conclusion

56 Specialists on the Atlantic devote part of their efforts to discovering new economic, geopolitical and geo-maritime interests that could lead to a new world order for the oceans. Cooperation and the development of a long-term strategic vision depend on the ability to mobilise human resources and foster social commitment. There is a need for policies that can assess power trends in the global political system, maximise available resources and implement strategies that prioritise alliances, institutions and networks in the ocean governance context.

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NOTES

1. The Republic of Cape Verde changed its official name in all languages to the Republic of Cabo Verde on 24 October 2013 in a request submitted to the Secretary-General by the country's Permanent Representative to the United Nations. In accordance with this request, only Cabo Verde will be referred to in this publication. In order to respect the titles of previously published works, references or printed sources mentioning "Cape Verde" (in French) or "Cape Verde" (in English) in their title have not been changed.
2. Mercosur: https://www.mercosur.int; African Union: https://au.int
3. The "blue economy" concept first emerged from the 2012 UN Conference on Sustainable Development (Río+20), which saw it as an essential tool to eradicate poverty and achieve sustainable development. This concept was promoted at the 32nd FAO Regional Conference for Asia and the Pacific in 2014, where a regional initiative to increase aquaculture as part of blue growth was supported to improve fish supply and livelihoods (http://www.fao.org/asiapacific/perspectives/blue-growth/es/). See also UN (2014) and Patil et al. (2016).

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Part III. Tools for marine spatial planning. Moving towards interdisciplinarity and innovation

Chapter 12. Marine spatial planning in data-poor contexts

To get the facts, reach for the sky

Adrien Brunel, Alessandre Giorgis, Noé Bente, Gilles Domalain and Sophie Lanco Bertrand

Introduction

1 The Paddle project ("Planning in a liquid world with tropical stakes") defines one of the objectives of marine spatial planning (MSP) as "reconciling human uses of the sea with conservation". A crucial starting point for this is to obtain information on these uses to inform future governance actions. One approach to this that partially overcomes possible data gaps on human activities is to extract spatially explicit information from satellite images available on Google Earth and process it using GIS (e.g. Quantum Geographic Information System software, QGIS). Currently, Google Earth is not widely used to inform MSP processes, yet it provides high-resolution optical satellite images (from Landsat) and aerial photographs that contain a wealth of information.

2 This chapter proposes a standardised methodology (for the purposes of sharing and reproducibility) for extracting data from this rich source of information. In concrete terms, this involves superimposing a discretisation grid on a background layer of Google Earth images and then manually pointing and clicking on each element of interest (fishing boats, seaside resorts, sun parasols, etc.) within each pixel of the grid. Then, an automatic count of these features can be performed by QGIS. The features counted per unit of space and their combination can be considered as relevant surrogates for fishing and tourism activities, for example, allowing density maps to be produced. Our case study for this approach is located on the coastline of Pernambuco, a state in northeast Brazil (the Nordeste region) on the Atlantic Ocean. The main activities on this tropical coastline are tourism and fishing.

Materials and methods

3 This section provides details for a standardised protocol for generating data based on a combination of Google Earth images and QGIS processing.

Tools

4 Google Earth (GE) and QGIS[1] are two free platforms available on all operating systems, allowing any user to access optical satellite and aerial images, with a resolution on the order of a metre. This data can then be manipulated to extract relevant information: for our purposes, concerning the spatial distribution of anthropogenic uses.

Google Earth

5 Google Earth is a software program that visualises the planet's surface through a combination of aerial and satellite photographs. The satellite images cover the entire surface of the Earth and currently come from Landsat 8 (launched by the National Aeronautics and Space Administration, NASA, in 2013). The program selects coverage dates that minimise cloud cover and guarantee a minimum resolution of 15 m at any point on the planet. The maximum resolution of geographical locations depends on their interest. For example, aerial photographs of urban areas can be observed with a sufficiently high resolution to be able to distinguish each individual building, house and even car (resolution on the order of a metre). In this case study, we used GE images as a background layer in QGIS to count objects of interest. In addition, Google Street Views were used to corroborate the nature of the counted objects: a closer view often helped to differentiate between types of boats or infrastructure.

QGIS

6 Quantum GIS (QGIS) is a widely used free GIS software. We used Madeira QGIS version 3.4 and installed the "Go2NextFeature3 2.00" extension. QGIS is a generic and user-friendly tool that overlays geographic layers and includes various useful features. It can be used, among other things, to view, browse, analyse, map, create, manage and export data. The relatively intuitive interface makes it easy to use even for a beginner, and the available extensions add even more functionality. The interest in using QGIS to collect and analyse data lies in its versatility (data collection and mapping), as well as in the fact that it allows working with different sources of information (satellite images, personal databases, data from agencies or institutes, etc.). In our case study, QGIS was a useful tool to conduct a count of features of interest in MSP: with the "Go2NextFeature" extension we were able to point and click on features in each pixel of the grid applied to the GE image backgrounds and thus semi-automate the count.

Method

7 Our method combined QGIS software with the GE image layer to extract a database of human uses. The overlay of a grid layer allows the discretisation of the study area and then automatically counts categorised features of interest within this grid that can then be treated as spatially explicit indicators of anthropogenic uses of coastal spaces.

Discretisation grid

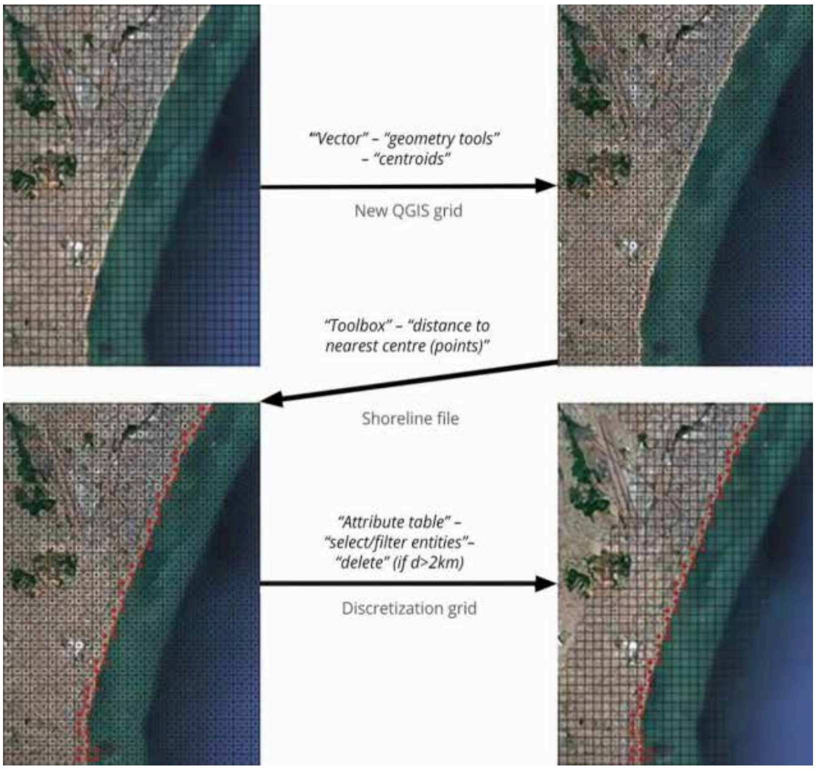
8 The grid was constructed to cover the irregularly shaped coastline of Pernambuco (fig. 1), which extends approximately from longitudes 35.19° W to 34.79° W and latitudes 8.92° S to 7.39° S. The grid was composed of 29,295 cells of 220 m x 220 m, which corresponds to a coverage area of about 1400 km². The resolution was high enough to distinguish and count features of interest (boats, sun parasols, etc.).

Figure 1. Discretisation grid (in red) of the Pernambuco study area and a zoom on Recife (yellow rectangle)

Source: Google Earth image processed with QGIS

9 The discretisation grid was generated using the dedicated QGIS function in the "Vector" tab. The default grid produced by QGIS is rectangular, which was not suitable to cover the latitudinally extended Pernambuco coastline. To remedy this, we created and positioned pixel centroids using the "Generate points (pixel centroids)" function in the "Vector" tab. Then, the "Distance to the nearest hub (points)" algorithm included in the QGIS toolbox was used between the pixel centroids and the file containing the shoreline coordinates. This procedure resulted in the final discretisation grid by deleting the pixels located more than 2 km from the shoreline (Fig. 2).

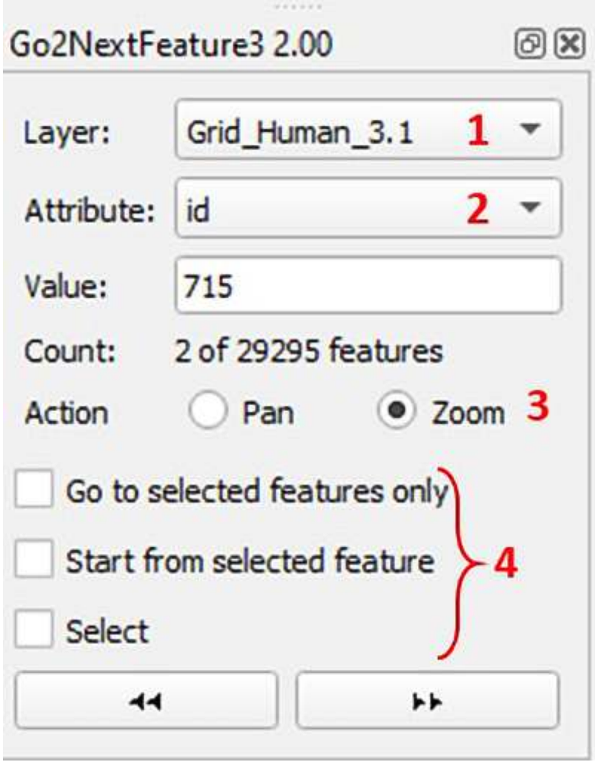
Figure 2. Workflow for developing the discretisation grid



In italics, path to desired commands in QGIS 3.4 Madeira
In bold, the files used
Source: Google Earth image processed with QGIS

10 Each pixel has an identification number and spatial coordinates. Once the grid is created and overlaid on the GE image background, it is possible to count the features of interest in each pixel and thus determine their spatial distribution. In practice, each pixel (identified by an ID number) is associated with a row in the QGIS attribute table, a spreadsheet used to retrieve the data. The QGIS "Go2NextFeature" extension allows the pixels to be listed (fig. 3) and the relevant information to be noted by point and click.

Figure 3. Go2NextFeature Extension Control Panel



This easy-to-use function allows you to choose the layer of the discretisation grid to be scrolled (1) according to the object considered (2), the action applied during scrolling (3), and the action applied on the object considered (4).
Source: QGIS

Categorisation

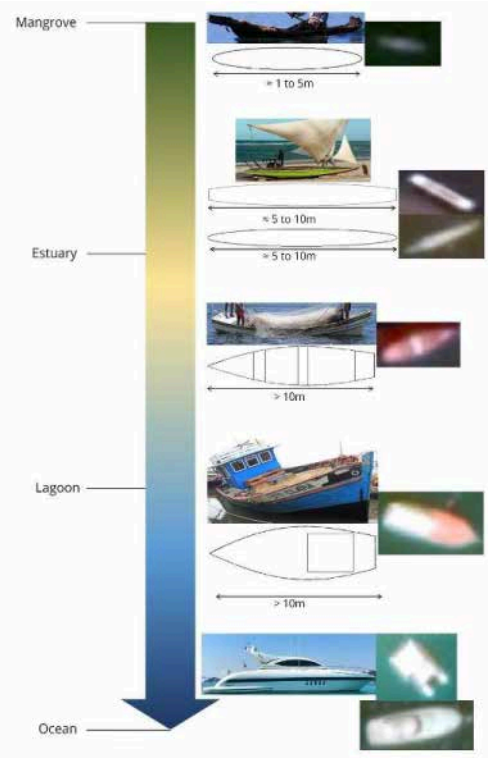
11 In this case study, we sought to identify objects that could be interpreted as indicators of human-induced pressures and that were identifiable in aerial views. In this area, where tourism and fishing activities are dominant, we counted the following objects: sun umbrellas, swimming pools, hotel infrastructure (four categories of hotel size: small, medium, large and very large), fishing gear (deployed nets and fish enclosures) and boats. Sun umbrellas, swimming pools and hotel infrastructure can be an indicator of tourism-induced anthropogenic pressure. Hotel infrastructure was subdivided into size categories to better describe the potential intensity of pressure created by tourism activity (fig. 4).

Figure 4. **Size difference between two types of tourist infrastructure**

The largest observed (left panel) and the smallest (right panel, circled in red).
Source: Google Earth

12 In terms of boats, a first category distinguished the use to which they are likely to be put (tourism or fishing) and a second category classified fishing boats according to their size: canoe-type fishing boat (*canoa*, non-motorised), raft-type fishing boat (*jangada*, possibly motorised, but low-powered and outboard), motorised fishing boat (inboard motor, with a deck or not), and finally boats for tourism. Each category of boat has a particular shape that can be recognised in aerial images (fig. 5). A *canoa* can be distinguished from a *jangada* by its size, the former being smaller. When there was doubt between two categories (between two types of engine, for example), the environment where the boat was located allowed us to determine its category. Motorised open boats are almost exclusively found in mangrove and estuary environments, whereas motorised boats with a deck are most often found in lagoons or at sea.

Figure 5. Illustration of the five categories of boats and the environments where they are most often found



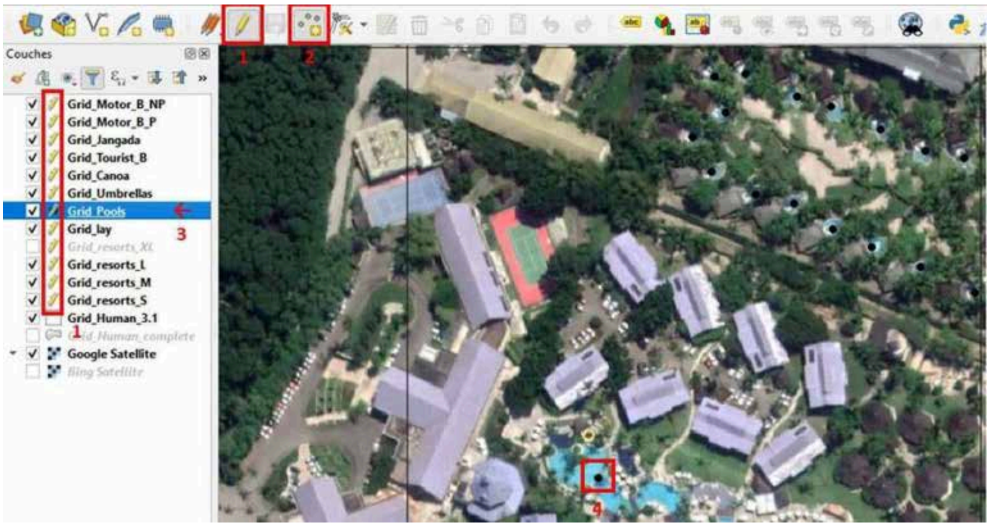
Each category includes a picture of the boat (top left), a schematic representation with the details important for its recognition (bottom left) and a screenshot of its appearance in GE images (right). From top to bottom: *canoa*, *jangada* (from the south of the state above, and from the north below), open motorised boat, motorised boat with deck, and tourist boat.
Source: A. Giorgis

Enumeration of the features

13 Once the features to be counted are identified, it is time for the most laborious part of the job, which is to point and click on each feature under consideration in each unit of the grid. QGIS automatically counts the selected features and provides a tabular output. This point-and-click approach allows for visual transparency and traceability, which hopefully allows for future improvements and possible corrections.

14 This method is made possible by two functions in QGIS. One allows the editing of several layers at the same time and the automation of an essential part of the count. This allows all layers to be put into edit mode at the same time (1 in fig. 6). To do this, the operator simply clicks on the “Add point feature” button (2 in fig. 6), selects the layer corresponding to the feature to be added and clicks on the feature in question (3 and 4 in fig. 6).

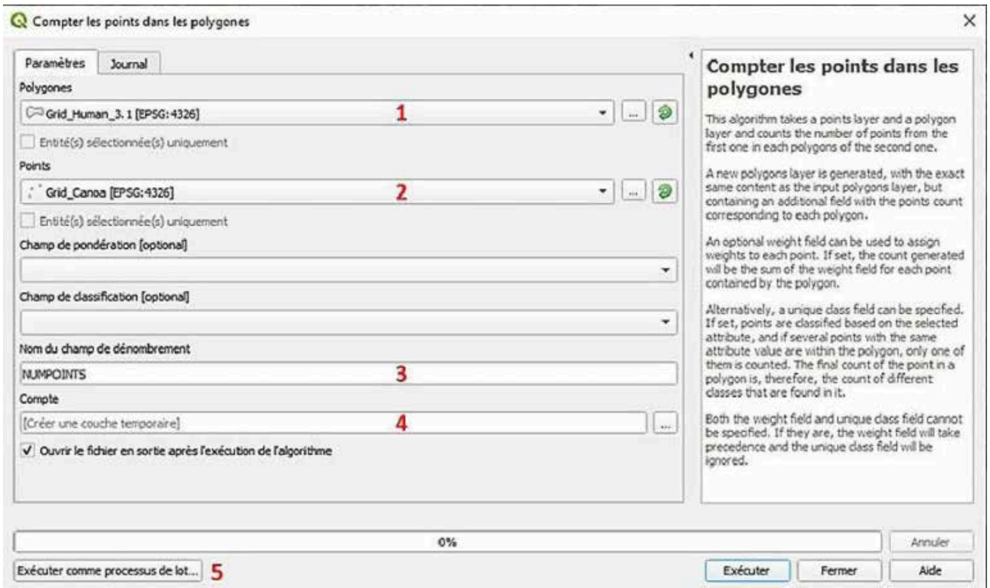
Figure 6. Screenshot of the counting area and application of the point-and-click method



(1) All layers are put in edit mode at the same time
(2) Click on the "Add point feature" button
(3) Select the layer corresponding to the feature to be added and (4) click on the feature.
Source: QGIS

Another function is based on the "Count points in polygons" function, which is a Python program, offered in the "Vector" tab of QGIS. This automates the counting of points resulting from the point-and-click process (fig. 7), which would otherwise be a very time-consuming task. This procedure depends on the creation of a layer for each category of anthropogenic pressure, detailed in the previous section.

Figure 7. Control panel for the "Count points in polygons" functionality



(1) Layer containing the polygons
(2) Layer with features to be counted
(3) Name chosen from the attribute table field in the future layer
(4) Name of this new layer
If the count is to be performed on a large number of layers, it is possible to run the algorithm in "batch" mode (5).
Source: QGIS

16 As soon as each pixel of the discretisation grid has been scanned, the “Count points in polygons” program can be launched for each object layer. QGIS then adds a new column to its attribute table with the number of points in each pixel. Finally, to centralise all counts, each count column of each feature layer is included in the attribute table of the count grid using the “Merge vector layers” functionality of QGIS (fig. 8).

Figure 8. Control panel for the “Merge vector layers” functionality

Select the layer to be linked (1), fill in the linking field (2), which must contain the same data format (name, number, etc.) in both layers, but must not have the same field name. It is then possible to select the fields to be linked (3).
Source: QGIS

Indicators of anthropogenic pressures

17 This section presents how to calculate indices of anthropogenic pressures (in our case study, related to fishing and tourism pressure along the Pernambuco coastline) from counting features in aerial images.

General calculation

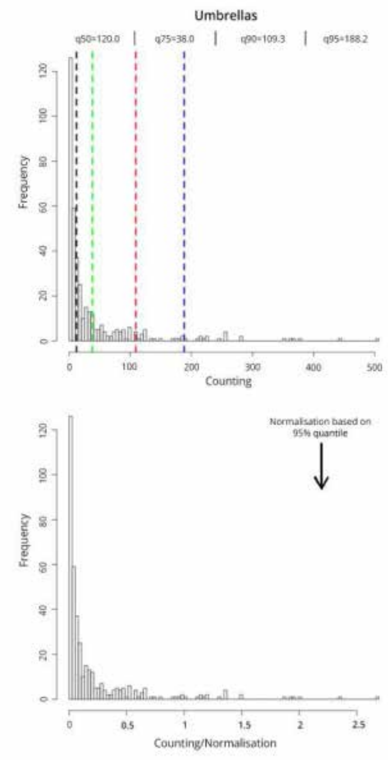
18 The main difficulty we encountered was the observable disparity between the count values obtained in each pixel for a given category and between the categories themselves. For example, in the “sun parasols” category, most of the values were less than 100 occurrences per pixel, while some reached 500 occurrences. The category “extra-large infrastructure” was far from this number of occurrences per pixel, representing only 48 objects in total. Such disparities prevent a normalisation with the maximum distribution value. We therefore decided to plot the distribution of the

histogram of each (non-spatialised) count to allow for further examination. In doing so, we determined that it made more sense to normalise the results based on the 95% quantile of non-zero values in each category (fig. 9). We removed the null values because they are the most represented value in the count, but are not meaningful in terms of occurrences of the category. After normalisation, each type of object counted became comparable and could be included in a weighted sum. It was then necessary to find a suitable formula, taking into account the fact that each category does not contribute equally to the anthropogenic pressure on the environment. In order to represent the unbalanced effects, adjustable relative weights were assigned to each category, which can be expressed as follows:

$$Index = \sum_{i=1}^{n} \omega_i \frac{x_i}{q_{95\%}(x)}$$

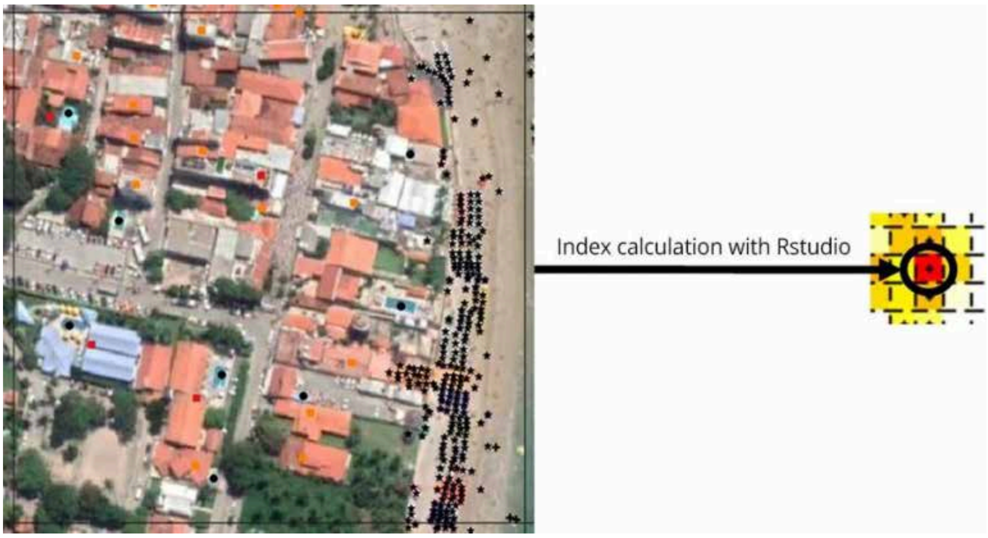
19 Using this calculation, we were able to provide an overall density map (fig. 10) of anthropogenic pressure. Its colours range from white (lowest density) to yellow, orange and red (highest density). The scale was calculated in relation to the pixel with the highest index value. In short, red represents maximum pressure, yellow/orange represents moderate pressure and white means that no pressure was identified.

Figure 9. Distributions of “sun parasol” histograms before (top) and after (bottom) the 95% quantile normalisation



The black, green, red and blue vertical lines represent a distribution of 50%, 75%, 90% and 95% quantiles of non-zero count histogram values respectively.
Source: A. Brunel, A. Giorgis, N. Bente, G. Domalain, S. Lanco Bertrand

Figure 10. An example of the conversion of raw count data (left) into coloured pixels based on the calculation of the tourism index (right)



In the left panel, each symbol (coloured square, star, circle, etc.) represents a feature belonging to the categories included in the calculation of the tourist pressure index. The right panel shows the density map of the surrounding pixels obtained by the calculation of our algorithm. It shows a pixel where tourist pressure is quite high, which can be explained by the large number of different features contributing to this.
Source: Google Earth

Fishing activity

20 A similar methodology can be applied to derive an index of fishing pressure based on counts of different types of boats (for an alternative source of data on boat monitoring, see Box 1). As an illustration, the following formula was applied successively to each pixel of the grid to calculate an overall index of fishing pressure per pixel:

$$0.3 \times \frac{Number\ of\ canoas}{Q95\ of\ canoas} + 0.7 \times \frac{Number\ of\ jangadas}{Q95\ of\ jangadas} + 0.05 \times \frac{Number\ of\ fishing\ boats}{Q95\ offishing\ boats}$$

$$+ \frac{Number\ of\ motorised\ boats\ with\ decks}{Q95\ of\ motorised\ boats\ with\ decks} + 0.7 \times \frac{Number\ of\ motorised\ boats\ without\ decks}{Q95\ of\ motorised\ boats\ without\ decks}$$

these different categories, we chose a weighting that simply optimises the graphic representation of the overall index. However, this pragmatic choice could easily be modified by a different balance of weights if objective criteria of other kinds are identified by experts in the field.

Box 1. How can automatic identification system (AIS) data be used for marine spatial planning?

Matthieu LE TIXERANT

While the value of MSP is now recognised and the legislative framework is being established, its operational implementation is sometimes tricky. One of the keys to success is the availability of evidence. The spatio-temporal development of maritime uses and conflicting or synergistic interactions between activities are essential information, but are particularly difficult to obtain in the marine environment. As a result, this type of data is often the weak link in information systems developed by maritime stakeholders.

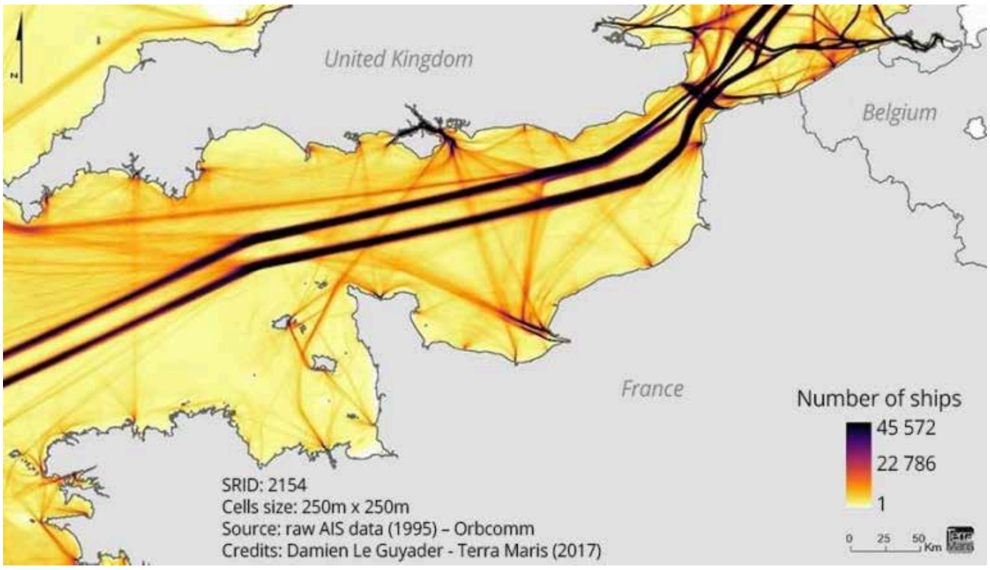
Since 2002, the use of the automatic identification system (AIS), essentially a tracking system used on ships, has been developing. Allowing real-time geolocation and identification of equipped vessels, the data from this system is a promising avenue for characterising certain human activities at sea. The relatively recent availability of archived data covering almost the entire coastal and offshore seas from the development of satellite AIS is a very useful resource in the field of operational oceanography. The analysis of AIS data can provide information on the spatial and temporal distribution of shipping and maritime fishing activities. This data is increasingly used for specific applications such as collision risk detection, real-time monitoring of ship behaviour, assistance with fisheries management and surveillance, risk assessment of infrastructure (submarine cables, ports, coastal nuclear power plants, etc.), estimation of marine currents, and measurement of chemical or noise pollution emissions generated by maritime traffic. This spatio-temporal information on maritime activities can also be associated with socio-

economic indicators that are of significant importance for MSP.
Within the framework of the Paddle project, studies have been carried out to evaluate the current uses of AIS for MSP at the European level and then to summarise a series of methods and results obtained in several operational research projects. The objective is to illustrate how the processing and analysis of AIS data can produce information suitable for MSP: maritime traffic density (fig. 11), shipping lanes and flows, hierarchical network of shipping routes, presumed fishing areas, spatio-temporal interactions between activities (conflicts of use or potential synergies between activities), etc. These studies have also examined the main legal issues relating to the use of AIS (access to non-anonymous data in principle reserved for public agencies for security, surveillance and monitoring purposes, use of personal data, commercial confidentiality, etc.).

For more information

LE TIXERANT M., LE GUYADER D., GOURMELON F., QUEFFELEC B., 2018
How can automatic identification system (AIS) data be used for maritime spatial planning? *Ocean & Coastal Management*, 166: 18-30.

Figure 11. Sample map showing the intensity of maritime traffic from AIS data in number of trajectories per pixel (2015, all types of vessels)



Source: Terra Maris/D. Le Guyader, 2017

Tourism

21 Similarly, we calculated an index of tourist pressure according to the following formula applied to each pixel of the Pernambuco coastline:

$$0.05 \times \frac{Number\ of\ swimming\ pools}{Q95\ of swimming\ pools} + \frac{Number\ of\ small\ hotels}{Q95\ of\ small\ hotels} + \frac{Number\ of\ medium\ hotels}{Q95\ of\ medium\ hotels}$$

$$+ \frac{Number\ of\ large\ hotels}{Q95\ of\ large\ hotels} + \frac{Number\ of\ very\ large\ hotels}{Q95\ of\ very\ large\ hotels}$$

$$+0.5 \times \frac{Number\ of\ tourist\ boats}{Q95\ of\ tourist\ boats} + 0.7 \times \frac{Number\ of\ sun\ parasols}{Q95\ of\ sun\ parasols}$$

22 Here again, the relative weights were chosen for illustrative purposes, to optimise the graphic representation of the overall index. This pragmatic choice can easily be modified by a different balance of weights if objective criteria of another nature are identified by experts in the field.

Results

23 The algorithm used for the calculation of pressure indices aimed to produce two types of files: a file containing raw counts per pixel and maps of pressure indices related to fishing and tourism.

Counts

24 The object tables for each count layer, as well as a summary layer, were exported in CSV format (comma-separated values, a text format with a comma or semicolon as separator), chosen because of its generic nature. This format facilitates sharing, storage and manipulation, both with Excel and with QGIS procedures. In addition, the procedure used to generate the anthropic pressure maps (in our case, related to fishing and tourism) can also create density maps of the raw count data. A total of 33,832 objects located along the Pernambuco coastline were counted and classified into the categories presented in Table 1.

Table 1. Objects counted by category

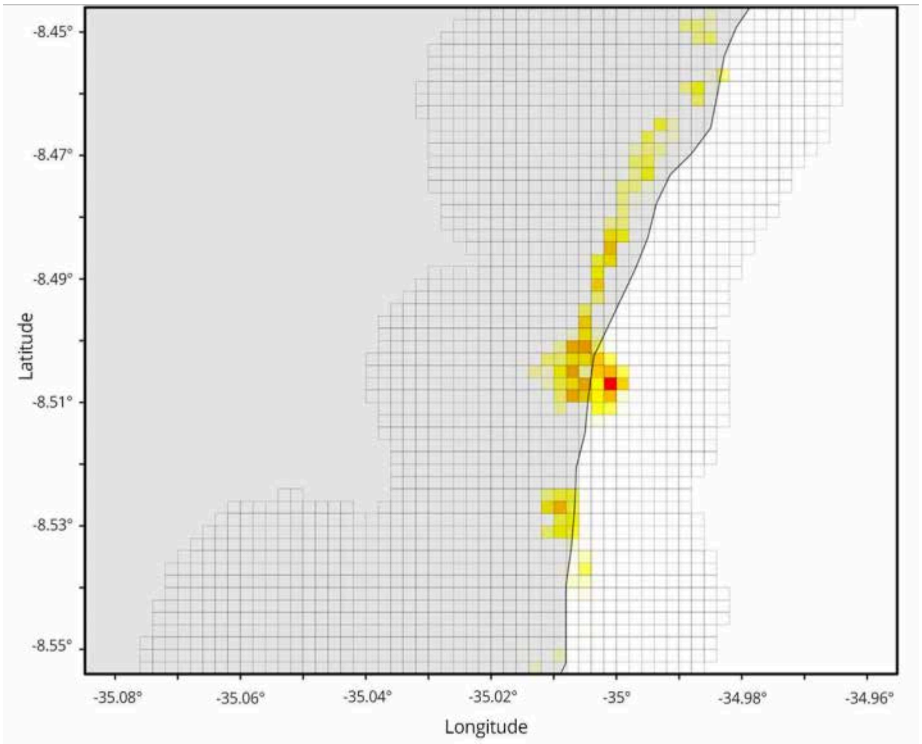
Category	Total number of objects
Tourism	**31,228**
Swimming pools	12,920
Small hotels	158
Medium hotels	802
Large hotels	243

Very large hotels	46
Tourist boats	1810
Sun parasols	15,249
Fishing	**2604**
Canoas	518
Jangadas	1199
Fishing boats	13
Motorised boats with decks	458
Motorised open boats	416

Pressure index maps

25 The resulting map of tourism-related pressures shows a linear and zonal distribution along the coastline in the south (fig. 12). The presence of many overlapping coloured pixels coincides with the location of the main cities of the state, such as its capital, Recife, or the seaside resort of Maracaípe. This indicates localised pressure, whose impacts are concentrated on a small area that can be identified by clusters of red or orange pixels surrounded by yellow pixels (fig. 12). The large white areas in the north overlap with those where mangroves are the dominant environment.

