WORKSHOP ON THE BAY OF BISCAY AND IBERIAN COAST ECOREGION AQUACULTURE OVERVIEW (WKBoBICAO)

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i Executive summary

The Workshop on Bay of Biscay and Iberian Coast Aquaculture Overview (WKBoBICAO) was established to assemble and synthesize aquaculture related data and information and to inform the aquaculture overview for this ecoregion.

The geographic extent of the Bay of Biscay and Iberian Coast ecoregion is extensive and ranges from southern Brittany in France through northern and northwestern Spain, it includes the entire coastline of Portugal (mainland) and culminates in the Gulf of Cadiz in southern Spain. It covers a wide range of habitat types and climatic conditions, which has a bearing on the types of aquaculture practiced in the ecoregion.

Aquaculture is practised throughout much of the ecoregion. Both intertidal and subtidal waters are utilized in addition to terrestrial pond culture. The aquaculture production within the ecoregion is dominated by shellfish which are largely produced in France (Oysters and Mussels) and Spain (mussels). Portugal production comprises a mix of shellfish, finfish and crustacean culture and while lower in terms of tonnage produced and value than the other countries.

In 2021, the aquaculture sector in the ecoregion reached 310 000 Tons produced and €775 million in value. Shellfish are the most produced in the ecoregion and contribute to almost 75% of total value. Crustacean production in Spain and shellfish and finfish production in Portugal show a clear increase since 2010, other species are static in terms of production. Spain produces the greatest tonnage but is second to France in terms of economic value. A number of other species (e.g. finfish, polychaete worms for bait) in addition macroalgae are also grown at smaller scales throughout the ecoregion.

In the ecoregion, aquaculture licencing, regulation and policy are the responsibility of the member state. While overarching policy is defined at the EU level, licencing can be different in the various countries. In Portugal a single federal body is responsible for licensing. In Spain and France, regional or local authorities are responsible for issuing licences and national approvals from relevant Ministries must be sought if public waters are to be used. It is however, acknowledged that EU legislation provides an overarching framework for important regulatory aspects including assessment and monitoring, among others, of environmental (e.g. EIA), food safety and fish health considerations. However, during licencing consultation submissions from other authorities are often required in addition to challenges presented under other legislation (e.g. Natura), which can add to the complexity of the process and lead to delays in the decision-making. Marine Spatial planning, whereby specific areas are designated for aquaculture practices, has been identified as mechanism to reduce delay of licensing decisions. Yet, conflicts with other newly developing sectors (e.g. offshore renewables) is inevitable.

Monitoring of shellfish culture practices are primarily focused upon food safety considerations, e.g. biotoxin and faecal coliform analysis. In addition, all species are subject to extensive animal health regulations that are wide ranging and derives primarily from EU legislation. Some persistent issues relate to ongoing bacterial (Vibrio) infections in shellfish hatcheries and mortalities associated with pathogens (e.g. OsHV-1) during grow-out. These represent a major challenge to the industry. Poor mussel recruitment in the wild is also leading to shortages of stock for on-growing.

Given the dominance of shellfish culture in the ecoregion, the primary environmental effects relate to interactions with habitats and species which might be measured via assessing ecological carrying capacity. In addition to some emerging contaminants that might affect aquaculture

species, aquaculture as a source of microplastics is an increasing cause of concern. The ability of shellfish to bioaccumulate nano-plastics is also considered a risk.

Small production units predominate the aquaculture sector within the ecoregion. As identified elsewhere, employment in the sector in all countries is considered modest, however, the importance of these (even part-time) roles in more isolated rural areas is acknowledged.

In terms of social interactions given the historical and cultural importance of shellfish farming in the ecoregion the sector has greater social licence and as such there is more a tolerance and less challenge to this sector from the wider public. It is apparent that finfish enterprises face considerably more scrutiny during licensing and subsequently. All aquaculture sectors are challenged by decreasing water quality as a result of terrestrial activities.

A number of issues are identified which may affect aquaculture development and are considered common across the ecoregion. Of particular concern are the potential effects or emerging pollutants (associated with industrial development). The impact of climate change on shellfish recruitment and disease proliferation in culture stock is also a concern.

ii Expert group information

Expert group name	Workshop on the Bay of Biscay and Iberian Coast ecoregion Aquaculture Overview (WKBoBICAO)
Expert group cycle	Annual
Year cycle started	2023
Reporting year in cycle	1/1
Chairs	Myriam Callier, France
	Francis O’Beirn, Ireland
Meeting venue and dates	3-5 October 2023, Sète, France, 25 participants

1 Introduction

Lead by Francis O'Beirn and Myriam Callier

ICES work on aquaculture seeks to advance and share scientific understanding of marine ecosystems and the services they provide with respect to aquaculture, and to use this knowledge to generate advice to inform conservation, management, and sustainability goals. ICES is developing a series of aquaculture overviews, which in this instance, is focused on the Bay of Biscay and Iberian Coast (BoBIC) ecoregion. This overview attempts to:

- summarize regional and temporal information on aquaculture activities, practices, and production of the cultured taxa;
- describe the relevant policy, legal foundation and management systems;
- consider the environmental and socio-economic interactions of aquaculture activities and practices and how these interactions influence the policy and planning of aquaculture developments in various jurisdictions;
- consider future projections, emerging threats and opportunities and;
- identify gaps in information thus informing likely management actions that might be considered.

Aquaculture practices (and species cultured) within the Bay of Biscay Iberian Coast Ecoregion while varied, consist primarily of extensive shellfish production practices. The inclusion of the interaction of environmental, economic, and social drivers is an important component of this advisory product. This report attempts to provide the most recent understanding on the potential interactions of these to aid aquaculture planning. It also indicates the growing capability of the ICES expert network to address socio-economic issues. In addition, perspectives on threats and opportunities are provided in this report. For example, effects of climate change, biological or ecological threats associated with aquaculture activities, and development trends (incl. new species and production methods) are considered.

The Bay of Biscay and the Iberian Coast ecoregion covers the southwestern shelf seas and adjacent deeper eastern Atlantic Ocean waters of the EU. The oceanography in this ecoregion is characterized by marked seasonal mixing and stratification of water masses typical of temperate seas. This general pattern is modified over the shelf by wind-driven upwelling, river outflow, and tidal-related processes, increasing the productivity of the system with large variation across the region. Habitats further offshore are shaped by the influence of Atlantic waters in the Bay of Biscay and western Iberia.

The ecoregion is defined physically by four key areas extending from Southern Brittany in France to the Gulf of Cadiz in Spain (Figure 1.1): A summary of these areas within the ecoregion as transcribed from ICES (2022) are:

- the Bay of Biscay, characterized by a wide shelf extending west of France. Upwelling events occur in summer, off southern Brittany, and low-salinity water lenses are associated with the river outflows of the Landes coastline;
- the Cantabrian Sea (northern Iberian shelf), characterized by a narrow shelf north of Spain with intermittent summer upwelling events west of Cape Peñes and a winter slope undercurrent, the Iberian Poleward Current;
- the western Iberian Shelf, characterized by a narrow shelf extending west of Spain and Portugal with upwelling events in summer and the Iberian Poleward Current in winter. Off Galicia (at its northern limit) the input of freshwater from rivers and estuaries form

the Western Iberian Buoyant Plume, which is an important shaping event under downwelling-favourable winds; and
- the Gulf of Cadiz, south of Portugal and Spain, characterized by a wide shelf strongly influenced by river inputs, zonal currents, wind patterns, and the deep inflow of Mediterranean water.

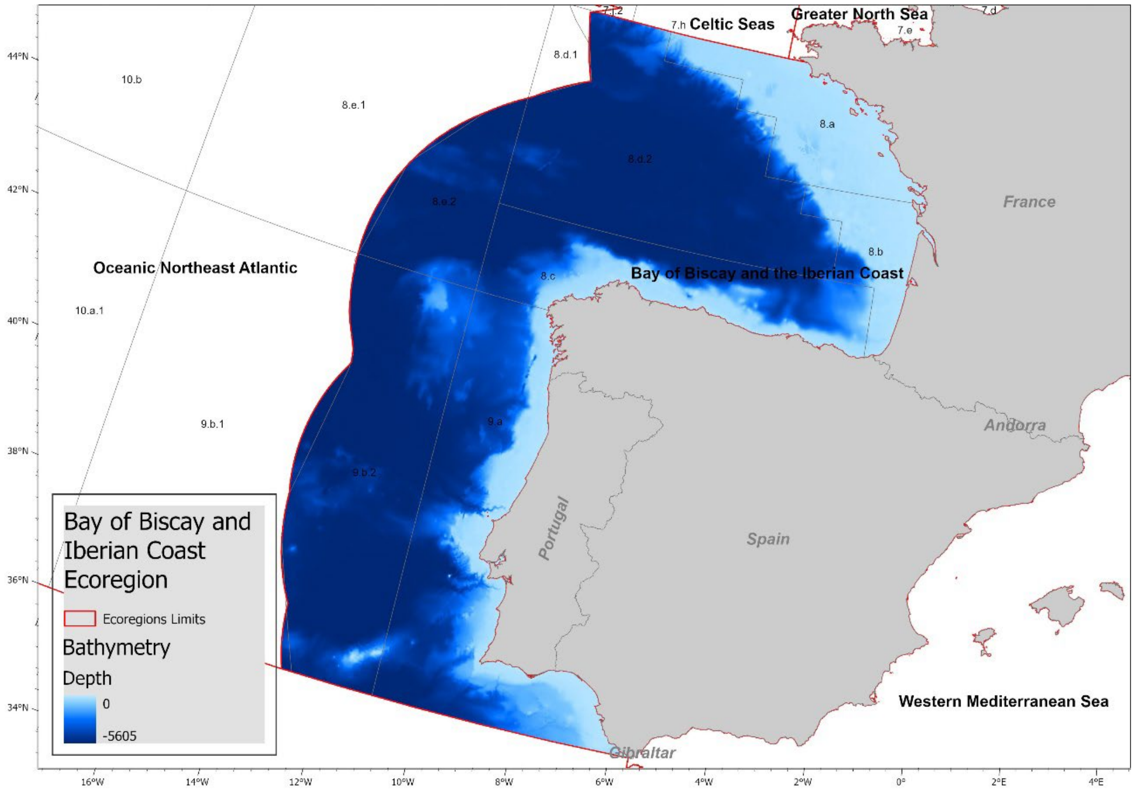

Figure 1.1 Geographic extent of Bay of Biscay Iberian Coast Ecoregion.

