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

Arnaud Bertrand and Martin Zimmer

EDITOR'S NOTE

Coordinated by Arnaud Bertrand and Martin Zimmer, with contributions from Corrine Almeida, Moacyr Araujo, Christophe Barbraud, Sophie Lanco Bertrand, Rebecca Borges, Andrea Z. Botelho, Timothée Brochier, Ana Carvalho, Liliana Carvalho, Daniela Casimiro, Ana C. Costa, Alex Costa da Silva, Hervé Demarcq, Malick Diouf, Gilles Domalain, Paulo Duarte, Éric Dutrieux, Werner Ekau, Beatrice P. Ferreira, Thierry Frédou, Flavia Lucena Frédou, Daniela Gabriel, Lucy G. Gillis, José Guerreiro, Fabio Hazin, Hélène Hegaret, Véronique Helfer, Ariane Koch-Larrouy, François Le Loc'h, Alciany da Luz, Inês Machado, Vito Melo, Albertino Martins, Vitor Paiva, Jaime Ramos, Pedro Raposeiro, Osvaldina Silva, Pericles Silva, Philippe Soudant, Modou Thiaw, Yoann Thomas, Sébastien Thorin, Paulo Travassos Varona and Maria Anunciação Ventura.

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.

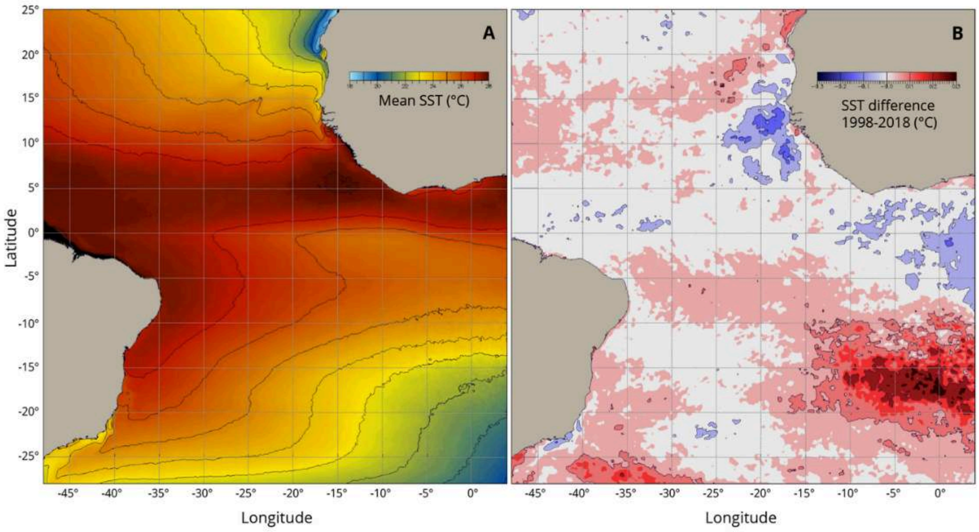
General trends in oceanographic conditions in the tropical Atlantic

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

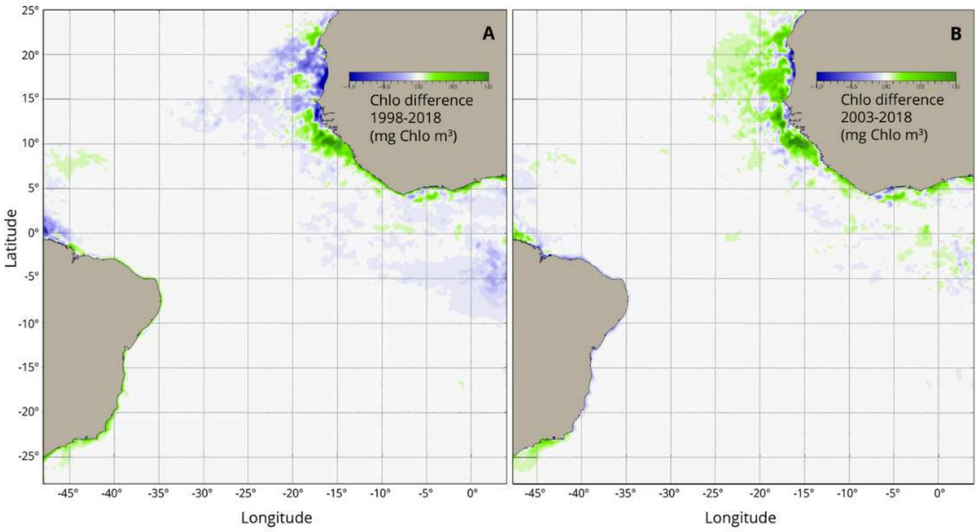
deeper waters to survive, or to significantly alter their behaviour, leading to local extinctions and range shifts that will have a significant impact on the trophic structure of ecosystems and their surplus production available to fisheries.