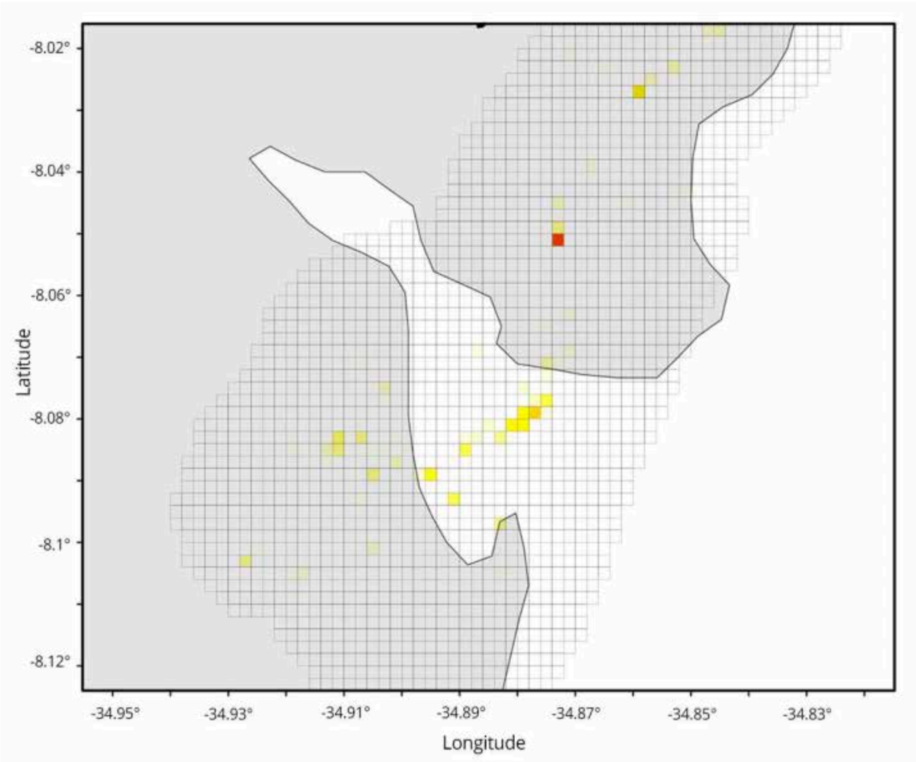
Figure 12. Extract of map resulting from the calculation of the tourism pressure index



The red pixel corresponds to the location of the city of Maracaípe. The yellow pixels are arranged concentrically around a red pixel, which shows high and localised pressure
Source: A. Brunel, A. Giorgis, N. Bente, G. Domalain, S. Lanco Bertrand

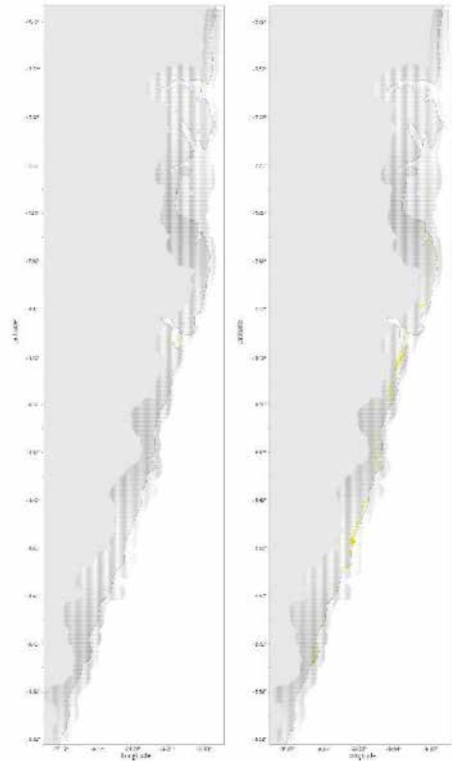
26 In the case of fishing, the trend is very different, indeed, the inverse. Fishing pressure is not concentrated around cities as in the case of tourism. Instead, yellow pixels are spread across all environments, from north to south (fig. 14). Although some impact zones are the same as those for tourism, the impact is much less significant. The pressure is more diffuse (fig. 13), i.e. exerted weakly to moderately on all environments, both in lagoon and mangrove ecosystems.

Figure 13. **Extract of map resulting from the calculation of the fishing pressure index**



The coloured pixels inland are due to the lack of coastline detail, which does not represent small estuaries.
Source: A. Brunel, A. Giorgis, N. Bente, G. Domalain, S. Lanco Bertrand

Figure 14. **Full maps of indices of fishing pressure (left) and tourism pressure (right)**



Source: A. Brunel, A. Giorgis, N. Bente, G. Domalain, S. Lanco Bertrand

Discussion

27 This section discusses the limitations of the method, the key points to be retained and offers recommendations for possible future improvements.

Limitations of the approach

28 One limitation to take into account is that during the enumeration process, problems of temporality were observed. The satellite images are selected by the program to minimise cloud cover; a selection that is necessary, but creates areas where two nearby images may correspond to different seasons. This can introduce a significant bias in object counts: for example, in our case beach umbrellas are highly dependent on the season. To remedy this bias in the count data, one could consider assigning an internal weighting factor that reflects, for each image, the season in which it was taken.

29 Secondly, GE images record static objects, which are useful for assessing the spatial extent of infrastructure and features linked to human activities, but which only act as indicators of the presence of different activities that approximate the actual uses of marine areas. To deduce the use of areas from these indicators, it is necessary to formulate hypotheses based on other data: for example, what is the average range of a *canoa*, a *jangada* or different types of motorised craft? Which areas are most frequented by tourist boats and for which types of activity (walking, diving, recreational fishing, etc.)? What is the average occupancy rate of the different categories of hotels according to the season? What is the percentage of tourists who engage in activities at sea? These

hypotheses can then be used to estimate, at a lower resolution than that of the counts, but still spatially explicit, the areas where the various marine uses are carried out. For example, the intensity of anthropogenic impacts on the seascape can be estimated by adopting an approach based on centres of gravity that combines the objects counted with the accessibility of different areas at sea, as proposed by CINNER *et al.*

30 A further limitation is that in order to develop indicators of fishing or tourism pressures based on counting different objects, we had to "compare apples and oranges". To compensate in part for the variable effects of the various objects on the occupation of space at sea, we proposed introducing weighting when integrating them in the form of an overall indicator of fishing or tourism activity. Clearly, this weighting is not insignificant in the final result, and it should therefore be the subject of consultation between experts and users of marine areas in order to best represent the reality on the ground. Ideally, a sensitivity analysis of the pressure maps produced with these weighting factors should be systematically carried out and opened up for discussion.

Points to keep in mind

31 Our case study allows us to conclude that:

- The combination of QGIS and Google Earth can provide relevant information based on free data with global coverage, which is particularly valuable in a data-poor context.
- It is possible to create a spatially explicit database that is traceable, reproducible, easy to share and capable of feeding into MSP scenarios (and prospective impact assessments, see Box 2).
- The effectiveness of the approach is highly dependent on the resolution and temporality of the satellite images, as well as on the choice of objects to be counted, their respective weights, and the assumptions used to deduce the uses of marine areas.

Box 2. Impact assessments: a tool for taking the environment into account in MSP

Philippe FOTSO

In international environmental law, two concrete measures have gradually become established as transversal tools in the procedures of environmental protection: environmental impact assessment (EIA) and public participation in environmental matters. These create a procedural framework for environmental protection. An environmental impact assessment is an opportunity to verify the feasibility of an activity and to plan in advance how to avoid and reduce its impact on the environment. There are two forms of EIA: (1) a so-called "classic" or "operational" impact assessment, i.e. one that concerns specific development projects, and (2) a strategic environmental assessment (SEA), which relates to proposed policies and programmes. The latter involves a formalised, systematic and comprehensive process of identifying and assessing the environmental consequences of proposed policies, plans or programmes to ensure that these consequences are fully taken into account and appropriately addressed at the earliest possible stage of decision-making alongside the consideration of economic and social factors (SADLER, 1996).

The first legal recognition of EIA in international law entered into force in 1997, with the Convention on Environmental Impact Assessment in a Transboundary Context (known as the Espoo Convention). The Protocol on Strategic Environmental Assessment (known as the Kiev Protocol), adopted in 2003, established a legal framework for SEA.

The signatories of these conventions are essentially European. In other countries, the legal framework for environmental impact assessments varies. In Brazil and Cabo Verde, there is currently no formal SEA instrument; "classic" EIA is a measure in framework laws on the environment and is enshrined in the Basic Law. In Senegal, the 2001 Environmental Code Act devotes a specific section to SEA in Chapter V on impact assessment. Like traditional EIA, the implementation of this measure falls within the regulatory domain, and the regulatory framework has not yet been adopted (FOTSO, 2019).

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SADLER B., 1996
Environmental assessment in a changing world. Evaluating practice to improve performance – final report. Quebec, Canadian Environmental Assessment Agency, 248 p.

Recommendations for future use of the approach

32 The approach proposed in this chapter could be improved with one or more of these guidelines:

- Other databases could be used to describe anthropogenic pressure more precisely. For example, the Airbnb database could provide more detailed information on "tourism infrastructure" objects.
- New satellite images and improved image processing can provide better image resolution. For example, the Sentinel 1 satellite, using synthetic-aperture radar technology, offers the possibility of obtaining images, regardless of cloud cover, at a resolution of 10 m. This could limit temporal phase shifts between two neighbouring images.
- Deep learning artificial intelligence methods for image processing could be a relevant approach to automate the counting task. However, while this seems quite feasible for use at sea due to the uniform blue background, it seems more difficult for use on land.
- Maps obtained from images from other years could be compared to better understand the temporal variability of human activities.

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NOTES

1. QGIS: www.qgis.org/en/site/; GE: www.google.com/intl/en_uk/earth/

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Chapter 13. Participatory and deliberative governance tools for marine spatial planning in the tropical Atlantic

Hilde Toonen, Pamela Bachmann-Vargas and Xander Keijser

Introduction

1 Over the past two decades, there has been a shift in marine management, accompanied by the emergence of ecosystem approaches (JAY *et al.*, 2013). Marine ecosystem-based management represents a move towards a holistic understanding of marine ecosystems as complex and dynamic networks of interactions, including humans and anthropogenic use of ocean spaces and resources, and how physical, biological and ecological processes are affected by this (KATSANEVAKIS *et al.*, 2011; MAES, 2008). In these approaches, the ecosystem is seen as the central unit (rather than a single species, issue or economic sector), bringing a spatial dimension that paves the way for the rise of marine spatial planning (MSP) (JAY *et al.*, 2013). In its early days, MSP was seen as a promising tool for marine conservation and responding to growing human claims on this space, but it soon proved to be much more than just a management tool (DOUVERE, 2008). Today it has become a leading approach to coordinate practices and policies aimed at reconciling conservation and environmental protection objectives with anthropogenic use of maritime space, particularly in the Global North (JAY *et al.*, 2013).

2 The tropical Atlantic lies between the latitudes of 23.5° North and South. It is bordered by South and Central America to the west and Africa to the east (HOYLE and DUNCAN, 2019). Tropical Atlantic ecosystems are critically important to global ecological, biological and climatic processes and are characterised by high biological diversity. Many people locally depend on the wealth and services provided by the ocean and coastal resources for their livelihoods and well-being. In the tropical Atlantic, this is

particularly the case for small-scale fisheries and coastal aquaculture/mariculture, which are essential for the well-being, food security and revenue of families and communities (BÉNÉ, 2006). Coastal tourism is also an important ecosystem service, a significant source of income for local and national economies, as well as an essential element in improving the quality of life of the populations concerned (ARKEMA *et al.*, 2015). In addition, maritime activities such as industrial fishing, shipping, oil and gas exploitation, deep-sea mining and renewable energy production represent significant potential economic value, both for countries locally and beyond. For example, the European Union (EU) Atlantic Strategy has clearly stated ambitions for the Atlantic Ocean, including its tropical areas, such as the sustainable exploration of natural resources on the seabed (EUROPEAN COMMISSION, 2013).

3 Since the emergence of MSP, guidelines, studies and policies have highlighted the importance of stakeholder participation beyond the "routine" involvement of citizens in decision-making such as through elections in representative democracies (FISCHER, 2009). The EU highlighted the need for such participation in its 2008 roadmap, and it is now included in its Maritime Spatial Planning Directive (2014/89/EU). At the international level, participation is encouraged, for example, by MSPGlobal, an international working group set up by the Intergovernmental Oceanographic Commission of the United Nations Educational, Scientific and Cultural Organisation (IOC-UNESCO) and the EU. MSPGlobal emphasises that participation is one of the keys to effective marine spatial planning (IOC-UNESCO, 2020a). Furthermore, experiences with integrated coastal zone management (ICZM) have shown that resource users often have a strong interest in participating in spatial planning, as their livelihoods and identities are often closely linked to coastal and marine places and spaces (UN, 1992). A resource user is an important stakeholder, which in its standard definition refers to "any group or individual who can influence or is affected by the achievement of an organisation's objective" (FREEMAN and MCVEA, 2001).

4 In addition to coastal stakeholders, a wider set of stakeholders have an interest in the spatial (re)organisation of coasts and seas, such as industry/market actors and non-governmental organisations (NGOs). The tropical Atlantic is divided into exclusive economic zones (EEZs) and the "high seas". This makes the space of concern to many different actors, with complex interactions at multiple levels (TOONEN and VAN TATENHOVE, 2020). Jurisdiction, as enshrined in the United Nations Convention on the Law of the Sea (UNCLOS), stipulates that the authority of a country diminishes with distance from the coast, thus international collaboration is essential, both between governments and with various non-governmental stakeholders.

5 To apply MSP in the tropical Atlantic, first one needs to understand how different stakeholders are involved in the space. Improving this understanding is of academic interest in itself, but it is also necessary to create a dialogue both between different disciplines and between academics and policymakers. This chapter will discuss certain tools that can support participatory governance approaches to reconcile conservation and use of ocean space. It should be noted that the supposed "contribution" of participatory approaches is much criticised in social science literature, particularly for MSP. Participation is not easy to organise, and there is a real risk that it may remain tokenistic, whether intentionally or not (FLANNERY *et al.*, 2016; RITCHIE and ELLIS, 2010; SMITH and JENTOFT, 2017). For example, if there is no space given to careful and meaningful consultation and deliberation beyond pre-established objectives, this could

be a limitation to participatory governance. To address these potential pitfalls, our participatory approach incorporates ideas from literature on deliberative governance.

6 This chapter first looks at the concepts of participatory and deliberative governance. It then presents two examples of tools linked to work carried out in the Paddle ("Planning in a liquid world with tropical stakes") project: serious games and participatory mapping. It concludes with a discussion on the potential application of these tools in MSP processes.

MSP and participatory and deliberative modes of governance

7 Before detailing the forms of participatory and deliberative governance, and what they mean for MSP in tropical seas, it is important to clarify our conceptualisation of MSP. Here, we adopt an analytical rather than a political definition, as MSP can be identified as a tool for marine governance. Marine governance is defined as "the sharing of policymaking authority in a system of negotiation between interlocking multi-level government institutions [...] on the one hand, and state actors, stakeholders and civil society organisations on the other, in order to manage activities at sea and their consequences" (VAN TATENHOVE, 2011). This definition understands MSP not as a process per se, but as a complex interplay of steering, negotiation and decision-making at several levels (from local to international) by public authorities and non-state organisations (stakeholders, NGOs and community-based organisations). The important steering role of governments is recognised here: laws, regulations, policies and state bureaucracies are seen as important governance tools for reconciling human use and nature conservation through MSP. At the same time, this definition does not necessarily promote hierarchical steering by the state, but allows for a focus on alternative approaches to (re)organising marine space, either in joint efforts or by non-state actors alone (CALADO *et al.*, 2012; TOONEN and VAN TATENHOVE, 2020; KARNAD and MARTIN, 2020). There is thus a need to consider forms of MSP in which it is not only governments that can, or should, take the lead in organising participation in the process.

8 The need for participation in MSP has been emphasised by many academics. It is widely recognised that there are multiple socio-economic issues at stake in coastal and marine areas (see Box 1). Indeed, there is a wide variety of interests and aims (sometimes conflicting) of stakeholders from various sectors, large and small NGOs, local communities, and sometimes individuals. Beyond taking into account this complexity, stakeholder participation in decision-making processes promotes the efficiency and effectiveness of decisions (PAPADOPOULOS and WARIN, 2007; RONDINELLA *et al.*, 2017). The democratic value of these participatory processes lies in the attempt to bring together all stakeholders who wish to influence policymaking at different levels and who hold relevant information (FUNG and WRIGHT, 2001). By participating in providing, sharing and influencing information, dominant stakeholders are identified as well as trade-offs and potential conflicts. The international MSPGlobal consortium is well aware of this: "the most important reason [for involving stakeholders] is that MSP aims to achieve multiple objectives (social, economic and ecological) and should therefore reflect as many expectations, opportunities or conflicts as possible in the MSP area" (IOC-UNESCO,

2020b). A participatory approach also creates a sense of ownership; stakeholders will be more willing to take responsibility and comply with decisions if they are united around a common commitment (REED, 2008; FISCHER, 2009). MSPGlobal observes that participation helps to "encourage 'ownership' of the sea use planning process and the final plan, build confidence among stakeholders and decision-makers, and encourage voluntary compliance with rules and regulations" (IOC-UNESCO, 2020b).

Box 1. The importance of public participation in MSP
Philippe FOTSO

Participation enables the public to be involved in decision-making and contributes to the effectiveness, impartiality, neutrality and objectivity of public policy. As early as the 1972 Stockholm Declaration and Action Plan for the Human Environment, the idea of public participation in environmental matters was latent. Principle 19 of this declaration states that one of the ways to raise the public's awareness of its responsibility in environmental matters is to provide education and information on the need to protect and improve the environment to enable the development of humanity. While participation as such was not specifically mentioned, the proclamation of a principle of informing citizens had the effect of improving public knowledge of environmental issues; information that enables citizens to understand public decisions. Information is a first step in including citizens in the decision-making process, a form of passive participation. The adoption of the Aarhus Convention on Access to Information, Public Participation in Decision-making and Access to Justice, which entered into force in 2001 and is legally binding for its signatories (which include the EU), translates the principle of participation into positive law and establishes it as a legal obligation for the implementation of projects with an impact on the environment. Latin American and Caribbean countries, including Brazil, adopted a Regional Agreement on Access to Information, Public Participation and Justice in Environmental Matters on 4 March 2018 (the Escazú Agreement), which entered into force on 22 April 2021.

In West Africa, a specific instrument for public participation in environmental matters has yet to be created. However, the legal foundations for this participation are provided for in sectoral instruments such as the Maputo Convention on the Conservation of Nature and Natural Resources and the Convention on Biological Diversity. These disparate legal instruments lay the foundations for public participation in plans and programmes in a differentiated but real way.

9 However, participation is not easy to organise, as REED (2008, p. 2426) points out: "the quality of decisions made through stakeholder participation is highly dependent on the nature of the process that leads to it. Failures in this process are most often attributed to shortcomings that lead to disillusionment with stakeholder participation". MSPGlobal also recognises that participation can "not work well", particularly if the timing and modalities of participation are not well defined (IOC-UNESCO, 2009; 2020a). A more major drawback of participatory governance arrangements is that they often depend on an authority to be responsible for the process and for achieving an outcome, which limits the possibility of the emergence of alternative, critical or radically different views (FLANNERY *et al.*, 2016). An emphasis on stakeholder inclusion and

engagement makes the success of participation highly dependent on assumptions that a common goal can be formulated or clear rules defined, for example. If stakeholders have very different historical backgrounds, capacities and skills, and/or conflicting interests or incompatible worldviews, expectations will often be unrealistic (DEWULF and ELBERS, 2018; FISCHER, 2009; OUNANIAN *et al.*, 2012). The participation process is then likely to fail, which may lead to undesired outcomes such as dissatisfied and disillusioned stakeholders who are then neither willing nor motivated to participate again (REED, 2008).

10 Social scientists distinguish between participatory and deliberative modes of governance (ESCOBAR, 2017; THOMPSON, 2008). These two modes are not contradictory, but deliberative governance places more emphasis on the input of relevant expertise, whether science-based or practice-based or concerning knowledge, values or emotions. A deliberative process is first and foremost a process of communication, discussion, reflection and better understanding. While the final goal is always to reach a decision, the starting point is a "state of disagreement" (THOMPSON, 2008). Deliberative governance is not so much an inclusive process in terms of the people involved, but a communication process based on everyone having an equal voice (ESCOBAR, 2017). Designing a deliberative process, however, is challenging. For example, there may be profound cultural differences in how to handle disagreement, which may not be obvious at the outset and are difficult to take into account in the design of the process (THOMPSON, 2008).

11 It is thus neither simple nor straightforward to design participatory and/or deliberation processes. Furthermore, it is important to recognise that they cannot be considered a panacea for solving major societal and environmental issues, such as spatial conflicts at sea. While these counter-arguments should not be overlooked, those promoting participation clearly point to the need to shape MSP processes in a way that stakeholders can engage with them. So how can we best move forward with participatory and deliberative processes in MSP? One response is the development of specific tools that can support these processes in MSP. Two of these tools that we have been involved in developing are: (1) serious games, and (2) participatory mapping in an art-based ecosystem assessment. Both tools are intended for use in design workshops, a widely used method in participatory governance (CHAMBERS, 2002). Participatory workshops have a specific, action-oriented objective. The social sciences provide rich literature on participatory methods and tools, highlighting their strengths and weaknesses in terms of design, applications and outcomes (for more information, SIMONSEN and ROBERTSON, 2012; CHAMBERS, 2002). This chapter introduces two tools that we helped to design and that were used in the framework of the Paddle project. These examples help to clarify the concepts of participatory and deliberative governance, while providing practical information on how to use these tools.

The serious game "MSP Challenge"

12 The development of this serious game was driven by the need for new and innovative tools to help shape the stakeholder consultation process in MSP. MSP Challenge is based on role play to facilitate communication and learning between stakeholders. Its rationale is based on the idea that stakeholders need to interact, practice and experience in a way that cannot be taught by books (ABSPOEL *et al.*, 2019; MORF *et al.*,

2014). Currently, MSP Challenge consists of three different types of serious games: a role play game, a boardgame and an interactive digital simulation platform (ABSPOEL *et al.*, 2019; MAYER *et al.*, 2013).

13 The role play game was initially developed in 2011 by policymakers from the Dutch Ministry of Infrastructure and Water Management (including one of the authors of this chapter, X. Keijser) and Dutch game designers (ABSPOEL *et al.*, 2019). This successful collaboration led to the development of a number of board and computer games. These different games are now used worldwide in workshops, conferences, educational sessions and stakeholder consultations (ABSPOEL *et al.*, 2019; KEIJSER *et al.*, 2017; MAYER *et al.*, 2013). The MSP Challenge boardgame was introduced in the framework of the MSPGlobal initiative, during a Paddle summer school held in Brest in September 2018 (co-facilitated by X. Keijser) (fig. 1). It was also introduced and used at the Paddle interdisciplinary seminar on MSP at the National Assembly of Senegal in Dakar in April 2022.

Figure 1. Use of the "MSP Challenge" boardgame during the Paddle summer school, Brest 2018

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14 "Serious" games, whether boardgames or their computer-based counterparts, are designed for a primary purpose other than entertainment. These games are used in different fields and for a wide variety of purposes, such as, for example, recruiting (in human resources), teaching (in education) or raising awareness (in a variety of contexts) (DEN HAAN *et al.*, 2018). MAYER (2009) defines serious games as "experiments with interactive, rule-based environments where players learn by making decisions and experiencing their effects through feedback mechanisms deliberately built into and around the game" (MAYER, 2009, p. 825). One of the main benefits of serious games is that they allow players to experiment and make mistakes, test scenarios and interact

with each other in a safe environment where actions are without consequences. Serious games also encourage collective awareness; players can reflect on what is happening in the game and what it would mean in a real situation (MAYER *et al.*, 2013).

15 By design, MSP Challenge is a tabletop strategy game that allows players to experience some of the dynamics and complex interactions of the MSP process. The game is designed to last one to three hours, and can involve 12 to 30 players, ideally from different backgrounds and cultures. During the game, players discuss planning options, share information and stories from their own experiences, and put forward arguments in order to jointly develop MSP for a fictitious marine space, while addressing the language, communication and information challenges of MSP (ABSPOEL *et al.*, 2019). MSP Challenge is a generic game, so its principles are easily replicable for different maritime or political regions. Since 2016, several versions of this boardgame have been developed, the latest being "#MSP Global Edition", a lighter travel version of MSP Challenge. The game has also been translated into different languages, including French, Italian, Portuguese and Chinese (Bohai edition) (ABSPOEL *et al.*, 2019; KEIJSER *et al.*, 2018). MSP Challenge focuses on spatial issues in the fictitious Rica Sea (fig. 1), represented on a large board (1.60 x 2.80 m), which is shared by three countries: Bayland, Peninsuland and Island. These countries have different profiles, but all have high-level political objectives regarding the future development of the Rica Sea. Players are assigned to a country and then take on the roles of maritime planners, conservationists or representatives of a maritime industry such as shipping, fishing, energy, tourism or recreation. They are given some basic background information about the sea and the high-level political objectives of their country. At the beginning of the game, sites of interest, such as ports, cultural sites and ecologically important areas (e.g. fish spawning or bird areas) are represented by tokens on the game board. However, most of the sea area remains unexploited, and it is up to the players to further develop it (by placing various tokens and connecting areas with threads, fig. 1). The game includes a moderator and is guided by a "game captain" – a political expert who can inform, decide or intervene on issues that are unclear or situations that arise from a game scenario (ABSPOEL *et al.*, 2019; KEIJSER *et al.*, 2017, 2018).

16 At the beginning of the game, the players stand around the board and the moderator starts by instructing them: "Develop the Rica Sea together so that at the end of the game you are all comfortable with the state of the sea and how you have worked together." To do this, the players have to use spatial planning for their marine area, taking into account economic, ecological and social objectives. Although the planning methods depend very much on the players, the moderator's instruction highlights two objectives that require a participatory approach: one is result-oriented ("the state of the Rica Sea") and the other is process-oriented ("how you worked together"). In the brief introduction, the moderator emphasises that, for the duration of the game, the "Rica Sea" is the players' world, and they are responsible for what happens in it.

17 After briefly discussing the rules, challenges and objectives of the game, the players start planning, placing tokens and connecting threads (fig. 2). The tokens symbolise a range of human activities (e.g. offshore wind power, offshore oil and gas production, fishing) and ecological features (e.g. fishing grounds, spawning grounds, etc.). The threads represent either linear infrastructure, such as cables and pipelines, or various types of ship lanes (e.g. cargo ships or ferries). It is up to the players to decide which tokens and threads to place on the board. As the game progresses and more and more

elements are placed on the board, players may gradually discover that these may begin to interfere with each other. This leads to the need to start "thinking and talking together" about their goals and the interactions between the different activities and the ecosystem (ABSPOEL *et al.*, 2019; KEIJSER *et al.*, 2017, 2018).

Figure 2. MSP Challenge boardgame session during the Paddle summer school, Brest 2018

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18 The moderator pauses at certain points in the process to discuss the progress of the game and the challenges observed. The players who have the role of planners are then asked to briefly explain the situation in their country, and the stakeholders to say whether they are satisfied with the planning process. The game captain asks questions and informs the players based on real MSP experiences. At the end of the game, the moderator and game captain lead a discussion with the players, asking about their first impressions of the game and moving to more complex topics ("What specifically happened and why?" and "How is this similar to real life?") (KEIJSER *et al.*, 2017, 2018).

19 The players are also asked to evaluate the game, so that the developers have an understanding of the experience – what worked and what did not – and any inconsistencies encountered, to improve the game. To date, MSP Challenge has been played in over 20 countries by over 1000 participants. Feedback from players in many sessions highlights that the "learning by doing" (or "learning by playing") approach is relevant (ABSPOEL *et al.*, 2019; KEIJSER *et al.*, 2018). Most participants, regardless of their sector or background, enjoy the experience of and learn from this serious game. Whether participants understand MSP better after playing depends on the characteristics of the session (such as the quality of the moderation, the number of participants, the length of the session and the quality of role-playing) and the characteristics of the participants (such as their level of familiarity with MSP) (KEIJSER *et al.*, 2017, 2018).

20 In general, the boardgame format is of particular interest and is suitable for a wide range of people: planners, stakeholders and the general public. In contrast, the game developers have found that the computer simulation game is higher level and is more suitable for stakeholders already involved in MSP. The boardgame and the simulation game can be used in a complementary way. There are currently several versions of the MSP Challenge computer simulation platform (e.g. North Sea, Baltic Sea and Clyde Marine Region)[1]. There is not yet a version that focuses on tropical seas.

Participatory mapping, an art-based qualitative assessment of coastal/marine ecosystem services

21 The second tool we will focus on here is participatory mapping. In our example, this is based on artistic methods combined with an ecosystem services assessment: specifically, the assessment matrix developed by BURKHARD *et al.* Ecosystem services in coastal and marine areas contribute to human well-being worldwide, and the spatial identification of these services is important for spatial planning and environmental management (VIGERSTOL and AUKEMA, 2011). IVARSSON *et al.* (2017: 13) point out that “the assessment of ecosystem services in relation to maritime spatial planning scenarios has the potential to shape and foster a common understanding of ecosystem-based management of sustainable maritime development”. However, the mapping of terrestrial ecosystem services has received much more attention in the literature than coastal and marine ecosystem services (NAHUELHUAL *et al.*, 2017). There is a wide variety of mapping methods, which makes the inclusion of economic, ecological and social values in management strategies complex (MARTÍNEZ-HARMS and BALVANERA, 2012). Combining different mapping methods can thus help to (1) identify the spatial distribution of ecosystem services related to changes in use (BURKHARD *et al.*, 2012; REILLY *et al.*, 2018) and (2) visualise the dynamics of various landscape (in our case, seascape) patterns and their relationships with the supply and demand of ecosystem services (BURKHARD *et al.*, 2012; TROY and WILSON, 2006).

22 The assessment matrix developed by BURKHARD *et al.* (2009) allows for a qualitative assessment of the capacity of the landscape to provide ecosystem services. This was the basis for the tool (developed by P. Bachmann-Vargas) used for the Paddle project and also employed in four workshops (August 2019) at the Federal University of Pernambuco (Recife, Brazil) with 47 undergraduate and graduate students in biology and oceanography (fig. 3). Artistic approaches were included to give the necessary attention to visualisation.

23 The two-hour workshops were conducted in five stages. The first stage, the introduction, lasts about 20 minutes. Depending on the target audience (beginners, advanced), this introductory phase can address different concepts/applications related to coastal/marine ecosystem services and marine spatial planning[2]. The specific objective of the university workshops was to introduce students to the concepts of ecosystem services, the evaluation matrix and qualitative evaluation (e.g. POTSCHIN and HAINES-YOUNG, 2016).

Figure 3. **Undergraduate and graduate students participating in workshops on qualitative assessment of coastal ecosystem services**

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24 In the second stage, participants individually draw the coastal/maritime space for approximately 20 minutes. Drawing is considered an artistic method of visualizing and sharing individual and/or collective perceptions of a social or physical phenomenon (MITCHELL *et al*., 2011). In the university workshops, drawings were used as a means to find out the participants' perception of the coastal area of the state of Pernambuco. In terms of spatial analysis, marine areas are difficult to draw in 3D, but participants are encouraged to include the different coastal/marine uses on vertical and horizontal profiles. To assist them, a provisional list of the different categories in the assessment matrix (e.g. beach, coastal vegetation, benthic vegetation, breeding areas) can be provided. The participants are then invited to share their drawings and learn more about the geographical area of interest. This moment of sharing helps to both (1) give a common meaning to what participants are expressing through their drawings (MITCHELL *et al*., 2011) and (2) reveal how and to what extent participants perceive the same landscape differently. For example, some people tend to draw the landscape from above, while others draw it from the side; some draw very roughly, others in more detail. In our workshops, students discussed different conceptualisations of the coastal space (fig. 4). The sharing and comparing of drawings proved to be a deliberative process, a way of revealing "difference" (rather than "disagreement", THOMPSON, 2008).

25 While this is an inclusive participatory tool, participants need to be given confidence in their drawings. During this hands-on activity, we found that some participants focused more on the artistic quality of their drawing than on its content based on their (inherent) knowledge. Although this was not the case in our workshops, particular attention needs to be paid to the drawing implements used according to the social characteristics of the participants (MITCHELL *et al*., 2011). For example, some may not be

familiar with certain types of markers, such as fineliners; in this case, chalk or coloured pencils may be more appropriate.

26 The third stage starts when the drawings are completed and shared. Participants are asked to identify four or five types of coastal and marine cover (e.g. beach, coastal vegetation, benthic vegetation, breeding areas). They are then asked to identify how they, or other specific users, benefit from these features. In our workshops, it was very clear that beaches were immediately linked to recreation, both for local people and tourists.

27 The fourth stage is to construct the evaluation matrix from the drawings. The matrix correlates coastal/marine use types with ecosystem services. The use types identified by the participants are the rows of the matrix, and the identified ecosystem services the columns. To construct the matrix, we used a broad definition of ecosystem services as "benefits that people derive from ecosystems" (MILLENNIUM ECOSYSTEM ASSESSMENT, 2005, p. 40). Depending on the target audience and the specific objectives of the workshops, a more detailed typology of ecosystem services can be introduced (see IVARSSON *et al.*, 2017, p. 29). For example, in another application, the assessment matrix was based on the Common International Classification of Ecosystem Services (CICES) (CENRE, 2016); the matrix was then completed with values from 0 to 5, with 0 representing "no relevant capacity to produce services" and 5 representing a "very high relevant capacity" in relation to land use types (BURKHARD, *et al.*, 2009; BURKHARD *et al.*, 2012). Regardless of the type of assessment, the joint analysis of this phase allows for dialogue between the participants.