1.1 Physical Oceanography

The main upper layer circulation patterns within the region are characterized by central waters (of 200–700 m depth) and Labrador Sea Water (LSW) (approximately 2 000 m) flowing from the northwest, while Mediterranean Overflow Water (MOW) spread from their origin at Gibraltar. Deeper waters undergo slow cyclonic flow. In the Gulf of Cadiz, the water exchange is governed by a two-layered inverse estuarine circulation with Mediterranean Overflow Water (MOW) flowing into the Gulf under ENACW flowing into the Mediterranean Sea.

Circulation in the Bay of Biscay is complex and is driven by a combination of tidal and density driven currents with other forcing elements of wind and bathymetric profiles. Broad surface circulation currents differ between anticlockwise currents in autumn/winter and clockwise currents in spring/summer. Coastal upwelling is also an important feature and is predominantly driven by offshore winds, especially off the west coast of Galicia.

The western Iberian coast is affected by the North Atlantic Upwelling Region, which extends from the northern Iberian Peninsula at 43N to the south of Senegal at approximately 10N (Relvas *et al.*, 2007). These large current systems are characterized off-shore by slow broad equatorward gyre recirculation and a predominant equatorward wind direction during a substantial part of the year (Relvas *et al.*, 2007). These equatorward winds result in offshore Ekman transport in the upper layer resulting in transport of cold and nutrient rich upwelled water.

The complex nature of windforcing, and subsequent upwelling events has the net effect of delivering nutrient rich deeper waters to more inshore shallower areas throughout the ecoregion at different times of the year. This combined with run-off from land is considered favoured for phytoplankton and hence will support extensive aquaculture systems, i.e. shellfish, throughout the ecoregion. The sheltered nature of the coastal rias along the Iberian Coast and the large intertidal flay along estuarine areas along the Bay of Biscay further support large-scale suspended mussel and trestles culture of oysters, respectively.

1.2 Habitats

While sand and muddy-sand areas dominate in the Bay of Biscay, the Cantabrian Sea and Galician shelf are covered by fine sediments with isolated rocky regions in the coastal- and inner-shelf areas, and by sand and mud in the mid- and outer-shelf. The western Iberian Shelf is characterized by sand-size sediments, with fine sediments forming significant mud bodies on the mid-shelf off the main rivers. In the Gulf of Cadiz, the inner shelf is covered by a sandy sediment belt with local gravels and rocky outcrops, and muddy patches in the proximity of the most important river mouths that also cover most of the mid- to outer shelf. The Gulf of Cadiz continental slope is dominated by muddy and sand sediments, depending on the intensity of the current above the seabed. The predominance of sedimentary habitats throughout the ecoregion, suggests a broad suitability in terms of exposure (i.e. wind and wave action) for the location of aquaculture structures, both suspended and intertidal forms. This is particularly relevant in nearshore environments.

1.3 Conservation Areas

Numerous areas throughout the ecoregion are designated under the EU Natura 2000 directives, i.e. the Habitats and Birds Directives (Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora; and Directive 2009/147/EC of 30 November 2009 on the conservation of wild birds), recorded in the respective Natura 2000 (N2K) databases. As of 2022, the ecoregion has a total of 206 Natura 2000 sites which represent 16.5% of EU waters (i.e. 132 737 km^2 of 803 327 km^2)[1] (Figure 1.2). Of note, 61% of nearshore areas (0–1 nm) within the ecoregion are designated under the Natura 2000 network (EEA, 2015). This is of particular relevance, given that the majority of aquaculture operations occur in nearshore or inshore areas. The qualifying features covered in the sites are extensive and cover a very broad range of habitats and species. Of note, within the Natura 2000 site there are a range of features likely to interact with aquaculture practices directly. Such QIs demonstrated to interact with aquaculture are any number of shorebird species, pinnepeds as well as and intertidal and subtidal sedimentary and reef habitats and the sensitive community types found therein, among others. This will have implications for the location and assessment of licensing applications. It is incumbent on licencing authorities to consider if any proposed aquaculture activity is likely to result in a significant effect on the conservation features.

[1] EEA geospatial data catalogue (europa.eu)

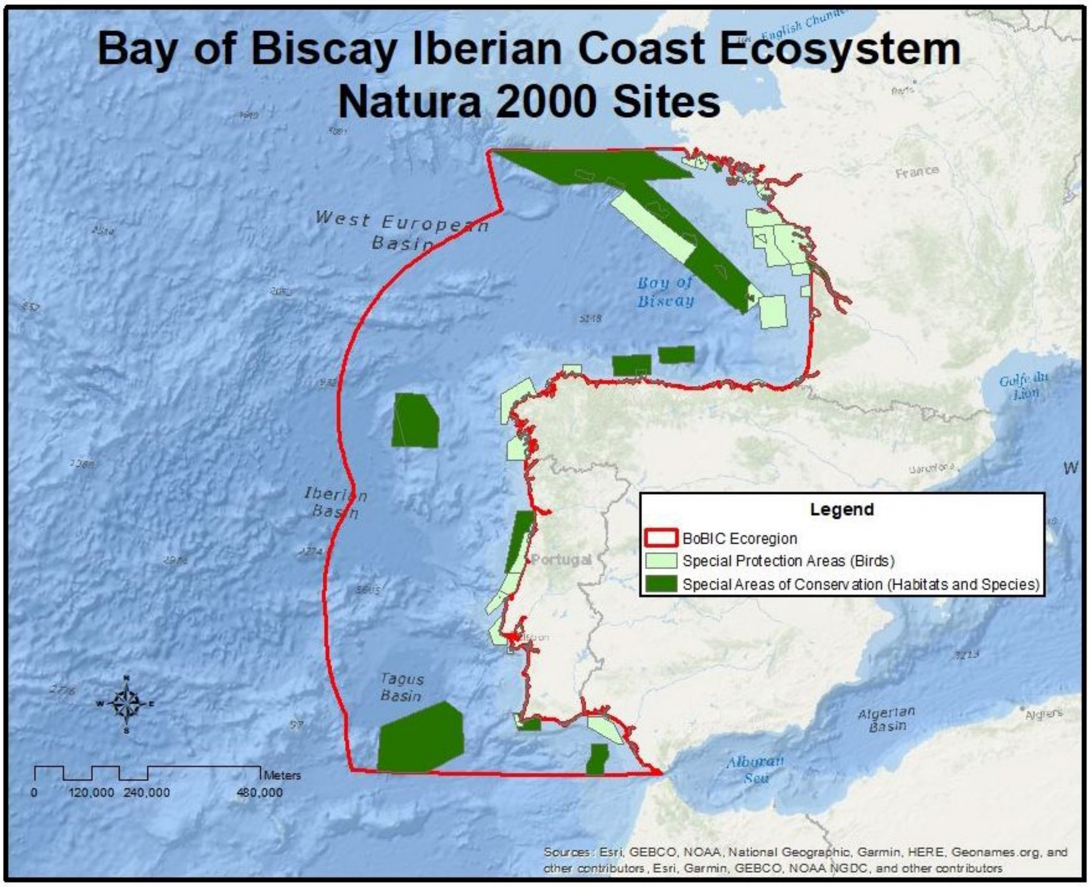

Figure 1.2. Natura 2000 sites in Bay of Biscay Iberian Coast Ecosystem. Source: EMODnet Map Viewer (europa.eu).

2 Description and location of marine aquaculture activities and practices

Lead by Montse Pérez and Laura Ribeiro

2.1 Introduction

Aquaculture operations are primarily carried out in intertidal or nearshore environments with some operations located at terrestrial sites.

Algae, shellfish and finfish species are produced using extensive, semi-intensive and intensive production systems. Extensive systems are characterized by minimal inputs and relatively low yields, very close to those of natural fisheries (Ottinger *et al.*, 2016). For extensive fish farming, oligotrophic lagoons are seeded with nutrients to activate the production of phytoplankton. They can be very productive, such as mussels in the Galician estuaries. These systems take advantage of favourable natural conditions. Good examples are marine filter-feeding organisms (oysters, clams, mussels) and marine macroalgae in Galician Rias (Spain) or bass and gilthead sea bream in Seville, Spain.

Semi-intensive rearing systems are more controlled and more productive than the extensive ones. The organisms are obtained from hatcheries, artificial feeds are used to complement natural food, and human interference occurs during growing to improve productivity.

