Chapter 5. Cultivating the sea

Shellfish aquaculture issues in marine spatial planning

Philippe Soudant, Hilde Toonen, Patricia Mirella Da Silva, Rui Trombeta, Odeline Billant, Nelly Le Goïc, Adeline Bidault, Christophe Lambert, Aurélie Chambouvet, Fernando Queiroga-Ramos, Andrei Félix Mendes, Marie Bonnin and Hélène Hégaret

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

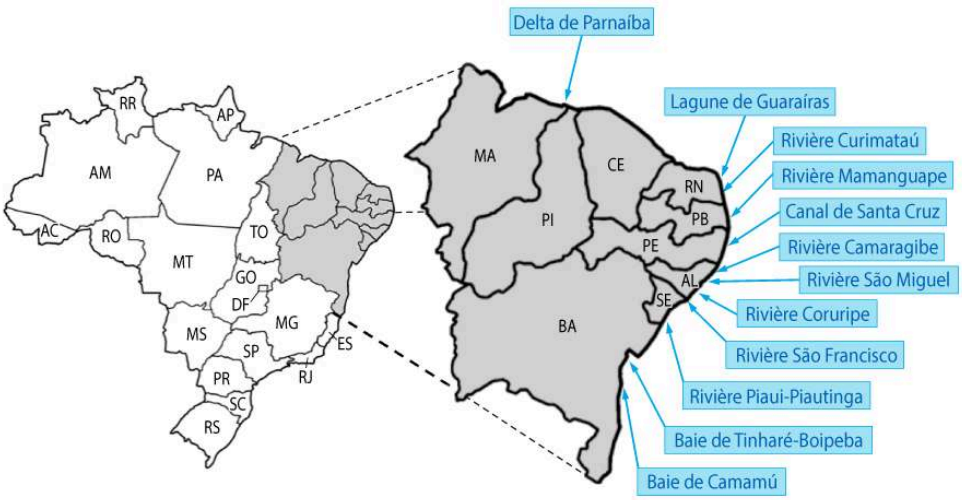
© R. Trombeta, P. M. da Silva

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.

BIBLIOGRAPHY

AKABOSHI S., PERERERIRA O. M., 1981

Ostreicultura na região lagunar de Cananéia, São Paulo, Brasil. 1. Captação de larvas da ostra Crassostrea brasiliana (Lamarck 1819) em ambiente natural. *Boletim do Instituto de Pesca*, 8: 87-104.

ANDREWS J., 1980

A review of introductions of exotic oysters and biological planning for new importations. *Marine Fisheries Review,* 42 (12): 1-11.

ARZUL I., CORBEIL S., MORGA B., RENAULT T., 2017

Viruses infecting marine molluscs. *Journal of Invertebrate Pathology*. 147: 118-135. https://doi.org/10.1016/j.jip.2017.01.009

ASC, 2019

ASC Bivalve Standard. Version 1.1. Utrecht, Aquaculture Stewardship Council, 53 p. https://www.asc-aqua.org/wp-content/uploads/2019/03/ASC-Bivalve-Standard_v1.1_Final.pdf

BARBER B. J., 2004

Neoplastic diseases of commercially important marine bivalves. *Aquatic Living Resources*, 17 (4): 449-466.

BARBOSA SOLOMIEU V., RENAULT T., TRAVERS M.-A., 2015

Mass mortality in bivalves and the intricate case of the Pacific oyster, *Crassostrea gigas*. *Journal of Invertebrate Pathology.* 131: 2-10. https://doi.org/10.1016/j.jip.2015.07.011

BÉNÉ C., BARANGE M., SUBASINGHE R., PINSTRUP-ANDERSEN P. MERINO G., HEMRE G.-I., WILLIAMS M., 2015

Feeding 9 billion by 2050. Putting fish back on the menu. *Food Security*, 7 (2): 261-274.

BOSTOCK J., MCANDREW B., RICHARDS R., JAUNCEY K., TELFER T., LORENZEN K., LITTLE D., ROSS L., HANDISYDE N., GATWARD I., CORNER R., 2010

Aquaculture: global status and trends. *Philosophical Transactions of the Royal Society B: Biological Sciences,* 365 (1554): 2897-2912.

BOYD C. E, MCNEVIN A. A., CLAY J., JOHNSON H. M., 2005

Certification issues for some common aquaculture species. *Rev Fish Sci,* 13 (4): 231-279.