28 The fifth and final stage is a group discussion. Depending on the target audience and the specific objective of the workshop, the facilitator prepares a series of questions to start the discussion. In general, participants are asked to share their qualitative assessment and to explain why they have assigned certain values. Contrasting assessments provide an arena for discussion; a large group can be divided to ensure this. The workshop ends with a general discussion and conclusion. In our workshops with students from the Federal University of Pernambuco, the group discussion was guided by five questions aimed at collecting their opinions on the concept of ecosystem services, the hands-on activity, the use of the evaluation matrix for their own studies/research, and the local situation. Specifically, these questions were: (1) What is your opinion on the concept of ecosystem services? (2) What do you conclude from this practical activity (e.g. mapping, conflicts)? (3) How could you use this tool in your research? (4) Who are the main beneficiaries of coastal ecosystem services in Pernambuco? (5) What are the main problems and challenges in the coastal areas of Pernambuco? The students, as knowledgeable inhabitants and stakeholders of the coastal areas of Pernambuco, were not only very interested in the workshops, but were also willing to analyse the results. By combining spatial analysis with the concept of ecosystem services, they came to the collective conclusion that access to coastal ecosystem services is largely determined by social status.

29 A very important point of the assessment matrix, informed by the drawings and discussions, is that it can feed into the next step, which is the discussion and prioritisation of future actions. If possible and desired, the assessment matrix can be supplemented with information from scientific experts and quantitative computer modelling tools. For example, spatial and functional interpretations of the drawings and the assessment matrix can be transferred to GIS platforms.

30 This drawing-based approach is an inclusive method because of its simplicity. Workshops are inexpensive and can be conducted on site; there is no need for PowerPoint or other software, only coloured pencils and paper, although markers and post-it notes are useful. One drawback of participatory processes in general is that they can be perceived as tiring and time-consuming, but we found that this two-hour workshop, divided into five stages, worked well, especially as it is centred around a hands-on activity.

Figure 4. Drawings from the workshops

These show different conceptualisations of the coastal space of the state of Pernambuco.
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Discussion

31 These two examples are tools that can be used to enhance participation and deliberation in MSP processes. Both tools are designed to facilitate knowledge exchange and to provide the opportunity to share experiences, not only by talking, but by listening and responding. A common and essential feature of these tools is that they are used in workshops that offer participants a practical "do-it-yourself" activity, through which they learn from themselves and from others. The two tools do this in different ways. MSP Challenge is a boardgame that requires participants to work as a team from the outset, guided by their roles and the material reality of the game board, its tokens and threads. In playing, participants contribute their knowledge, skills and expertise on the content, but are also called upon to plan, collaborate and negotiate. In contrast, participatory mapping is an artistic and progressive approach, in which each participant focuses on his/her own knowledge before moving on to social interaction.

32 Both tools can be useful in exploring MSP processes. For example, they can be useful in identifying and anticipating conflicts. With MSP Challenge, conflicting interests

become visible on the game board, and discussions can also reveal conflicting views on how to collaborate and negotiate. Participatory mapping can also reveal commonalities and differences in the understanding of coastal/maritime space and its qualitative evaluation, again not only in content, but also in perceptions and feelings, as the drawings literally add a personal touch. Furthermore, by introducing the concept of ecosystem services, the focus is on the different uses, users and trade-offs, which are discussed in the assessment phase. As the assessment matrix requires collective prioritisation, it also calls on the debate skills of the participants.

33 For both tools, the final stage, in which participants are invited to reflect, is of paramount importance. This requires participants to step out of the game or evaluation, and apply the lessons to their own reality. However, it is too early to draw conclusions about the extent to which participants take these lessons away with them. The MSP Challenge boardgame has now been used in many contexts, and participants are generally very positive about how the game has stimulated their MSP learning (KEIJSER *et al.*, 2018). The fact that the game was developed and taken up by the international MSPGlobal consortium also indicates its value. Indeed, the game can be seen as having gained legitimacy in the field of MSP, creating a link for learning, transmitting and exchanging not only content, but views on how to collaborate and negotiate. It would be of interest to use this game at a future Paddle event on the tropical Atlantic and learn from what arises. However, it is essential to have clear predefined objectives (REED, 2008). In a given context, is the purpose of the game to raise awareness about the particular challenges of the MSP process, or as a strategic tool to improve collaboration and negotiation? The participatory mapping tool has not yet been used in a formal MSP process, but in our experience, it has the potential to aid participation and deliberation. Another advantage is that this tool is inexpensive to implement and does not require formal arrangements as is the case with the MSP Challenge boardgame.

34 In understanding MSP as an act of marine governance, it should be noted that it takes place at several levels. Most often, MSP is seen as a national policy process, with a focus on international collaboration in a regional sea. The MSP Challenge boardgame and the conditions of use are clearly in line with this. Moreover, the possibility for the moderator and the game captain to take a break during the game resembles a situation in which an authority organises participation. However, the use of this game at a local level is also possible. Playing MSP Challenge in its current form with local stakeholders would, for example, help raise awareness about planning issues in a marine space. It would also improve understanding around the discussions that arise when trying to reconcile spatial conflicts; the lessons learned could then be transferred to the local level. This tool could also be useful in the operational phase of MSP, after the scoping phase in which objectives are defined, and the strategic phase, in which the means to achieve these objectives are identified (FLANNERY and MCATEER, 2020). Participatory mapping, on the other hand, is more suitable in a preliminary phase, to help formulate objectives and define priorities. It can be used from the local to the global level, although it is essential to predefine a geographical scale in order to identify and assess the ecosystem services in that space in a meaningful way. Participants should have some level of knowledge of the coastal/marine area concerned.

35 It should also be noted that MSP is part of a wider range of steering, negotiation and decision-making processes, in which many different stakeholders are involved. The

MSP Challenge boardgame is an interesting tool that is available both to governments, but also to non-state actors such as industry and (large) NGOs. To date, specific sessions with this boardgame have been organised with NGOs and representatives of the maritime sector. The participatory mapping tool can also be used by different stakeholders, including local communities, as it is inexpensive and very accessible. However, promoting discussions that lead to a better understanding of the coastal/ maritime space and ensuring respectful and relevant debates on the different views and values of ecosystem services requires skilled and well-trained facilitators. This applies not only to the participatory mapping tool and the boardgame; as REED (2008) points out, good facilitation is imperative for any type of successful participation.

36 The two tools presented in this chapter are by no means the only instruments available to support participatory and deliberative processes in MSP. Our aim here is simply to provide a detailed description of how they have been designed to meet certain objectives and to illustrate how their use can contribute to achieving these goals. Those steering the MSP process should think carefully about which tool can best assist participation and deliberation in order to make the most relevant choice.

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NOTES

1. See www.mspchallenge.info
2. Slides available on request from P. Bachmann-Vargas.

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Chapter 14. Marine spatial planning and recreational uses of the sea

Protection of surfing sites

Mauricio Duarte dos Santos, Solange Teles da Silva and Carolina Dutra

Introduction

1 Coastal and marine environments and their resources are governed by a fragmented framework of international, national and regional institutions. But their conservation and sustainable use depends on planning and managing social uses both within and beyond areas of national jurisdiction. This fragmentation in governance can be problematic, as marine areas need to be considered holistically, a need recognised in the preamble to the 1982 United Nations Convention on the Law of the Sea (UNCLOS): "State parties to this convention are conscious that the problems of ocean space are closely interrelated and need to be considered as a whole." The 1992 Convention on Biological Diversity (CBD) reinforced an ecosystem approach and the use of area-based management tools in spaces under national jurisdiction (EHLER and DOUVERE, 2009).

2 After decades of international discussions, theories and practices on coastal and marine governance, marine spatial planning (MSP) emerged in the early 1980s. Going beyond other area-based management tools, it is an innovative policy process for the spatial and temporal allocation of living and non-living resource use, supporting sectoral policies to find a balance between use and conservation (SCOTT, 2015).

3 Since then, MSP has been part of broader marine strategies in many countries and defined and practised in different ways, reflecting a range of governance systems and political priorities. Prior to 2000, a few countries began to use spatial planning of maritime areas: for example, China, where marine functional zoning was first proposed by the government in 1998 and became a mandatory basis for marine development planning, marine resource management and the establishment of marine nature reserves (FENG *et al.*, 2016). In the same year, Australia set out its Oceans Policy to guide the implementation of ecosystem-based ocean planning and management,

incorporating previous Great Barrier Reef zoning plans and bioregional plans focusing on marine conservation (DAY, 2002). In 2002, the European Union (EU) promoted the adoption of MSP in national jurisdictions and regional seas, with a focus on maritime rather than marine spatial planning: i.e. as a tool to promote blue growth in maritime economies (SCHULTZ-ZEHDEN *et al.*, 2019). This trend has spread to Africa, Asia and the Americas along a similar path, highlighting potential economic gains as a relevant – and for some, the main – objective (UNESCO, 2019). While there is still no single globally accepted concept of MSP, the United Nations Educational, Scientific and Cultural Organization (UNESCO) described it in 2009 as "a public process of analysis and spatial and temporal allocation of human activities in marine areas to achieve ecological, economic and social objectives that are usually specified through a political process". By 2019, MSP initiatives were being developed in more than 70 countries, ranging from agenda setting and plan formulation to adoption, implementation and evaluation (UNESCO, 2019).

4 Nevertheless, in order to meet the challenges of an overexploited ocean in flux, there is a growing demand for broader marine governance, and for more effective and concrete public engagement in coastal marine issues taking a holistic perspective. Governments, institutions, civil society and academia are interested in the capacity of MSP to manage the use and protection of coastal marine resources in a sustainable manner. Theoretical and empirical studies on the different dimensions of MSP have recently been developed in fields such as geography, ecology, economics and social sciences to examine its rationale, methods and outcomes.

5 This research shows that MSP is an essential tool for effective marine policy, improving decision-making in coastal marine environments (EHLER *et al.*, 2019). It highlights the potential of MSP to strengthen ecosystem-based management and biodiversity conservation, addressing the cumulative effects of many stressors as well as promoting tools such as marine protected areas, coastal zone management and others. MSP is seen as an open and dynamic approach that improves the regulation of marine activities and harmonises economic outcomes and social benefits to better reconcile the heterogeneous interests of the diverse users of these spaces – hence its complexity.

6 Yet much remains to be done on the social pillar of MSP. Fundamental issues, such as the scope and process of MSP, need to be studied through a "social lens", inspiring critical analyses and data-driven solutions. Understanding of the interaction of the marine world and society needs to be deepened, contributing to new approaches to planning (JAY *et al.*, 2011).

7 In the context of debates on the ecological and social variables to include in MSP, this chapter analyses the link between MSP and emerging initiatives to protect surfing zones. Surfing zones are a scarce marine resource and provide ecosystem services and opportunities for non-extractive/low-impact activities, which should encourage their consideration in policy decisions. The protection of the "surfing ecosystem" represents an opportunity to foster coastal marine governance as set out in MSP strategies and coastal and marine protected area management plans. Innovative systems such as "surfing reserves" have arisen, favouring bottom-up management, including the involvement of the surfing community in decision-making on coastal and marine use.

8 Based on a review of the literature on the social dimension of MSP, the chapter first presents the theories that have given rise to debates on coastal marine planning. The second section critically assesses the literature on public participation in this process.

Lastly, the chapter looks at current legal and voluntary frameworks for surfing site protection, with an end to recognising collective interests in the MSP agenda and improving public participation in the process.

The social pillar of MSP

9 Despite the complexity of MSP and the variability of its adoption around the world, it is expected that this process should produce more than maps. To sustainably develop marine space, a range of ecological, social and economic objectives need to be considered, with the real participation of stakeholders in decision-making on the multiple uses of coastal marine space. While ecological and economic sustainability receive significant political and scientific attention, social sustainability needs to be better understood and integrated into policy practice (BOSTRÖM, 2012). This issue has arisen in the governance and management of natural resources, so it is not surprising that this is also the case in MSP. Assuming that research has an important role to play in improving the consideration of social sustainability in MSP, how much of the scientific literature is devoted to the human/social dimension of MSP?

10 Focusing on the conceptualisation of social sustainability in MSP, SAUNDERS *et al.* (2019a) question whether social benefits are taken into account in the consideration of environmental and economic components in coastal marine planning. The authors point out that while social concerns are partly – and differently – taken into account in the ecological and economic dimensions, they are rarely considered in their own right. From the economic point of view, development on a societal scale holds out the hope of well-being for all; from the point of view of environmental protection, it is a question of ensuring the sustainability of resources and conditions in order to maintain market potential and capital accumulation. Even if there are exceptions to this, for these authors, "referring to purely economic priorities such as blue growth or even 'sustainable growth' (with environmental protection in mind) as an objective of MSP does not take into account other factors related to the economy, such as the unequal distribution of wealth and access to resources".

11 Rather than viewing the three pillars – social, economic and environmental – as a means to an end, the achievement of each pillar should be justified in its own right. To meaningfully integrate social sustainability into MSP (or overcome the lack of consensus on its definition), several key questions need to be asked: What are the objectives of MSP? Who decides on access to marine resources and how? Who should benefit? To promote social inclusion and equity and avoid power disparities, social sustainability needs to be a part of MSP in its constitutive (objectives), procedural (decision-making process) and substantive (outcomes) aspects. Without this, MSP will not be able to serve as a "promising means of pluralistic marine governance capable of mediating the tensions between competing values and interests to achieve a 'common public interest' in how we should use the sea" (SAUNDERS *et al.*, 2019a). To this end, these authors have developed a conceptual framework to consider social sustainability in MSP, outlining key guidelines that can be adapted for different practices and contexts (table 1).

Table 1. Conceptual approach to considering social sustainability in MSP

Guideline	**Description**	**Analytical perspectives**
Strengthening democracy in the decision-making process	Who is included? What is included? How are they included?	The extent to which the interests of those who legitimately matter in the specific context of MSP (inclusion/exclusion), including values, and the experience of stakeholders are taken into account, including the knowledge of non-experts.
Meaningful inclusion of socio-cultural values, knowledge and benefits	Consideration of diversity, usually based on values attached to place, knowledge and benefits (material and immaterial)	The extent to which (and how) certain social groups, place-based knowledge, values and benefits are effectively considered and represented in the MSP results.
Promoting equity	Distributional effects (now and in the future)	The extent to which social diversity concerns are mapped and integrated within MSP, including the extent to which these are considered in planning processes.
Promoting social cohesion	The promotion of harmonious societal coexistence or, at the very least, reducing the potential for explicit and harmful social conflict	The extent to which consideration has been given to reducing dysfunctions that exist in societies, in order to strengthen social relations and build trust between different social groups.

Source: adapted from SAUNDERS *et al.* (2019a)

12 Each of the guidelines in this conceptual framework for social sustainability gives rise to a series of related questions that may also be useful for the development of assessment indicators.

13 With regard to the question of democracy, the central concern is the extent of truly participatory spaces. Based on a literature review of MSP decision-making (including JENTOFT, 2017; RITCHIE and ELLIS, 2010; JONES *et al.*, 2016; TAFON, 2019, etc.), SAUNDERS *et al.* (2019a) point out that MSP needs to be reconfigured to enable (1) more socially cooperative approaches, including more stakeholders (public, private and non-profit entities, i.e. government, civil society, business, NGOs, general public, vulnerable social groups, trade unions) and (2) their engagement in planning decisions in which they have an interest (receive tangible and/or intangible benefits) and which affect them. Of course, this will require more effort from all stakeholders, especially the planners, but the result will be more effective, avoiding potential conflicts in the implementation of MSP by taking into account the values, interests and knowledge of all concerned. While some authors consider this response insufficient, as it does not address the material and non-material distributional implications of MSP (FLANNERY *et al.*, 2016; TAFON *et al.*, 2019), according to SAUNDERS *et al.* (2019a), a more democratic form of MSP is possible based on a pluralistic view of power, without naively assuming that all stakeholders have equal power to advance their interests.

14 SAUNDERS *et al.* (2019a) extend this idea by examining how specific groups, their knowledge, values and location-related benefits – i.e. socio-cultural elements – have been effectively considered in decision-making and shaped the outcomes of MSP. The emerging literature on this topic explores mainly cultural services from ecosystems. It appears that MSP tends to neglect the intangible values associated with culture, which is "problematic, as they contribute to human well-being and are considered to have a strong influence on the way we conceptualise sustainability" (SOINI and BIRKELAND, 2014). One difficulty is that cultural services depend on cultural practices and frameworks to be reproduced, recognised and valued, which are difficult to incorporate into planning and management tools such as MSP as the latter rely on quantitative data and methods (KENTER *et al.*, 2011). Yet "the representation of socio-cultural elements in essentially spatial and economic terms misses not only the infinite spatiality and intrinsic affective character of these values, but also their incommensurability with material (economic) benefits", which can lead to the marginalisation of those who hold these values (TAFON, 2017). To avoid this, SAUNDERS *et al.* (2019a) stress the need to go beyond the simple expression of socio-cultural elements in the MSP process in order to promote "a dialogue and exchange in decision-making that will lead to more equitable outcomes" (KIDD and ELLIS, 2012). These authors offer some ideas on how to do this: for example, through participatory mapping or deliberative interaction (SAUNDERS *et al.*, 2019a).

15 Another element in the SAUNDERS *et al.* (2019a) conceptual framework is the choice of equity as a guideline for planning. This focuses on the existence (or not) of explicit/specific recognition/accounting for distributional implications in marine planning: who wins and who loses in MSP decisions and outcomes? Indeed, there are different views of what equitable MSP would look like. According to these authors, "equity in marine planning could be seen as not further harming already disadvantaged or vulnerable social groups and making decisions about the sea in the direction of equality (recognising that people/groups flourish in different ways; based on different values/benefits/conditions)" for current and future generations. Their proposal is to rethink MSP to give "adequate attention to the distribution of costs and benefits of sea use (now and in the future) [...] within society and how different elements of quality of life are affected (e.g. work, access to leisure, aesthetics, money, etc.). Of course, this creates challenges that could be overcome by engaging 'MSP equity planners' who would advocate for equitable outcomes via MSP, thus going beyond the boundaries of rational planning (or the role of a 'neutral' planner) to objectively balance the competing arguments for the goals of the three pillars of sustainability" (SAUNDERS *et al.*, 2019a).

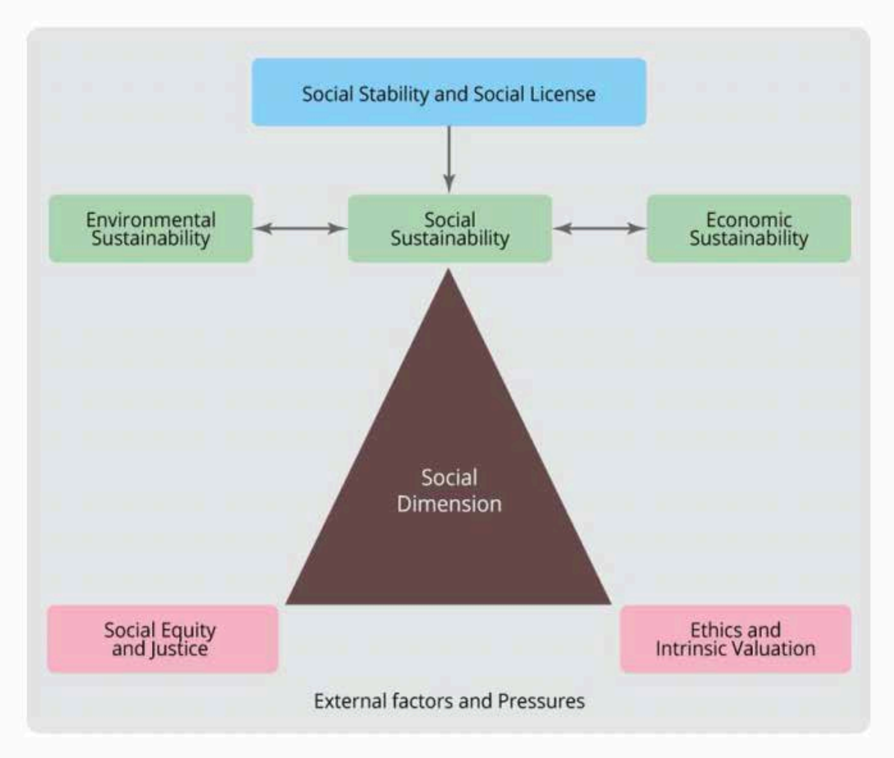
16 The final guideline in this innovative proposal is social cohesion, understood by the authors as "the processes (i.e. shared views, values, norms, perceptions and behaviours) that underpin social relationships (individuals, social groups, communities, etc.)" (PRELL *et al.*, 2009), aiming to "accommodate diversity while promoting equality". Social cohesion fosters social bonds and trust through opportunities, which in the context of MSP means promoting collaborative planning to reduce disruptions that lead to harmful conflicts. Even in a situation of intractable conflict, a sense of social cohesion can help "ensure that the process of planning for plurilateral space does not exacerbate existing schisms in society through processes of exclusion or the reinforcement of existing privileges (intentionally or unintentionally)". In practice, the guidelines described above (democracy, inclusion of socio-cultural elements, equity and social cohesion) are related and overlapping, yet they are different: "when taken

together, they help to conceive of social sustainability as a pillar of sustainability – covering both substantive and procedural aspects of MSP" (SAUNDERS *et al*., 2019a).

17 Concerned about the currently weak consideration of social aspects and impacts (e.g. exclusion or loss of ocean space, diversion of resources away from traditional users, disregard of cultural values, etc.) in processes supporting MSP decision-making, GRIMMEL *et al.* (2019) propose developing socially inclusive guidelines to strengthen social justice and inclusiveness in existing processes, promoting a new approach to ocean sustainability that integrates all dimensions of planning. Based on a literature review on the social dimension of MSP (including BENNETT *et al*., 2015; FLANNERY *et al*., 2016; BENNETT, 2018), the authors provide a conceptual model that is very similar to the framework of SAUNDERS *et al.* (2019b), including the same objective: to foster the equitable integration of social, economic and environmental interests in MSP, assuming that equity becomes possible with the consideration of all three pillars of sustainability.

18 Also of interest, GRIMMEL *et al.* (2019) present two possible aims in including the social dimension in MSP. The first aim is described as a set of connected layers. The first level (the base) is "the integration of social sustainability, social equity and justice as well as ethics and intrinsic value". At a second level, "social stability and social licence are measures of social sustainability and should be inherent objectives of MSP processes". Social equity here means "an equal and fair distribution of the costs and benefits of measures, the involvement of stakeholders at all levels and a focus on livelihood maintenance or alternatives". They stress that "ethical and moral obligations exist towards the environment, other species, as well as all human beings, while intrinsic valuation refers to the values and beliefs, culture and traditions that are present". All these components must be valued and maintained in MSP processes and derived practices. As for the second aim of the social pillar of MSP, this should "refer to all socially relevant aspects that contribute to the present and future status quo in the planning area in socio-economic and socio-ecological domains and be adequately included in the planning process by finding balanced and ethically sound trade-offs between social, economic and environmental sustainability" (GRIMMEL *et al*., 2019). Given the different scales of the social dimension (from the individual to the global), and the fact that it is driven by the economy, Grimmel *et al.* (2019) propose an alternative model (fig. 1).

Figure 1. Conceptual model of the social dimension in MSP



Source: Adapted from GRIMMEL *et al.* (2019)

19 The social science concepts and theories that the authors adopted to produce this model are, in sum, ethics and morality as a basis for thinking about social justice, and social resilience and vulnerability as a basis for the adaptive capacity of vulnerable social groups, prompting changes in economic, environmental and social factors. Social licence and responsibility are achieved through social justice and equity, and enable long-term social acceptance of marine governance processes and outcomes (GRIMMEL *et al.*, 2019). Some of these rationales have been explored by SAUNDERS *et al.* (2019a), who argue that the social sciences include many categories that should guide MSP and further develop its social sustainability. The authors recommend the adoption of practical tools such as social impact assessment, socio-economic impact assessment and tools designed to link mainstream "common" knowledge with traditional or local knowledge (including ecological knowledge). Another possibility to be explored is to link the social and environmental pillars, using socio-ecological systems and the systems approach as references (GRIMMEL *et al.*, 2019).

The socio-cultural dimension in MSP

20 MCKINLEY *et al.* (2019) focus on the social dimension of MSP, including socio-cultural thinking and practices, based on three theoretical approaches: cultural ecosystem services, societal connection to the sea, and well-being. Cultural components have been taken into account in coastal marine planning efforts, but insufficiently so far. These authors discuss the meaning of the term "socio-cultural", pointing out that the connection between people and their environment is defined by a set of religious,

aesthetic, economic and place-related values, and not only explains attitudes and behaviours, but can also "shape sense of place, personal identity and a wide range of opportunities for recreation, leisure and work" (MCKINLEY *et al.*, 2019). A literature search on the subject leads these authors to define the socio-cultural element as a "term that incorporates those many facets of human society, including attitudes, values, behaviours as well as structures that frame social organisations and actions". Concepts that express this notion in ocean governance include ecosystem services, ocean literacy, marine citizenship and well-being (MCKINLEY *et al.*, 2019) (table 2).

Table 2. Selection of key socio-cultural concepts from McKinley *et al.* and their application in MSP

Concept	**Definition and potential application**
Cultural ecosystem services	"Intangible benefits that people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation and aesthetic experiences" (MEA, 2003). This definition is widely contested. It has been explicitly used as a framework for MSP in a few cases.
Ocean literacy	Understanding the impact of the sea on human life and people on the sea – a relatively new term that has the potential to improve public awareness, knowledge and capacity to support the implementation of MSP.
Marine citizenship	Understanding individual rights and responsibilities towards the marine environment, having an awareness of and concern for the marine environment and the impacts of individual and collective behaviour, and enhancing the ability of the public to play a role in ensuring sustainable management of the marine environment.
Well-being	A measure of quality of life related to the marine space and its increasingly recognised impact on human health and well-being, reflected in marine planning policies and in the potential criteria for assessing the outcomes of marine planning.
Seascape	"A space of sea, coastline and land, as perceived by people, whose character results from the actions and interactions of the land with the sea, through natural and/or human factors." A concept occasionally developed as evidence to support marine planning through seascape characterisation, seascape assessments or visual impact assessments (NATURAL ENGLAND, 2012; FALCONER *et al.*, 2013).

Source: adapted from MCKINLEY *et al.* (2019)

21 MCKINLEY *et al.* (2019) also explore the application of these concepts to MSP. Cultural ecosystem services, seascapes and well-being emerge as the most recurrent concepts in MSP (e.g. attitudes and perceptions, cultural heritage, human activities, social, monetary and non-monetary values, and socio-demographics) (for more information on these concepts see MCKINLEY *et al.*, 2019).

22 An ecosystem approach that considers the complexity of an area in its entirety is essential for marine management and decision-making. Taking ecosystem services into account is important in MSP, including the socio-cultural benefits that people derive from nature. Yet cultural ecosystem services present enormous challenges in terms of recognition and valuation. This is because they are defined as "non-material benefits that humans obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation and aesthetic experiences" (MEA, 2003), including: "cultural diversity, spiritual and religious values, knowledge systems, educational values, inspiration, aesthetic values, social relationships, sense of place, cultural heritage values, and recreation and ecotourism". A growing number of studies are focusing on the relationship between cultural ecosystem services and coastal marine planning (e.g. RUIZ-FRAU *et al.*, 2013 and GUERRY *et al.*, 2012), putting forward innovative tools to integrate cultural ecosystem services in the context of MSP (MCKINLEY *et al.*, 2019).

23 The concept of seascape represents a sense of connection between the coastal marine environment and the individual/society; it takes into account how people interact with and use this environment based on different values, attitudes, perceptions, beliefs and experiences. Clearly, this concept also poses a challenge for MSP, due to the difficulty of capturing heterogeneous visions and considering them in the planning process. Nonetheless, the seascape provides a starting point for improving public engagement, generating the interconnected concepts of marine citizenship and ocean literacy, which promote a society more conscious of the importance of the marine environment, ultimately leading to positive behaviour change (MCKINLEY *et al.*, 2019).

24 The integration of the notion of well-being within MSP is also linked to the objective of public engagement, but with a view to improving the quality of human life (STIGLITZ *et al.*, 2009). Beyond producing maps of marine uses, MSP is expected to result in greater human well-being – an ideal far from that of economic prosperity – well-being that needs to be measured and achieved (MCKINLEY *et al.*, 2019). However, these authors argue that despite international objectives and the increasing importance given to the "human" element in interactions within environmental governance, the lack of understanding of its functioning impacts the effectiveness of maritime spatial planning. To address this, McKinley *et al.* make recommendations for overcoming the challenges associated with socio-cultural factors in coastal marine planning, suggesting a greater understanding and inclusion of the concepts discussed in MSP practice, with particular attention to different scales and epistemologies and other factors. In their concluding remarks, they argue that "it is, however, the socio-cultural dimension and the key concepts explored [...] that often form the basis for engaging the public within the planning process and demonstrating the societal relevance of MSP" (MCKINLEY *et al.*, 2019).

25 All of these concepts can contribute to developing more comprehensive MSP that considers all values associated with the coastal marine space in a holistic approach, including ecological, social and economic aspects related to the range of resources and services provided by the ocean, as well as the variety of extractive and non-extractive uses (and their respective degrees of impact). There are a multitude of options and opportunities for improving ocean governance and MSP through public participation and the engagement of traditional communities. One promising area is coastal marine recreational activities, which can offer innovative tools based on the expertise of the

stakeholders. An example is the protection of surfing sites, considering their natural, social and economic value. The following section focuses on the importance of surf breaks in all three pillars of sustainability, the ongoing initiatives to protect them and the need to integrate them in the MSP process where relevant.

The natural, social and economic value of surfing sites

Surfable waves: a rare phenomenon

26 Surf breaks are a scarce resource, formed by complex natural features (SKELLERN *et al.*, 2013). The New Zealand Coastal Policy Statement describes them as “a natural feature composed of swell, currents, water levels, seabed morphology and wind”, which gives rise to a “surfable wave” (NZCPS, 2010). They occur in the inshore marine area, at the transition between the open ocean and the wave-forming zone, arising from a combination of hydrodynamic characteristics (waves, currents and tides), seabed morphology and wind patterns. Water depth, for example, is one of the main physical factors governing wave breaking.

27 A surf break includes the “swell corridor”, the movement of the swell and the morphology of the seabed in this swell corridor to the point where the waves dissipate and become unsurfable. The swell corridor refers to the area off a breaker where the ocean swell moves and becomes a “surfable wave” (a wave that can be caught and surfed). Surfable waves have a breaking point that flows along the crest of the unbroken wave, so that the surfer is propelled laterally along the wave crest (HUTT, 1997; MEAD and BLACK, 2001).

28 The features that create surf breaks span both short and long timescales and can be artificial or natural (REIBLICH and REINEMAN, 2018). In ecological terms, these features are responsible for shoreline stabilisation and sediment control, protection of breakwaters and seawalls, composition of seascapes, living and non-living resources, and serve as habitats, particularly in the case of coral reefs and rock formations.

The multiple services of surf breaks

29 Different kinds of activities have been developed on and around surf breaks (THOMPSON, 2007; STOCKER and KENNEDY, 2009), some for economic purposes, e.g. tourism and the water sports industry. In addition, they also hold social value (spiritual/religious values, knowledge, heritage/cultural diversity, sense of place, aesthetic values, social relationships, etc.), and are appreciated for their recreational uses, not only by surfers, but by all beachgoers.

30 Surf breaks are important for maintaining the balance between ocean and terrestrial environments for current and future generations, involving as they do social, cultural and economic relationships, and protecting them can also protect biodiversity (SANTOS and BLACKWELL, 2020). Around the world, there are initiatives to define strategies to safeguard them. Surf breaks have a singular place in surfers’ careers and are also important social, competitive and cultural gathering points that equally boost the local economy; but these areas so important for surfing and, more broadly, for society, are little known (LAZAROW and OLIVE, 2017). Surfers themselves have contributed to

knowledge about these systems, informing the study of waves and the coastal environment (BOUNDY, 2008; BREWIN *et al.*, 2015; REINEMAN *et al.*, 2017). It is known that waves are very sensitive to changes, natural or otherwise, in the coastal environment (REIBLICH and REINEMAN, 2018).

31 The environmental services provided by "surfing ecosystems" are not only important for surfers, but also for local communities given the improved economic and social context linked to this activity. In these unique coastal marine areas, both a top-down approach by government policymakers and a bottom-up approach including the participation of local communities (LAZAROW and OLIVE, 2017; TELES DA SILVA *et al.*, 2015), with a specific effort to protect biodiversity, are needed (SANTOS and BLACKWELL, 2020).

32 Citizen-led initiatives, favouring a bottom-up approach, play an important role in biodiversity protection and restoration. They are usually led by (1) non-governmental organisations (NGOs), which provide political support and activism for better governance, and/or (2) environmental philanthropists and community volunteers who provide important benefits to the environment. Good management by individuals remains essential (SANTOS and BLACKWELL, 2020).

33 Surfing generates approximately US$4 billion globally (MCGREGOR and WILLS, 2017). Recent studies have focused on the surfing economy in many different regions of the world: South Stradbroke Island, Australia (LAZAROW and NELSEN, 2007), Mundaka, Spain (MURPHY and BERNAL, 2008), Gold Coast, Australia (LAZAROW, 2009), Half Moon Bay, United States (DURHAM and DRISCOLL, 2010), Trestles, United States (NELSEN *et al.*, 2013), Uluwatu, Indonesia (MARGULES *et al.*, 2014), Pichilemu, Chile (WRIGHT *et al.*, 2014), Huanchaco, Peru (HODGES, 2015b), Bahía de Todos Santos, Mexico (HODGES, 2015a), and Guarda do Embaú, Brazil (BOSQUETTI and SOUZA, 2019).

34 Surfing economics, or "surfonomics", analyses data on surfing-related income, taking into account standards and the quality of surfable waves using different methodologies in surfing areas. In both developing and developed countries, the "surfonomics" approach aims to assess the importance of waves, the "lifestyle" of beach culture (PLUMMER, 1974) and surfing ecosystems, as well as how these might be threatened and all the socio-economic impacts this might entail.