Intensive aquaculture is carried out in facilities separated from the natural environment (tanks or pools) includes fish cages, land-based in flow-through or recirculating aquaculture systems (RAS). There is total control of the environment and of the individuals and relies on aquaculture feeds and other inputs (energy, oxygen) (Ottinger *et al.*, 2016). Turbot or sole, for example, are produced in intensive systems.

2.2 Species and Cultivation method description (Ecoregion level)

2.2.1 Shellfish: trestles, bottom, bouchot, bateas and longlines

Several species of shellfish (bivalves) are cultivated within the ecoregion. The main groups of bivalves produced are mussels (*Mytilus galloprovincialis* and *Mytilus edulis*), oysters (Pacific oyster (*Magallana gigas*) and native flat oyster (*Ostrea edulis*), clams (Manila clam *Ruditapes philippinarum)*. Other species cultured are Grooved carpet shell *(Ruditapes decussatus)* and Pullet carpet shell *(Venerupis corrugata*) and other species, such as cockles (*Cerastoderma edule*), queen scallops (*Aequipecten opercularis*), variegated scallops (*Mimachlamys varia*) and king scallops (*Pecten maximus*). The production systems used include trestles, on-bottom culture, bouchot, bateas (rafts) and longlines.

The seed necessary to maintain molluscan shellfish aquaculture is obtained either from hatcheries or from natural seed collection. For instance, shellfish hatcheries are the primary seed source for oyster and clam culture. The hatcheries are on land typically located adjacent to marine areas to access seawater and remain close to nursery and grow-out sites. In Portugal, clams and cockles are obtained from natural recruitment; just recently a hatchery for pullet carpet shell started its activity. Cockles and species of scallops rely on the collection of juveniles from the wild for its culture.

Shellfish trestles

The primary culture system used for oysters and clams are plastic mesh bags secured to trestles (tray-like structures), which allow water flow above and below the bivalves (Figure 2.1). Mesh size varies depending on the size of the oyster and clams in culture. Oyster trestles vary in height and are usually arranged in paired rows that are oriented perpendicular to the tideline. They can be accessed directly from land using vehicles or by sea in small boats (Figure 2.2). The type of location is typically shallow shelving intertidal shorelines with good access and mixed substratum in relatively low energy environments. This system is not very commonly used in Spain, but there are two licences for oyster culture in trestles in Asturias (Spain). This system is very common in Portugal for oysters (Cyanopica, 2017).

Figure 2.1 Pointe-er-Vil-Locmariaquer (©Ifremer R. Gabellec).

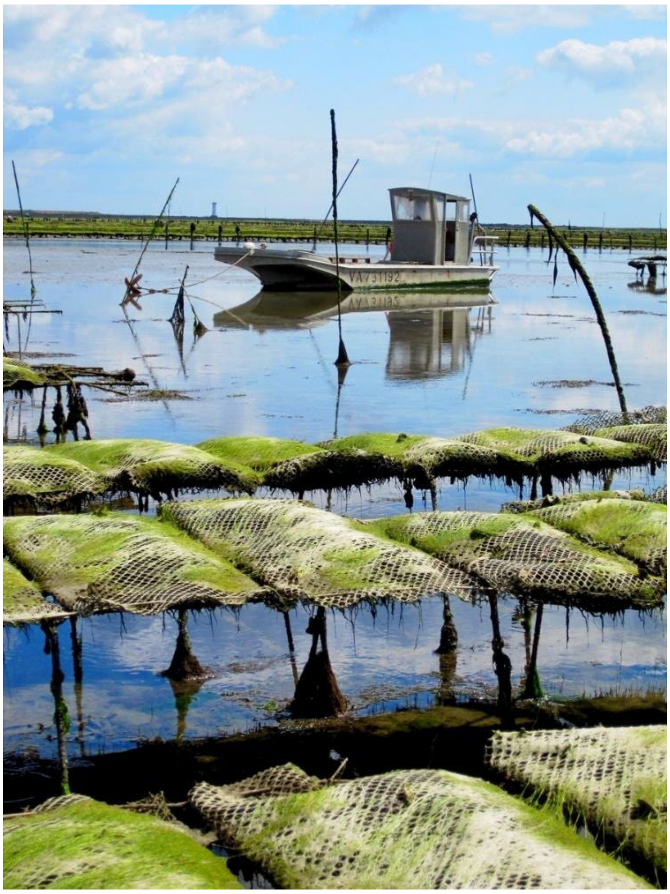

Figure 2.2 Poches-riviere-Penerf-Morbihan (©Ifremer F.Gaussem).

Bottom culture or Onshore tidal farming

Bottom (or on-bottom) culture is normally located in intertidal areas, lagoons or estuaries. Usually, bivalves are directly seeded onto the seabed in defined licensed areas, i.e. culture parks. The use of larger individuals at seeding greatly improves survival, therefore an intermediate on-growing period is usually adopted using suspended culture in lantern nets or trays in rafts or in bags in trestles from 2–3 mm seed to reach a final size of 10–12 mm. Production volume and quality are strongly related to culture location. Therefore, selection for bottom culture areas must consider sea level, adequate water circulation, food availability, unpolluted areas, among others. Although several bivalve species are cultured on bottom culture the more common are clams and cockles. Substratum in cultivation parks should be conditioned before prior to planting the seed to facilitate clam burial and to remove predators (crabs and sea stars). Juvenile clams are usually planted at a size of 10–12 mm and they reach commercial size after 14–18 months (Joaquim *et al.,* 2023; Guerra-Díaz, 2013).

Figure 2.3 Culture parks in Carril, Galicia, Spain (F. da Costa).

Bouchot

The bouchot method of mussel culture is employed on intertidal habitats, primarily in France (Aubin *et al*., 2018). Seed mussels are collected in lower intertidal areas on (natural fibre) ropes suspended between stakes (Figure 2.4). These remain *in situ* for approximately 2 months for the mussels to attain a certain acceptable size. Upon removal from the settlement areas the seeded ropes are moved to areas where poles (bouchot) are driven into the intertidal substratum. The ropes are coiled around the poles and tended as they grow to harvest size. The sites are accessed via vehicles or boats. Approximately 80% of mussel production in France is via the bouchot method.

Figure 2.4 Bouchot poles with mussels, Le-Marescle-Penestin (Ifremer R. Gabellec).

Bateas

Bateas (also called rafts) are floating structures for the cultivation of bivalve molluscs, mainly mussels that were designed in Galicia (Spain). This traditional farming system is a floating nursery consisting of a eucalyptus wood lattice of roughly rectangular shape on which the strings are attached mussel and remains suspended by a system of floats.

The culture process is divided into four stages: obtaining the seed, growing the seed, thinning out the ropes and transferring the seed onto new ropes and final harvesting and sale. These operations differ from one estuary to another and from one area of the estuary to another (Pérez-Camacho *et al.,* 1991; Figueras and Cáceres-Martínez, 2007).

Seed can be obtained directly from the coastal rocks or from collectors over the rafts, or both. The seeds are tied to ropes that will be threshed two or three times before they reach marketable size. Collectors are placed in spring and the mussel seed ropes are placed in the sea throughout the whole year, but specially from November to March. The thinning out process is usually carried out between June and October (Pérez-Camacho *et al.,* 1991).

The molluscs are arranged on cultivation ropes hanging from a floating structure. This type of platform works very well, and it is highly productive in sheltered waters, as is the case in the Galician estuaries (Rías). The system is also used for growing oysters, clams or scallops in suspended culture in lantern nets, oyster baskets and cemented oysters in ropes.

Figure 2.5. Bateas with mussels in the Ría de Vigo, Galicia (M. Pérez).

Figure 2.6. Batea. mussel production in the Ría de Pontevedra, Galicia, Spain (M. Pérez).

Longlines and suspended longlines

Longlines are non-rigid structures consisting of a headrope, arranged between buoys in a linear fashion on the sea surface, from which the cultivation ropes (droppers) hang. This system is suitable for open water, as is the case for experimental mussel farming in the Basque Country (Bilbao *et al.,* 2020). Suspended mussel culture relies heavily on settlement of larvae from the water column, normally in the culture bays.

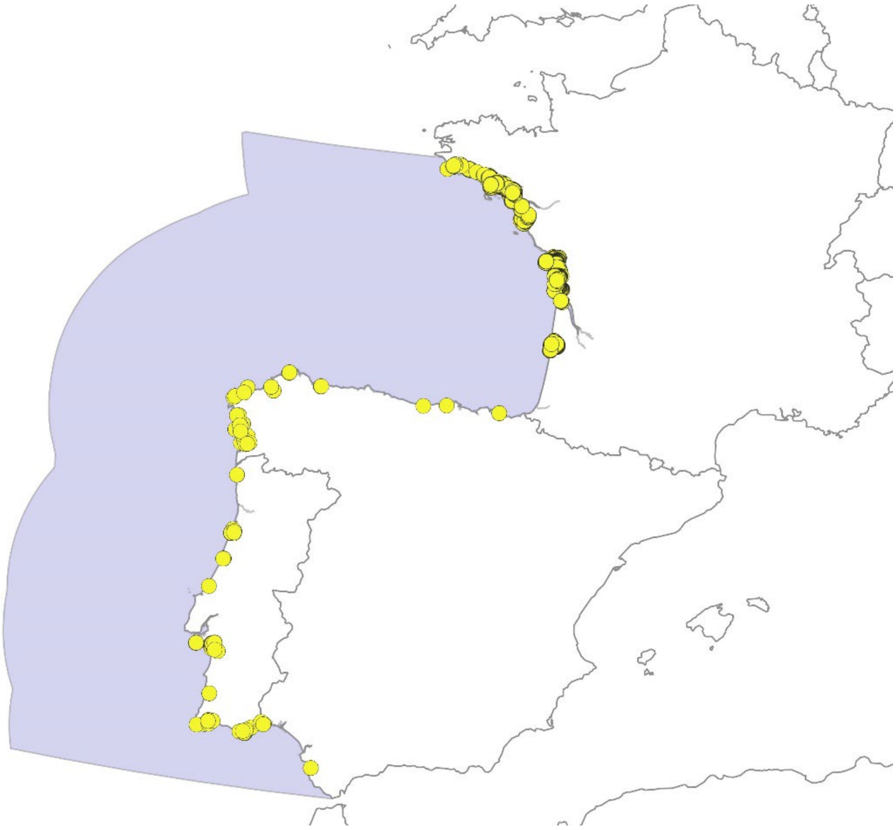

Figure 2.7 Location of shellfish aquaculture sites in the Bay of Biscay and the Iberian Coast ecoregion.