BRUGÈRE C., AGUILAR-MANJARREZ J., BEVERIDGE M. C., SOTO D., 2019

The ecosystem approach to aquaculture 10 years on – a critical review and consideration of its future role in blue growth. *Reviews in Aquaculture*, 11 (3): 493-514.

BURKHOLDER J. M., 1998

Implications of harmful marine microalgae and heterotrophic dinoflagellates in management of sustainable marine fisheries. *Ecological Applications* 8 (Suppl.): S37-62.

BUSH S. R., BELTON B., HALL D., VANDERGEEST P., MURRAY F. J., PONTE S., OOSTERVEER P., ISLAM M. S., MOL A. P. J., HATANAKA M., KRUIJSSEN F., HA T. T. T., LITTLE D. C., KUSUMAWATI R., 2013
Certify sustainable aquaculture? *Science*, 341 (6150): 1067-1068.

CARBALLAL M. J., BARBER B. J., IGLESIAS D., VILLALBA A., 2015
Neoplastic diseases of marine bivalves. *Journal of Invertebrate Pathology*, 131: 83-106.

CHINA B., DE SCHAETZEN M. A., DAUBE G., 2003
Bivalve molluscs, dangerous foods? *Annals of Veterinary Medicine*, 147: 413-422.

CHRISTIE N., SMYTH K., BARNES R., ELLIOTT M., 2014
Co-location of activities and designations: a means of solving or creating problems in marine spatial planning? *Marine Policy*, 43: 254-261.

CRAEYMEERSCH J., JANSEN H., 2019
"Bivalve shellfish assemblages as hotspots for biodiversity". In Smaal *et al.* (eds): *Goods and Services of Marine Bivalves*. Cham, Springer: 275-294.

CRANFORD P. J., 2019
"Magnitude and extent of water clarification services provided by bivalve suspension feeding". In Smaal A. C., Ferreira J. G., Grant J., Petersen J. K., Strand Ø. (eds): *Goods and Services of Marine Bivalves*. Berlin, Springer Nature: 119-142.

CRANFORD P. J., KAMERMANS P., KRAUSE G., MAZURIE J., BUCK B. H., DOLMER P., FRASER D., VAN NIEUWENHOVE K., O'BEIRN F. X., SANCHEZ-MATA A., THORARINSDOTTIR G. G., STRAND O. 2012
An ecosystem-based approach and management framework for the integrated evaluation of bivalve aquaculture impacts. *Aquac. Environ. Interact,* 2: 193-213.

DA SILVA P. M., VIANNA R. T., GUERTLER C., FERREIRA L. P., SANTANA L. N., FERNÁNDEZ-BOO S., RAMILO A., CAO A., VILLALBA A., 2013
First report of the protozoan parasite *Perkinsus marinus* in South America, infecting mangrove oysters *Crassostrea rhizophorae* from the Paraíba River (NE, Brazil). *Journal of Invertebrate Pathology*, 113 (1): 96-103.

DA SILVA P. M., SCARDUA M. P., VIANNA R. T., MENDONÇA R. C., VIEIRA C. B., DUNGAN C. F., SCOTT G. P., REECE K. S., 2014
Two *Perkinsus* spp. infect *Crassostrea gasar* oysters from cultured and wild populations of the Rio São Francisco estuary, Sergipe, northeastern Brazil. *Journal of Invertebrate Pathology*, 119: 62-71.

DA SILVA P. M., COSTA C. P., DE ARAÚJO J. P. B., QUEIROGA F. R., WAINBERG A. A., 2016
Epizootiology of *Perkinsus* sp. in *Crassostrea gasar* oysters in polyculture with shrimps in northeastern Brazil. *Revista Brasileira de Parasitologia Veterinária*, 25 (1): 37-45.

DA SILVA P. M., FARIAS N. D., QUEIROGA F. R., HÉGARET H., SOUDANT P., 2018
Disseminated neoplasia in cultured *Crassostrea gasar* oysters from northeast Brazil. *Journal of Invertebrate Pathology*, 159: 1-5.

DÍAZ S., IGLESIAS D., VILLALBA A., CARBALLAL M. J., 2016
Long-term epidemiological study of disseminated neoplasia of cockles in Galicia (NW Spain): temporal patterns at individual and population levels, influence of environmental and cockle-based factors and lethality. *Journal of Fish Diseases*, 39 (9): 1027-1042.