35 In these studies, regardless of the surf waves considered around the world – low quality, high quality or world class – and their natural assets, improvements in economic returns are observed at various scales. However, if the quality of surf waves varies in one location (e.g. with the artificial creation of a new surf break), resonating negative or positive economic impacts can be observed up to a 50-km radius around these locations (MCGREGOR and WILLS, 2017).

36 In terms of the environment, some surfing communities are involved in conservation efforts and partnerships. Of course, not all surfers are necessarily environmental activists who participate in environmental protection actions (HILL and ABBOTT, 2009; LAZAROW and OLIVE, 2017). The low involvement of surfers in the protection of these natural, freely accessible places can make them "irresponsible consumers". And while surfing itself is considered a low-impact activity (SANTOS and BLACKWELL, 2020), it can have negative impacts, such as those related to the surfing industry/companies, unsustainable surf tourism (PONTING *et al.*, 2005), contamination by chemicals from the surf equipment industry, incompatibility and conflicts with other beach users or

coastal marine activities (THOMPSON, 2007; STOCKER and KENNEDY, 2009), such as with using waves as a renewable energy resource (RYAN *et al.*, 2015; HEMER *et al.*, 2017), etc.

Consideration of surf breaks in MSP

37 Typically, MSP pays little attention to recreational activities. References to surfing are rare. However, the International Guide to Marine Spatial Planning of the Intergovernmental Oceanographic Commission of UNESCO (IOC-UNESCO) mentions surfing as a human activity in the marine environment (see Step 5 of its MSP approach). This guide also mentions that this activity could be included as an example of spatial management by recreational sectors (see Step 7, UNESCO, 2009). Some countries have considered surfing, including those with existing MSP or those known for their high-quality or world-class waves, namely Australia, Brazil, Chile, Costa Rica, Ecuador, El Salvador, France, Indonesia, Mexico, Morocco, New Zealand, Nicaragua, Panama, Peru, Portugal, South Africa, Spain and the United States. An Olympic sport, surfing is also considered a popular leisure activity rooted in coastal culture, with significant economic and cultural impacts and often profound effects on those who practice it (REIBLICH and REINEMAN, 2018).

38 The capacity of MSP to manage high-impact activities and economic development in coastal marine areas – such as oil exploration/development, fishing, mining, urbanisation, etc. – is well recognised. It could also be useful for creating sustainable standards for recreational activities, including surfing, avoiding impacts on beach access (REBLISH and REINEMAN, 2019). In doing so, MSP should take into account natural, social and cultural aspects and ensure the principle of effective participation (TELES DA SILVA *et al.*, 2016a) as well as more equitable planning processes (FLANNERY and MCATEER, 2020).

39 Given the different characteristics of surf break ecosystems, what objective(s) should MSP take into account? Nature conservation or generating economic benefits? Should these areas be classified as sacrosanct natural sites and efforts made to protect surfing as an activity? The answer is certainly context dependent and requires a multidisciplinary and systemic approach to ascertain.

40 There is no consensus on the main objectives of MSP in the literature (FLANNERY and MCATEER, 2020). Initially, in the late 1970s, MSP focused on marine protected areas in order to improve their effectiveness and avoid threats and negative impacts of human activities on marine environments (FOLKE *et al.*, 2005): marinas, ports, jetties, breakwaters, urbanisation, industrial pollution and run-off, oil platforms, seabed mining, shipping industries, overfishing, ocean grabbing, climate change, beach access, etc.

41 The use of the term “marine” in planning shows a concern for the biodiversity of coastal marine areas (the natural environment), while the term “maritime” emphasises the economic relationships between sea-related commercial or military activities (EHLER *et al.*, 2019). The latter term has been criticised as encouraging post-political planning dominated by the logic of neo-liberalism and undermining participation in spatial planning decision-making (CLARKE and FLANNERY, 2019).

42 A number of MSP initiatives have been developed worldwide, through processes led by governments and non-governmental institutions, taking into account marine protected

areas, coastal zone management policies and other legal and administrative frameworks, as well as local characteristics of the marine environment and maritime activities (JAY, 2017). Several countries have established marine protected areas (MARINE CONSERVATION INSTITUTE, 2020), which can be considered in MSP strategies; however, low-impact nature-based recreational activities such as surfing do not receive the same attention.

43 For example, EU Directive 2014/89/EU13 refers to the need to establish maritime spatial plans considering a range of pressures such as human activities, the effects of climate change, natural hazards and coastal dynamics (erosion and accretion). But the perception of nature-based recreational activities still seems to be exclusively linked to tourism. The MSP process could go beyond this, considering surf breaks as limited natural resources that merit legal protection, as is the case in Peru, the first country in the world to protect waves by national law (SCHESKE *et al.*, 2019; MONTEFERRI *et al.*, 2019): the Law on the Preservation of Waves for Sport[1] in Peru (Law No. 27280/2000 and Supreme Decree No. 015-2013/2013).

44 Aside from this, there are a number of countries that recognise the importance of surf breaks for the environment, the economy and the maintenance of coastal marine culture, such as Costa Rica, Ecuador, El Salvador, Indonesia, Maldives, Mexico, Morocco, Nicaragua, Panama, Portugal, South Africa, the United Kingdom, the United States, Uruguay (ORFILA, 2020), etc. There are also specific legal texts aimed at the protection of marine and/or terrestrial areas such as the New Zealand Coastal Policy Statement (NZCPS, 2010), as well as a series of laws in Australia (in the states of New South Wales and Victoria) (SANTOS and BLACKWELL, 2020) and some legal framework initiatives in Brazil and Chile (SANTOS, 2018) and on the Gold Coast in Australia (QUEENSLAND GOVERNMENT, 2020b). Some of these legal texts are described below in relation to MSP initiatives.

MSP initiatives and surf site protection

New Zealand

45 New Zealand has not developed MSP at a national level. However, a regional document was developed in 2016 that encompasses the Hauraki Gulf Marine Park, where there are some surf breaks, although these are not formally considered to be "nationally significant". New Zealand's legal framework for ocean governance consists of the ocean management principles developed under the Resource Management Act (RMA) of 1991, the New Zealand Coastal Policy Statement (NZCPS) of 2010 and the definition of the exclusive economic zone (EEZ) of 2012 (SCOTT, 2016).

46 The 2010 New Zealand Coastal Policy Statement (NZCPS, 2010) was a response to demands from civil society (SURF BREAK PROTECTION SOCIETY, 2006, 2008). Among its measures, it includes a specific policy to protect nationally important surf breaks: "Protect surf breaks of national importance for surfing listed in Annex 1 by: (a) ensuring that activities in the coastal environment do not adversely affect surf breaks; and (b) avoiding adverse effects of other activities on access, use and enjoyment of surf breaks" (Measure 16). In addition, NZCPS 2010 includes a measure relating to strategic planning (Measure 7) and provides "that this must be carried out by persons exercising

functions and powers under the Act". New Zealand has a large number of high-quality, world-class surf breaks (ORCHARD, 2020). While it does not specifically use MSP, there is scope to create marine coastal management initiatives and policies linked to the surf break protection programme.

Peru

47 To date, MSP is not used in Peru. However, the recent National Maritime Policy 2019–2030[2] is oriented towards a sustainable economy and includes legal provisions to protect waves and surf[3]. This is the first legal act in the world to protect waves and adjacent areas, and to define them as natural heritage and the "inalienable" property of the Peruvian state (SCHESKE *et al*., 2019). It is also the first legal act to consider waves as a legal entity once registered by the Peruvian Navy (Directorate General of Ports and Coastguards, National Wave Registry)[4].

48 The law does not fall under the legal environmental framework for protected areas managed by the Ministry of Environment, but is the responsibility of the Navy, which is part of the Ministry of Defence. The Navy manages the allocation of aquatic use rights (SCHESKE *et al*., 2019) and has taken the lead in developing a multi-sectoral strategic plan up to 2024, covering aspects related to MSP[5]. This creates opportunities to link MSP with the surf break protection agenda in Peru. This legal governance framework, together with a multitude of marine and environmental legal acts, could stimulate the development of MSP strategies in Peru that take into account the need for good governance and management of coastal marine areas where recreational practices, including surfing, have been appropriated by local communities and contribute to the natural environment, the blue economy and the culture.

Chile

49 In Chile, MSP has not yet been adopted. Chile is among the top 20 countries with a considerable number of surf breaks (MCGREGOR and WILLS, 2017), although there is no specific legislation to protect them. Nevertheless, two recent examples of good governance to protect surf breaks exist within the legal framework of Chile's marine protected areas, led by a coalition of stakeholders:

- The Punta de Lobos surf break has been certified as a World Surfing Reserve by the non-profit Save The Waves (STW) coalition. In addition, under Chilean Law No. 20930-2016, the NGO Fundación Punta de Lobos was founded to acquire marine coastal properties and manage them for conservation purposes (SCHESKE *et al*., 2019). The state's real right to the Mirador area was transferred in perpetuity to the World Surfing Reserve of Punta de Lobos under binding conditions, in order to protect its ecosystems, regardless of who owns the land[6].
- The NGO Fundación Rompientes has developed an initiative whose main objective is to dialogue with fishermen regarding the protection of surf breaks within the benthic resource management areas (AMERB), based on quotas defined in the management plans and seeking economic opportunities for fishermen through surf tourism. The territorial rights for fishing (Turf-Surf) and AMERB-Surf include the protection of six Chilean surf breaks located in the Piedra del Viento Marine Sanctuary (SANTOS, 2020), a marine protected area approved

by the Chilean Ministerial Council of the Environment under Article 31 Title VII of Chilean Law No. 17288 (CHILE, 2020).

50 The development of an MSP policy does not yet seem to be part of the Chilean government's priorities despite the fact that its coastal marine areas have important biodiversity and cultural interest, as well as considerable potential for sustainable economic development, and these areas are under threat (AGUILERA *et al*., 2019). There is thus an urgent need to create and consolidate the surf zone protection programme and to improve initiatives to protect these areas, making them more effective and linking them to the global MSP sustainable development agenda.

Spain

51 Spain has recently developed national MSP. Draft MSP plans were finalised in 2021, including the draft Royal Decree approving these plans and the strategic environmental assessment study. Subsequently, the Spanish government launched a public consultation on the proposed MSP, as well as a cross-border consultation with neighbouring countries (France, Portugal and Italy). The final versions of these drafts were submitted to the Environmental Administration, which then published the Strategic Environmental Report, with a view to approving the plans by Royal Decree. The Spanish MSP was adopted in February 2023, and the implementation of the measures and monitoring will take place between 2022 and 2027.[7] According to the executive summary of these MSP plans, the planning objectives indicate a clear commitment to the protection of surf breaks, due to the importance of this resource for tourism and recreational activities (ESPAÑA, 2021). The Mundaka surf break received legal protection in 2016 (Decree 139 of the Basque Government), becoming the first to obtain this status in Europe. The protection considers the singularities of the wave as a natural heritage. It is included as part of the Urdaibai Biosphere Reserve, on the coast of the Bay of Biscay, north of the Iberian Peninsula (Basque Government, Decree 139/2016; TRUEBA and RODRIGO, 2021).

Australia

52 Australia has a diverse legal framework in relation to coastal sea issues (MSP GLOBAL, 2020), with some key planning examples such as the Great Barrier Reef Marine Park Act 43 of 1975, the Marine Bioregional Plan for the North-west Marine Region, the Marine Bioregional Plan for the North Marine Region, the Marine Bioregional Plan for the South-west Marine Region, the Marine Bioregional Plan for the East Temperate Marine Region and the South-east Marine Region (SCOTT, 2016). The country is considered the best place in the world to surf (PIERSON, 2018). It was also the first country to introduce a model surfing recreation reserve (land-based) (Bells Beach Surfing Recreation Reserve in 1973) and a national surfing reserve programme. Australia also holds the largest number of World Surfing Reserve certificates, mainly for two beaches, Gold Coast and Noosa (SANTOS, 2018).

53 Under the Crown Land (Reserves) Act 1978, the Bells Beach Recreational Surfing Reserve is located in the South-east Marine Region (COMMONWEALTH OF AUSTRALIA, 2015), around Point Addis Marine National Park and Great Otway National Park. It is managed by the Surf Coast Shire. It is governed by the Coastal Management Act 1995, the Draft

Western Regional Coastal Plan 2015–2020, the Victorian Aboriginal Heritage Act 2006, the Aboriginal Heritage Regulations 2007 and the Heritage Act 1995, which includes Bells Beach as part of Victoria's cultural heritage (SANTOS, 2018).

54 The City of Gold Coast introduced an innovative tool in 2015 – the Gold Coast Surf Management Plan – which covers 52 km of surf around the Gold Coast World Surfing Reserve (GCWSR). The plan aims to balance the interests of beach users and the ocean through keeping the beaches open and inclusive while remaining ecologically healthy and clean. The plan also aims to implement global best practice in coastal management strategies to preserve and enhance surfing by recognising the key role it plays in the city's economy, culture, sporting life and social capital (CITY OF GOLD COAST, 2015). Recently, the state of Queensland (where the City of Gold Coast is located) has also begun a process to create specific legislation for its two World Surfing Reserves, GCWSR and Noosa (QUEENSLAND GOVERNMENT, 2020b).

55 Australia has great potential to link these initiatives to national or regional MSP, and to show how surfer-driven surf break protection (REINEMAN, 2016) could help improve sustainable coastal marine management policies elsewhere in the world.

Brazil

56 Brazil includes 17 coastal states and 279 coastal municipalities covering an average area of 10,900 km (IBGE, 2020) (fig. 2). Brazil made a commitment at the 2017 UN Ocean Conference to implement MSP by 2030, so a national MSP programme has gradually gained prominence in recent years. The Interministerial Commission on Marine Resources (CIRM), which coordinates national policy for marine resources, established a Working Group on Shared Uses of the Marine Environment (GT-UCAM) in 2013 (resolution no. 1/2013). In 2014, within the framework of GT-UCAM, the Marine Spatial Planning subgroup was formed to propose guidelines, tools and methodologies to support decision-making related to GT-UCAM's activities. In 2017, this group established a roadmap towards a national MSP process. In 2020, Federal Decree No. 10,544 enacted the 10th Sectoral Plan for Marine Resources, with the objective of promoting the shared use of marine resources through the implementation of comprehensive MSP.

57 There is no doubt that MSP is on the agenda of Brazilian ocean and marine resources policy. Nevertheless, governmental actions are lacking to coordinate participatory governance to address the challenges and opportunities of national MSP. At the regional level, a few bottom-up MSP initiatives have been designed and implemented, such as in Babitonga Bay (GERHARDINGER *et al.*, 2019; HERBST *et al.*, 2020). Given this limited experience, Brazil lags behind international MSP programmes (GERHARDINGER *et al.*, 2019). This could hinder the inclusion of all stakeholders and activities in MSP, including in the protection of surf zones. There is still work to be done in this country to construct a wide democratic process that recognises all activities that contribute to sustainable development.

Figure 2. **Coastal states and municipalities in Brazil**

Source: IBGE (2020)

58 In 2019, a surf break in Brazil was recognised by STW as one of the 11 World Surfing Reserves (Guarda do Embaú World Surfing Reserve, state of Santa Catarina). There are also a large number of legal acts concerning coastal marine environments, which could be used as a legal framework to establish links between environmental law, integrated ocean policies and governance initiatives focused on the inclusion of recreational and low-impact activities in Brazilian planning strategies (SANTOS and BLACKWELL, 2020).

59 The Brazilian Constitution has a specific chapter (Article 225) on environmental issues that underlines the duty of the national government, the states and the municipalities to create protected areas. This represents a real opportunity to implement innovative legal frameworks regarding specific areas or even small ecosystems, for example, the surf break protection programme. TELES DA SILVA *et al.* (2016a) have highlighted some Brazilian surf breaks located in national protected areas (national system of conservation units[8], Law No. 9 985/2000). These surf breaks have the potential to become surfing reserves in line with the criteria of the STW World Surfing Reserves programme: (1) wave quality and consistency; (2) significant environmental features; (3) surfing culture and history; (4) governance capacity and local support or included in the management plans/strategies of protected areas (national, regional or local).

60 The inclusion of the Guarda do Embaú World Surfing Reserve in the management plan of the Baleia Franca Environmental Protection Area (APA) (ICMBIO, 2018) in southern Brazil is a good example of the integration of different measures to protect coastal marine environments. Although there is no specific legislation to protect its surf breaks, Brazil has sufficient legal acts from environmental, administrative and urban law applied through jurisprudence to protect these sites. A legal governance

framework linked to an MSP programme will need to take into account new patterns of use of marine spaces and their resources. The management of small coastal marine areas through innovative initiatives around low-impact recreational activities, such as surfing, and through a surf break protection programme, should be considered.

Conclusion: recognition of the value of surf breaks in MSP

61 Integrating socio-cultural values in decision-making faces the challenge of defining acceptable valuation methods. Stakeholder consultation and deliberation offers a way to take into account diverse deeply held cultural values alongside the other ecosystem service valuation approaches needed for MSP.

62 All values – tangible and intangible – associated with the coastal marine space need to be considered in a holistic approach, with a broad understanding of the ecosystem services provided by the ocean, including cultural services.

63 In relevant contexts, surf breaks should be taken into account in MSP, involving the participation of the citizens concerned. There are a number of international examples in which surf areas are protected by legal or voluntary mechanisms.

64 The way we govern and manage ecosystems and natural resources must be enhanced to not only consider development opportunities, but tackle inequality and poverty, ensure livelihoods, avoid conflict and improve human well-being.

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1. Ley de Preservación de las Rompientes apropiadas para la Práctica Deportiva.
2. Decreto supremo nº 012-2019-DE.
3. Ley de Preservación de las Rompientes Apropiadas para la Práctica Deportiva, Act 2728/2000. Decreto Supremo 015-2013-DE
4. Dirección General de Capitanías y Guardacostas (DICAPI), Registro Nacional de Rompientes (RENARO)
5. See the MSPGlobal initiative: https://www.mspglobal2030.org/msp-roadmap/msp-around-the-world/americas/peru/
6. See Fundación Punta del Lobos: https://www.puntadelobos.org/que-hacemos/
7. See https://www.mspglobal2030.org/msp-roadmap/msp-around-the-world/europe/spain
The Spanish MSP adopted in 2023 establishes plans for each of its five marine subdivisions. See https://maritime-spatial-planning.ec.europa.eu/countries/spain
8. Sistema Nacional de Unidades de Conservação.

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Chapter 15. Strengths and weaknesses of decision support tools

A didactic example on the archipelago of Fernando de Noronha

Adrien Brunel and Sophie Lanco Bertrand

Introduction

1 Marine environments are now often considered as the territories of tomorrow for "blue growth" (EUROPEAN COMMISSION, 2014, 2017; WWF, 2018). However, these spaces are already subject to multiple anthropogenic pressures (fishing, aquaculture, maritime routes, seabed exploitation, recreational activities, renewable energies, etc.). In this context, marine spatial planning (MSP) is positioned as a collective and rational decision-making process that aims to regulate the use of marine spaces and resources in order to reduce tensions between uses and conservation and between ocean stakeholders. MSP has spread widely, becoming the governance paradigm favoured by management institutions in search of sustainable development. MSP involves collective mobilisation, as its process is based on transversal, spatially explicit information (ecological, legal, social, economic, etc.). In this data analysis-based framework, decision support tools (DSTs) have proven to be indispensable for rationally informing the decision-making process. DSTs take the form of spatially explicit tools, involving interactive software with maps, models, communication modules and additional elements that can help solve multifaceted problems that are too complex to be solved by human intuition or conventional approaches alone (Box 1).

2 While the number and types of DSTs have continued to grow, those that focus on systematic conservation planning and selection of sites for nature reserves (e.g. Zonation, Marxan, prioritizR) have gained particular popularity. The United Nations (Aichi Target 11 in the Convention on Biological Diversity, Sustainable Development Goal 14) encourages the coverage of 10% of coastal and marine areas by marine protected areas (MPAs) by 2020. More recently, the International Union for

Conservation of Nature (IUCN, 2014 and 2016) has set an ambitious target of 30% protection for each marine ecoregion by 2030, up from less than 8% today. Therefore, systematic site selection tools are needed to delineate, with as little opacity as possible (PRESSEY, 1994; PRESSEY and TULLY, 1994), areas dedicated to conservation. DSTs for nature reserve design have rapidly become central to conservation research and have been used globally, particularly to address MSP challenges.

3 Early attempts to design nature reserves were based on intuitive rules: estimating a conservation value associated with a given area (HELLIWELL, 1967; TUBBS and BLACKWOOD, 1971; GOLDSMITH, 1975; WRIGHT, 1977), then classifying areas according to their values (TANS, 1974; GEHLBACH, 1975; RABE and SAVAGE, 1979), and finally enriching the process with iterative classification approaches to overcome the lack of complementarity between reserves (KIRKPATRICK, 1983; MARGULES *et al.*, 1988; PRESSEY and NICHOLLS, 1989). However, since COCKS and BAIRD (1989), the problem of conservation site selection has been mathematically understood, in a consensual manner, as a constrained optimisation problem. This mathematical framing of the problem has the advantage of bringing back to the forefront the need to preserve anthropic uses as much as possible, while protecting the biodiversity of natural areas. However, it involves more complex numerical procedures, such as the integer programming framework (POSSINGHAM *et al.*, 1993, 2000; MARGULES and PRESSEY, 2000; POSSINGHAM *et al.*, 2006), or more recently, exact optimisation solvers (CHURCH *et al.*, 1996; BEYER *et al.*, 2016). The increasing complexity of these procedures carries the risk of depriving some stakeholders of a critical view of the space and rights allocation process.

4 In this context, the objectives of this chapter are (1) to make the mathematical functioning of commonly used DSTs more accessible to users through graphical illustrations of a simplified case study and (2) to raise awareness of conservation site selection DSTs by deciphering the effects that data (or lack of data) and parameterisation options can have on the results. To do this, we consider a small-scale and deliberately simplified didactic example: the Fernando de Noronha archipelago in the tropical Atlantic, northeast of Brazil.

Box 1. Decision-making tools: the challenges and importance of regulation
Philippe Fotso
Marie Bonnin

According to the joint "roadmap" published by the European Union and the Intergovernmental Oceanographic Commission of UNESCO, DSTs are technical means enabling the decision-maker to envisage MSP that takes into account all possible scenarios. This refers to the set of technical tools and systems that inform and facilitate decision-making in the planning process (TROUILLET, 2008). DSTs operate using algorithms, characterised by "the input of a mass of initial data [which is processed by mathematical formulae], to arrive at results by correlation" (BARRAUD, 2018). These computer programmes serve to formalise policy objectives through mathematical operations on the basis of scientific data.
A guide published in 2011 by the Center for Ocean Solutions (COS) lists the main DSTs used in MSP. The four functions of DSTs according to this guide are (1) combining data of various kinds (ecological, economic and social), (2) transparent assessment of different management scenarios, (3) stakeholder participation and (4) assessment of progress towards management objectives. The document

recognises that not all the selected tools perform equally well. Furthermore, depending on their function, DSTs can be used at different stages of the planning process (STELZENMUELLER *et al.,* 2013). They can be useful during the phase of defining objectives and analysing existing conditions, which consists of collecting scientific data, carrying out a baseline survey, mapping uses, identifying conflicts and compatibilities. They can also be used during the phase of analysing future conditions, which consists of establishing trends according to needs and different possible scenarios.

It is up to the public authority to determine the solution deemed most effective to achieve the planning objectives based on the expertise offered by the tool. The result is that MSP DSTs are developing within a rationale of performance, but in a poorly regulated context. Apart from the regulation of data, there are no standards or norms that make it possible to control the way in which this data is processed, the practices of professionals or the results of the tools. This opacity represents a risk that a public authority will use DSTs to provide the illusion of the consideration of environmental issues in public processes. To overcome these shortcomings, upstream regulation is essential. This would make it possible to define good practices that could potentially be accompanied by official certification (PAVEL and SERRIS, 2018); it would also make it possible to establish the different frameworks of responsibility of operators and practitioners. This would provide legal certainty both for the public authority and for users and professionals. In the absence of such measures, one of the legal bulwarks is to carry out both a priori and a posteriori controls on the basis of existing instruments of environmental law.

While the use of DSTs plays an essential role in the formulation of public policies, this does not imply transferring the responsibility for environmental decision-making to DST operators. The public authority remains the sole guarantor of administrative decisions, even if its actions are counterbalanced by the role of scientific expertise in decision-making (GONOD and FRYDMAN, 2014).

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Materials and methods

5 The methodology used was based on Marxan and prioritizR, two (free and open source) optimisation-based DSTs developed for conservation site selection purposes. The data processing scripts were written in the R language for reasons of sharing and simplicity[1]. Acoustic, bathymetric and fisheries data were used. These data were collected at a workshop of the "Planning in a liquid world with tropical stakes" (Paddle) project in November 2019 in Recife, Brazil. The data collection was carried out in situ during different scientific campaigns carried out in recent years.

Tools for the systematic selection of conservation sites

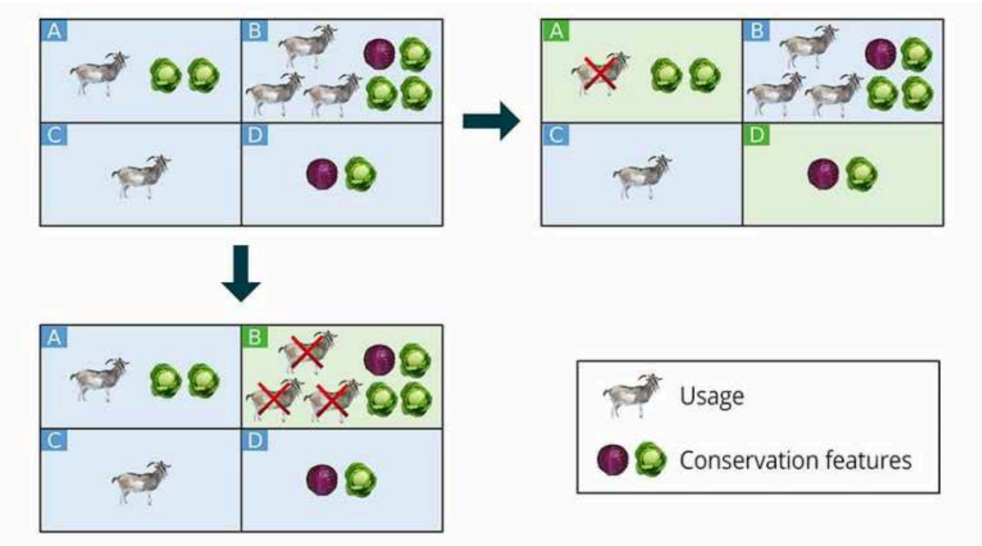
6 Protected areas are commonly considered an essential contribution to conservation efforts to ensure the sustainability of biodiversity. In this context, DSTs have been proposed to systematically determine which sites should be included in a nature reserve or an MPA. DSTs can help planners find the best trade-off between human activities and conservation objectives such as ecosystem health. Two main formulations of the problem have been proposed: maximising a nature reserve's coverage of conservation features[2] under an a priori budget constraint (maximum coverage problem) or minimising the cost of the reserve (cost being understood as a limitation on human activities) while ensuring the coverage of conservation features at a minimum level established a priori (minimum set problem). Here, we focus more on the latter, as this is dominant in the scientific literature and is addressed by Marxan and prioritizR.

Optimisation for maths dummies

7 We present here an illustration of an optimisation problem that is a relevant example of the spatially explicit problems solved by conservation site selection algorithms, such as those implemented in Marxan and prioritizR. Imagine that green and red cabbages are growing in goat pens. Naturally, if the goats are free to access their usual pens, they will eat all the cabbages. We need to establish a conservation plan to protect a predefined, ecologically relevant amount of cabbage. To do this, we need to determine which pens should be closed in order to protect enough cabbage while affecting as few

goats as possible. The data used in the problem is "spatially explicit", because we can count and locate the goats and cabbages. In practice, imagine four pens (labelled A, B, C, D) with goats and cabbages distributed as shown in figure 1, and a conservation target of at least three green and one red cabbage. Consequently, it seems better to close pens A and D rather than just B, as both meet the cabbage targets (three green, one red), but only one goat is affected instead of three. Pen C is not worth protecting, as it contains no cabbages and one goat uses it. In other words, systematic selection tools for conservation sites attempt to ensure the conservation of a given number of features (here, cabbages) while limiting the loss of benefits associated with a given use (here, goats).

Figure 1. Example of an optimisation problem solved by systematic selection of a conservation site



The blue background means that the pen is open and the green background that it is closed (i.e. it is part of the reserve). From the initial situation (top left), which access to the pens should be prohibited in order to protect three green and one red cabbage while minimising the impact on the goats? If pen B is locked (bottom left), the conservation objective is achieved and three goats are affected, whereas if pens A and D are locked (top right), only one goat is affected and the objective is still achieved.
Source: A. Brunel, S. Lanco Bertrand

Underlying mathematics

8 Since conservation site selection problems are expressed in an optimisation framework, the field of conservation science largely overlaps with the scientific fields of decision theory and operations research. The Marxan and prioritizR software packages are "simply" optimisation solvers, more or less encapsulated in user-friendly features. Here, we give a general overview of optimisation in order to understand what exactly conservation site selection tools do. An example of a minimum set problem is also provided to allow a better understanding of the optimisation problem.

Overview

An optimisation problem can always be expressed by an objective function $f : \mathbb{R}^n \rightarrow \mathbb{R}$ and p inequality constraint functions

$c_i : \mathbb{R}^n \to \mathbb{R} c_i : R^n \to R$.The inherent question is to derive,under the existence hypothesis,the decision variable $\mathrm{x} \in \mathbb{R}^n$ that minimises the objective function f while respecting all constraints c_i, with a negative value. Mathematically, this can be expressed as follows:

$$\begin{cases} \min_{\mathrm{x} \in \mathbb{R}^n} f(x) \\ i \in [\![1, \mathrm{p}]\!], c_i(\mathrm{x}) \leq 0 \end{cases} \quad (1)$$

9 Optimisation problems are often divided into classes according to their nature. The most common is “continuous programming”, which contains the subclasses “convex programming” and “linear programming”, and in which the existence theorems and solution methods are well known and widely tested. However, our conservation site selection problem belongs to an intrinsically different class of optimisation, namely “integer programming”, and more specifically, the sub-class of “binary non-linear programming”. Indeed, our decision variable reflects a binary choice of whether to include a specific bounded area in the nature reserve. Therefore, $x \in \mathrm{D} = \{0,1\}^{\mathrm{N}}$ where *N* is the number of units resulting from the division of the study area. Naively, one might think that this problem is simpler than the continuous programming problem because we “only” have to calculate all possibilities for the elements *x*, which is a finite number (equal to $|\mathrm{D}| = 2^{N}$),and take the smallest value from *f*(*D*) (such a task is obviously impossible with a continuous decision variable).However, a finite set does not necessarily mean that today’s computers can explore it in a reasonable time. For N>266 the number of evaluations of *f* is larger than the number of atoms in the universe ($\sim 10^{80}$).For example, in the very simple didactic case study we are considering, *N=756*, which corresponds to more than 10^{227} possibilities for *x*. Furthermore, solving the associated relaxed problem (i.e. allowing *x* to explore the smallest continuous set comprising D) and rounding the computed solution does not theoretically or practically guarantee finding a relevant solution. Unlike in continuous programming, the derivative of *f*, although it is the basis of most, if not all, continuous optimisation solvers, is meaningless.

Application to conservation site selection

10 In short, conservation site selection tools simply provide a method of solving the optimisation for binary programming. Why do we need a binary approach to frame the problem? First, the study area is divided into planning units (PUs), i.e. pixels of the grid used to discretise the study area. Each PU is associated with a socio-economic cost[3], but also with the quantity of each conservation feature (CF) considered. Keep in mind that the data is spatially explicit, i.e. quantitatively located in space, which makes it possible to associate a cost and a number of CFs (quantity such as biomass or abundance) to each PU (location by latitude and longitude). Secondly, overall conservation objectives, defined on the basis of available ecological knowledge (e.g. minimum population size to be viable, important connectivity patterns, etc.) are specified, representing the minimum total number of each CF that should be included in the final protected area.

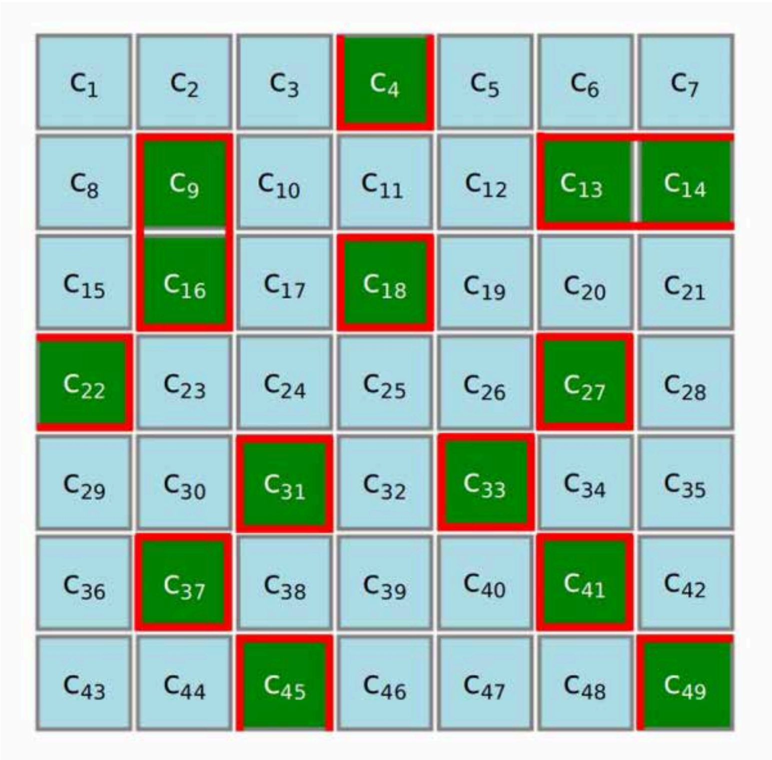
The objective of systematic site selection (in the minimum set problem) is to find which conservation area, represented by a list of PUs, achieves the predefined conservation objectives at minimum socio-economic cost. The decision is therefore about the activation (0 or 1) of a PU representing the inclusion of a site in the nature reserve. In a mathematical optimisation formula (see equation 1), the problem solved by the DST can be expressed as follows:

$$\begin{cases} \min_{x \in \{0,1\}^n} Cost(x) + BLM \times BoundaryLength(x) \\ i \in [\![1, p]\!], TargetedCF_i - ReservedCF_i(x) \leq 0 \end{cases} \quad (2)$$

11 A conservation site is mathematically represented by a vector $x \in \{0,1\}^N$ (the value of the row is 1 if the corresponding PU is selected,0 otherwise).The cost function *Cost* depends on the conservation site and gives the total cost of the selected PUs, i.e. the sum of the costs of all PUs selected as belonging to the protected area. The function $ReservedCF_i$ depends on the conservation site and gives the total amount of the i^{th} conservation feature in the protected area. The constant $TargetedCF_i$ is the user-defined target level of the i^{th} conservation feature. The function *BoundaryLength* depends on the conservation site and simply indicates its boundary. BLM (*boundary length modifier*) is a weight associated with the perimeter of the protected area leading to a greater or lesser penalty in the objective function and allows for a possible increase in the compactness of the site according to the stakeholders' point of view. The detail of the calculation of the value of the objective function is illustrated by a didactic example in figure 2.