2.2.2 Finfish: land-based facilities, sea cages, earthen ponds

A large number of finfish species are produced in the ecoregion. There is production of turbot (*Scophthalmus maximus*), gilthead sea bream (*Sparus aurata*), sea bass (*Dicentrachus labrax*), Senegalese sole (*Solea senegalensis*), European sole (*Solea solea*), Atlantic bluefin tuna (*Thunnus thynnus*), blackspot sea bream (*Pagellus bogaraveo*), pollack (*Pollachius pollachius*), European eel (*Anguilla anguilla*), meagre (*Argyrosomus regius*), spotted sea bass (*Dicentrarchus punctatus*), white sea bream (*Diplodus sargus*), mullet (*Mugil spp.*), greater amberjack (*Seriola dumerili*), big-scale sand smelt (*Atherina boyeri*) and different Sparidae species (e.g. *Diplodus spp.*, *Pagrus pagrus*). These fish species are cultured using a range of production systems (APROMAR, 2023; EP, 2023).

Species	Scientific name	Type	Hatchery/ nursing	Fattening	Cycle time*	Production 2021
Seabass	*Dicentrarchus labrax*	Marine, intertidal	Tanks, open systems or RAS	Floating nurseries or estuaries	18-24 months	23.924 t
Seabream	*Sparus aurata*	Marine, intertidal	Tanks, open systems or RAS	Floating nurseries or estuaries	16-24 months	9.632 t
Meagre	*Arygorosomus regius*	Marine, intertidal	Tanks, open systems or RAS	Floating nurseries or estuaries	20-24 months	5.981 t
Turbot	*Psetta maxima*	Marine	Tanks, open systems or RAS	Tanks, open systems or RAS	18-20 months	7.629 t
Sole	*Solea senegalensis*	Marine	Tanks, closed systems or RAS	Tanks, closed systems or RAS	18-20 months	1.020 t
Tuna	*Thunnus thynnus*	Marine	-	Floating nurseries	< 12 months	10.062 t
Amberjack	*Seriola dumerili*	Marine	Tanks, open systems or RAS	Floating nurseries	-	123 t
Rainbow trout	*Oncorhynchus mykiss*	Inland	Tanks, open systems or RAS	Tanks, open systems or semi-RAS	12-24 months	15.537 t
Sturgeon	*Acipenser naccarii, A. baerii*	Inland	Tanks, open systems or RAS	Tanks, open systems or semi-RAS	3-9 years	131 t
Eel	*Anguilla anguilla*	Inland	Tanks, open systems or RAS	Tanks, open systems or RAS	~24 months	320 t

Figure 2.8. Summary of the different species of Spanish aquaculture, indicating the type and systems production, and the duration of the cycle (APROMAR 2023b).

Land-based facilities

Some finfish species are produced under intensive production methods in land-based facilities that include hatcheries for larval culture, nurseries and for some species, such as turbot and sole, individuals are grown in tanks until they reach commercial size. Most of the facilities operate using a flow through water circulation system, but there is a trend to adapt the production to Recirculating Aquaculture Systems (RAS). In France, one of the largest hatcheries is located in the BoBIC region and it uses the RAS system to produce sea bream, sea bass, meagre and shrimp juveniles (80–90 millions of fingerlings produced in 2022). In RAS, the culture water is continuously purified and reused. They are almost completely closed circuits. RAS are designed to control the environmental aspects of production by continuously filtering, treating and reusing water, which increases operational efficiency and reduces the risks of contamination and pathogens. The purified water is saturated with oxygen and returned to the tanks. Non-degradable waste products have to be removed and evaporated water replenished. Recirculating aquaculture systems allow high stocking densities but require large amounts of energy and therefore have high production costs and waste disposal problems.

Sea cages

Sea cages are production units for intensive aquaculture of marine finfish, located either inshore or in open waters (off-coast and offshore). Marine coastal aquaculture contribution for global aquaculture increased last decade, related with the high productivity and cost-effective operations compared to on-land facilities (Chu *et al.*, 2020) and the capacity to contribute with large-scale production to comply with the increasing consumers seafood demand. Sea cages are normally divided into fixed, floating, submersible, and submerged, and selection is based on factors such as, site conditions, environmental features, culture fish species, among other factors. Environmental issues, conflict with other activities like tourism are forcing sea cage farming to move offshore to mitigate conflicts with other sea space users (Chu *et al.*, 2020, Moro *et al*., 2021). Although some environmental advantages (deeper water depth and the constant water flow) and high-quality product are envisioned by moving towards the open ocean (>3 km), it represents high economical costs (Chu *et al.*, 2020) and insufficient data exist on fish welfare. The sea cage structures commonly used in BoBIC region are floating flexible surface-based structures with high-density polyethylene collars, holding large nets (double net panels for protection against storms and predators, mitigating fish escapees), are normally located in bays or coastal areas.

In the BoBIC region there are finfish reared in sea cages. In France one finfish farm is producing with sea cages, this farm is located in the South of Brittany (Morbihan department) and produces rainbow trout (*Oncorhynchus mykiss*) in an estuary. Water depth is around 7 m with very important tides and high currents. In mainland Portugal there are sea cage fish farms on the Alentejo (Sines's harbour) and Algarve coast (APPA Fuzeta and APPA Monte Gordo) southern Atlantic coast and all of them using floating type sea cage structures. Detailed information is available for Sines's fish farm, which consists of 16 cages, each holding on average 150 000 sea bass at different development stages, with an average annual production of 500 t year-1 (Gomes *et al.*, 2020). At each sea cage site depth varied from 14 to 30 m, with water renewal forced mainly by tidal currents since the breakwater protects sea cages from strong coastal currents. The fish species produced in sea cages are gilthead sea bream (*Sparus aurata*), sea bass (*Dichentrachus labrax*) and meagre (*Argyrosomus regius*).

Until 2020 there was a company based in the Ría de Sada (Lorbé, Galicia, Spain) that produced sea bream in sea cages (Isidro de la Cal) which is no longer active. The company Viveros flotantes Pesquerías de Almadraba maintains and fattens Atlantic Bluefin Tuna in sea cages in Barbate, Cádiz (Spain).

Earthen ponds

Aquaculture in earthen ponds is common in Portugal and the south of Spain. Usually, these facilities are old salt pans converted for aquaculture activity (Ramalho and Dinis, 2011). These rearing structures are normally located in coastal lands or wetlands of estuarine areas, that are often protected natural areas. The shape and size of the ponds is variable, the sloped bottom, forces water circulation towards an outlet, where water levels are controlled by a monk gate.

The regime of production can be extensive or semi-intensive, with rearing densities around 0.5–1 kg/m^2 or 2-4 kg/m^2 respectively (Ramalho and Dinis, 2011). It can be a monoculture or polyculture of different fish species. For extensive production fish larvae and/or juveniles are naturally recruited, whereas for semi-intensive and intensive production fish juveniles are obtained from hatcheries. The target species are gilthead sea bream, sea bass, sole and meagre, and in extensive regimes species like mullets, eels, breams (*Diplodus spp.*), can also be present.

The Finca Veta la Palma (Puebla del Río, Sevilla, Spain) wetland has been one of the emblematic examples of extensive aquaculture production in the Atlantic coast of Spain. They produced sea bass, sea bream, mullet and shrimp in extensive and semi-extensive regimes. Since 2023 it has become the property of the Andalusian regional government, which will decide its use.