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)

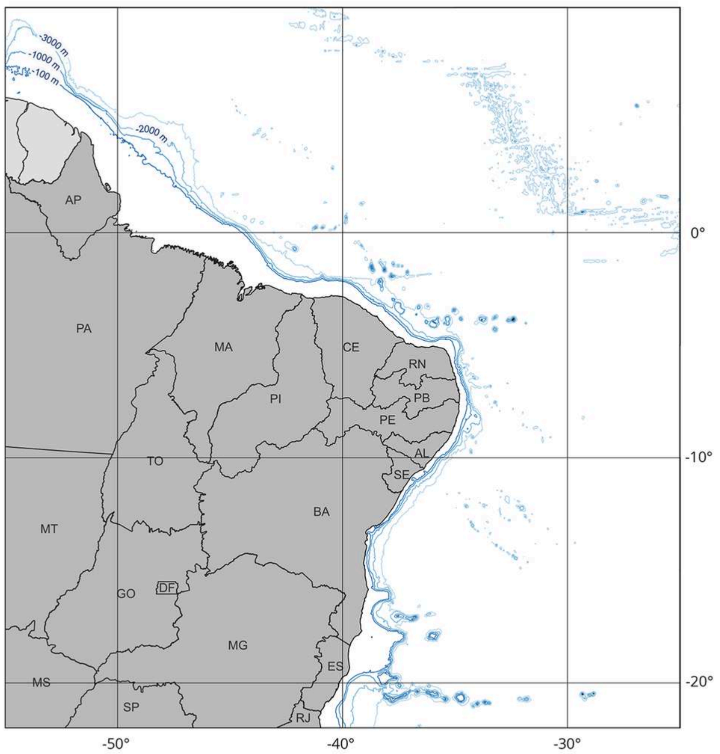
The tropical Atlantic: a diversity of ecosystems

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.

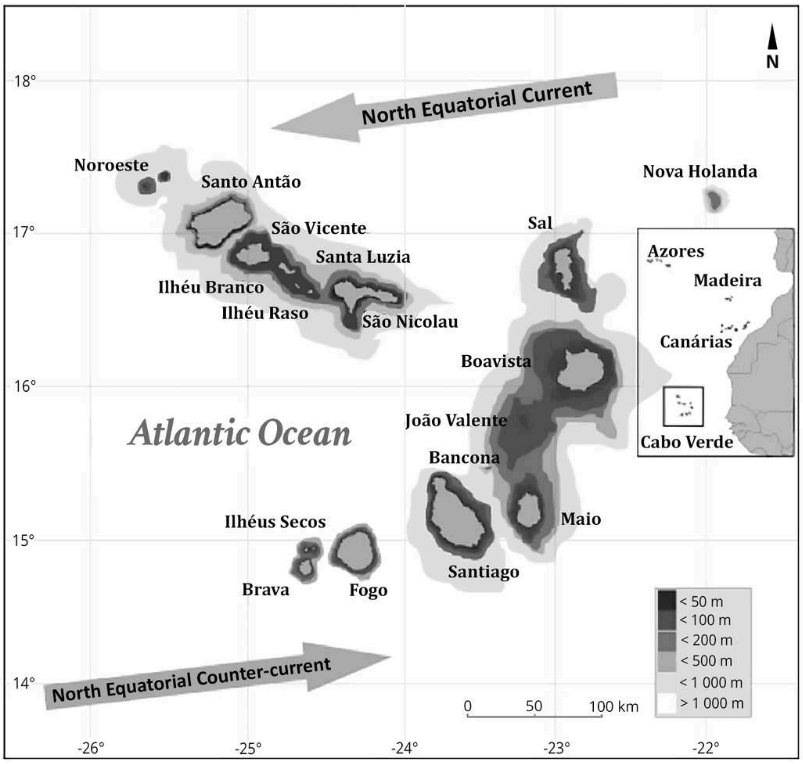
10 Marine extractive reserves represent the most significant government-supported effort to protect common property resources on which small-scale traditional fishermen depend. They are generally owned by the government, but rights of access and use, including extraction of natural resources, are allocated 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.