12 Historically, debates about the geometry and general shape of protected areas originated in the scientific field of island biogeography (MACARTHUR and WILSON, 1967). This discipline crystallised around a debate over "single large or several small" (SLOSS) reserves, which questioned whether a single island could support more species than several small ones, assuming that both environments had the same total size. The relevance of this debate in conservation biology was illustrated by an analogy: an island and a reserve can both be considered as species-friendly places, separated by unfriendly areas of ocean or damaged habitats respectively. Consequently, interesting lessons were drawn from the literature on island biogeography (DIAMOND, 1975; MAY 1975), although they later demonstrated their practical failure for conservation (SIMBERLOFF, 1976; SIMBERLOFF and ABELE, 1976) and their inability to provide general answers (SOULÉ and SIMBERLOFF, 1986). A remnant of this debate in conservation science is the implementation in systematic site selection tools of a compactness control, i.e. the BLM parameter. A direct penalty is applied in the objective function, proportional to the length of the site boundaries, with the proportionality factor equal to the BLM (see equation 2). In this way, if the BLM parameter is on (i.e. strictly positive), it forces the optimisation solvers to prefer solutions with aggregated PUs rather than dispersed PUs. Selected PUs sharing a boundary imply the removal of the common boundary from the total perimeter calculation.

Figure 2. Example of a conservation site solution and the value of the objective function



The selected planning units are in green, the others in blue.
$Cost(x)=c_4+c_9+c_{13}+c_{14}+c_{16}+c_{18}+c_{22}+c_{27}+c_{31}+c_{33}+c_{37}+c_{41}+c_{45}+c_{49}$.
BoundaryLength(x)=46 is the sum of the red segments.
Source: A. Brunel, S. Lanco Bertrand

Marxan/prioritizR

13 Here we illustrate two widely used optimisation DSTs developed for conservation site selection purposes, namely Marxan and prioritizR:

- Marxan is free and open-source software (BALL and POSSINGHAM, 2000; GAME and GRANTHAM, 2008; BALL *et al.*, 2009; ARDRON *et al.*, 2010) that is the most widely used and successfully tested DST for marine protected area design (e.g. Great Barrier Reef, Channel Islands of California, Gulf of Mexico). In particular, The Nature Conservancy and the World Wildlife Fund (WWF) are well-known users and promoters. Marxan proposes a metaheuristic algorithm called "simulated annealing", which offers a good compromise between computational speed and optimality evaluation. Moreover, Marxan is able to handle all integer programming problems with non-linear optimisation. A priori, Marxan never provides the optimal solution, but many near-optimal solutions. The amount of near-optimal solutions is user-defined, a feature that planners can use to their advantage, as it yields various interesting backup solutions that can feed into the conservation discussion. Marxan's downside is that it may seem unintuitive to non-technical users, which can lead to clumsy use and misinterpretation of results. In particular, fine-tuning is required to achieve the conservation objectives through an infeasibility penalty weight directly included in the objective function. Formally speaking, the basic Marxan executable file is called in R scripts.
- prioritizR is an R package (HANSON *et al.*, 2020) that can formulate conservation site selection problems based on a free open-source integer linear programming (ILP) solver called

Symphony[4]. This recently developed R package provides an exact solution to the optimisation problem in a time-efficient manner. Although ILP solvers deal with linear problems, prioritizR takes into account the quadratic constraints of the BLM due to the binary nature of the problem. Unlike Marxan, no tuning is required to achieve solution feasibility. The prioritizR package has turned calls for ILP solution methods (CHURCH *et al.*, 1996) into a practical reality, opening up broader perspectives (Monte-Carlo approach, irreplaceability analysis, etc.).

14 The choice of Marxan or prioritizR illustrates one of the earliest debates in conservation science, namely whether to favour fast but sub-optimal solutions over slow but accurate ones. The improved performance of ILP algorithms (SCHUSTER *et al.*, 2020) has enabled the development of ILP algorithms and initiated a possible paradigm shift recognised by the creator of Marxan (BEYER *et al.*, 2016). While we compare the two DSTs in this case study, most of the results were obtained via exact resolution methods using prioritizR.

Input data

15 Marxan and prioritizR require only a few input files providing the essential information for the expression of the optimisation problem:

- pu.dat: a list of the reference indices of the PUs (column 1) and the corresponding socio-economic cost (column 2). It thus represents the grid of PUs in the study area on which the map of cost functions is appended
- spec.dat: a list of the CFs considered (column 1) with the corresponding total targeted amount in the final conservation site (column 2)
- puvsp.dat: a list giving the quantitative geographical distribution of each CF (column 1). It contains the amount of the CF (column 2) associated with the corresponding PU (column 3).
- bound.dat: a list giving the shared boundary length (column 3) between two PUs (columns 1 and 2)
- input.dat: a list of all the high-level setting parameters (algorithms, display, save options, etc.).

Output data

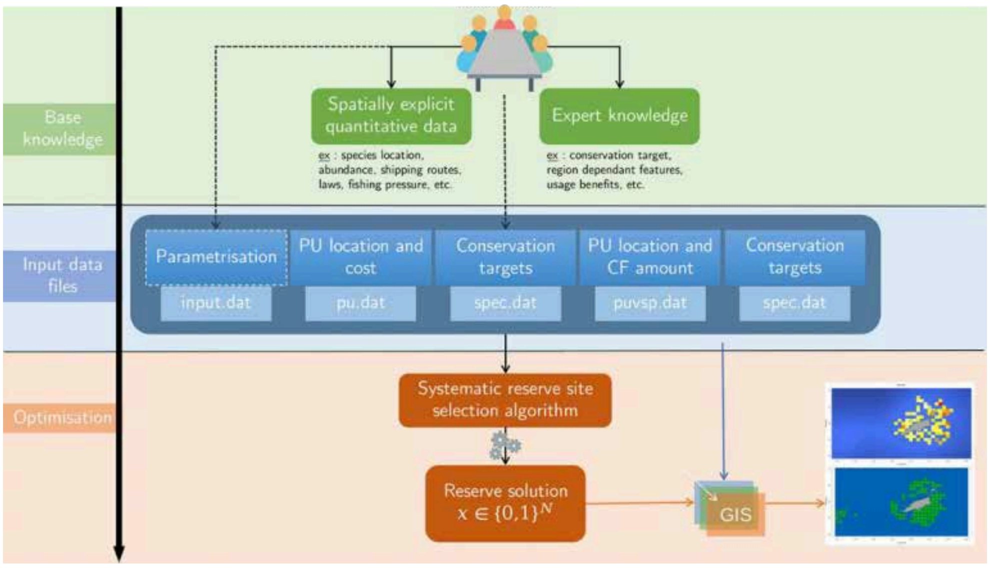
16 The output of the conservation site selection algorithms is the selected site in the form of a two-column text file that contains a list of PU references and the corresponding decision variable (0 or 1). Note that Marxan provides many more files, since three files (solution, feasibility information, summary) are generated for each run of the algorithm.

Graphical representation of the analysis flow

17 The different steps in selecting a conservation site are summarised in figure 3. The first step (green) consists of establishing ecological objectives and building consensus between stakeholders. The second step (blue) translates these discussions and the spatially explicit information available into quantitative input files for the DSTs. The last step (in orange) calculates the solutions through site selection algorithms. Their visualisation is provided by geographic information systems (GIS). The whole process

can be iterated to converge on a solution that is satisfactory to stakeholders and decision-makers.

Figure 3. Analysis flow for systematic selection of conservation sites



Source: A. Brunel, S. Lanco Bertrand

Data

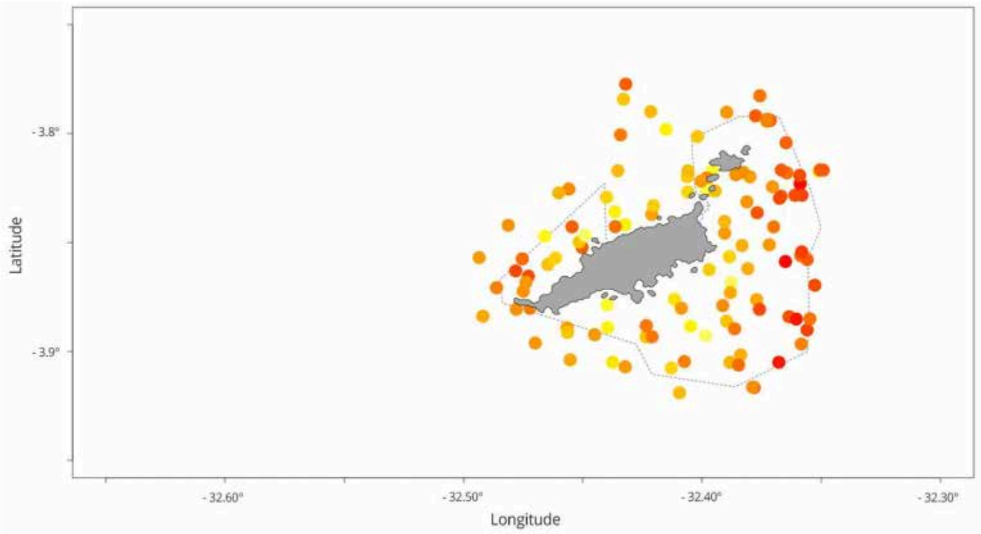
18 In this section, we present the data used for our case study, i.e. the Brazilian archipelago Fernando de Noronha in the tropical Atlantic. We explain how we discretised the input data to make it understandable to site selection software. The study area was defined as an extension grid in latitude and (which represents approximately 1.05 km at Fernando de Noronha's latitude), resulting in a 36 x 21 grid of 756 PUs (numbered from left to right and from bottom to top), in order to capture fisheries data in an exhaustive manner.

Acoustics

19 Recent at-sea campaigns around Fernando de Noronha collected raw in situ acoustic data (fig. 4) on fish abundance and distribution (Farofa3 campaign, April 2019, collaboration between the French National Research Institute for Sustainable Development, IRD, the Federal Rural University of Pernambuco, UFRPE, and the Federal University of Pernambuco, UFPE). Sampling was generally conducted in or around the existing Fernando de Noronha Marine Park. This means that no acoustic data was available outside this area. The existing marine park is shown in figure 4. The raw acoustic data consisted of a list of measurement points with latitude, longitude and S_A (an acoustic indicator of fish biomass). The acoustic data was considered here as a proxy for CF. To make the information understandable for site selection tools, we summed all S_A values located within a PU[5]. In this way, we were able to prepare the input file "puvsp.dat", visualised in figure 5. We can see the resolution and the boundaries of the chosen grid, and the colour gradient and displayed values describe

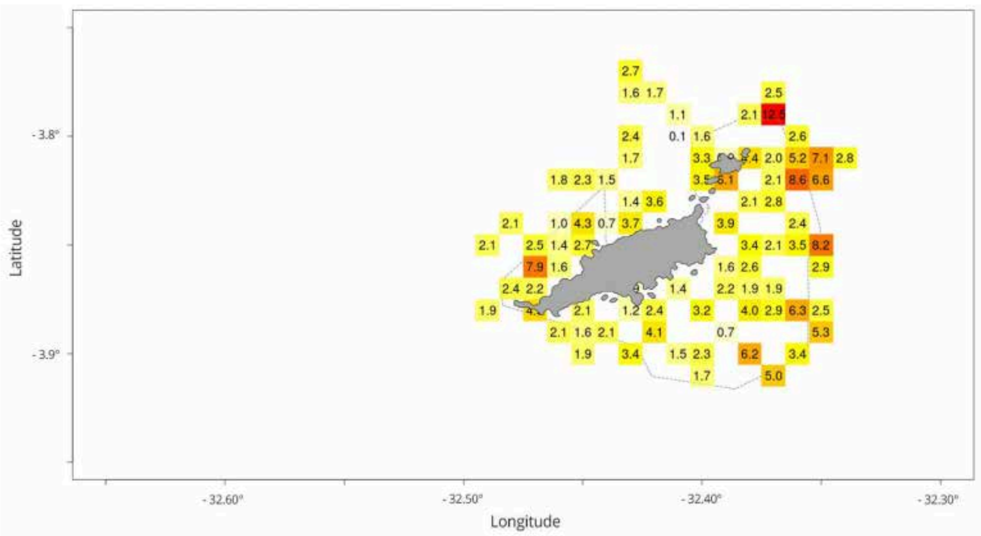
the process of converting the raw acoustic data for Marxan/prioritizR by summing up all the S_A values observed within a PU.

Figure 4. **Raw acoustic data, collected around Fernando de Noronha, represented with a yellow to red colour gradient indexed on the values**



The dotted line around the archipelago is the current marine park.
Source: A. Brunel, S. Lanco Bertrand

Figure 5. **Acoustic data processed in a grid adapted to the DST, represented by a yellow to red colour gradient indexed on the S_A values**



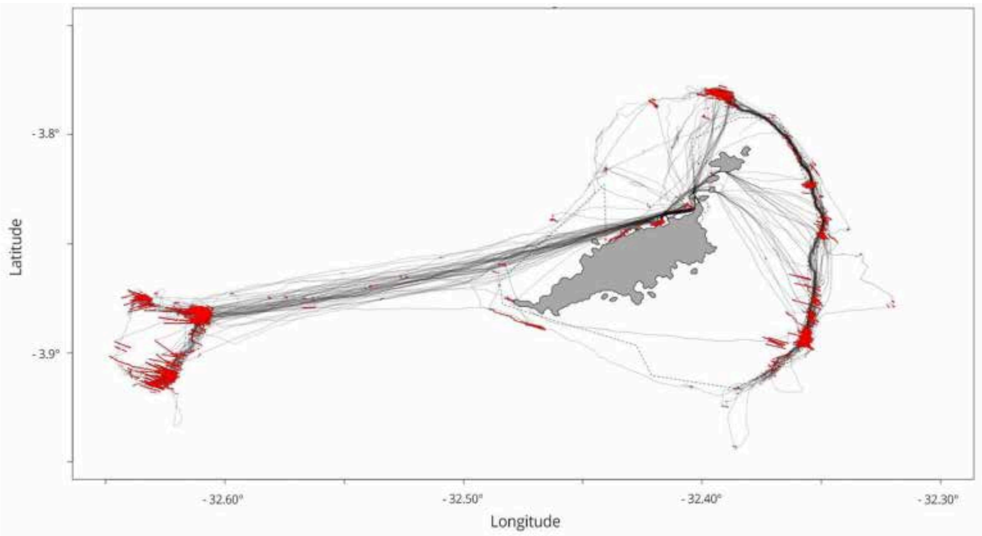
This information was used as the spatial distribution of CF no. 1.
Source: A. Brunel, S. Lanco Bertrand

Fishing

20 The raw fishing data (fig. 6) was composed of 69 GPS trajectories corresponding to the movements of fishing boats collected in situ over the last five years in Fernando de Noronha. A first statistical model (hidden Markov segmentation model) was applied (BELTRÃO, 2019) to classify each segment of these GPS trajectories into two behavioural

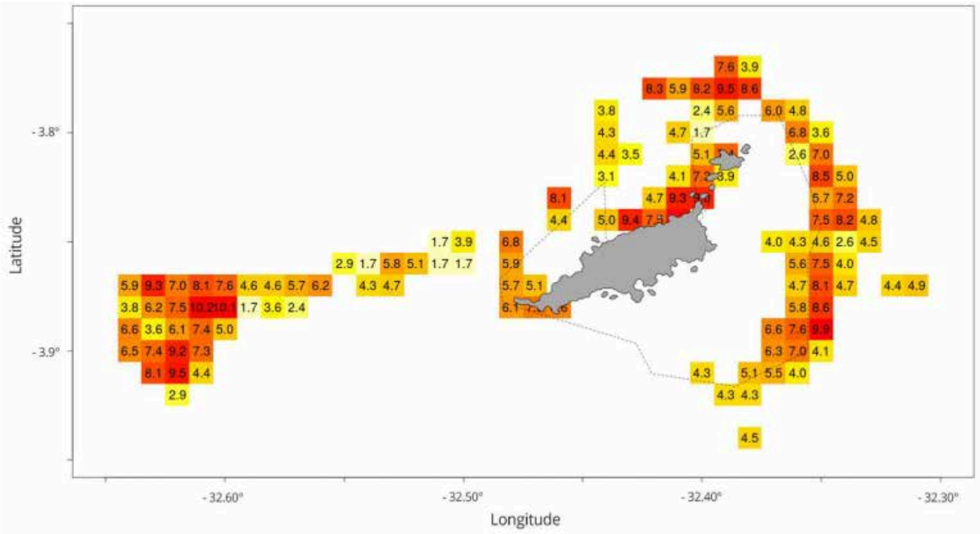
states: fishing and travel. Despite the inherent uncertainty in the modelling, we can consider the amount of "fishing" points as a quantitative index of fishing pressure. In order to calculate a fishing-based scalar value for each PU, we counted the number of fishing points in each PU and called this quantity "fishing count" (FC). This derived value for each PU contributes to the construction of the input file "pu.dat" if we want to represent the fishing pressure in a conservation scenario. FC values vary from a few hundred (moderate fishing activity) to over 10,000 (high fishing pressure), with some areas having no fishing at all (FC = 0). We then applied a logarithmic transformation, resulting in FC values ranging from about 0 to 10 (fig. 7). The FC values in this case study represent the socio-economic cost and are considered from the manager's perspective. Thus, selecting a PU with a high concentration of fishing points in the conservation site will represent a high cost to human communities while relieving pressure on biodiversity. Other socio-economic costs could also be tested (e.g. diving pressure, surface area of the PU).

Figure 6. Raw GPS fishing data (black) and segments estimated as fishing activity (red dots)



Source: A. Brunel, S. Lanco Bertrand

Figure 7. Fishing data processed in a grid adapted to the DST, represented by a yellow to red gradient indexed on the number of fishing points in each PU

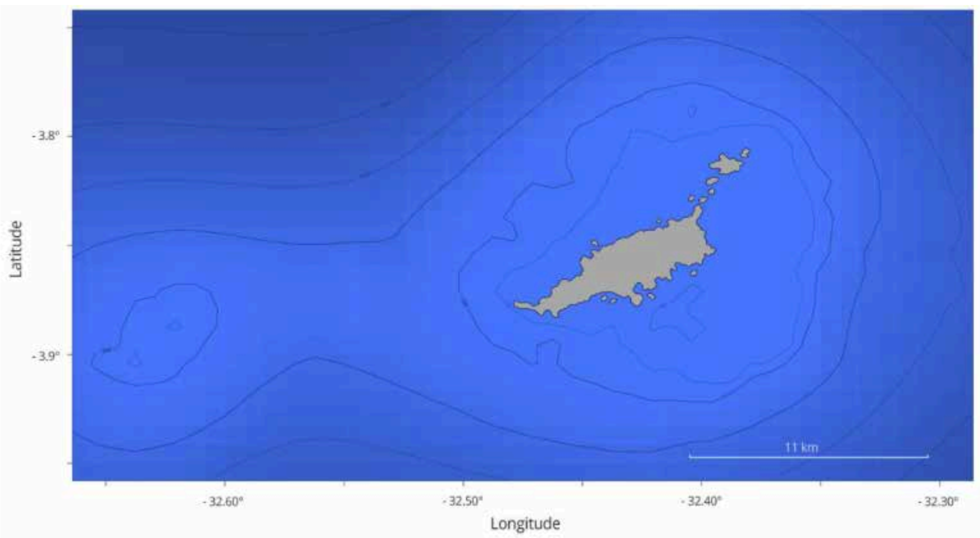


Source: A. Brunel, S. Lanco Bertrand

Bathymetry

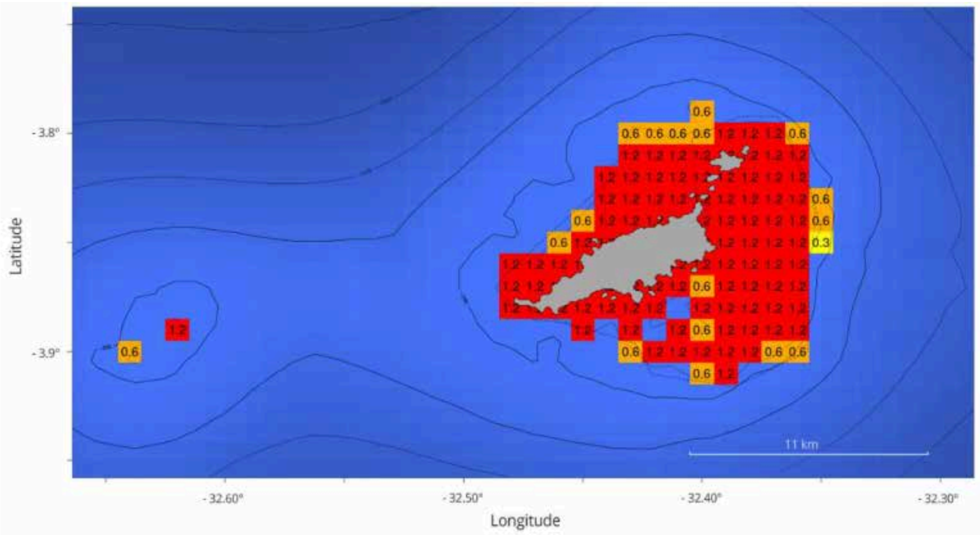
21 The bathymetric data (fig. 8) was obtained from GEBCO (General Bathymetric Chart of the Oceans, 2014 update) as a list of latitudes, longitudes and ocean depths. Since the continental shelf and the slope can be considered as two quite different and appropriate habitats that deserve protection and thus included in the reserve, the bathymetric data was used to derive two types of CF. We chose to define the continental shelf (CF no. 2, fig. 9) and the continental slope (CF no. 3, fig. 10) as corresponding to the depth intervals and . For each PU, the quantity of these two CFs was equal to the area occupied in the PU in km². The input file "puvsp.dat" was modified accordingly.

Figure 8. Raw bathymetric data (GEBCO 2014) represented by a blue gradient and isobath lines in black (50 m, 200 m, 1000 m, 2000 m, 3000 m, 4000 m)



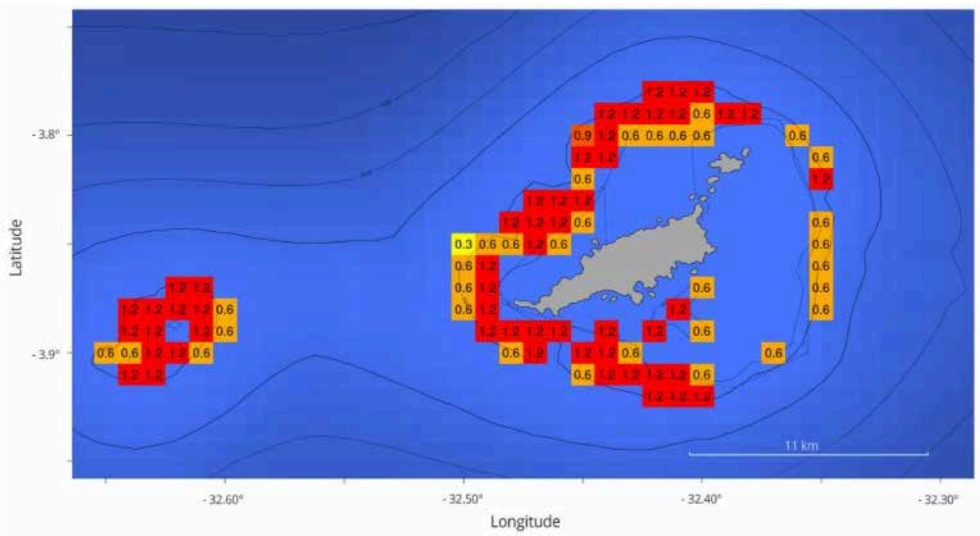
Source: A. Brunel, S. Lanco Bertrand

Figure 9. Continental shelf habitat included as CF no. 2, yellow to red colour gradient and % of PU occupied by this habitat type (in km²)



Source: A. Brunel, S. Lanco Bertrand

Figure 10. Continental slope habitat included as CF no. 3, yellow to red colour gradient and % of PU occupied by this habitat type (in km²)



Source: A. Brunel, S. Lanco Bertrand

Summary of scenarios

22 In this section, we present the summary of our simulation design. Tables 1, 2, 3, 4 and 5 show the parameterisation of the conservation site selection problem of the scenario studied and then presented in the results section. The experimental design consisted of numerous sensitivity analyses. Parameter sensitivity analysis is the preferred method to understand the influence of a given parameter on a simulation result. The main advantages of such an approach are to evaluate the relative importance of the different parameters included in the optimisation model by numerical trial and error. The basic

principle is to run simulations for different values of a given parameter while the others are fixed at a given value. In this way, the influence can be observed qualitatively and/or quantitatively through a simple comparison between the simulations.

23 First, we performed a sensitivity analysis of the BLM parameter in order to understand how the weight associated with the site perimeter influenced the final calculated site. To perform the BLM sensitivity analysis (values tested: 0, 0.5, 1, 2, 5 and 10), we arbitrarily chose a target of 50% for the three CFs and incorporated a constant cost function of 1, which led the optimisation solvers to minimise the number of PUs selected (and thus to choose the smallest site area since PUs had approximately the same size). A simple constant cost is often chosen as a first approximation; in our case, this allowed us to better illustrate the influence of the BLM compactness parameter.

Table 1. Summary of scenarios considered for the BLM sensitivity analysis

Scenario	CF	Targets	Cost	BLM
1.1	3	50%, 50%, 50%	1	0
1.2	3	50%, 50%, 50%	1	0.5
1.3	3	50%, 50%, 50%	1	1
1.4	3	50%, 50%, 50%	1	2
1.5	3	50%, 50%, 50%	1	5
1.6	3	50%, 50%, 50%	1	10

24 We examined various spatial distributions of costs to clarify their implications. As the cost directly influences the expression of the optimisation objective function, we performed a sensitivity analysis on the cost function. In addition to the logarithmic transformation already mentioned (see above), we evaluated other cost options (table 2):

- Scenario 2.1: cost = 1, simple and constant cost, adapted to consider all PUs equally, a relevant approach as a first approximation.
- Scenario 2.2: cost = 1 + FC, using our raw count of fishing points. We added 1 to avoid PUs of 0, as these can contaminate the solution search.
- Scenario 2.3: cost = 1 + ln (1+FC), a natural logarithm was applied to FC (where we added 1 for consistency of the logarithm definition domain). We added 1 to the expression to avoid PUs with a cost of 0 for the same reasons as above.
- Scenario 2.4: Cost = FC scale of 1 to 10; we transformed the FC value into a score from 1 to 10. This type of transformation has the advantage of being calculable, regardless of the format of the input cost data.
- Scenario 2.5: Cost = FC scale of 1 to 100; as above, but with a scale of 1 to 100 to better capture the influence of scale resolution.

25 With these sensitivity analyses, we addressed different questions:

- What are the implications of these differences in cost allocation in the calculated optimal site?
- Do correlated cost distributions imply a correlated solution?

26 In order to conduct our sensitivity analysis on the cost expression, we considered three CFs each with a target of 50% and a fixed BLM = 0, because a given BLM would imply a different quantitative share of the BLM term in the target function, since the range of the cost term changes considerably with the way it is derived (e.g. more than 10,000 in scenario 2.2, less than 10 in scenario 2.4).

Table 2. Summary of the parameters of the scenarios considered for the sensitivity analysis of the cost function

Scenario	CF	Targets	Cost	BLM
2.1	3	50%, 50%, 50%	1	0
2.2	3	50%, 50%, 50%	1+FC	0
2.3	3	50%, 50%, 50%	1+ln (1+FC)	0
2.4	3	50%, 50%, 50%	FC 1 to 10 scale	0
2.5	3	50%, 50%, 50%	FC 1 to 100 scale	0

* FC function projected on a scale of 1 to 10

27 We then compared the results of Marxan and prioritizR when fed with the same data. We compared the optimisation performance between the metaheuristics and the exact algorithms by applying the Marxan and prioritizR DSTs to our case study. In practice, we selected certain scenarios:

- one or three CFs with a 50% target each
- a constant cost of 1 or 1+ln (1+FC)
- a fixed BLM of 0 or 1.

28 This allowed us to explore extensively the performance of Marxan and prioritizR and their behaviour in various situations. To compare the results of the two software packages, we calculated two metrics, the optimality gap and the average correlation (table 3). The optimality gap quantifies the extent to which Marxan's solutions are sub-optimal compared to prioritizR. As Marxan provides a user-defined number of suboptimal solutions (100 in our case), the output of the Marxan "score" consists of a distribution of scores. To compare the outputs of Marxan and prioritizR, we averaged the Marxan scores and then calculated the optimal deviation according to the following formula:

Average Marxan score = (1 + optimal deviation) x prioritzR score.

29 As for the average correlation, the statistical correlation between each Marxan run and the prioritizR solution was calculated and then averaged.

Table 3. Summary of the parameters of the scenarios considered for the comparative performance analysis of Marxan/prioritizR

Scenario	CF	Targets	Cost	BLM
3.1	1	50%	1	0
3.2	1	50%	1	1
3.3	3	50%, 50%, 50%	1	0
3.4	3	50%, 50%, 50%	1	1
3.5	3	50%, 50%, 50%	1+ln (1+FC)	0
3.6	3	50%, 50%, 50%	1+ln (1+FC)	1

30 Then we carried out scenario simulations with different target values. The target values can be used as adjustment parameters if they are not ecologically driven. We performed a sensitivity analysis of the target values, while keeping the cost and BLM parameters constant (table 4). For simplicity, we increased each of the three CF targets simultaneously. Two scenarios with a single CF were considered.

Table 4. Summary of the parameters of the scenarios considered for the sensitivity analysis of the target values

Scenario	CF	Targets	Cost	BLM
4.1	3	10%, 10%, 10%	1	1
4.2	3	20%, 20%, 20%	1	1
4.3	3	30%, 30%, 30%	1	1
4.4	3	40%, 40%, 40%	1	1
4.5=1.3	3	50%, 50%, 50%	1	1
4.6	3	60%, 60%, 60%	1	1
4.7	3	70%, 70%, 70%	1	1
4.8	3	80%, 80%, 80%	1	1
4.9	3	90%, 90%, 90%	1	1
4.10	3	95%, 95%, 95%	1	1

31 A change in resolution was then applied to assess its effect on the delineation of the site area. The choice of grid resolution is important and depends on the trade-off between the level of detail aimed for (sufficient number of PUs) and the computational time

required for the analyses. It will also be partly determined by the quality of the raw data when provided as grid (raster file) or vector data (points or lines) recorded with a given accuracy. Here, we investigated the effect of increasing the resolution in latitude and longitude, by comparing the results obtained with the initial resolution of 0.01° for each axis (21 x 36 grid cells = 756 PUs), with those obtained with a resolution of 0.005° (41 x 71 grid cells = 2911 PUs). The resolution comparison was made for scenarios with constant cost (equal to 1), with a BLM set to 1 and for a CF equal to 1 or 3 (table 5).

Table 5. Summary of scenario parameters for the analysis of the influence of resolution

Scenario	CF	Targets	Cost	BLM	Resolution
5.1	1	50%	1	1	21x36
5.2	1	50%	1	1	41x71
5.3	3	50%, 50%, 50%	1	1	41x71

32 Lastly, the concept and calculation of irreplaceability can be useful for mapping and prioritising conservation actions. Irreplaceability distribution maps can be provided by prioritizR (CABEZA and MOILANEN, 2006); the Marxan selection frequency cannot be used as a measure of irreplaceability (it is only a numerical artefact, ARDRON *et al.*, 2010). Irreplaceability is indicated with values between 0 and 1, which indicate the extent to which a PU cannot be replaced by another (1 = irreplaceable, 0 = replaceable). For example, a PU that is unique in containing a rare species will be irreplaceable (value 1) in the sense that the protection of this species cannot be achieved otherwise, whereas a PU with an irreplaceability of 0 can be exchanged elsewhere in the study area, because other PUs contain similar species. The calculation of irreplaceability is relevant, as it provides a richer picture and potentially allows targeted priority conservation actions.