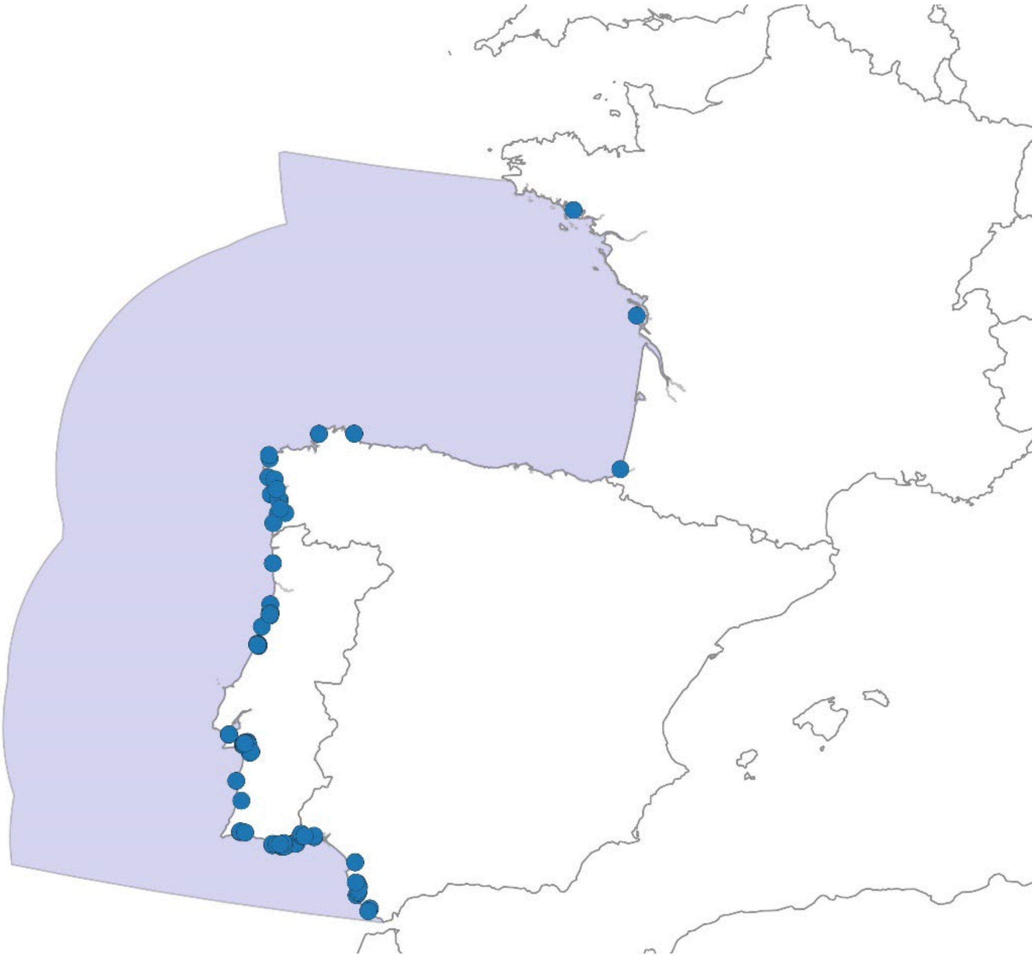

Figure 2.9 Location of finfish aquaculture sites in the Bay of Biscay and the Iberian Coast ecoregion.

2.2.3 Seaweed

Macroalgae are mainly harvested from the natural environment without greater human intervention than the removal by hand or the collection of macroalgal arrivals (arribazones in Spanish), but there are several initiatives underway for their cultivation. These seaweed cultivation initiatives produce species with high added value for direct human consumption or as a source of bioactive compounds (Matos *et al.*, 2021). The species cultivated include *Codium tomentosum*, *Codium vermilara, Gracilaria spp., Gracilaria coriacea, Gracilaropsis longissimi, Gracilaria dura, Laminaria spp., Ulva spp.*, sea lettuce (*Ulva Lactuca*), chicory sea lettuce (*Ulva rigida*), sea belt (*Saccharina latissimi*), *Palmaria palmata* and wakame (*Undaria pinnatifida*).

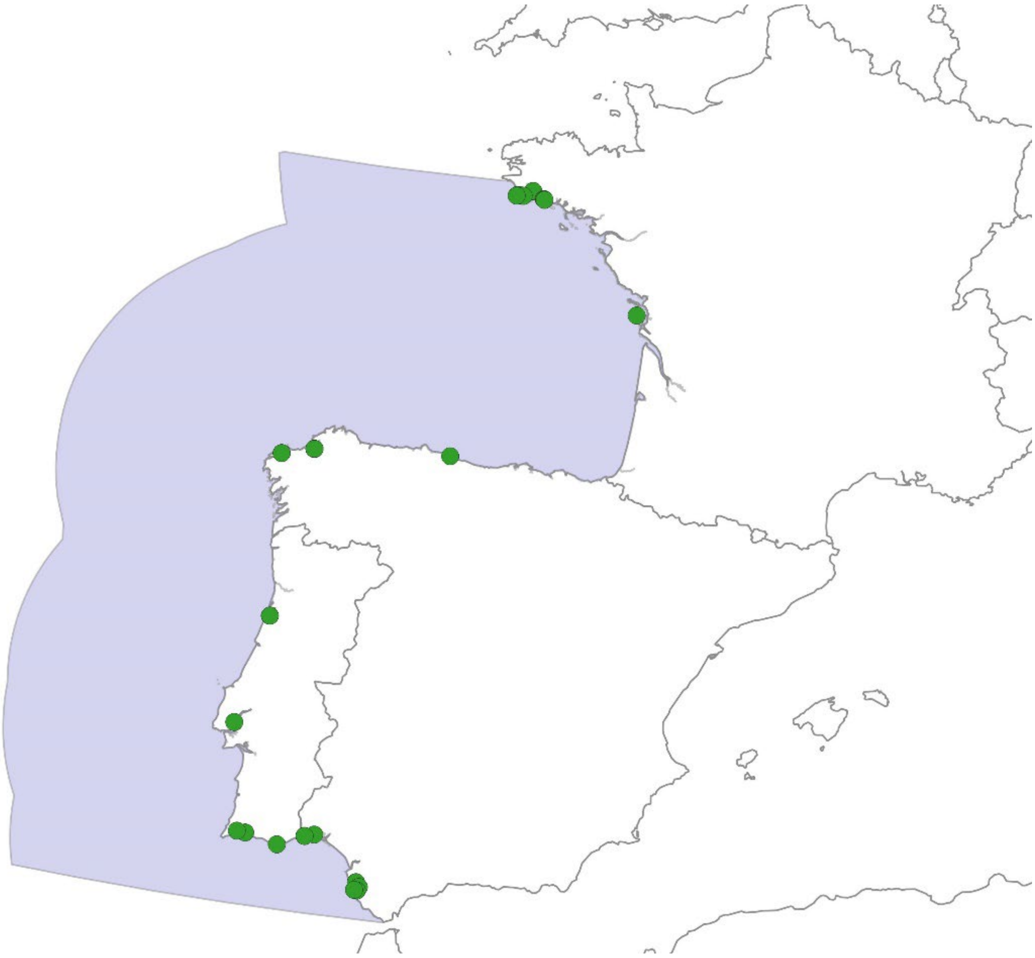

Figure 2.10 Location of aquaculture sites for seaweeds and microalgae in the Bay of Biscay and the Iberian Coast ecoregion.

In Portugal, seaweed aquaculture is currently carried out by one enterprise in Aveiro region (ALGAPLUS), producing several species of green (*Ulva rigida*, *Fucus vesiculosus*, *Codium tomentosum*), and red seaweeds (*Chondrus crispus*, *Graciliaria gracilis*, *Plamaria palmata*, *Porphyra dioica*, *Porphyra umbilicalis*), with application on food and cosmetic sectors. The whole process has organic certification, being land-based in earthen ponds, integrated with fish culture scaled to provide sufficient organic matter for seaweed production. The production of marine macroalgae is very important for achieving the objectives set for sustainable aquaculture and favouring the ecological transition due to their richness in nutrients, fibres and bioactive compounds, together with their important role in bioremediation and carbon utilization (Cardoso *et al.*, 2023). At least other two locations exist with scale-up production at experimental level.

In Portugal, wild macroalgae harvesting continues to be an important economic resource, with several companies involved in harvesting for agar extraction and other biotechnological applications.

2.2.4 Crustaceans

There is some production of crustaceans within the ecoregion. The species produced are the Atlantic ditch shrimp (*Palaemon varians*), whiteleg shrimp (*Penaeus vannamei*), Kuruma prawn (*Penaeus japonicus*), Caramote prawn (*Penaeus kerathurus*), Palaemon shrimps (*Palaemon spp.*) and common prawn (*Palaemon serratus*). The whiteleg shrimp is produced in an inland hatchery with

RAS system (Portugal) as well as *Penaeus vannamei* (France) while the rest of crustaceans are produced with semi-intensive or extensive culture methods, primarily in earthen ponds.

2.2.5 IMTA

In integrated multi-trophic aquaculture (IMTA), multiple aquatic species from different trophic levels are reared in an integrated manner. The aim of IMTA is to improve efficiency, reduce waste and provide ecosystem services, such as bioremediation. Lower trophic level species (usually plants or invertebrates) use waste products from higher trophic level species (usually fed species) as nutrients. Inorganic nutrients are used by primary producers (micro, macroalgae, or plant) and organic waste (faeces and uneaten food) are ingested by heterotrophic species such as invertebrates (Fraga-Corral *et al.,* 2021). Lower trophic level species can be harvested or used as fish food. In addition to mollusc production, extensive finfish aquaculture and IMTA are considered the most sustainable forms of aquaculture production.

Few IMTA systems are commercially effective in the BoBIC region, but many projects are underway testing IMTA pilots both in open and inland waters (see chapter 6 and chapter 9). Some examples of commercial IMTA:

In France, one marine finfish hatchery on-land uses a series of around a dozen downstream ponds to allow sedimentation of particulate waste and the culture of macroalgae that benefit from the dissolved waste. This system allows effective mitigation of the waste from the hatchery.

Also in France, many producers of pacific oysters in ponds have diversified their production by adding Japanese tiger prawns (*Penaeus japonicas*) in the ponds in summer. The prawns eat the macrobenthos in the sediment and allow the resuspension of organic matter which can benefit the oysters. The association favours oyster growth and allows the production of additional biomass, often without feeding the shrimps.