EHLER C., DOUVERE F., 2011
Marine spatial planning: a step-by-step approach toward ecosystem-based management. *Intergovernmental Oceanographic Commission Manual and Guides,* 53, Paris, Unesco.

FAO, 2020
The State of World Fisheries and Aquaculture (SOFIA) 2020. Sustainability in Action. Rome, FAO. https://doi.org/10.4060/ca9229en

FLANNERY W., CINNEIDE M. Ó., 2008
Marine spatial planning from the perspective of a small seaside community in Ireland. *Marine Policy*, 32 (6): 980-987.

GAA, 2016
Best Aquaculture Practices Factsheet. Portsmouth, Global Aquaculture Alliance. www.aquaculturealliance.org/wp-content/uploads/2016/03/BAP-Fact-Sheet-LT.pdf

GLIBERT P. M., BURKHOLDER J. M., 2018
"Causes of harmful algal blooms". In Shumway S. E. (eds): *Harmful Algal Blooms: a Compendium Desk Reference*, New Jersey, J. Wiley & Sons: 1-38.

HALLEGRAEFF G. M., 1993
A review of harmful algal blooms and their apparent global increase. *Phycologia*, 32: 79-99.

HANCOCK B., ERMGASSEN P., 2019
"Enhanced production of finfish and large crustaceans by bivalve reefs". In Smaal *et al.* (eds): *Goods and Services of Marine Bivalves.* Cham, Springer: 295-312.

HARVELL G., KIM K., BURKHOLDER J. M., COLWELL R. R., EPSTEIN P. R., GRIMES D. J., HOFMANN E. E., LIPP E. K., OSTERHAUS A. D. M. E., OVERSTREET R. M., PORTER J. W., SMITH G. W., VASTA G. R., 1999
Emerging marine diseases. Climate links and anthropogenic factors. *Science* 285 (5433): 1505-1510.

LESTER S. E., STEVENS J. M., GENTRY R. R., KAPPEL C. V., BELL T. W., COSTELLO C. J., GAINES S. D., KIEFER D. A., MAUE C. C., RENSEL J. E., SIMONS R. D., WASHBURN L., WHITE C., 2018
Marine spatial planning makes room for offshore aquaculture in crowded coastal waters. *Nature Communications*, 9 (1): 1-13.

LINDAHL O., 2011
"Mussel farming as a tool for re-eutrophication of coastal waters: experiences from Sweden". In Shumway S. E. (ed.): *Shellfish Aquaculture and the Environment.* Wiley Blackwell, Hoboken.

LUZ CUNHA A. C., PONTINHA V. DE A., DE CASTRO M. A. M., SÜHNEL S., MEDEIROS S. C., MOURA DA LUZ Â. M., HARAKAVA R., TACHIBANA L., MELLO D. F., DANIELLI N. M., DAFRE A. L., MAGALHÃES A. R. M., MOURIÑO J. L., 2019.
Two epizootic *Perkinsus* spp. events in commercial oyster farms at Santa Catarina, Brazil. *J. Fish Dis.* 42: 455-463. https://doi.org/10.1111/jfd.12958

MELLO D. F., DANIELLI N. M., CURBANI F., PONTINHA V. A., SUHNEL S., CASTRO M. A. M., MEDEIROS S. C., WENDT N. C., TREVISAN R., MAGALHÃES A. R. M., DAFRE A. L., 2018
First evidence of viral and bacterial oyster pathogens in the Brazilian coast. *Journal of Fish Diseases*, 41: 559-563.

MURRAY G., D'ANNA L., 2015
Seeing shellfish from the seashore: the importance of values and place in perceptions of aquaculture and marine social-ecological system interactions. *Marine Policy*, 62: 125-133.

NETO M. P. D., GESTEIRA T. C. V., SABRY R. C., FEIJÓ R. G., FORTE J. M., BOEHS G., MAGGIONI R., 2016
First record of *Perkinsus chesapeaki* infecting *Crassostrea rhizophorae* in South America. *Journal of Invertebrate Pathology*, 141: 53-56.

NUNES J. P., FERREIRA J. G., BRICKER S. B., 2011
Towards an ecosystem approach to aquaculture: assessment of sustainable shellfish cultivation at different scales of space, time and complexity. *Aquaculture*, 315 (3-4): 369-383.