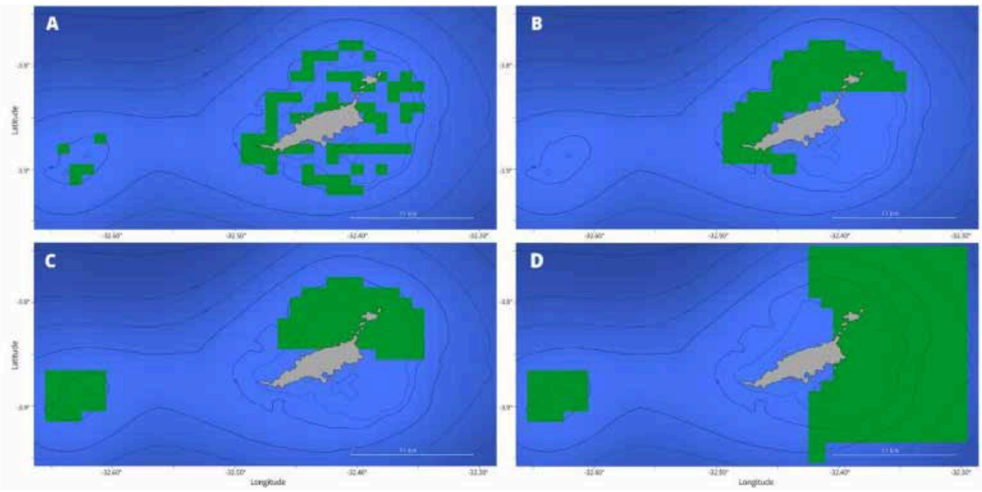
Results

Reserve compactness

33 The scenario in which the perimeter penalty was not activated (BLM 0, see fig. 11, panel A) naturally shows a dispersed conservation site solution, with most of the selected PUs around the Fernando de Noronha Marine Park, which can be explained by the fact that the fish biomass (CF no. 1, identified with acoustic data) is only found in the marine park. The aggregation effect of a non-zero BLM, i.e. with the compactness penalty activated, is immediate and visually striking (see e.g. figure 11, panel B where BLM = 1). As the BLM increases (e.g. with BLM = 5 in figure 11, panel C), the calculated solution seems to change, as the algorithm then favours the PUs of the continental shelf west of Fernando de Noronha, despite the absence of fish biomass in this area according to the acoustic data. Finally, with a BLM equal to 10 (fig. 11, panel D), i.e. forcing the prevalence of the boundary length penalty on the cost of the PU in the objective function, the conservation site solution degenerates. A numerical but unavoidable "boundary effect" occurs, which can be explained by the absence of a boundary cost for PUs at the boundary of the study area, as these PUs simply do not have neighbours. The

boundary effect is unavoidable, as a BLM that tends to infinity theoretically implies total coverage of the study area, as such a configuration would cancel out the cost term of the PUs in the optimisation objective and eventually produce an objective function equalling the total area perimeter. Note that the boundary effect can also occur for smaller BLM values if an area of interest is close to the edge of the study area. One idea to slow down and mitigate this purely numerical effect would be to create a ring of empty PUs with a “locked” status, i.e. a PU that cannot be selected.

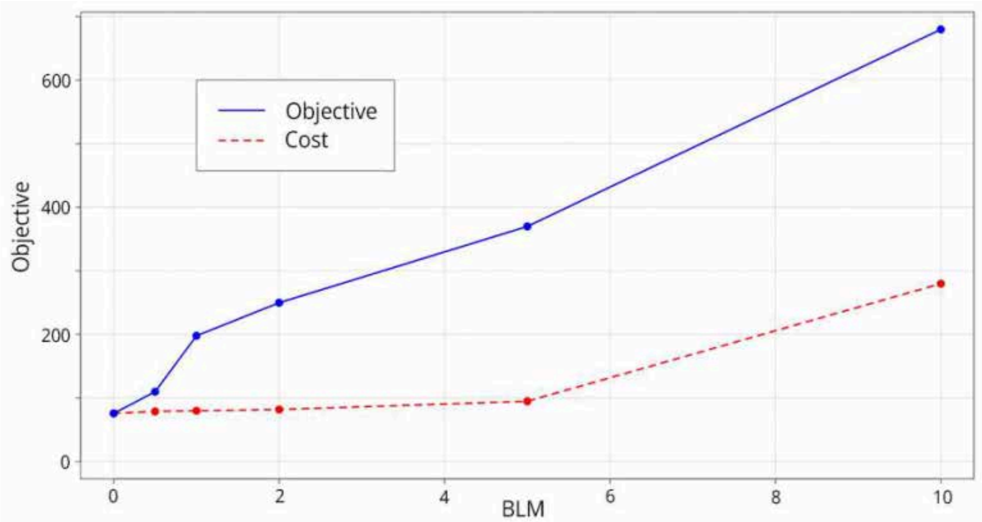
Figure 11. Three CFs each with a protection target of 50%, cost =1 and BLM in {0, 1, 5, 10} (shown in panel A, B, C, D respectively)



The selected PUs in the optimal conservation site solution are coloured green.
Optimisation performed with prioritizR.
Source: A. Brunel, S. Lanco Bertrand

34 The quantitative influence of the BLM parameter on the optimisation results is illustrated in figure 12. We first observe the continuous growth of the objective function with increasing BLM, which is a logical phenomenon since BLM directly increases the share of the boundary length in the objective function. Two trends can be identified in the curve in figure 12: the cost of the conservation site (number of selected PUs) remains stable, but then increases for BLMs above 5. The share of the BLM in the objective function (difference between the solid blue and dashed red lines) continues to increase with BLM although it stabilises at around 60–70% for a BLM above 1. In conclusion, the BLM parameter is necessary to force the optimisation solver to seek compactness, which makes sense for management objectives and is also ecologically desirable as indicated in the SLOSS discussion. Thus, it is relevant to activate the BLM compactness parameter, but it should remain reasonably small to avoid a numerical boundary effect. For all other analyses, we considered a default BLM of 1, to account for the compactness of the site.

Figure 12. The number of selected PUs (i.e. the cost of the conservation site) and the value of the associated objective function are represented by a dotted red line and a solid blue line respectively. The BLM's share of the objective function is the difference between the red line and the blue line.



Source: A. Brunel, S. Lanco Bertrand

Influence of cost allocation

35 Figure 13 illustrates how the way cost is expressed affects the cost distribution map. A more quantitative comparison is provided by the correlation matrix[6] (symmetric) between the cost distributions where the row/column number corresponds to the scenario number:

$$R_{cost} = \begin{bmatrix} 1 & - & - & - & - \\ & 1 & 0.62 & 0.99 & 1 \\ & & 1 & 0.54 & 0.61 \\ & * & & 1 & 0.99 \\ & & & & 1 \end{bmatrix}$$

36 For example, the cost correlation matrix R_{cost} indicates that scenarios 2.4 and 2.5 are almost identical to scenario 2.2. This is to be expected since these scenarios are simply a projection to a new scale of the distribution of the CF, which can also be understood as a (linear) change of unit. Conversely, the use of a natural logarithm implies a much lower correlation coefficient compared to scenario 2.2 (and thus to scenarios 2.4 and 2.5 due to the transitive nature of the correlation equivalence relationship). Note that the first dotted line of the correlation matrix, corresponding to scenario 2.1, is not defined, as the standard deviation of a constant distribution is 0 and is used in the denominator of the correlation formula[7].

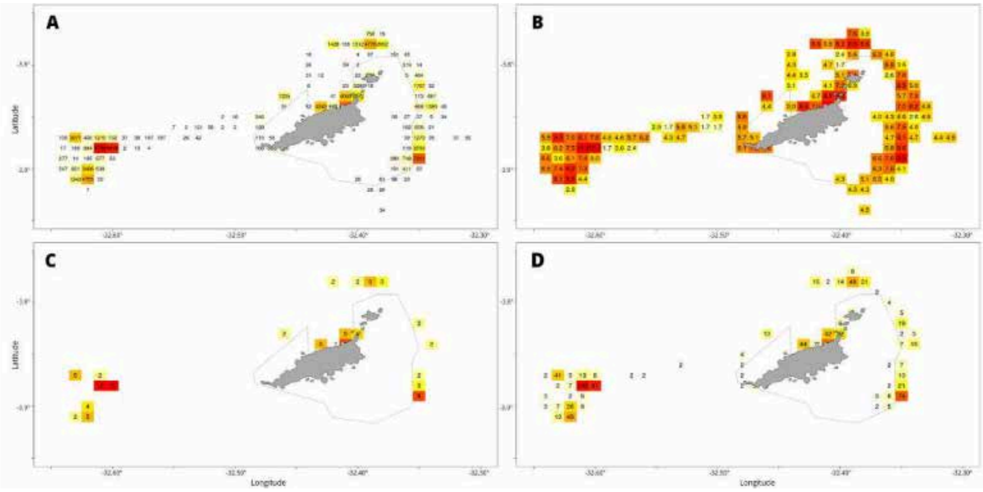
37 As we used BLM = 0, the PUs belonging to the conservation site were scattered (fig. 14) and visual comparison was difficult. We therefore opted for a quantitative comparison based on the correlation matrix between all solutions for the site:

$$R_{sol} = \begin{bmatrix} 1 & 0.44 & 0.42 & 0.71 & 0.62 \\ & 1 & 0.93 & 0.52 & 0.68 \\ & & 1 & 0.52 & 0.67 \\ & * & & 1 & 0.69 \\ & & & & 1 \end{bmatrix}$$

38 The first row of the matrix R_{sol} shows the correlation between any scenario and scenario 2.1 (i.e. with constant cost). The correlation is not zero, because the scenarios have common characteristics (same distribution of conservation characteristics). The correlation is weak, because the cost function definitely influences the solution. The correlation matrix shows that scenario 2.4 (FC scale 1–10) is closer to scenario 2.1 (cost = 1), while scenario 2.5 (FC scale 1–100) is closer to the other scenarios. This highlights the fact that the scale projection reflects its quality: it smooths out sparse data, but may fail to capture variations.

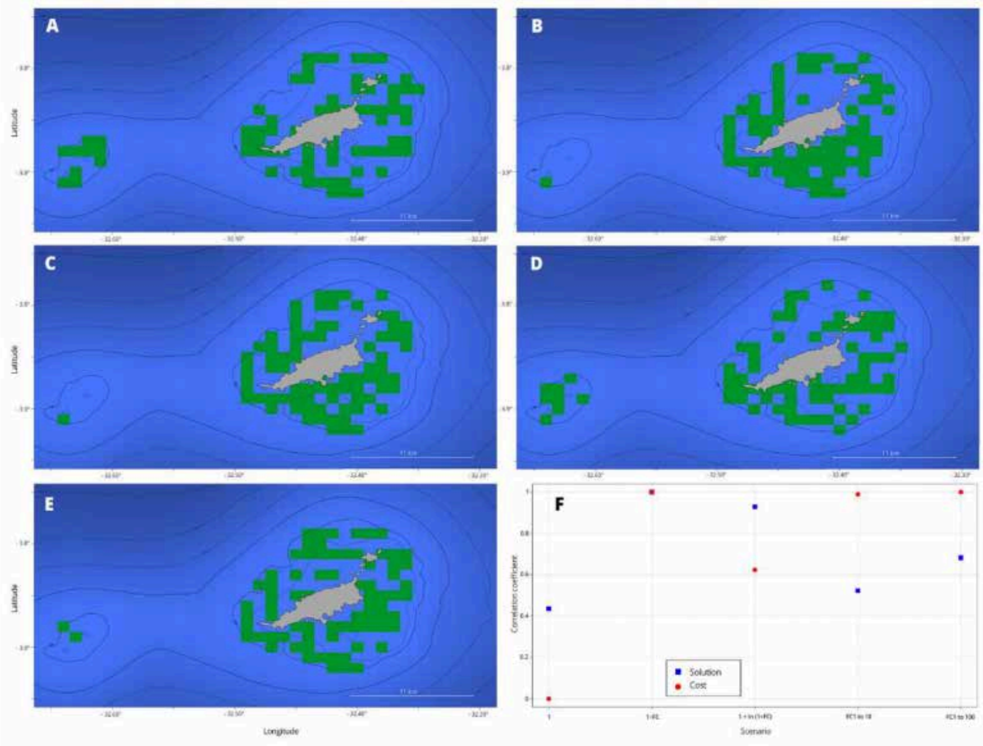
39 Despite the logarithmic transformation, the conservation site solutions of scenarios 2.2 and 2.3 are very similar (correlation of 0.93).

Figure 13. The spatial distribution of costs is represented by a colour gradient from yellow to red



White pixels have a cost of 1, which is not displayed.
The costs {1+FC, 1+ln (1+FC), FC1to10, FC1to100} are shown in panels A, B, C, D respectively.
Source: A. Brunel, S. Lanco Bertrand

Figure 14. Three CFs each with a protection target of 50%, a cost in {1, 1+FC, 1+ln (1+FC), FC 1to10, FC1to100} and BLM = 0 (shown in panels A, B, C, D, E respectively)



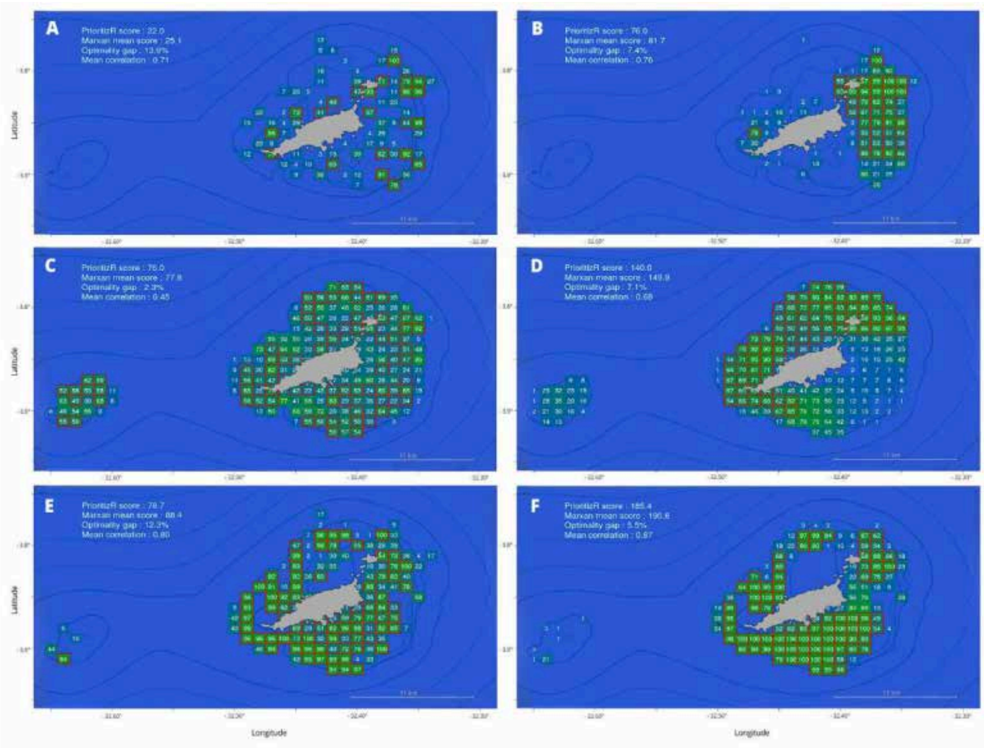
The PUs selected in the optimal conservation site solution are coloured in green. The optimisation was performed with prioritizR. Panel F shows the correlation coefficient between the spatial distributions of costs (red circle) and solutions (blue square) across scenarios. Scenario 2.2 (cost = 1+FC) is chosen as a reference. The correlation coefficient for scenario 2.1 does not exist (because the cost distribution is constant) and is arbitrarily set to 0.
Source: A. Brunel, S. Lanco Bertrand

40 Looking at the relationship between the cost distribution (red circles) and the correlation of the associated conservation site solutions (blue squares), taking the arbitrary scenario 2.2 as a reference (2nd coefficient row of the above-mentioned correlation matrices), it can be seen that a similar cost distribution can lead to a different site solution (see costs “FC1 to 10” and “FC1 to 100”), while a different cost can lead to a similar site solution (see cost “1+ln (1+FC)”) (fig. 14, panel F).

Metaheuristic (Marxan) and exact (prioritzR) algorithms

41 By nature, Marxan gives a user-defined number (set to 100 in this example) of sub-optimal solutions, unlike prioritizR, which provides a single optimal solution. The average Marxan score ranges from 2% (fig. 15, panel C) to 14% (fig. 15, panel A) of the optimal solution depending on the scenario considered. The average correlation between the optimal solution of prioritizR and the Marxan iterations varies from 0.45 (panel C) to 0.87 (panel F). We observed a similar order of magnitude for the computation time for Marxan and prioritizR.

Figure 15

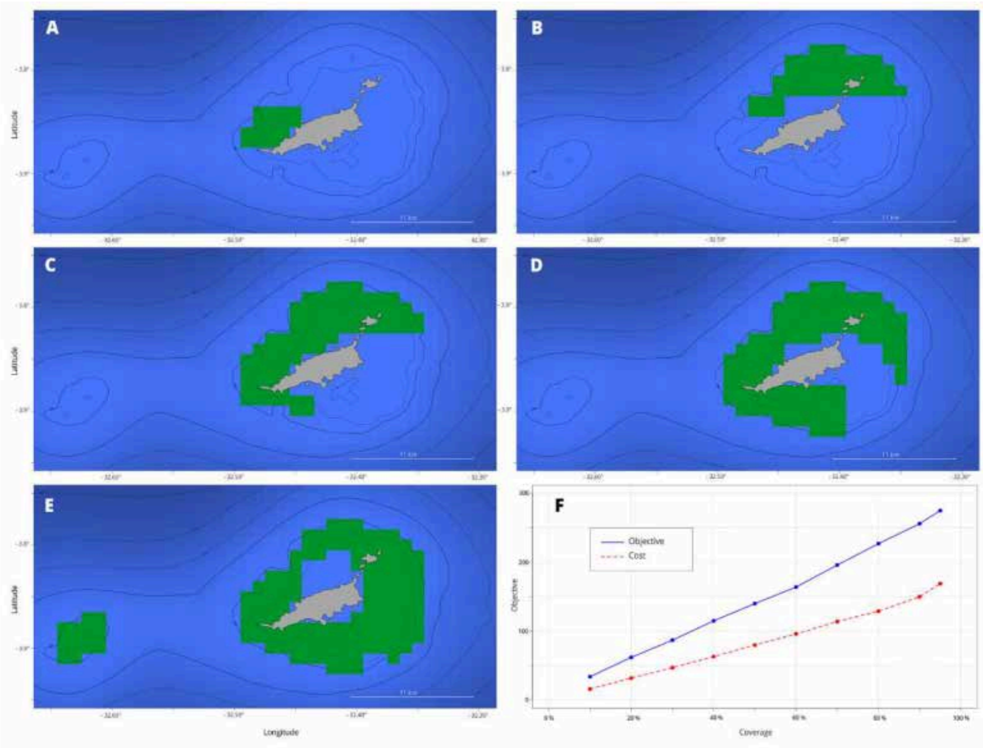


(A) A CF with a protection target of 50%, cost=1 and BLM=0.
(B) A CF with a protection target of 50%, cost=1 and BLM=1.
(C) Three CFs each with a protection target of 50%, cost=1 and BLM=0.
(D) Three CFs each with a protection target of 50%, cost=1 and BLM=1.
(E) Three CFs each with a protection target of 50%, cost=1+ln (1+FC) and BLM=0.
(F) Three CFs each with a protection target of 50%, cost=1+ln (1+FC) and BLM=1.
The PUs selected in the optimal conservation site solution by Marxan are represented by a gradient from blue to green according to the frequency of selection among 100 Marxan iterations (white number inside the PU). The red border around the PU indicates the selection by prioritization.
Source: A. Brunel, S. Lanco Bertrand

Target sensitivity analysis

42 The most obvious effect of increasing the conservation target value was the increase in the area of the conservation site solution (fig. 16). Moreover, the reserve seemed to be concentrated in the Fernando de Noronha Marine Park, and in the case of a 90% conservation target value, covered the park (fig. 16, panel E). This result should be taken with caution, as it is due to the distribution of CF1, as acoustic data was only available in the marine park. The fact that the conservation site solution gradually surrounds Fernando de Noronha is caused by the activation of the BLM, as the optimisation solver favours a compact site (and in one piece) if possible. By plotting both the objective function and the cost values for the different target values (fig. 16, panel F), we can inform/support decision-making, as planners can quantitatively choose a level of protection (target value).

Figure 16. **Three CFs each with a protection target in {10%, 30%, 50%, 70%, 90%}, cost=1 and BLM=1 (in panels A, B, C, D, E respectively)**

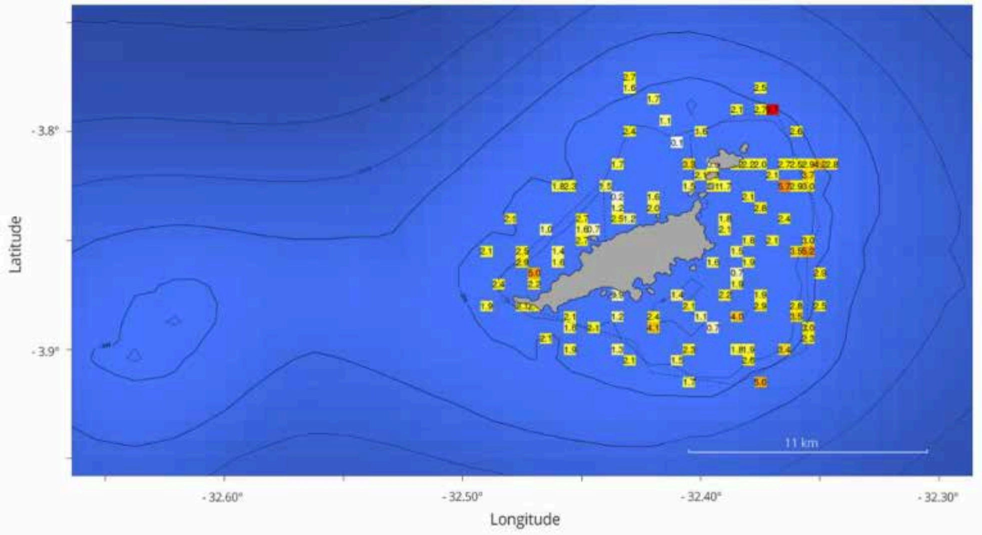


The selected PUs in the optimal conservation site solution are coloured green. The optimisation was performed with prioritizR. Panel F shows the respective changes in the objective function (in blue) and the cost (i.e. the number of selected PUs, in red) as a function of the chosen conservation objective.
Source: A. Brunel, S. Lanco Bertrand

Influence of the resolution

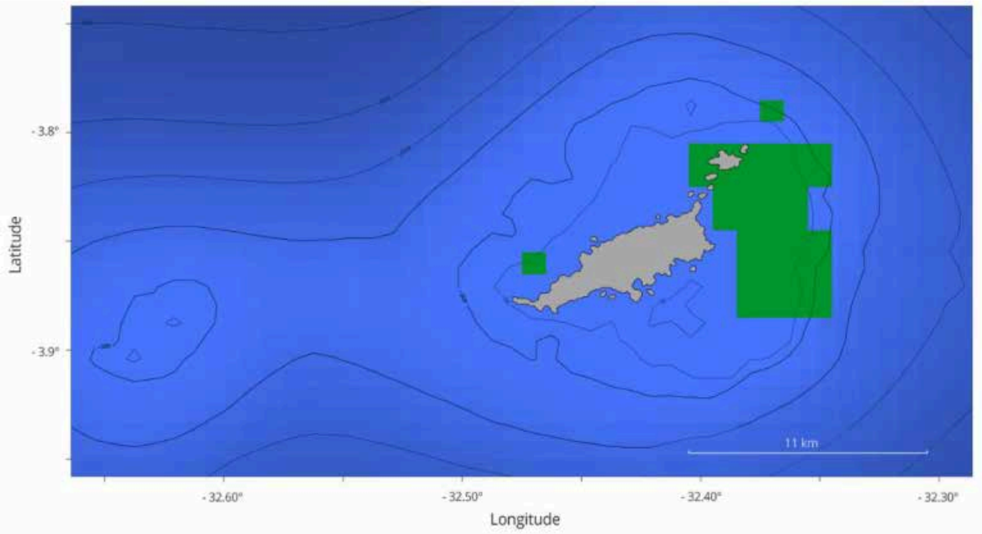
43 Figure 17 illustrates what happened to the acoustic data when the resolution of the grid was four times finer than that of the data. The increase in resolution resulted in a more precise delineation of the conservation site, with more scattered PUs (comparison between figures 18 and 19), and a total site area that was four times smaller (38 PUs of 0.01° resolution versus 41 PUs of 0.005° resolution). On the basis of this observation, it seems wise to collect data that is as detailed as possible in order to obtain a fine resolution.

Figure 17. CF1 based on acoustic data processed with a resolution of 0.005 °, i.e. a grid of 41 x 71 cells



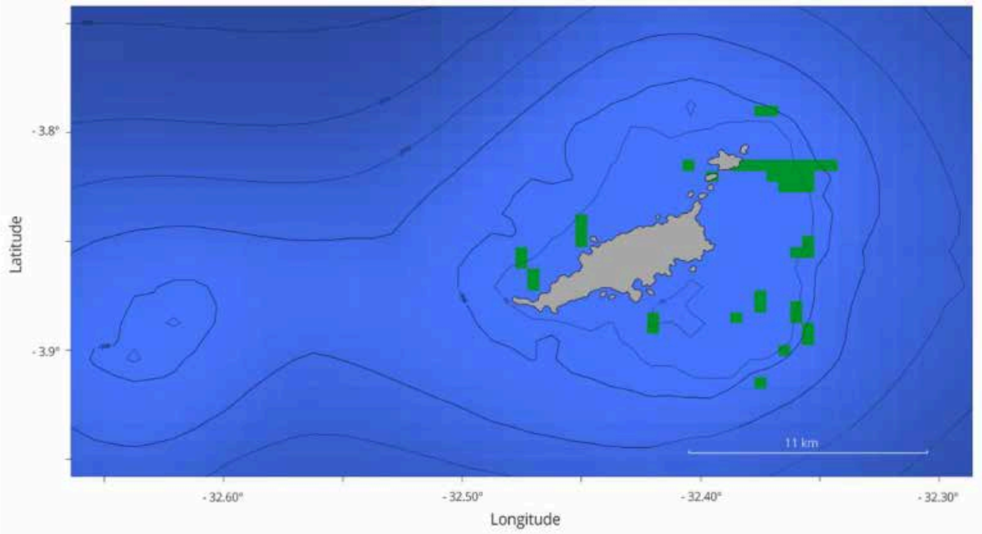
Source: A. Brunel, S. Lanco Bertrand

Figure 18. A CF with a protection target of 50%, a cost of 1 and a BLM of 1 (scenario 5.1)



The PUs selected in the optimal conservation site solution are coloured in green. Optimisation performed with prioritizR with a grid resolution of 21 x 36.
Source: A. Brunel, S. Lanco Bertrand

Figure 19. **A CF with a protection target of 50%, a cost of 1 and a BLM of 1 (scenario 5.2)**

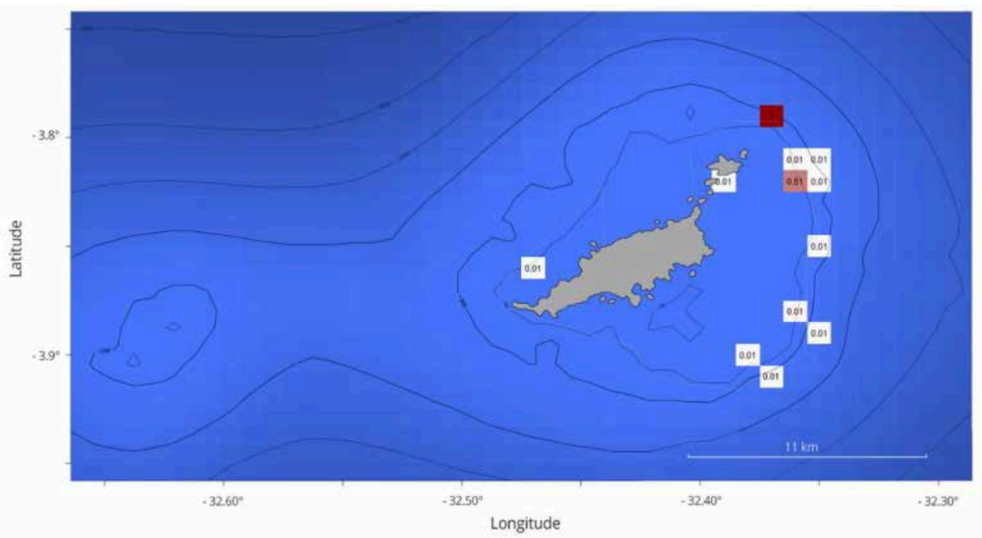


The PUs selected in the optimal conservation site solution are coloured in green. Optimisation performed with prioritizR with a grid resolution of 41 x 71.
Source: A. Brunel, S. Lanco Bertrand

Irreplaceability

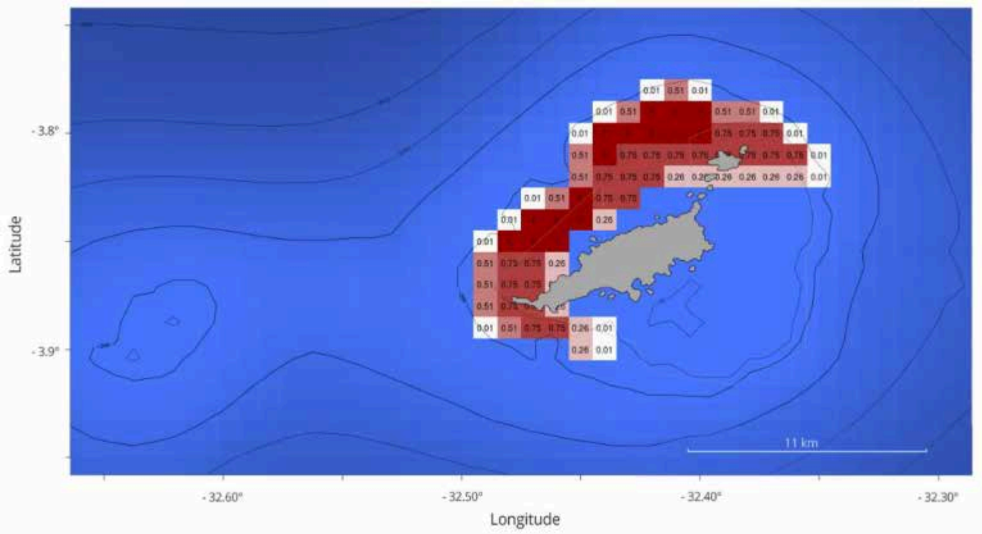
44 We can see from the maps calculated for scenarios 3.1 (fig. 20) and 1.3 (fig. 21) that irreplaceability showed different spatial patterns depending on the scenario, with most of the PUs not irreplaceable (except for the northeastern PU, which had a value of 1) for scenario 3.1, while there was a gradient of irreplaceability from the core to the periphery for scenario 1.3, probably due to a BLM effect.

Figure 20. **Distribution map of irreplaceability for scenario 3.1**



Source: A. Brunel, S. Lanco Bertrand

Figure 21. Distribution map of irreplaceability for scenario 1.3



Source: A. Brunel, S. Lanco Bertrand

Discussion

Limitations of DST approaches

45 The choice of raw data inputs, which represent one particular viewpoint among others, will strongly influence the outcome of DSTs. Therefore, depending on the purpose of the conservation actions, and to integrate the interests of a wide range of stakeholders, all necessary datasets should be included to ensure that all needs are properly taken into account in the site selection process. For example, our didactic example only represented the activity of a few fishermen, which eliminated from our scope the needs of unaccounted for fishermen and those of other stakeholders from completely different sectors (tourism, energy, marine transit, etc.). In the case of different stakeholder views, it is advisable to construct several single view cost functions rather than a complex multiple view for reasons of clarity.

46 Secondly, an inherent drawback of any MSP approach is the influence of the process of transforming the initial raw data into an input that is compatible and understandable by the DST. Indeed, there are many ways to transform spatially explicit data into a geographic scalar value and thus build an input file, and we have demonstrated the major influence of the generation of the cost function (constant, 1+FC, 1+ln (1+FC)) derived from the same initial information (raw data). This underlines the importance of the transparency of the approach in order to critically interpret the results of the DST. In this context, sensitivity analyses are extremely valuable and informative.

47 Another issue is that, as we repeatedly observed with our use of acoustic data, Marxan understands a zero abundance index as a definite absence when in fact it may be due to a lack of data (the boat transects simply did not cover this area). It is clear that fishermen would not go west of Fernando de Noronha if there are no fish. The conservation site result is a reflection of the quality and quantity of the input data, which is a key issue if there are gaps in the data or if it is heterogeneous. This highlights the complex need for a data surrogate or processing to achieve the same

data resolution and representativeness without distorting the information. Nonetheless, even if the acoustic data were perfect, this does not mean that the observed level at the observed location is certain. The optimisation framework as formulated by the tools implemented here prevented the consideration of data uncertainty, which is a major weakness of this approach; this has been identified as a gap to be addressed in the PINARBAŞI *et al.* (2017) meta-analysis on DSTs.

48 From a more philosophical point of view, we could suggest that DSTs should at least include the MinSet and MaxCov formulations, as both are equally subjective, but the latter may in some cases be more satisfactory, as the conservation objective is explicitly stated in the optimisation problem: maximising biodiversity conservation under a predetermined constraint of human use of space and resources. While this paradigm was initially dominant, the development and use of Marxan has imposed the "minimum set" formulation as standard to date.

49 Finally, DSTs are spatially explicit and static (data is not time dependent) and focus on the loss of benefits from human use of space and resources. It is therefore rather difficult to demonstrate the benefit obtained from a marine protected area using such tools.