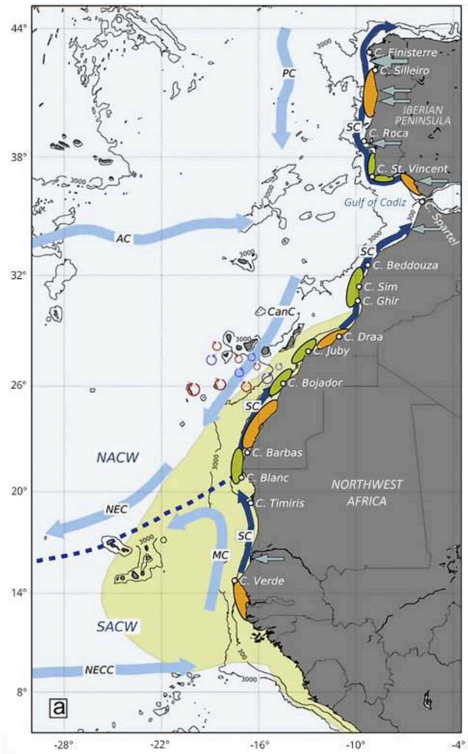
15 The World Bank considers tourism one of the most important investments for the future of Cabo Verde. If the country is to make tourism a major contributor to the gross domestic product (GDP), it will need to address key issues such as sanitation, waste management and illegal aggregate extraction. 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).

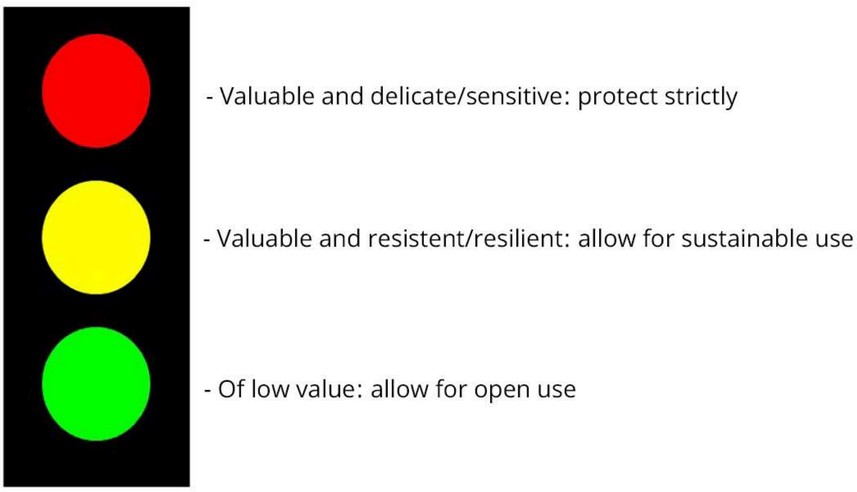
Conclusion

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.

AUTHORS

ARNAUD BERTRAND

Marine ecologist, MARBEC, IRD, France

MARTIN ZIMMER

Marine ecologist, Leibniz Centre for Tropical Marine Research (ZMT), Germany

Edited by
M. Bonnin, S. Lanco Bertrand

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