NUTTERS H. M., DA SILVA P. P., 2012
Fishery stakeholder engagement and marine spatial planning: lessons from the Rhode Island Ocean SAMP and the Massachusetts Ocean Management Plan. *Ocean & Coastal Management*, 67: 9-18.

OSPAR, 2010
Quality Status Report 2010. London, OSPAR Commission, 176 p.

PETERSEN J., HOLMER M., TERMANSEN M., HASLER B., 2019
"Nutrient extraction through bivalves". In Smaal A., Ferreira J. G., Grant J., Petersen J. K., Strand O. (eds): *Goods and Services of Marine Bivalves*. Cham, Springer: 143-177.

POLI C. R., 2004
"Cultivo de ostras do Pacífico (*Crassostrea gigas*, 1852)". In Poli, A. T. *et al.* (eds): *Aquicultura: experiências brasileiras*, Florianópolis, SC, Multitarefa Editora Ltda: 251-266.

POLI C. R., SILVERA N. J. R., SILVA F. C., 1990
Introdução da ostra do Pacífico no sul do Brasil. *Red Acuicultura Bol*, 4: 14-15.

RENAULT T., 1996
Appearance and spread of diseases among bivalve molluscs in the northern hemisphere in relation to international trade. *Scientific and Technical Review of the Office International des Epizooties*, 15: 551-561.

ROBLEDO J. A. F., VASTA G. R., RECORD N. R., 2014
Protozoan parasites of bivalve molluscs: literature follows culture. *PLoS One*, 9: e100872. https://doi.org/10.1371/journal.pone.0100872

SABRY R. C., ROSA R. D., MAGALHÃES A. R. M., 2009
First report of *Perkinsus* sp. infecting mangrove oysters *Crassostrea rhizophorae* from the Brazilian coast. *Diseases of Aquatic Organisms*, 88 (1): 13-23.

SABRY R. C., GESTEIRA T. C. V., MAGALHÃES A. R. M., BARRACCO M. A., GUERTLER C., FERREIRA L. P., VIANNA R. T., DA SILVA P. M., 2013
Parasitological survey of mangrove oyster, *Crassostrea rhizophorae*, in the Pacoti river estuary, Ceará state, Brazil. *Journal of Invertebrate Pathology*, 112 (1): 24-32.

SANCHEZ-JEREZ P., KARAKASSIS I., MASSA F., FEZZARDI D., AGUILAR-MANJARREZ J., SOTO D., CHAPELA R., AVILA P., RIVERO J. C., TOMASSETTI P., MARINO G., BORG J. A., FRANICEVIC V., YUCEL-GIER G., FLEMING I., BIAO X., NHHALA H., HAMZA H. A., FORCADA A., DEMPSTER T., 2016
Aquaculture's struggle for space: the need for coastal spatial planning and the potential benefits of allocated zones for aquaculture (AZAs) to avoid conflict and promote sustainability. *Aquaculture Environment Interactions*, 8: 41-54.

SANTOS C. F., MICHEL J., NEVES M., JANEIRO J., ANDRADE F., ORBACH M., 2013
Marine spatial planning and oil spill risk analysis: finding common grounds. *Marine Pollution Bulletin*, 74 (1): 73-81.

SANTOS C. F., DOMINGOS T., FERREIRA M. A., ORBACH M., ANDRADE F., 2014
How sustainable is sustainable marine spatial planning? Part II. The Portuguese experience. *Marine Policy*, 49: 48-58.

SAPEA, 2017
Food from the oceans: how can more food and biomass be obtained from the oceans in a way that does not deprive future generations of their benefits? Berlin, Brussels, Science Advice for Policy by European Academies

SARGENT J. R., TACON A. G., 1999
Development of farmed fish: a nutritionally necessary alternative to meat. *The Proceedings of the Nutrition Society*, 58 (2): 377-383.

SCARDUA M. P., VIANNA R. T., DUARTE S. S., FARIAS N. D., DIAS CORREIA M. L., ARAÚJO DOS SANTOS H. T., DA SILVA P. M., 2017
Growth, mortality and susceptibility of oyster *Crassostrea* spp. to *Perkinsus* spp. infection during on growing in northeast Brazil. *Revista Brasileira de Parasitologia Veterinária*, 26 (4): 401-410.