Key points to keep in mind

50 Here we aim to provide key messages for stakeholders involved in MSP using DSTs in the process, regardless of their technical level and role:

- Conservation site selection DSTs calculate a solution that covers conservation characteristics in relation to preestablished protection objectives while minimising a cost in terms of impact on human activities.
- The site selection process is inherently subjective and therefore requires a high degree of transparency regarding the data and parameters used in the DST in order to encourage constructive criticism and improvements.
- Exact algorithms should be favoured, as they facilitate the interpretation of processing and solutions (a single optimal solution to be interpreted versus a multitude of sub-optimal solutions for Marxan), as well as opening up perspectives on protected area design in general (simulation of multiple scenarios).
- As the results can be highly dependent on the data used and its processing, they should be considered with great caution; sensitivity analyses are strongly recommended.
- Any "NA" value (which potentially means a lack of sampling) in the input data is in practical terms treated as a zero value, thus interpreted as a definite absence.
- Data processing is inherently subjective and must always be open to criticism and improvement.
- Although based on the same observations, the processing of the data can potentially lead to different conservation site solutions.
- The better the resolution of the data, the smaller the conservation site size.
- The higher the coverage targets, the larger the site size. Targets are not setup parameters and should be guided by ecological considerations.
- The BLM parameter, which regulates the compactness of the site, should be activated and its exact value should be motivated by the results of a sensitivity analysis. Too high a BLM value can lead to undesirable digital artefacts such as the "boundary effect".

- Although computationally expensive, irreplaceability maps shed a different light on the conservation issues at stake, as they allow the mapping and prioritisation of conservation actions and planning units.
- Sensitivity analyses (on conservation targets, BLMs, data selection and processing) should be carried out to provide a critical understanding of the problem formulation and the calculated conservation site solutions.
- The multiplication of scenario simulations allows for a better understanding of conservation issues and potential conflicts. They allow an assessment of whether the results are robust or not, i.e. whether they are highly dependent on the data used or whether they are generalisable. Simulating multiple scenarios from a single point of view (i.e. at a single cost) makes it possible to represent the interests of all stakeholders and thus to better resolve conflicts and avoid the risks of ocean grabbing.

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NOTES

1. These Marxan and prioritizR scripts are available at: https://github.com/AdrienBrunel/reserve-site-selection

2. A "conservation feature" is a given biotic or abiotic entity that deserves conservation consideration (species, habitat, etc.).

3. Assessed from the manager's perspective.

4. It is possible to use the commercial Gurobi solver instead to improve computational performance.

5. We avoided data kriging for the sake of simplicity.

6. Two spatial distributions (cost or solution) were considered as independent random variables X and Y. The statistical correlation between X and Y was then given by: rXY=cov (X, Y) XY. A correlation of 1 means that the maps are equivalent.

7. Two spatial distributions (cost or solution) were considered as independent random variables X and Y. The statistical correlation between X and Y was a metric of interest and was given by : . A correlation of 1 means that the maps are identical.

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Chapter 16. Questions around interdisciplinarity

Olivier Ragueneau

Introduction

1 The health of coastal marine ecosystems continues to decline at an unprecedented rate, despite numerous interventions by scientists, governmental and non-governmental organisations and various stakeholders (BENHAM and DANIELL, 2016). Oceans and coastal regions are increasingly threatened, degraded or destroyed by human activities such as marine pollution, overfishing or unsustainable extraction of marine resources, as well as by anthropogenic climate change and its associated effects on rising sea levels, increasing ocean temperature, ocean acidification and deoxygenation (IPCC, 2013; UN, 2017). With the rise of resilience science (HOLLING, 2001) and sustainability science (KATES *et al.*, 2001), integrated approaches are more salient than ever, and interdisciplinarity (FRODEMAN *et al.*, 2017), transdisciplinarity (LANG *et al.*, 2012) and participatory approaches (BARRETEAU *et al.*, 2010), are increasingly seen as essential to support decision-making to reconcile human uses of ecosystem services with the conservation of the integrity of these ecosystems.

2 The first-ever UN Ocean Conference, held in 2017, emphasised the crucial need for an "integrated, interdisciplinary and cross-sectoral approach, as well as enhanced cooperation, coordination and policy coherence, at all levels" (UN, 2017, p. 2). Similarly, the UN Decade of Ocean Sciences for Sustainable Development, which runs from 2021 to 2030, seeks to "mobilise, stimulate and coordinate interdisciplinary research efforts" (UN, 2019, p. 8).

3 Integrated coastal zone management (ICZM) and marine spatial planning (MSP) are the two main instruments that have been created to address critical issues in the coastal zone. They illustrate the move towards a more integrated research community on global change (MOONEY *et al.*, 2013) as well as a renewal of science policy in the coastal zone, which should be considered as a "governance framework" (BREMER and GLAVOVIC,

2013). MOONEY et al. (2013) described the evolution of the main global environmental research programmes – the International Geosphere-Biosphere Programme (IGBP), the International Human Dimensions Programme on Global Environmental Change, (IHDP), etc., following the creation of the Intergovernmental Panel on Climate Change (IPCC) in 1988, eventually merging into the Future Earth platform in 2012. In this context, research is becoming more interdisciplinary – in particular between the vast spheres or "two cultures" (SNOW, 1959) of the natural sciences and the social sciences – more participatory and collaborative, involving more non-academic stakeholders; it is also becoming more solution-oriented, with a view to helping decision-making (Future Earth 2025 vision).

4 Examples of participatory governance are described elsewhere in this handbook (see chapter 13), as are innovative tools that promote interactions between communities, stakeholders and governmental organisations in the MSP context in the tropical Atlantic. This chapter will focus on interdisciplinarity through questions that can be applied to MSP, but that are also of broader interest for any type of emerging instrument that aims to take into account the complexity of so-called socio-ecological systems (LIU *et al*., 2007; OSTROM, 2009).

5 The chapter starts with a definition of the concepts: what is interdisciplinarity? Is it something that lies between multi- and transdisciplinarity? Or between discipline and indiscipline? What is the difference between true or superficial, broad or narrow, interdisciplinarity? Which seems most appropriate for MSP? The chapter then looks at the reasons for the need for interdisciplinarity, given the complexity of the challenges and the context of the Anthropocene. It then explores the barriers to true interdisciplinarity and possible bridges for building it. Boundary objects and boundary frameworks are essential in this respect, and MSP is a good example. The final section explores the implications of interdisciplinarity, both in epistemological terms – especially with regard to education and training young researchers – and in "philosophical" terms, given the many current forms of inward-looking attitudes and the crucial need for collaboration to address the major challenges we face as a species today.

Interdisciplinarity: what are we talking about?

Between pluri- and trans-

6 Pluridisciplinarity, multidisciplinarity, interdisciplinarity, transdisciplinarity ... These terms are often confused and misused, although they refer to very different epistemological definitions and research processes. When I asked F. Conway (Oregon State University, Corvallis, United States) about these terms, I liked the metaphor she used to distinguish them: different types of fruit scattered in their own orchards for "pluri-"; different types of fruit separated in crates but in the same shop for "multi-"; fruits mixed in a fruit salad but still recognisable for "inter-"; and, finally, a smoothie for transdisciplinarity. It is a vision that resembles the scale of interactions between disciplines provided by BLANCHARD and VANDERLINDEN (2010) or the four scenarios of combining knowledge described by MACMYNOWSKI (2007): from mutual – even conflicting – ignorance to radical transformation through profound interactions. To illustrate this

diversity of possible interactions, I will use the example of my laboratory, my institute and my university.

7 The University of Brest is multidisciplinary, with its faculties of humanities, social sciences, "hard" sciences (a problematic concept in itself as we will discuss), law, sport, etc., with little interaction between them. In 1997, the laboratories and researchers working on the sea came together to form an institute, the European University for Marine Studies (IUEM), a faculty at the university that is multidisciplinary, but still with little interaction between the various disciplines. Because geographical proximity plays an important role in the construction of interdisciplinarity (RECKERS and HANSEN, 2015), bringing these scientists together in the same corridors of the same building has stimulated strong interactions and increased interdisciplinary cooperation between scientists from different disciplines: for example, to work on sustainability issues in the Bay of Brest (RAGUENEAU *et al.*, 2018). In this sense, true interdisciplinarity involves sharing methods, tools and concepts to work together on a common subject, with all disciplines treated equally.

8 Transdisciplinarity deserves a special mention, as it has several meanings, which can lead to confusion. BLANCHARD and VANDERLINDEN (2010) define it as transcending disciplines, sometimes leading to the creation of a meta-discipline. The smoothie metaphor illustrates this well, conveying the idea that the interactions between disciplines become so strong that it is no longer even possible to recognise the contribution of each to the final outcome. The communication sciences are taken as an example by WOLTON (2013), even leading to biases previously attributed to disciplines when these meta-disciplines seek institutional recognition as one discipline. But there is another definition of transdisciplinarity, often used in the field of sustainability science, which involves working with people outside academia: communities, stakeholders, governmental and non-governmental organisations, etc. Such a definition is used by LANG *et al.* (2012) and many other researchers, as well as in many official documents promoting integrated approaches (Future Earth platform, UN documents, EU calls for projects, EU, etc.). Action research is an example of this transdisciplinarity, as illustrated in the Future Earth knowledge-action networks (KANs).

9 POHL (2011) has provided a good overview of transdisciplinary definitions and approaches, in which transdisciplinarity involves crossing disciplinary boundaries and may, in addition, involve some work with external stakeholders. Or not – and this is where confusion can arise. For BENHAM and DANIELL (2016), it is both the transcendence of disciplines *and* the engagement with stakeholders around societal problems – to solve complex issues and provide support in decision-making – that distinguish transdisciplinary from interdisciplinary approaches. But at the same time, they note: "Transdisciplinary research, when undertaken in a participatory manner with stakeholders (i.e. transdisciplinary and participatory research), can inform public decision-making and offer a new approach to understanding complex problems." So is transdisciplinarity the sum of interdisciplinarity and stakeholder engagement? Given the plurality of definitions, it seems preferable that each researcher defines from the outset the meaning in which he or she will use this term and, above all, that the term transdisciplinarity is not used for all purposes, otherwise it will quickly become a "catch-all" term and lose its force, like other important concepts in this field (e.g. co-construction or co-production of knowledge).

Why interdisciplinarity?

10 Perhaps one way to avoid these difficulties would be to use the term "interdisciplinarity" in a more generic sense, "to cover inter-, multi-, cross-, trans- and other extra-disciplinary frameworks", as FRODEMAN and MITCHAM (2007) suggest. In fact, these authors call for a "critical interdisciplinarity" that poses the essential question of relevance: knowledge for what purpose?

11 Knowledge for knowledge's sake, first of all. Throughout most of the history of science, this knowledge has been broad: pre-disciplinary rather than interdisciplinary. Specialisation – and especially the separation between the natural sciences and the humanities and social sciences (DESCOLA, 2005) – emerged in the 19th century with industrialisation and the idea of society, leading to the different branches of the natural sciences (physics, chemistry, biology, etc.), the social sciences (sociology, economics, political science, etc.) and the humanities (philosophy, ancient and modern languages, history, art history, etc.). This separation between disciplines was exacerbated in the 20th century (although science and technology have merged for better or worse, leading to a very ambiguous perception of science by society [STENGERS, 1997; JARRIGE, 2016]). While this has clearly led to major improvements in each branch of knowledge, with both dramatic and exciting consequences for humanity, it also has its drawbacks.

12 Two major elements have been lost on this path to specialisation: the ability to deal with complexity and the link with society, with science confined to laboratories. The link with politics was also lost: at the very beginning of the 20th century, Weber clearly distinguished between "the scientist and the politician (WEBER, 1919). After the Second World War, the Great Acceleration began and 30 years later, a trend towards rationalisation became widespread with huge impacts on many, if not all, areas of human activities. We became "ruled by numbers" (SUPIOT, 2015), with even greater losses: as T.S. Eliot asked in his 1934 play, "Where is the wisdom we have lost in knowledge? Where is the knowledge we have lost in information?" In our age, F. TADDEI (2018) adds, information has disappeared behind data. All areas of life are affected, including those that one might imagine to be most immune to this trend: law, healthcare, education, etc. Science is no exception: the notions of expertise, of excellence itself (necessarily disciplinary), of objectivity and neutrality are a major epistemological component of science.

13 Yet over the last two to three decades, a notable shift has emerged, with increasing calls for interdisciplinarity in order to address complexity, linking fields rather than separating them (MORIN, 2005). The planet's entry into the Anthropocene (CRUTZEN, 2002) is not unconnected to this. Indeed, interdisciplinarity is increasingly seen by science and society as an important means of dealing with the complex problems we face, particularly those at the interface between humans and nature (KLEIN, 2004). Integrating different types of knowledge is seen not only as a way to better understand this complexity, but also to inform public policy (FRODEMAN and MITCHAM, 2007). Many argue that we have entered so-called "postnormal times" (SARDAR, 2010) characterised by chaos, complexity and uncertainty. In this context, in which "facts are uncertain, values are contested, stakes are high and decisions are urgent", policymakers and managers are under pressure and desperately need new approaches that could help

inform their decisions (BENHAM and DANIELL, 2016, citing FUNTOWICZ and RAVETZ, 1993). Interdisciplinary, participatory approaches involving different stakeholders are the premise of these systems approaches, whether they are called transdisciplinary (BENHAM and DANIELL, 2016) or critical interdisciplinary approaches (FRODEMAN and MITCHAM, 2007).

14 Unfortunately, the challenge of achieving true interdisciplinarity is proportional to its promise.

Between narrow and wide interdisciplinarity

15 Let us start by exploring the different degrees of interdisciplinarity – narrow or broad – in different academic disciplines. The move towards specialised disciplines in the 20th century was probably necessary. As FRODEMAN and MITCHAM (2007) state, "this analytical and disciplinary approach has advanced our understanding of nature and contributed to the development of technological power" – again, for better or worse. But it is problematic that disciplinarity is often seen – or even developed – in opposition to interdisciplinarity (although philosophers such as Heidegger have developed a complementary thesis: "compartmentalisation does not split one science off from another ... it yields a border traffic between them" [HEIDEGGER, 1977]). Increasing specialisation has led to two major, perhaps unexpected, problems: (1) Instead of enriching points of view, interdisciplinarity between relatively close scientific fields (e.g. within the natural sciences or the social sciences, or even between different subfields such as biology), what J. KELLY (1996) would call narrow interdisciplinarity, has led to an ever larger number of disciplines and to ever narrower fields of investigation: physics and geology merged into geophysics, biology and chemistry into biochemistry, etc., creating yet "more regional ontologies" (FRODEMAN and MITCHAM, 2007). (2) Specialisation has become so strong in the different disciplines that "border traffic" has become extremely difficult to undertake.

16 In my case, I am a biogeochemist, a narrow interdisciplinary field, perhaps transdisciplinary in the sense of BLANCHARD and VANDERLINDEN (2010), with a focus on the silicon cycle. Although I have taken courses on nitrogen cycles, phosphorus cycles or those of other elements, I am a silicon biogeochemist (almost a discipline of itself). So to study the functioning of ecosystems, it is necessary to collaborate with specialists on nitrogen, phosphorus, iron cycles, etc., not to mention scientists with expertise in physics or ecology. Indeed, the field is even more narrow – a biogeochemist specialising in the silicon cycle in a terrestrial environment works in a very different world from a biogeochemist specialising in the study of the marine cycle of this same element. To bridge these fields, I coordinated a Research Training Network (RTN, EU Marie Curie Actions) to foster "interdisciplinary" collaboration between land and marine biogeochemists to work on the silicon cycle along the land–sea continuum (RAGUENEAU *et al.*, 2010). This same specialisation is true for scientists working on silicon in ocean surface waters and those trying to understand the benthic cycle of silicon or using siliceous debris in sediment cores as a palaeoceanographic proxy for past relationships between climate and ocean productivity; they too work in parallel highly specialised worlds, but would benefit greatly from "interdisciplinary" collaboration, for example, in terms of proxy calibration (RAGUENEAU *et al.*, 2000)

17 I would describe this type of interdisciplinarity as "very narrow", although it already requires a great deal of time and intellectual effort to be able to collaborate and to understand each other. I will come back to these costs, as they seem essential to consider, both for epistemological and philosophical reasons. Narrow interdisciplinarity, for example, is when marine biogeochemists work with physical oceanographers and/or biologists to explore the functioning of marine ecosystems. This remains in the broad field of natural sciences, and the scientists involved stay in their "comfort zone" where they can talk to each other. As interdisciplinarity becomes increasingly wide, we have to move out of our comfort zones and collaborate with scientists from other spheres, such as the humanities and social sciences.

18 For example, experimental archaeologists studying stone age toolmaking may require highly specialised expertise in fields such as physics, chemistry or materials science (LÉA, 2020). Several disciplines have even developed from interactions between the natural and social sciences (political ecology, ethnobiology, ecopsychology, etc.): the environmental humanities are also growing rapidly (BIRD ROSE, 2019). But the vast majority of interactions between the natural and social sciences tend to focus on the Great Acceleration and our entry into the Anthropocene (CRUTZEN, 2002). MOONEY et al. (2013) provide a good overview of the evolution of climate change research agendas to integrate the natural and social sciences over the last three decades, culminating in the creation of the Future Earth platform in 2012. They demonstrate the crucial role of global climate and biodiversity assessments (creation of the IPCC in 1988, the Global Biodiversity Assessment in 1995, the Millennium Ecosystem Assessment in 2005) and of key disciplines such as geography, which was pre-adapted to interdisciplinary studies, in the development of programmes and funding for these large integrated programmes.

19 These authors also describe the birth of sustainability science (KATES *et al.*, 2001) and the tremendous increase in publications in this field, around the notions of socio-ecological systems (LIU *et al.*, 2007) and adaptive co-management (KOFINAS, 2009). As noted above, exploring the functioning and trajectories of socio-ecological systems requires dialogue between these spheres, particularly to explore the links between humans and nature, and between social and biophysical models of socio-ecological conceptual frameworks (OSTROM, 2009; COLLINS *et al.*, 2010; BRETAGNOLLE *et al.*, 2019). The same is true when considering the use of instruments such as ICZM and MSP. Of course, the enormous time and intellectual cost of engaging in such collaborations between these "two cultures" is equally evident (SNOW, 1959, see below).

20 Interdisciplinarity becomes even broader when it becomes critical or transdisciplinary – when it leaves the campus and seeks collaborations with the "real world" outside the academic environment. This requires a further step: that scientists recognise that knowledge is distributed across all parts of society and that the hybridisation of knowledge is necessary to inform decision-making in times of uncertainty (PESTRE, 2013; ZANOTTI and PALOMINO-SCHALSCHA, 2016).

Between true and superficial interdisciplinarity

21 It is important to note that this shift in research towards interdisciplinary integration to address major challenges such as climate change remains highly theoretical. While there are many calls for interdisciplinarity, this does not necessarily mean that true

interdisciplinarity is actually being achieved (NIELSEN and D'HAEN, 2014). For example, an analysis of the IPCC reports published only a decade ago has shown that interdisciplinarity remains very narrow, typically confined to the natural and climate sciences, with very few forays into the qualitative social sciences (BJURSTRÖM and POLK, 2011). I will return to the difficulties of integrating disciplines with dissimilar epistemologies in the next section, but first want to emphasise the definition of "true interdisciplinarity".

22 By true interdisciplinarity I mean that different disciplines are included in more than a superficial way or just to play a "service" role. The latter is nicely described in VISEU (2015), who reports on her difficult integration as a sociologist in a medical research institute and describes a context in which the social sciences are allowed to observe what is done, but not to disturb it. In this case, social scientists are mainly seen as facilitators of the dialogue between ("real") scientists and society. This "service" role is also present when social scientists (or humanities scholars) are called upon to study only perceptions or acceptability. As ALLMENDINGER et al. (2013) argue in a note on the EU Horizon 2020 initiative: "The role of the humanities and social sciences should not be simply to help science and business reduce public resistance to or increase acceptance of scientific and technological innovations." It is more difficult to document superficial interdisciplinarity, but this relates to the list of challenges discussed below, as it has long reinforced the lack of trust between the natural sciences and the social sciences. There are many accounts of social scientists or humanities scholars being called 24 hours before a project submission deadline just to tick a box, or simply being asked to study perceptions and representations of this or that research object or technological innovation (CHLOUS, 2014). This so-called interdisciplinarity is cosmetic when social scientists are not asked how their research questions can be integrated into the project or, better, how they could actually engage with the project with their own research questions as a contribution to the overall problem at hand.

23 In contrast, true interdisciplinarity requires that (1) all research components and researchers are treated equally, from the design of the project to the analysis of the results and their dissemination (ALLMENDINGER *et al.*, 2013), (2) appropriate communication between disciplines (which is often lacking, see NIELSEN and D'HAEN, 2014) is ensured throughout the research process, both with regard to research results and research methods, and (3) perhaps most challenging, integration is ensured through the development of methods, tools and concepts that allow for the synthesis of knowledge across very heterogeneous data, approaches, and sometimes even schools of thought. In this respect, a major difference between the natural sciences and the humanities and social sciences lies in the qualitative/quantitative debate and the integration of these approaches; this is crucial and will form a major part of the last section of this chapter.

24 The next section will explore the factors that hinder such true interdisciplinarity, before providing some avenues for fostering it; firstly, through boundary objects and boundary frameworks, and secondly and perhaps most importantly, beyond approaches through the inclusion of epistemological and philosophical considerations to demonstrate how crucial it is that we succeed in *truly* developing these integrated approaches. The obstacles are so numerous and so strong that a veritable "indiscipline" will be required if we are to succeed in this endeavour (WOLTON, 2013).

Barriers and bridges to true interdisciplinarity

25 There is extensive literature on barriers to interdisciplinarity. It is interesting to note, as MACMYNOWSKI (2007) has pointed out, that while the need for more and better interdisciplinarity has emerged in environmental science literature, the discussion barely refers to the decades of extensive literature on interdisciplinarity in science and technology studies (STS).

26 In the scientific literature on global change, explanations for the lack of interdisciplinarity fall into different categories, ranging from epistemological considerations to problems of organising research and education on campus. In terms of epistemology and ontology, the biophysical and social sciences simply belong to two different cultures (SNOW, 1959), with distinct concepts, methods and schools of thought. The discourses, with their different "jargon", are extremely difficult to reconcile (WEAR, 1999). In terms of structural problems in research, researchers refer to challenges in the evaluation process as well as in funding. In education, universities are often organised in disciplinary silos, which prevents cross-fertilisation (HART *et al.*, 2015). Young researchers are recruited from within recognised disciplines, and it is widely accepted that the breadth of interdisciplinarity cannot replace the depth or even excellence of disciplinary training. This debate between "breadth" and "depth" is a real divide between those for and against the idea of interdisciplinary education (FISCHER *et al.*, 2011). Time is another major constraint, as it is sorely lacking in our period of acceleration (ROSA, 2012), although it is absolutely necessary to allow for the learning and trust-building required by these interactions (STRANG, 2009). I will come back to this aspect of time, because underlying this is the very organisation of our research and education system and the priorities that need to be rediscussed between researchers and funders/decisionmakers.

27 While environmental researchers exploring interdisciplinarity have focused on these aspects, STS researchers have conducted investigations into disciplines and disciplinary migration. What is a discipline? What authority is associated with a given discipline? Why are disciplines hierarchical? What power lies behind such a hierarchy? What is their status in the academy and in society? How does these hinder interactions between the social and biophysical sciences? Power and knowledge are closely linked (FOUCAULT, 1980; MAZÉ *et al.*, 2017) and this has profound implications for our discussion of interdisciplinarity between these two major spheres of scientific research as well as at the interface between science and society (MACMYNOWSKI, 2007).

28 Indeed, a major obstacle to interactions between some of the humanities and social sciences and the so-called "hard" sciences is the separation between the qualitative and the quantitative, which reflects different worldviews, scientific status and power. At school (at least in France), if you were a good student, you were encouraged to take maths or physics. If you were a bit less good, you took chemistry. If you weren't good at science, you took economics or geography, which still involve numbers. If not, well ... you might study foreign languages (with their own hierarchy: German if you were good, Spanish if not), literature or sociology. This hierarchy clearly reflects the status of these disciplines and their social recognition. As mentioned above, today we are governed by numbers (SUPIOT, 2015). Qualitative analyses have been gradually rejected, mainly because they are subjective, whereas data, the "real science", is objective and

approaching the "truth". MACMYNOWSKI (2007) cites this tendency in key authors in the field of STS: "A claim to pure objectivity is a claim to know the 'truth', and thus, a claim to authority and power (HARAWAY, 1992, MERCHANT, 1992, FEYERABRAND, 1993)." It should be noted that this divergence between qualitative and quantitative also exists within the field of social sciences, where quantitative analyses (e.g. closed questionnaires) are clearly favoured over more qualitative methods (e.g. interviews), which are believed to provide less rigorous results – even the same person may give inconsistent, or even contradictory, results during an interview (BERCHT, 2021). Disciplines with rational and quantitative methods are also clearly prioritised in discussions on global change over more human and qualitative analyses (STOKNES, 2014).

29 These assumptions reflect the different nature of the objects of study of the natural sciences and the humanities and social sciences. Nature has long been considered comprehensible and able to be described by numbers and regular laws, in a Cartesian and deductive approach, with working hypotheses that can be tested experimentally. In contrast, humans, who are characterised by great complexity, emotions and values, cannot be tested experimentally, which prevents purely rational analysis. Asking a Cartesian naturalist to engage with a humanities scholar or social scientist who takes humans and society as research subjects can make biophysicists despair (MACMYNOWSKI, 2007), as BRADSHAW and BEKOFF (2001) perfectly summarise: "Integrating biophysical and social sciences means bringing back the very concepts and attributes (e.g. subjective experience) that, by their historic exclusion from science, defined science. Incorporating social sciences into biophysical studies has brought attention to not only the interactions between humans and ecological systems, but also to how science functions as part of a larger system of knowledge, nature and society."

30 Reflecting on the interactions between the natural and human sciences refers directly to these questions of power, hierarchy, authority and, above all, the place of knowledge in society and the place of researchers in the quest for solutions to the major problems we confront, particularly at the interface between humans and nature. It is clear that environmental and social problems can no longer be treated separately (CHAKRAVARTY *et al.,* 2009; RAGUENEAU, 2020). Nature cannot be described by simple mathematical laws in these postnormal times (FUNTOWICZ and RAVETZ, 1993), nor can humans be considered as purely rational and conscious (KAHNEMAN, 2012) or even neuronal (CHANGEUX, 2012). Complexity is omnipresent, and tenfold when it comes to socio-ecological systems. The climate system and the problem of climate change perfectly illustrate the need for the better integration of qualitative social sciences with natural sciences, especially climate science (JASANOFF, 2010). Yet STS and critical climate research have shown that climate studies too often ignore the qualitative and interpretive dimension that is essential for understanding the political and ethical dimensions of climate change (JASANOFF, 2010; KLEPP and CHAVEZ-RODRIGUEZ, 2018). Issues around the social inequality exacerbated by climate change – between poor and rich, the Global South and North, men and women, past, present and future generations – are overshadowed by the search for technological solutions, notably in the form of green or blue growth (BAER *et al.*, 2008; RAGUENEAU, 2020). A similar debate is taking place regarding instruments such as MSP, questions around whether it should be used as an economic tool to maximise the use of the environment and coastal resources in a blue growth perspective, or, in a more radical perspective, as a policy tool to improve the well-being of local communities, as described by FLANNERY *et al.* (2016).

31 Researchers reviewing the IPCC reports may lament the lack of lead authors in the social sciences – even in Working Group II on Impacts, Adaptation and Vulnerability (VICTOR, 2015). They may also note the predominance of natural science and neoclassical economics in broader climate studies (STOKNES, 2014), neglecting human behaviour, so critically important though hard to grasp (see the environmental psychosociology approach developed by GIFFORD, 1987). FLANNERY *et al.* (2016) report that "insufficient attention is paid to the wide range of potential distributional impacts caused and tolerated by an uncritical MSP approach". In fact, only a fifth of the 1200 or so articles on MSP these authors reviewed (in Scopus) came from the social sciences, only a handful of which took a critical stance. More often than not, as with climate, a positivist tradition of rational natural resource management is clearly dominant, without really exploring who actually benefits from MSP as a new form of coastal management: "without a wider appreciation of the social and distributive impacts, we may end up adopting systems of MSP that are socially regressive and even possibly 'evil', at least as used by BAUM (2011) to indicate neglecting the needs of the vulnerable" (FLANNERY *et al.*, 2016). In this special issue on MSP of the journal *Planning Theory & Practice*, it is clearly stated that these risks can be limited by using a participatory approach, involving all stakeholders and adopting a flexible planning process (KELLY, 2016, in FLANNERY *et al.*, 2016).

32 This very important aspect will be valuable in moving from barriers to bridges to interdisciplinarity, in particular through the idea of "boundary work" and the co-production of knowledge. In fact, MACMYNOWSKI (2007) reminds us that the need for interdisciplinarity goes back almost a century: before the dawn of the Anthropocene and the postnormal era, although our current context has reinforced the need for an integrated approach to respond to urgent societal challenges. The barriers to interdisciplinarity discussed above were actually identified long ago (e.g. CHUBIN, 1976). These obstacles that slow down the "border traffic" (HEIDEGGER, 1977) between disciplines have been explored more recently by STS researchers seeking ways to transcend them and facilitate interactions between disciplines. This is particularly the case of those working on interfaces and boundaries, who analyse "the acts and structures that create, maintain and break down boundaries" (see KLEIN, 1996, for a review). Boundary work can be applied to the intersection between disciplines (STAR and GRIESEMEIER, 1989; KLEIN, 1996), or between people and organisations, or between science and society (see the pioneering work of GIERYN, 1983, or JASANOFF, 1987 for work between science and policy). It can also be applied to joint work between academics and Indigenous communities to foster intercultural research that truly takes "different ways of knowing" seriously (ZANOTTI and PALOMINO-SCHALSCHA, 2016), or between art and science, to encourage different ways of exploring an object or concept and challenge these different approaches to complexity, uncertainty, creativity (BENESSIA *et al.*, 2012).

33 MATTOR *et al.* (2014) have demonstrated the utility of boundary work as applied to the study of environmental governance. They discuss how boundary concepts, defined as "loose concepts that create alliances between fields of knowledge and professional domains while protecting the authority and legitimacy of the participants' home field" (LÖWY, 1992), helped them to develop a common language and shared understanding across very different disciplines, including facilitating their subsequent work beyond academia. They developed a boundary object (STAR, 2010) – in the form of a theoretical governance framework – to strengthen integration between disciplines, to take into

account the different factors affecting environmental governance in their region and to better account for the crucial roles of power, knowledge and scale in this governance. Moreover, they highlight how fortunate they were to have a favourable external and internal boundary framework to transcend the institutional and logistical barriers identified by MORSE *et al.* (2007), both for research and for education/training.

34 The "Planning in a liquid world with tropical stakes" (Paddle) project is an excellent example of such a boundary framework, creating the conditions for working at different interfaces because of its interdisciplinary structure, because it is part of the EU "Research and Innovation Staff Exchange" (RISE) programme to promote cross-border and cross-sectoral collaboration, and because it focuses on MSP.

35 MSP itself is a good example of a boundary framework that promotes cross-sectoral activities: it encourages vertically integrated work between multiple stakeholders (an area's managers, users, policymakers) working together horizontally in the different sectors of maritime activities (shipping, ports, oil and gas exploitation, aquaculture, fisheries, offshore energy production, tourism, nature protection, etc.). Such integration involves working across boundaries at professional, geographical, institutional and administrative levels. This cross-sectoral integration is closely related to that of stakeholder involvement and participatory governance, as discussed in TOONEN *et al.* (see chapter 13).

36 The EU RISE programme is also a boundary framework, as it encourages international and intersectoral collaborations. In the case of the Paddle project, it provides an excellent context for exploring the idea of implementing MSP – an instrument developed in the Global North that includes approaches such as integrated coastal zone management to improve the sustainability of oceans and coastal waters – in countries in the Global South through practices such as secondments of scientists, international conferences, or training and capacity-building workshops. In this sense, it participates in the ongoing "decolonisation process" (FERDINAND, 2019; ZANOTTI and PALOMINO-SCHALSCHA, 2016) that aims to offer attention and respect for plural epistemologies and ontologies, well beyond the Western ontology based on a clear separation between nature and culture (see also ESCOBAR, 2018).

37 To explore these cross-sectoral and cross-cultural dimensions of MSP, the Paddle project itself is organised as a boundary framework that fosters inter- and transdisciplinary approaches. The project consists of disciplinary work packages (e.g. WP 2 on ecological processes, WP 3 on policy and governance), but interdisciplinarity is encouraged through secondments, workshops and a dedicated WP for interdisciplinary analysis (WP 5). Transdisciplinarity plays a particular role in WP 4 (challenges and solutions) at study sites in Senegal, Cabo Verde and Brazil, where local scientists are actively working with local stakeholders.

38 Several tools have been used as boundary objects to reinforce inter- and transdisciplinary approaches during the Paddle project, demonstrating their relevance for this purpose. They can be found in the chapters of this handbook (BRUNEL and LANCO BERTRAND, chapter 15; SOUDANT *et al.*, chapter 5; TROUILLET *et al.*, chapter 10), but a few examples can be provided here for the purpose of illustration. Decision support tools are widely used in MSP (PINARBAŞI *et al.*, 2017) and have been studied by both natural scientists and social scientists in the Paddle project, resulting in guidance that identifies their usefulness as well as potential biases related to data availability, ethics

and lack of stakeholder participation (e.g. BRUNEL and LANCO BERTRAND, chapter 15). Similarly, geographers and lawyers have worked together to produce a cartographic atlas of environmental law in West Africa (LE TIXERANT *et al.*, 2020). The exploration of its use by different governmental and non-governmental institutions has demonstrated the potential of such a spatial projection of jurisdictions in the context of the development of MSP in Senegal, notably for monitoring purposes. But it also reveals that such maps have not yet been widely used, for reasons that need further exploration: whether this is due to the fact that MSP is still not effective in Senegal, to the status of maps, which have proven to be excellent boundary objects for fostering stakeholder involvement in the context of ICZM (RITCHARDS *et al.*, 2018), or to the power that a map holds (HARLEY, 2008), which may constitute a barrier to collaboration and knowledge sharing (LE TIXERANT *et al.*, 2020).