In the framework of the project "Integrated aquaculture: Pilot experience for multi-trophic aquaculture development (2008–2011)" financed by Spanish National Advisory Board for Mariculture (JACUMAR) several inland and offshore pilot experiences of integrated culture systems in six Spanish regions were carried out (Macías *et al.,* 2008). One of them developed in Galicia (Spain) was a combination of *Saccharina latissima* (sugar kelp) combined with mussel rafts as described in Freitas *et al.* (2016). In this experience the authors show that the seaweed uses ammonium from the molluscs as a nitrogen source, contributing to improving the water quality.

2.2.6 Other species

Other invertebrate species and microalgae are produced in the ecoregion.

Other invertebrate species

In Andalusia (Spain) there is one pilot scale facility commercially producing the worm *Marphysa sanguinea* for bait.

Located on the island of Noirmoutier in the Vendée (85), the Ferme Marine de Noirmoutier, with a surface area of 13 hectares, is dedicated to the breeding of marine worms (*Arenicola marina*) for a company (Hemarina) using worm blood for medicine. That is combined with the production of the green abalone (*Haliotis discus hannai*) in land-based facilities.

Common octopus (*Octopus vulgaris*) is on-grown in cages from juveniles collected in the wild, which are fed until they reach the commercial size. Currently, there are 3 active licenses in Galicia (Spain). The Nueva Pescanova group, located in Galicia, plans to start production of *O. vulgaris*. The research was conducted at the Instituto Español de Oceanografía (IEO-CSIC). In 2019, the institute reached an exclusive patent agreement with Nueva Pescanova, where research now continues at the Biomarine Center of Nueva Pescanova (O Grove, Galicia, Spain).

Microalgae

Microalgae is usually grown in photobioreactors in land-based facilities. The microalgae produced are a product in themselves, we are not talking about auxiliary aquaculture to feed other species. As an example, in A Coruña (Galicia) three species of microalgae (*Isochrysis galbana*, *Nannochloropsis gaditana* and *Tetraselmis chuii*) are produced. In the south of Portugal, there is a land-based microalgae production unit, Necton. Different species of microalgae (*Nannochloropsis*, *Tetraselmis*, *Isochrysis Phaeodactylum*, *Skeletonema*, *Porphyridium*, *Chlorella*, *Spirulina*) are produced in bioreactors for feeds, cosmetics, and food and nutraceuticals. There are other companies producing microalgae, although with smaller production volumes.

Figure 2.11 Production of microalgae in photobioreactors by Necton in the South of Portugal (Necton).

2.3 Aquaculture activities by country

2.3.1 France

The aquaculture sector in France is dominated by farming of Pacific oysters (*Magallana gigas*). In 2020, oyster production reached 86 000 tonnes (84 800 tonnes of Pacific oysters and 1 200 tonnes of flat oysters). Mussel farming is also an important activity in the French shellfish aquaculture industry: in 2020, 61 000 tonnes of mussels were produced in France (80% of mussels come from farming on bouchot, which represents a particularity of French shellfish farming). Other shellfish are produced but in much lower quantities: the production of cockles, clams and abalone was 2 000 tonnes in 2020. Some producers are turning to the farming of scallops, but this production remains underdeveloped for the moment.

While the primary species cultured in the French portion of BoBIC region is the Pacific oyster (*Magallana gigas*), the blue mussel (*Mytilus edulis*) and the cockle (*Cerasterderma* sp) are also cultured. Shellfish culture operations are concentrated primarily in estuarine areas along the Atlantic seaboard. From an administrative perspective the Atlantic seaboard within the ecoregion is split into three broad areas, Bretagne Sud (approximately n= 422 companies), Loire-Atlantique and Vendee (n=41 companies) and Nouvelle Aquitaine (Figure 2.12). Within the region, there are many more individual culture sites. In the Bretagne Sud region, there are 5729 ha licensed cites for aquaculture, 86% of which are currently exploited. The majority of shellfish hatcheries are located in the Loire-Atlantique and Vendée area. In addition, this area is where most cockle farming occurs on the seabed. Finally, the Nouvelle Aquitaine area is the leading shellfish growing region in Europe. Production consists primarily of oyster farming which is concentrated in the two large basins of Marennes-Oléron and Arcachon, to which is added the mussel farming in Charente-Maritime. As mentioned above many producers of pacific oysters in ponds (“claires”) have diversified their production by adding Japanese tiger prawns in the ponds in summer.

Commercial production of prawns using landbased biofloc technology commenced in 2022.

Marine finfish production in the French portion of the ecoregion, is confined to 3 farms:

- A sea cage farm in brackish water producing rainbow trout in the Auray River (Bretagne Sud, in the Morbihan department).
- A single hatchery in the Charente-Maritime department on Oléron Island) is the primary site for the production of fingerlings of sea bream and sea bass and for a smaller proportion of meagre and shrimp (Peneus japonicus). The hatchery produced approx. 80 million fingerlings (equiv. 200 t year-1). 80% of their production is exported to other countries. The farm is also producing macroalgae in an IMTA, where the fish farm effluents are being re-cycled to produce *Ulva sp*. in ponds (11 t year-1).
- A land-based farm producing sole (*Solea senegalis*) based in the Southwest, in the Pyrénées-Atlantiques department.

Figure 2.12 French marine shellfish concentration areas (yellow) and finfish fam sites (white) within the BoBIC ecoregion.

The DGAMPA has developed a national geoportal with the location of all aquaculture site: https://experience.arcgis.com/experience/45e186df09854fd3b0115fc2db6a27f7/page/Tableau-de-bord/.

2.3.2 Portugal

The aquaculture sector in Portugal is dominated by marine aquaculture, which represents 95% of the total production volume (17 900 tonnes in 2021, EP, 2023). Aquaculture statistics from 2021 indicates that Portuguese aquaculture continues to be mainly land-based, characterized by marine extensive and semi-intensive systems located in lagoons, estuaries, and intertidal areas along the coast, but also intensive systems. Algarve (south of Portugal) and Centre (western coast of Portugal) are the regions with higher contribution for marine aquaculture production (16 224 tonnes), respectively 55% and 27%.

The number of active productive units is slightly lower than the number of licenses. In transitional and marine waters, active units varied between 93 to 95% of the licenses granted in the last five years. Based on data collected in 2021 by DGRM, the number of active units with production in transitional and marine waters was 1 156, occupying an area of 1 955 ha (INE, 2023). The number of active units correspond mainly to on-growing units (99% of the total number of licenses). Licences for bivalves culture parks represent the larger number of active units (1 097; 95.2%) occupying an area around 565.4 ha, followed by tanks/ponds (38; 3.3%) and floating structures (17; 1.5%), respectively occupying an area of 442.6 and 863.0 ha (INE, 2023).

The Directorate-General for Natural Resources, Safety and Maritime Services (DGRM) in collaboration with the Portuguese Agency for Environment (APA -Agência Portuguesa do Ambiente) participated on the development of a geoportal with the location of the different aquaculture facilities distributed along the Portuguese coast, including some information about the facility (e.g. TAA number, name, type of production system, rearing medium, exploitation regime, species produced https://webgis.dgrm.mm.gov.pt/portal/apps/webappviewer). This work was included in the Portuguese Maritime Spatial Planning Situation Plan (PSOEM - Plano de Situação do Ordenamento do Espaço Marítimo), which included planning of space and access to water for marine aquaculture.

In Portugal, extensive rearing systems are defined, by law, as production that relies on the natural conditions available, that organisms are obtained in the wild or in hatcheries and feeding is exclusively based on ambient levels of food in the surrounding waters. In semi-intensive rearing systems organisms are obtained in hatcheries, artificial feeds are used to complement natural food, and human interference occurs during growing to improve productivity. In an intensive rearing system, organisms are obtained in hatcheries, rearing parameters are fully monitored and controlled, feeding is exclusively on artificial feeds, and high human intervention occurs.

An example (Figure 2.13) of the aquaculture facilities on the eastern part of Algarve; in the Ria Formosa lagoon (shellfish culture parks and earth ponds fish farms) and coastal aquaculture (sea cages, longlines, tuna fattening).