SEGARRA A., PÉPIN J. F., ARZUL I., MORGA B., FAURY N., RENAULT T., 2010
Detection and description of a particular Ostreid herpesvirus 1 genotype associated with massive mortality outbreaks of Pacific oysters, *Crassostrea gigas*, in France in 2008. *Virus Research*, 153: 92-99.

SHUMWAY S. E., DAVIS C., DOWNEY R., KARNEY R., KRAEUTER J., PARSONS J., RHEAULT R., WIKFORS G., 2003
Shellfish aquaculture in praise of sustainable economies and environments. *World Aquaculture*, 34 (4): 8-10.

SMAAL A. C., FERREIRA J. G., GRANT J., PETERSEN J. K., STRAND Ø., 2019
Goods and Services of Marine Bivalves. Berlin, *Springer Nature*. 591 p.

SMAAL A. C., VAN DUREN L. A., 2019
"Bivalve aquaculture carrying capacity: concepts and assessment tools". In Smaal A. C., Ferreira J. G., Grant J., Petersen J. K., Strand Ø. (eds): *Goods and Services of Marine Bivalves.* Berlin, *Springer Nature*: 451-483.

TRAVERS M.-A., BOETTCHER MILLER K., ROQUE A., FRIEDMAN C. S., 2015
Bacterial diseases in marine bivalves. *Journal of Invertebrate Pathology,* 131: 11-31. https://doi.org/10.1016/j.jip.2015.07.010

WAKAMATSU T., 1973
A ostra de Cananéia e seu cultivo. São Paulo, SP, Sudelpa. 141 p.

WEEKS P., 1992
Fish and people: aquaculture and the social sciences. *Society & Natural Resources*, 5 (4): 345-357.

WIJSMAN J. W. M., TROOST K., FANG J., RONCARATI A., 2019
"Global production of marine bivalves. Trends and challenges". In Smaal A. C. *et al.* (eds): *Goods and Services of Marine Bivalves*. Springer, Cham: 7-26.

ZANNELLA C., MOSCA F., MARIANI F., FRANCI G., FOLLIERO V., GALDIERO M., TISCAR P. G., GALDIERO M., 2017
Microbial diseases of bivalve mollusks: infections, immunology and antimicrobial defense. *Marine Drugs,* 15: 182. https://doi.org/10.3390/md15060182.

ZHU C., SOUTHGATE P. C., LI T., 2019
"Production of Pearls". In Smaal, A. C. *et al.* (eds): *Goods and Services of Marine Bivalves*, Berlin, Springer Nature: 73-93.

NOTES

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

---

AUTHORS

PHILIPPE SOUDANT

Marine biologist, LEMAR, CNRS, France

HILDE TOONEN

Political scientist, Wageningen University & Research, The Netherlands

PATRICIA MIRELLA DA SILVA

Marine ecologist, Federal University of Paraíba, Brazil

RUI TROMBETA

Marine ecologist, University of Brasília, Brazil

ODELINE BILLANT

Legal expert in environmental law, LEMAR, University of Western Brittany (UBO), France

NELLY LE GOÏC

Marine ecologist, LEMAR, CNRS, France

ADELINE BIDAULT

Marine ecologist, Laboratory of Marine Environmental Sciences (LEMAR), National Centre for Scientific Research (CNRS), France

CHRISTOPHE LAMBERT

Marine ecologist, LEMAR, CNRS, France

AURÉLIE CHAMBOUVET

Marine ecologist, LEMAR, CNRS, France

FERNANDO QUEIROGA-RAMOS

Marine ecologist, Federal University of Paraíba, Brazil

ANDREI FÉLIX MENDES

Marine ecologist, Federal University of Paraíba, Brazil

MARIE BONNIN

Legal expert in environmental law, LEMAR, IRD, France

HÉLÈNE HÉGARET

Marine biologist, LEMAR, CNRS, France

Edited by
M. Bonnin, S. Lanco Bertrand

Marine spatial planning in the tropical Atlantic

From a Tower of Babel to collective intelligence

IRD Éditions

Marine spatial planning in the tropical Atlantic

From a Tower of Babel to collective intelligence

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
Fisherman at Tamandare, Brasil (2019) | Paddle RISE
Cover credits
© UBO/Sébastien Hervé