Implications for education and training

39 The organisation of universities into disciplinary silos is recognised as a major obstacle to interdisciplinarity (HART *et al.*, 2015). Some sociologists and philosophers have harsh words against universities, considering that academic departments produce ignorant specialists, blind intelligence (MORIN, 2005), or even mediocrity (CHOMSKY, 2010). ROSA and MARSHLIS (2002) use the term “trained incapacities” to identify the problem that specialised disciplinary training, while critical, is proving insufficient to solve increasingly complex scientific (SILLITOE, 2004) and societal (KLEIN, 2004) problems.

40 Interdisciplinary training is intended to facilitate complex problem-solving and is itself complex; this complexity should be embodied throughout the research and education process. What is considered an obstacle for some may be a bridge for others. Above all, it is a personal and ontological way of looking at research, striking a balance between discipline and indiscipline, between safety and risk-taking, between short-term and long-term, between depth and breadth, between applied and fundamental research. Currently students are trained to prioritise discipline, safety, the short-term and depth in order to become researchers who will approach, if not the truth, then at least excellence in fundamental research. How can we reconcile the need for training specialists who allow major advances in their field with the need to address increasingly complex scientific and – perhaps even more importantly in the Anthropocene – societal problems? To embody complexity, it is important to move away from these binary oppositions and find the best balance between these needs, depending on the students, the issue to be addressed and the academic/programme constraints.

41 The cultural context is crucial in relation to these constraints, as I found out when I visited several sustainability centres in the United States and Canada in 2016 to learn more about how they stimulate interdisciplinarity in both research and education. France, for example, has a very centralised organisation, with a strong emphasis on linear curricula, degrees and excellence, perhaps a result of a system in which universities are considered second class in relation to the “*grandes écoles*” that select the best students. Equally, a clear priority is given to intellectual professions over vocational training: the aforementioned opposition between depth and breadth and basic and applied research represent very strong barriers to inter- and transdisciplinary education in France. In contrast, less centralised countries such as the

United States, where a more pragmatic individual experience and less linear curricula are recognised and students can choose their courses almost “à la carte”, may offer a more favourable context for interdisciplinary education. Indeed, it was in the United States and countries with an Anglo-Saxon tradition that the first sustainability centres emerged some 15 years ago (HART *et al.*, 2015). In North America, Australia and northern Europe, there seems to be more of a perspective that a breadth of education can allow high employment potential outside and even within the academy, and applied research is no longer seen as opposed to basic research, but rather part of a continuum from scientific discovery to application for societal needs with mutual benefits, whereas in France, strong indiscipline is needed to overcome institutional and cultural barriers against interdisciplinarity (WOLTON, 2013).

42 Yet it is important to note that even in countries where the context appears to be more favourable, as the US-based MORSE et al. (2007) have noted: “many academic institutions continue to address critical topics such as biodiversity conservation and sustainable development through disciplinary approaches”. This is often because “students are required to meet traditional departmental degree requirements” and, I would add, because the research system still favours disciplinary research, so it is still very risky for students to take interdisciplinary courses or for universities to take their students down uncertain avenues. This can be seen in the way young researchers are recruited in academia or in scientific institutes, in the way careers are evaluated for promotion, or in the fact that publications are still a major criterion in the evaluation system. Of course, it is easier to publish in one’s own discipline, both because we have been trained that way and because there are many more disciplinary journals than interdisciplinary opportunities to publish outside one’s field. Any attempt to foster interdisciplinarity during the training of young researchers, or any exploration of ways to stimulate interdisciplinarity must thus be accompanied by real efforts to change the research system and its evaluation so that it can accommodate this interdisciplinarity and embrace the complexity of science in a postnormal age.

43 Things are slowly changing as academics and civil society recognise the need for interdisciplinary education to prepare future managers, scientists and leaders to solve complex socio-environmental problems (EWEL, 2001). Early calls to train scientists in sustainability were made 20 years ago (CLARKE, 2002), and today courses are offered on issues (climate change, biodiversity conservation, etc.) that involve different disciplines as well as different perspectives (scientists, managers, journalists, policymakers, artists, etc.). MSP can represent a boundary framework that provides an ideal support for interdisciplinary training, a necessary step to strengthen the development of this instrument (GISSI and DE VIVERO, 2016).

44 Over the past 15 years, universities have increasingly provided “education at the boundary” between disciplines in postgraduate and doctoral programmes. For example, MORSE *et al.* (2007) describe their experience of launching an interdisciplinary postgraduate programme, noting the barriers they encountered and the bridges that helped them overcome these barriers at individual, disciplinary and programme levels, and providing a set of recommendations for conducting postgraduate interdisciplinary research. These include individual accountability, developing formal and informal communication strategies (especially to address rather than avoid conflict), careful consideration of team building, mentoring, joint goal setting, focus and framing of

problems, addressing issues of spatial and temporal scale, and respecting discipline-specific time constraints.

45 To overcome the barriers we have described, these authors emphasise several ways to bring the crucial personal and human dimension to the epistemological and institutional components of the problem: personal vision, commitment, working across boundaries, collaborating with others, etc. As L. Cianelli, who developed a wonderful interdisciplinary graduate programme at Oregon State University (United States) told me: "Sometimes it's easier to get disciplines to work together than it is to get people to work together." It is all about being willing and able to step outside of our comfort zone. Teaching students how to work together in our competitive world becomes crucial, bringing us to the last section of this chapter, which stresses the importance of interdisciplinarity in these uncertain times.

A look back at the importance of inter- and transdisciplinary research

46 Overcoming the challenges and obstacles to the development of interdisciplinarity, in education as well as research, is exactly what makes it crucial. It is a form of resistance to the unsustainable path we are on, which is causing environmental degradation, increasing inequality and multiplying inward-looking attitudes, which are endangering democracy in many parts of the world (RAGUENEAU, 2020).

47 Time is perhaps the first element that comes to mind. Interdisciplinarity is a time-consuming activity (STRANG, 2009); the time needed to step aside and meet the "other". The "other" that comes from another discipline, or even from outside the academic world if our critical understanding of interdisciplinarity is taken to include transdisciplinarity (FRODEMAN and MITCHAM, 2007). The further the distance from the "other", the longer it will take for discussion, mutual understanding, and trust building. Moreover, interdisciplinarity cannot be achieved without comparative epistemology, without in-depth analysis of the conditions of knowledge production in the different disciplines (WOLTON, 2013) – which requires additional time. Unfortunately, in these times of alienation and acceleration there is a feeling of perpetual time famine (ROSA, 2012), and the scientific community is no exception. Researchers must constantly look for more projects and more funding, publish more articles, speak at more conferences, obtain more patents. "Slow science" (see ALLEVA, 2006), like "slow food" or "slow cities", would be a response to resist the Great Acceleration, which is so closely linked to our system. It would leave more room (and time!) for collaboration rather than competition, for quality rather than quantity. It would leave more time for interdisciplinarity.

48 Competition is the social engine of acceleration. Thus, the question of time reflects our modern organisation of life, our vision of progress (ROSA, 2012). Resisting acceleration through slow science means moving from competition to collaboration. Interdisciplinarity is an excellent way to train researchers, young and old, to develop all the faculties needed to work with this strange "other": intellectual flexibility, patience, willingness to negotiate, skills in communication, trust in collective intelligence. It is also an excellent school in humility, desperately needed to counteract "Homo Deus" (HARARI, 2017), requiring each of us to acknowledge our shortcomings,

lack of ability and the crucial need for complementary expertise, with some sociologists of science even calling for an "accepted policy of ignorance" (PESTRE, 2013). This is probably not the quickest way to boost your scientific career, but it could contribute to a shift from data and information to knowledge and wisdom (as per T.S. Eliot), so urgently needed in the transition to greater sustainability (RAGUENEAU, 2020).

49 The road is long, but it is of primary importance to resist the rise of populism all over the world that is riding the wave of short-termism and simplicity. As E. OSTROM (2005, cited in LARA, 2005) says: "complex problems require complex solutions and explanations". Engaging in interdisciplinary collaboration is a powerful way to escape the simplistic reasoning of populist leaders who propose "solutions" that ultimately lead to nationalism, totalitarianism and/or war (ARENDT, 1982). Interdisciplinarity, in this sense, can contribute to the quest for a common world, with strong implications for freedom (see ARENDT, 1993). It is important that seeking this common world has a strong international dimension, especially between modern and non-modern cultures. As WOLTON (2013) argues, there can be no interdisciplinarity without a comparative approach to the development of scientific fields in different cultural contexts. And if we take the broader meaning of interdisciplinarity to include science–society interactions, it is essential to recognise that non-modern cultures have much to say and likely to teach to modern science, which tends to grant itself a monopoly on knowledge (ESCOBAR, 2018). In his book *Thinking-Feeling with the Earth*, A. ESCOBAR (2018) demonstrates the benefits of joint efforts between civil society movements and researchers towards sustainability in Latin America. He argues that modern science should be analysed by political ontology, in the vein of cultural studies, critical geography and political ecology, contributing to the decolonisation movement in ecology (FERDINAND, 2019).

50 What is sorely lacking in this search for a common world is a new grand narrative, something "bigger than ourselves", but different from a religion, an empire or capitalism; different from the anthropological options between transhumanism or the collapse of civilisation (REY, 2018) or the political pseudo choice between nationalism or unbridled globalisation (FRASER, 2017). Interdisciplinarity between the two major spheres of scientific research (natural sciences and humanities and social sciences) as well as work at the interface between science and society can contribute to this quest by helping us to escape from (RAGUENEAU, 2020): (1) rationalisation and governance by numbers (SUPIOT, 2015), (2) the dominance of quantity over quality (see discussion on the qualitative/quantitative divide, NIELSEN and D'HAEN, 2014; BERCHT, 2021), (3) the short-term vision and commodification of knowledge and universities (CHOMSKY, 2010), and more generally, (4) the absence of a global political vision, which is not masked by the positivist vision of our supposed salvation by technoscience (REY, 2018).

51 However, neither interdisciplinarity alone, nor the noble ideas of transdisciplinarity, collaboration, co-production of knowledge, participation – although essential in the sustainability transition – will be sufficient. As D. PESTRE (2013) argues, these approaches must not hide the dark side of power asymmetries. Domination, influence, interests ... it would be idealistic to forget these darker aspects as we engage in collaborative, inter- and transdisciplinary processes aimed at transforming our societies towards sustainability (MAZÉ and RAGUENEAU, 2022). Indeed, this makes the debates around MSP so crucial: should it be a predominantly rational and scientific

instrument aiming to maximise the use of coastal waters in a blue growth perspective, or should it be more radical, with a more human and social perspective aiming to rebalance power between local communities and different stakeholders (FLANNERY *et al.*, 2016)?

52 The Paddle project is a forum for such debates (for example, at the WP 3 workshop held in Tamandaré, Brazil, in November 2019). Beyond seeking true interdisciplinarity, it forces each of us to reflect on science–society interactions, on our position in power games and on the political vision of MSP. This is critical in these uncertain times of the Anthropocene when our responsibility as scientists is engaged (PAASCHE and ÖSTERBLOM, 2019; RAGUENEAU *et al.*, 2020) in a context of decolonial ecology (FERDINAND, 2019) and the search for increased sustainability for all, human and non-human alike.

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Glossary

1 The Paddle project created an opportunity for researchers from a range of scientific disciplines (law, political science, public administration, sociology, geography, economics, marine ecology, biology and physics) and a number of countries (in Europe, as well as Cabo Verde, Senegal and Brazil) to enrich understanding around marine spatial planning issues in an interdisciplinary and intercultural way. To foster effective communication within the consortium it was necessary to develop a common language in order to build a shared representation and to facilitate both training and innovation.

2 This glossary is a first step towards a common understanding of key concepts in the field of marine spatial planning.

Why a glossary?

3 The first step in interdisciplinary scientific collaboration is ensuring mutual understanding and a common language to talk about scientific knowledge. We have repeatedly observed that definitions of key words can vary from one discipline to another, leading to confusion or, worse, misinterpretation (Table 1).

4 This glossary aims to lay a foundation for interdisciplinary work with non-native speakers of English.

Table 1. Geographical, environmental and jurisdictional concepts

Concepts	
Geographic and environmental	**Jurisdictional**

Area	Baselines
Coastal area	Contiguous area
Coastal zone	Continental shelf
Coastal zone system	Ecological protection zone
Environmental impact assessment	Exclusive economic zone
Integrated coastal zone management	Fishing area
Interface	High seas
Sustainability	Historic bays
Sustainable development	Inland waters
	Territorial sea

Source: Suarez de vivero (2015)

Methodology

5 At the Paddle project kick-off meeting, we asked for a list of terms considered essential in the disciplines represented in each working group. Working group members were then asked to provide definitions. Compiling the definitions revealed a spectrum of similarities and differences. Wherever possible, we use definitions shared within the consortium. If it was not possible to reach a consensus, the discipline related to the proposed definition is specified.

Structure of the glossary

6 Several presentation options were considered: by type (theoretical basis, principles and instruments), by theme or by discipline. In the end, the chosen presentation underlines the importance of the definition of key words in the study of MSP processes. The limited number of themes compared to other glossaries produced during the research projects allows an alphabetical classification.

Baseline

7 “The normal baseline for measuring the breadth of the territorial sea is the low-water line along the coast as marked on large-scale charts officially recognized by the coastal State.”

8 Source: United Nations Convention on the Law of the Sea (UNCLOS), Article 5 of Part II, 1982

Biodiversity

9 Derived from the Greek *bios* “life” and the Latin *diversitās* “diversity, difference”, biodiversity refers to the degree of variety in the living world, including the taxonomic and functional diversity of species, the genetic diversity within species, as well as the diversity of habitats, ecosystems and landscapes.

Coastal zone

10 The coastal zone is defined as a strip of land and sea of variable width depending on the nature of the environment and management needs. It rarely corresponds to existing administrative or planning units. Natural coastal systems and areas where human activities involve the use of coastal resources may therefore extend well beyond the limit of territorial waters, and several kilometres inland.

Source: EU, http://ec.europa.eu/environment/iczm/situation.htm

Connectivity

11 Two approaches are typically used to model connectivity: (1) the Lagrangian approach describes motion by following an individual element (particle, organism) as it moves through space and time; (2) the Eulerian approach describes motion by focusing on specific locations in space through which elements pass over time.

Continental shelf

12 "The continental shelf of a coastal State comprises the seabed and subsoil of the submarine areas that extend beyond its territorial sea throughout the natural prolongation of its land territory to the outer edge of the continental margin, or to a distance of 200 nautical miles from the baselines from which the breadth of the territorial sea is measured, where the outer edge of the continental margin does not extend up to that distance."

Source: UNCLOS, Article 76 of Part VI, 1982

Ecosystem

13 Derived from the Greek *oikos* "house" and *systêma* "system", an ecosystem is the assemblage of interacting organisms (bacteria, archaea, protists, fungi, plants, animals – the biocenosis) in their abiotic environment (biotope or habitat).

Ecosystem processes

14 Physical, chemical or biological activities or reactions (such as production or decomposition) that link organisms and their environment.

Exclusive economic zone

15 "The exclusive economic zone is an area beyond and adjacent to the territorial sea, subject to the specific legal regime established in this Part, in which the rights and jurisdiction of the coastal State and the rights and freedoms of other States are governed by the relevant provisions of this Convention. The exclusive economic zone shall not extend beyond 200 nautical miles from the baselines from which the breadth of the territorial sea is measured."

Source: UNCLOS, Articles 55 and 57 of Part V, 1982

Extension of the continental shelf

16 "For the purposes of this Convention, the coastal State shall establish the outer edge of the continental margin whenever the margin extends beyond 200 nautical miles from the baselines from which the breadth of the territorial sea is measured, by either: (1) a line delineated in accordance with paragraph 7 by reference to the outermost fixed points at each of which the thickness of the sedimentary rocks is at least 1 per cent of the shortest distance from such a point to the foot of the continental slope; or (2) a line delineated in accordance with paragraph 7 by reference to fixed points not more than 60 nautical miles from the foot of the continental slope. (b) In the absence of evidence to the contrary, the foot of the continental slope shall be determined as the point of maximum change in the gradient at its base.

Source: UNCLOS, Article 76

Food web

17 An assemblage of organisms of different trophic levels that share the same habitat (even if only temporally) and are linked to each other by trophic relationships, i.e. one eats the other. The classical trophic levels of a food web are (primary) producers (normally photosynthetic plants), primary consumers (secondary producers) (herbivores), secondary consumers (carnivores or predators), etc. Only a few food webs comprise more than four trophic levels (top predators at the highest level), but since consumption of a food source may occur at more than one trophic level and many organisms are omnivorous (i.e. they feed on more than one trophic level, e.g. both plants and animals), it is sometimes impossible to clearly assign a species to a trophic level, and food webs are therefore made up of complex trophic interactions.

Habitat

18 Derived from the Latin *habitāre* "to inhabit", a habitat is the natural environment in which an organism lives, or the physical space in the environment that is suitable for providing the conditions for a set of organisms to live.

Integrated coastal zone management

19 "Integrated coastal zone management (ICZM) is a dynamic, multidisciplinary and iterative process to promote sustainable management of coastal zones. It covers the full cycle of information gathering, planning (in its broadest sense), decision-making, management and monitoring of implementation. ICZM uses the informed participation and cooperation of all stakeholders to assess the societal objectives in a given coastal area, and to take actions towards meeting these objectives. ICZM seeks, over the long term, to balance environmental, economic, social, cultural and recreational objectives, all within the limits set by natural dynamics. "Integrated" in ICZM refers to the integration of objectives and to the integration of the many instruments needed to meet these objectives. It means integration of all relevant policy areas, sectors and levels of administration. It means integration of the terrestrial and marine components of the target territory, in both time and space."

Source: EU, COM (2000) 547

Management plan

1. "A written, circulated and approved document which describes the site or area and the problems and opportunities for management of its nature conservation, landform or landscape features, enabling objectives based on this information to be met through relevant work over a stated period of time." (EUROSITE, 1999).
2. "The guide by which Parks Canada manages the resources and uses of a national park. It contains the management objectives and the means and strategies for achieving them. The plan is not an end in itself; rather, it constitutes a framework within which subsequent management, implementation and planning will take place." (PARKS CANADA, 1978).
3. "A document that guides and controls the management of a protected area. It details the resources, uses, facilities and personnel needed to manage the area in the future. It is a working document that presents a programme for the coming 5–10 years." (NDOSI, 1992).
4. "A document that guides and controls the management of protected area resources, the uses of the area and the development of facilities needed to support that management and use. Thus, a management plan is a working document to guide and facilitate all development activities and all management activities to be implemented in an area." (THORSELL, 1995).
5. "A document that sets forth the basic and development philosophy of the park and provides strategies for solving problems and achieving identified management objectives over a ten-year period. Based on these strategies, programmes, actions and support facilities necessary for efficient park operations, visitor use and human benefit are identified. Throughout the planning effort, the park is considered in a regional context that influences and is influenced by it." (YOUNG and YOUNG, 1993).

Source: https://portals.iucn.org/library/efiles/documents/pag-010.pdf

Marine governance

20 Marine governance is the way in which society has established objectives, priorities and systems of cooperation concerning the maritime space. Governance can be achieved at international, regional, national and local levels. It is the conduct of policy, actions and affairs concerning the world's oceans. Governance incorporates the influence of non-governmental actors (i.e. stakeholders, NGOs), so the state is not the only power acting in policymaking.

Source: United Nations

Marine protected areas

1. Marine protected areas (MPAs) involve the protective management of natural areas to maintain them in their natural state. MPAs can be conserved for a number of reasons, including to protect economic resources, biodiversity or specific species. They are created by delimiting an area and defining permitted and non-permitted uses within that area.
2. "Any area of intertidal or subtidal terrain, together with its overlying waters and associated flora, fauna, historical and cultural features, which has been reserved by law or other effective means to protect part or all of the enclosed environment."

Source: International Union for Conservation of Nature (IUCN)

Marine spatial planning

21 “A process by which the relevant member state’s authorities analyse and organise human activities in marine areas to achieve ecological, economic and social objectives.”

Source: EU MSP Directive 2014
Source: International Union for Conservation of Nature (IUCN)

Ocean governance

22 “International ocean governance is about managing the world’s oceans and their resources together so that they are healthy and productive for the benefit of current and future generations.”

Source: EU, https://ec.europa.eu/maritimeaffairs/policy/ocean-governance_en

Oligotrophic

23 An oligotrophic aquatic ecosystem is characterised by low primary productivity, due to the low nutrient content. These ecosystems often have very clear water. The oxygen content is high.

Pelagic/demersal/benthic area

- The term “pelagic” comes from the Greek *pelagos* “open sea”. It refers to the water column of the open sea. Organisms that live in the pelagic zone are called pelagic organisms.
- Benthic is derived from the Greek *bénthos* “the depths”. The benthic zone is the ecological region at the very bottom of the sea. It includes the seabed and some subsurface layers. The marine organisms that live in this zone are called benthos.
- Demersal is derived from the Latin *demersus* “the descent”. The demersal zone is the part of the sea consisting of the water column close to the seabed and the benthos, which is significantly affected by it.

Resilience

24 Derived from the Latin *resilire* “to return”, this is the ability of an ecosystem to respond to a disturbance by resisting damage and recovering quickly to return to its original state.

Territorial sea

25 “The sovereignty of a coastal State extends, beyond its land territory and internal waters and, in the case of an archipelagic State, its archipelagic waters, to an adjacent belt of sea, described as the territorial sea. This sovereignty extends to the air space above the territorial sea as well as to its bed and subsoil. Every State has the right to establish the breadth of its territorial sea up to a limit not exceeding 12 nautical miles, measured from baselines determined in accordance with this Convention.”

Source: Unclos, Articles 2 and 3 of Part II, 1982

Upwelling

26 Upwelling is a wind-driven oceanographic process in which deep, cold and generally nutrient-rich water rises to the surface. The upwelled, nutrient-rich water stimulates the growth and reproduction of primary producers such as phytoplankton.

Zoning plan

27 "These are produced when different areas or 'zones' of a protected area are to be managed in different ways. They identify the boundaries of the zones and contain detail on how each of the zones is to be managed. Zoning plans provide additional definition and help implement the management plan, and are sometimes a part of it."

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List of acronyms

ACP: Africa–Caribbean–Pacific
AfCFTA: African Continental Free Trade Area
AI: Artificial intelligence
AIS: Automatic identification system
AMERB: Areas of Management and Exploitation of Benthic Resources (Chile)
ANAM: National Agency for Maritime Affairs (Senegal)
ANAT: National Agency for Spatial Planning (Senegal)
ANGIL: National Authority for Integrated Coastal Management (Senegal)
ANM: National Mining Agency (Brazil)
ANP: National Agency for Petroleum, Natural Gas and Biofuels (Brazil)
ANR: National Research Agency (France)
ANSD: National Agency for Statistics and Demography (Senegal)
ANTAQ: National Agency for River Transport (Brazil)
APA: Environmental Protection Area (Brazil)
AR: Artificial reef
ASC: Aquaculture Stewardship Council (non-profit organisation)
ASP: Amnesic shellfish poisoning
BAP: Best aquaculture practices
BLM: Boundary length modifier
BRICS: Brazil, Russia, India, China and South Africa
CAMP: Centre for the Motorisation of Pirogues (Senegal)
CAPAS: Senegalese Artisanal Fisheries Support Centre
CBD: Convention on Biological Diversity
CCADT: Municipal Commission on Territorial Planning and Development (Senegal)
CCSBT: Commission for the Conservation of Southern Bluefin Tuna
CDADT: Departmental Commission on Territorial Planning and Development (Senegal)
CDE: Code on the domain of the state (France)
CEEAC: Economic Community of Central African States
CEMAC: Central African Economic and Monetary Community
CEMZA: Combined Exclusive Maritime Zone for Africa
CF: Conservation feature
CIAT: Interministerial Council for Land Use Planning (Senegal)
CICES: Common International Classification of Ecosystem Services

CIRM: Interministerial Commission on Marine Resources (Brazil)
CLPA: Local Artisanal Fisheries Councils (Senegal)
CNADT: National Commission for Territorial Planning and Development (Senegal)
CNPS: National Committee of Senegalese Fishermen
COFI: UN Committee on Fisheries
COMHAFAT: Regional Convention on Fisheries Cooperation between African States bordering the Atlantic Ocean
CONAMA: National Council on the Environment (Brazil)
COOPMER: Cooperative for the Supply and Distribution of Sea Products (Senegal)
COREP: Gulf of Guinea Regional Fisheries Commission
COS: Center for Ocean Solutions (interdisciplinary research programme)
CPADT: Presidential Council for Territorial Planning and Development (Senegal)
CPLP: Community of Portuguese Speaking Countries
CPRM: Mineral Resources Exploration Company (Brazil)
CRODT: Dakar-Thiaroye Oceanographic Research Centre (Senegal)
CSE: Ecological Monitoring Centre (Senegal)
CSV: Comma separated values
CU: Conservation unit
DAMCP: Directorate of Marine and Community Protected Areas (Senegal)
DEEC: Directorate of the Environment and Classified Establishments (Senegal)
DGEM: Directorate General for the Maritime Economy (Cabo Verde)
DGL: Coastal Management Division (Senegal)
DGRM: Directorate General of Maritime Resources (Cabo Verde)
DICAPI: Directorate General of Captaincies and Coastguard (Peru)
DNA: National Directorate for the Environment (Cabo Verde)
DPM: Directorate of Marine Fisheries (Senegal)
DPSP: Directorate of Fisheries Protection and Surveillance (Senegal)
DSP: Diarrhetic shellfish poisoning
DST: Decision support tool
EC: European Commission
ECOWAS: Economic Community of West African States
ECS: Extended continental shelf
EDF: European Development Fund
EEZ: Exclusive economic zone
EFS: French Elements in Senegal
EIA: Environmental impact assessment
EMAR: Escola do Mar (Cabo Verde)
ENP: European Neighbourhood Policy
ENPI: European Neighbourhood and Partnership Instrument
ENSO: El Niño–Southern Oscillation
EU: European Union
FAO: UN Food and Agriculture Organization
FCWC: Fishery Committee for the West Central Gulf of Guinea
FPSO: Floating production storage and offloading (vessel for the offshore oil and gas industry)
GAA: Global Aquaculture Alliance (non-profit organisation)
GAIPES: Group of Shipowners and Fishing Industries in Senegal
GCG: Gulf of Guinea Commission

GCWSR: Gold Coast World Surfing Reserve (Australia)
GDP: Gross domestic product
GE: Google Earth
GEBCO: General Bathymetric Chart of the Oceans
GI-Gerco: Integrated Coastal Management Group (Brazil)
GNP: Gross national product
GT: Gross tonnage
HAB: Harmful algal bloom
HASSMAR: High Authority for the Coordination of Maritime Safety, Security and Environmental Protection (Senegal)
HSS: Humanities and social sciences
IBA: Important bird and biodiversity areas
IBAMA: Brazilian Institute for the Environment and Renewable Natural Resources
ICCAT: International Commission for the Conservation of Atlantic Tunas
ICMBio: Chico Mendes Institute for Biodiversity Conservation (Brazil)
ICSF: International Collective in Support of Fishworkers (NGO)
ICZM: Integrated coastal zone management
IGBP: International Geosphere-Biosphere Programme
IHDP: International Human Dimensions Programme
ILP: Integer linear programming
IMAR: Instituto do Mar (Cabo Verde)
IMP: Maritime and Port Institute (Cabo Verde)
INDP: National Institute for Fisheries Development (Cabo Verde)
INE: National Institute of Statistics (Cabo Verde)
INGT: National Institute of Land Management (Cabo Verde)
IOC: Intergovernmental Oceanographic Commission (UNESCO)
IPCC: Intergovernmental Panel on Climate Change
ISRA: Senegalese Institute for Agricultural Research
ITCZ: Intertropical convergence zone
IUEM: European Institute for Marine Studies
IUU: Illegal, unreported, unregulated (fishing)
IWRM: Integrated water resources management
JAES: Joint Africa–EU Strategy
KAN: Knowledge–action networks
LOADT: Orientation law for the planning and sustainable development of territories (Senegal)
MMA: Ministry of the Environment (Brazil)
MPA: Marine protected area
MSP: Marine spatial planning
NAO: North Atlantic Oscillation
NASC: Nautical area scattering coefficient
NATO: North Atlantic Treaty Organisation
NE: Nordeste (Brazil)
NFZ: No-take fishing zone
NGO: Non-governmental organisation
NOAA: National Oceanic and Atmospheric Administration (United States)
NS: Natural sciences
NSPSA: National Strategic Plan for the Development of Aquaculture (Europe)

NZCPS: New Zealand Coastal Policy Statement
OIE: World Organisation for Animal Health
ONAS: National Sanitation Agency of Senegal
ONT: National Observatory of Territories (Senegal)
OPEC: Organisation of Petroleum Exporting Countries
PA: Protected area
Paddle: Planning in a liquid world with tropical stakes project
PAF: Federal Action Plan (Brazil)
PAF-CZ: Federal Coastal Zone Action Plan (Brazil)
PAG: Development and Management Plan (Senegal)
PAH: Polycyclic aromatic hydrocarbon
PALOPs: Portuguese-speaking African countries
PCB: Polychlorinated biphenyl
PDO: Pacific Decadal Oscillation
PEGC: State Coastal Zone Management Plan (Brazil)
PMGC: Municipal Coastal Zone Management Plan (Brazil)
PNADT: National Territorial Land Use Development Plan (Senegal)
PNAT: National Land Use Plan (Senegal)
PNBA: Banc d'Arguin National Park (Mauritania)
PNCMar: National Policy for the Conservation and Sustainable Use of the Brazilian Marine Biome
PNGC: National Coastal Management Plan (Brazil)
PNIEB: National Investment Plan for the Blue Economy (Cabo Verde)
PNIUM: National Marine Emergency Response Plan (Senegal)
PNMA: National Environmental Policy (Brazil)
PNRM: National Policy for Marine Resources (Brazil)
POOC: Coastal Strip Management Plan (Brazil)
POP: Persistent organic pollutant
PRCM: Regional Partnership for Coastal and Marine Conservation (West Africa)
PROMEB: Programme for the Promotion of the Blue Economy (Cabo Verde)
PSE: Plan for an Emerging Senegal
PSP: Paralytic shellfish poisoning
PSRM: Sectoral Plan for Maritime Resources
PU: Planning unit
QGIS: Quantum geographic information system
RBDS: Saloum Delta Biosphere Reserve (Senegal)
RENARO: National Surf Registry (Peru)
RISE: Research and Innovation Staff Exchange (EU)
RMA: Resource Management Act (New Zealand)
SAPEA: Science Advice for Policy by European Academies
SATO: South Atlantic Treaty Organisation
SDGs: Sustainable development goals
SEA: Strategic environmental assessment
SEAFO: South East Atlantic Fisheries Organisation
SEMA: Special Secretariat for the Environment (Brazil)
SFPA: Sustainable Fisheries Partnership Agreements (EU)
SIGERCO: Coastal management information system
SISNAMA: National Environment System (Brazil)

SLOSS: Single large or several small (reserves)
SMA-ZC: Coastal Zone Environmental Monitoring System (Brazil)
SMHPM: Mauritanian Company of Hydrocarbons and Mining
SNUC: National System of Protected Areas (Conservation Units) (Brazil)
SPF: Small pelagic fish
SRFC: Sub-Regional Fisheries Commission (West Africa)
SST: Sea surface temperature
STS: Science and technology studies
STW: Save the Waves (non-profit organisation)
TAGP: Beach Management Agreement (Brazil)
TME: Trace metal elements
TNC: The Nature Conservancy (non-profit organisation)
TNI: Transnational Institute (non-profit think tank)
UEMOA: West African Economic and Monetary Union
UNCLOS: United Nations Convention on the Law of the Sea
UNESCO: United Nations Educational, Scientific and Cultural Organization
UPAMES: Employers' Union of Senegalese Fishmongers and Exporters
USAID: United States Agency for International Development
UTA: Atlantic Technical University (Cabo Verde)
VMS: Vessel monitoring system
WACA: West Africa Coastal Areas Management Programme
WASCAL: West African Science Service Centre on Climate Change and Adapted Land Use
WFFP: World Forum of Fisher Peoples
WP: Work package
WSR: World Surfing Reserve
WWF: World Wildlife Fund (non-profit organisation)
ZAP: Priority Development Zone (Senegal)
ZEEC: Ecological Economic Zoning of Coastal Regions (Brazil)
ZEEMSV: Maritime Special Economic Zone in São Vicente (Cabo Verde)
ZOPACAS: South Atlantic Peace and Cooperation Zone
ZUS: Sensitive Urban Zone (France)

The goal of marine spatial planning is to manage uses of marine space to reduce tensions between human activities and the health of marine ecosystems. This is a major and complex challenge, as oceans lie at the intersection of multiple and increasing interests: biodiversity conservation, climate change regulation, economic development, food security.

This handbook takes an interdisciplinary, sustainability science approach to explore the potential and limitations of marine spatial planning, a tool developed in the Global North, and its current or possible future applications in the tropical South Atlantic – specifically in Brazil, Senegal and Cabo Verde.

To protect our global ocean commons, communities of stakeholders need to transcend disciplinary boundaries and bring together diverse knowledge to move towards a shared goal of sustainability (part 1). The development of this collective intelligence in tropical marine ecosystem research must take into account local, national and international issues (part 2) and can be supported by innovative interdisciplinary tools (part 3).

This handbook is aimed at decision-makers, researchers and, more generally, all users of marine areas, highlighting crucial points to consider when implementing marine spatial planning.

Marie Bonnin is an expert in environmental law. She is a research director at the French Research Institute for Sustainable Development (IRD) and a member of the joint Laboratory of Marine Environmental Sciences (LEMAR). Her focus is the legal protection of the marine environment. In her position at the European Institute for Marine Studies (IUEM), she interacts extensively with researchers in natural and physical sciences. With her background in translating marine ecology research into law, today she is interested in the applicability and effectiveness of environmental protection legislation. She has worked specifically on marine environmental law in West Africa, in collaboration with universities and research institutes in Senegal, Mauritania and Cabo Verde, and more recently has extended her area of specialisation to the broader tropical Atlantic.

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9 782709 929967
ISBN: 978-2-7099-2996-7

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