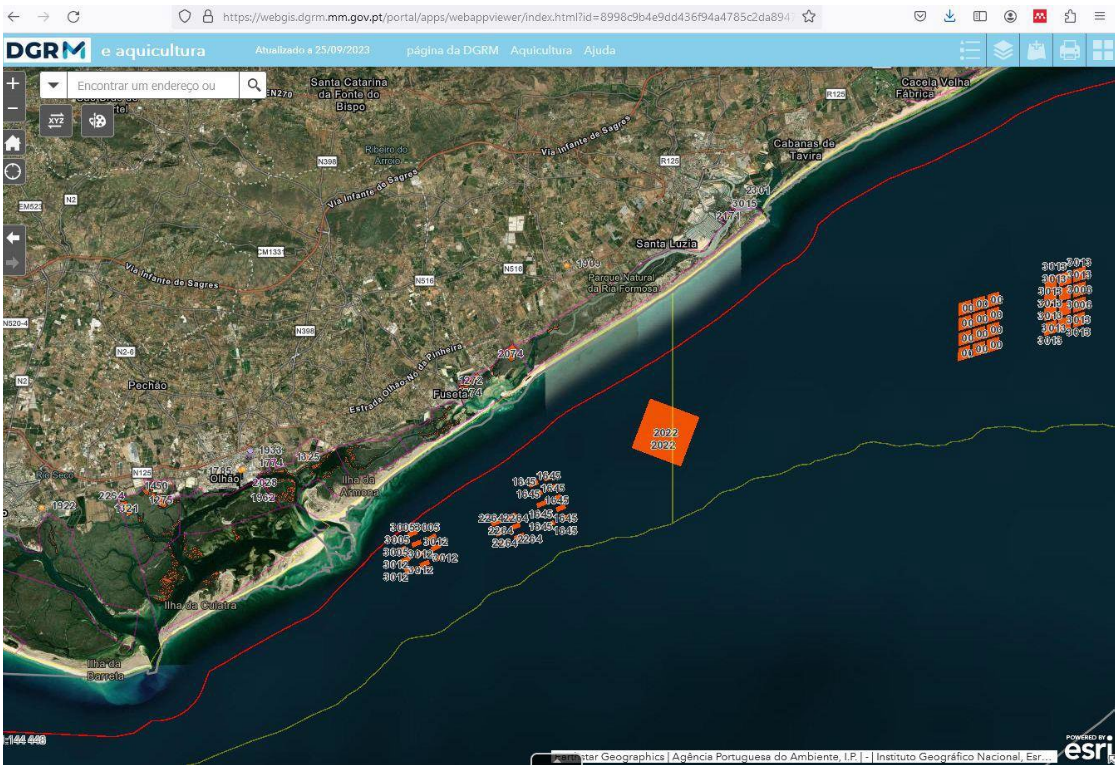

Figure 2.13 Location of aquaculture farms off coast in the eastern south of Portugal, APPA Fuzeta and APA Monte Gordo, using the Portuguese geoportal for aquaculture.

Portugal- finfish aquaculture

The structures normally used for finfish aquaculture rearing are earthen ponds, tanks, sea cages and more recently RAS.

The marine fish species more representative of aquaculture production are turbot (*Scophthalmus maximus*), gilthead sea bream (*Sparus aurata*), sea bass (*Dicentrachus labrax*) and Senegalese sole (*Solea senegalensis*). Other fish species have been produced to diversify aquaculture production, namely meagre (*Argyrosomus regius*) and a different Sparidae species (e.g. *Diplodus spp*., *Pagrus pagrus*), among others, although at small production volumes.

Turbot is produced in intensive regime in fibreglass and/or cement tanks in two fish farms land-based (western coast). Turbot production volume was 3 538.25 tonnes in 2021 (INE, 2023). Water circulation is in flow through, but future plans include adaptation to RAS.

Gilthead sea bream production volume was 3 090.70 tonnes in 2021 (INE, 2023). This fish species is produced in earthen ponds located in transition waters (wetlands, estuaries) along Portuguese under extensive and semi-intensive regime. It is also produced under intensive regime in sea cages on Atlantic western coast (Sines harbour) and south of Portugal.

Sea bass production reached a production volume of 954 tonnes in 2021, of which 67% was in semi-intensive regime in earthen ponds and the remaining in under intensive aquaculture in sea cages (Sines harbour) (INE 2023).

Senegalese sole (*Solea senegalensis*) is produced mainly in RAS in intensive regime with a production volume of 327.48 tonnes (INE, 2023). Just residual production volumes originate in semi-intensive regimes in earthen ponds.

Other species reared in Portugal are meagre (*Argyrosomus regius*) in earthen pond and sea cages, different Sparidae species (e.g. *Diplodus spp.*, *Pagrus pagrus*), mullet reared in earthen ponds, originated from natural recruitment.

In the south of Portugal there are also facilities for the fattening of Atlantic bluefin tuna (*Thunnus thynnus*). For privacy reasons tuna production is not reported since the number of tuna farms is inferior to three.

Portugal – Shellfish Aquaculture

The main shellfish species cultured in Portugal are clams (grooved carpet shell, *Ruditapes decussata*; pullet carpet shell, *Venerupis corrugata*), cockles (*Cerastoderma edule*), oysters (*Magallana gigas, Crassostrea angulata, Ostrea edulis*) and mussels (*Mytilus spp.*). Grooved carpet shell is cultivated in the sediment in culture parks, under extensive regime, in the intertidal areas (e.g. estuaries, lagoons) along the Portuguese coast. Pullet carpet shell is produced in suspended ropes off coast of Algarve. The production volume in 2021 was 3 584.7 tonnes (INE, 2023).

Figure 2.14 Culture park for clam (grooved carpet shell *Ruditapes decussatus*) in Ria Formosa lagoon (south of Portugal). (IPMA, D.Matias).

Figure 2.15 Lantern structure for pullet carpet shell (*Venerupis corrugata*) off coast Algarve (south of Portugal). (Oceano Fresco).

Oysters are produced in tables, rack or trestle in intertidal areas of estuaries and lagoons along Portuguese coast. The production volume in 2021 was 2 293.4 tonnes (INE, 2023).

Figure 2.16 Structures used for oyster production in the south of Portugal: A) Baskets and B) Table (IPMA, D. Matias).

Mussels production volume reached 3 044.1 tonnes in 2021 (INE, 2023). This species is mainly reared in longlines off coast of Algarve.

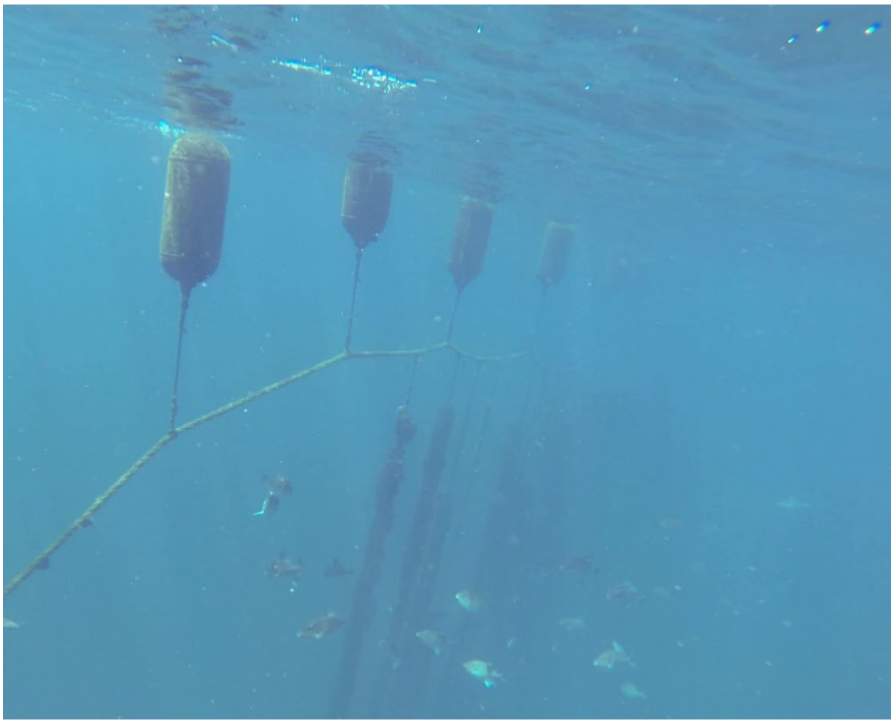

Figure 2.17 Mussels rearing in longlines off coast of Algarve (Sagresmarisco).

2.3.3 Spain

Spain has almost 8 000 km of coastline. The Bay of Biscay and the Iberian Coast Ecoregion comprises 2 723 km of coastline with a diversity of climates due to a particular orography, making it an ideal place for the development of marine aquaculture. The Spanish ecoregion covers five regions (Galicia, Asturias, Cantabria, Basque Country and the Atlantic side of Andalusia). Therefore, the scope of the ecoregion and the administrative boundaries do not match, requiring data analysis to disaggregate the information at ecoregion level.

Aquaculture in Spain is highly diverse. Marine aquaculture exists on all Spanish coasts, including offshore cages (for sea bass, sea bream and meagre), rafts (bateas) and longlines (for mussels and oysters), land-based tanks (for turbot and sole), and onshore intertidal farming (for clams, oysters and other bivalves).

The primary species produced by aquaculture in Spanish marine waters are sea bream, sea bass, turbot, meagre, sole, bluefin tuna, mussels, clams, oysters and abalone. Other aquaculture species of interest include European eel, blackspot sea bream, greater amberjack, shrimp, microalgae and macroalgae are also mentioned in this report.

The main species produced by aquaculture in Spain is mussel, with a production in the ecoregion of 219 703 t in 2022. The marine fish species produced in aquaculture in the ecoregion are turbot, sea bass and sea bream. For marine fish farming in Spain, Galicia ranked third in 2022, with a total production of 9 627 t, equivalent to an increase of 16% compared to 2021 (8 273 t). This increase was mainly due to the production of turbot. Depending on the species there are various types of aquaculture facilities.

Data of aquaculture licensed sites correspond to registered data by the end of 2022 and it was extracted from Acuivisor, a GIS tool created by the Spanish Ministry of Agriculture, Fisheries and Food affairs.

Shellfish aquaculture

While shellfish production in Spain focuses largely on mussels, oysters, clams and other species are also produced. Mussel production occurs mainly in Galicia, but some culture also takes place in the Basque Country[2]. In Galicia the cultivation method is by bateas, following a traditional system. Due to the high level of primary production in the Rías, the location of the facilities is conditioned by the licensing system rather than by the environmental considerations. Currently there are 3 435 sites licenced to produce mussels, producing on average around 200 000 tonnes per year. Ría de Arousa hosts the largest number of licensed sites in Galicia (2 290), which represents 67% of the Galician licensed sites.

The legal framework sets the maximum number of ropes (500) and length (12 m) to optimize feeding and impact. The seed, between 15 and 25 mm in size, is either extracted from the coastal rocks or through spat collector ropes suspended in the raft. Spat collection from the rocks, depending on the time of year, starts to be harvested and placed on the cultivation ropes from November onwards. The spat collector ropes are hung in the rafts between March and October and kept submerged during the mussel breeding season, allowing the larvae to settle. The recruited seed is available from July onwards for handling. In 66% of the bateas, only seed from coastal rocks are used, while the rest use a combination of spat from both sources.

For an annual mussel harvest of 250 000 t, seed requirements are estimated at around 7 000 t per year. There has been a decline in the availability of seed in recent years (Avdelas *et al.*, 2021),

[2] Facilities in Andalusia are located in the Mediterranean coast, therefore outside the ecoregion.

which has intensified the competition for accessing the rocky areas where other shellfish are also gathered (e.g. the goose barnacle *Pollicipes pollicipe*s).

In the Basque country, there are only two active licenses for longlines; but currently there is no production.

Two oyster species are cultivated in Spain: Pacific oyster (*Magallana gigas*) and native flat oyster (*Ostrea edulis)*. Production methods include mesh bags held in trestles in intertidal bays, mesh bags in trestles in *esteros* (earthen ponds) or in rafts (suspended culture) using oyster baskets or lanterns. Production is located mostly in Galicia (90% of the total 232 marine aquaculture licensed sites in the Spanish area in the ecoregion), but also in Andalusia, Asturias, Basque Country and Cantabria.

While the number of licensed sites is higher for native flat oyster (155) the production volume is higher for the Pacific oyster (see section 3). The availability of seed explains these figures. Pacific oyster seed is easier to produce in hatcheries than the flat oyster, with the main providers located in France and other European countries. Oyster seed production is almost non-existent in Spain, despite several attempts through the years to ensure continuous supply mainly through hatcheries. Hence the culture is based mainly on the import of seed and 12 to 18-month-old oysters from several European countries.

Three clam species are cultivated in Spain: Manila clam (*Ruditapes philippinarum)*, Grooved carpet shell *(Ruditapes decussatus)* and Pullet carpet shell *(Venerupis corrugata*). The number of facilities is concentrated mainly in Galicia (87.1%), followed by Andalusia (9.5%), Asturias (2.8%) and Cantabria (0.5%). Although the number of facilities is similar for the three species, Manila clam is the main species cultivated in Spain representing 82% of total clam production in 2022.

The production of clams takes place in beach or intertidal areas where the animals are placed directly on the substratum. Most of the seed required for their production in Spain come from hatcheries. Manila clam seed is sourced nationally (there are two active hatcheries in the ecoregion) and from other European hatcheries. Pullet carpet shell seed is only produced in Galician hatcheries. The hatchery production of grooved carpet shell seed is extremely complex. In fact, the seed proceeds only from natural areas where it is extracted and relocated, which explains the low production figures. Clam seed of a size around 5 mm is grown in nursery facilities (land-based facilities, in mesh bags in trestles or in suspended culture in rafts) until it reaches a size of 15–18 mm, where it can be transferred to the substratum.

As for other bivalve species, a total of 134 installations are dedicated to the production of cockles (*Cerastoderma edule*), queen scallops (*Aequipecten opercularis*), variegated scallops (*Mimachlamys varia*) and king scallops (*Pecten maximus*). More than 99% of the facilities are located in Galicia, while a single active one in the Basque Country is a licensed site for variegated scallop culture. The seed for these species is obtained from natural beds, but the statistics only report seed harvesting in wild beds for *Ruditapes decussatus* (MAPA, 2023). Cockles are produced on-bottom in intertidal areas. The scallop species are produced in suspended systems such as lantern nets in *bateas*.

Other invertebrate species

In Galicia there are two active licenses for abalone (*Haliotis tuberculata*) and three licenses for common octopus (*Octopus vulgaris*). The active licensed site is for *Haliotis tuberculata* but the recorded species in the statistics is green abalone (*Haliotis discus hannai*). Abalones are produced in hatcheries and land-based facilities until they reach commercial size. Currently in two facilities in A Coruña, Galicia. The common octopus is reared in cages and cultivation relies on the capture of juveniles, which are fed until they reach commercial size.

Andalusia has an active license for the production of the worm *Marphysa sanguinea* that is used as fishing bait.

Finfish Aquaculture

Turbot (*Scophthalmus maximus*)

The amount of wild turbot caught by the Spanish fleet is increasingly scarce and testimonial therefore, more than 99% of the production of this species in Spain now comes from aquaculture. Although imports into Spain of turbot from other European fishing fleets, mainly from the Netherlands, are significant. Galicia is the only region farming turbot with sixteen active licensed sites in 2022. In Europe, the main country producing turbot is Spain, with Portugal as the second producer. Turbot production is carried out in land-based facilities under controlled conditions nearby the coast where juvenile and adult turbots are maintained in concrete circular tanks.

Sea bass (*Dicentrarchus labrax*)

In 2022 thirty facilities were active in Andalusia for sea bass production using twenty-nine earthen ponds and one nursery. There is one active hatchery in Huelva, which supplies the nursery belonging to the same company. The rest of the juveniles come from hatcheries from elsewhere in Spain and other countries.

Sea bream (*Sparus aurata*)

In 2022, thirty-nine facilities were active in Andalusia for the production of sea bream in thirty-eight earthen ponds and one nursery: Cádiz (26); Huelva (12); and Seville (1). There are two active hatcheries in Huelva producing sea bream juveniles. Juveniles come from the active hatcheries in the ecoregion, and national and international hatcheries in the Mediterranean.

Sole (*Solea senegalensis* and *Solea solea*)

Two sole species are produced in the ecoregion: *Solea senegalensis* and *Solea solea*. Seventy percent of the sole production in 2022 was from Galicia, the remaining 30% was produced in Andalusia. There are 35 facilities, 30 in Andalusia (Cádiz (26), Huelva (3) and Seville (1). Among these, one is dedicated to common sole (Cádiz). The remaining five are located in Galicia (A Coruña (2), Lugo (2) and Pontevedra (1)). In Andalusia the production is carried out in one land-based facility (one hatchery and nursery operated in RAS) and in earthen ponds and in Galicia in land-based facilities.

Other finfish species

Atlantic bluefin tuna (*Thunnus thynnus*)

The almadrabas method catches tuna as they swim across the almadraba trap, targeting mostly bluefin tuna. Fishing boats use a series of nets to intercept tuna schools on their journey towards the Mediterranean Sea across the strait of Gibraltar, located around six nautical miles from the coast. The facility included in the Ecoregion (Cádiz, western Andalusia) captures juvenile tuna that are then reared in sea cages.

Mullet (*Mugil spp.*)

In 2022, thirty-two facilities were active in Andalusia (Cádiz (28), Huelva (2) and Seville (1) for mullet production in earthen ponds under semi-intensive culture methods.

Spotted sea bass (*Dicentrarchus punctatus*)

In 2022, nine facilities were active in Andalusia, all of them in Cadiz, for spotted sea bass production. Its production is carried out under semi-intensive culture methods in earthen ponds.

Blackspot sea bream (*Pagellus bogaraveo*)

Until 2019, black spot sea bream cultivation in Europe was only carried out in Galicia, but production ended that year. Currently, research projects are being developed on the cultivation of this species in several other Spanish regions with the aim of recovering its cultivation on an industrial scale.

Pollack (*Pollachius pollachius*)

Data from aquaculture licensed sites in Spain (Acuivisor) does not include any licensed site for this species in 2022, even if production statistics reported production between 2005 and 2009.

Greater amberjack (*Seriola dumerili*)

Aquaculture of the species *Seriola dumerili*, also called Lemonfish, is progressively being incorporated into commercial-scale aquaculture production in Spain. It is considered one of the species with the greatest potential for Spanish aquaculture. Production is incipient and has been achieved thanks to scientific research in diversification and technological development. Juveniles are produced in Andalusia. There are two licensed sites in Cadiz (Andalucía) and cultivation is carried out under semi-intensive and intensive aquaculture methods.

Wreckfish (*Polyprion americanus*)

Wreckfish farming is kept exclusively on an experimental scale, and it is considered a species of great potential. The Instituto Español de Oceanografía (IEO-CSIC) maintains a line of research on the species to solve the bottlenecks in farming. Several Spanish companies are interested in starting pre-industrial scale farming in collaboration with the IEO-CSIC.

Crustacean aquaculture

Except for the white leg shrimp (*Penaeus vannamei*), produced in an inland hatchery with a RAS system, all crustacean species are produced with semi-intensive or extensive culture methods. In 2022, there were eighteen licensed marine sites for Atlantic ditch shrimp (*Palaemon varians*) production, seventeen in Cádiz and one in Seville.

There are eight licensed sites for the production of Kuruma prawn (*Penaeus japonicus*) in Andalusia, three in Huelva and five in Cádiz. Among them, there is one active hatchery producing Kuruma prawn juveniles.

Caramote prawn (*Penaeus kerathurus*) has been produced since 2010 in six facilities, all of them in Cádiz, Andalusia.

For the common prawn (*Palaemon serratus*) and Palaemon shrimps nei (*Palaemon spp.*), there is currently no production.

Seaweed and microalgae aquaculture

There is one licensed site for the production of sea lettuce (*Ulva lactuca*) in Huelva (Andalusia).

There are four facilities in Andalusia (Cádiz (3) and Huelva (1)) and one in A Coruña, Galicia, devoted to chicory sea lettuce (*Ulva rigida*) and *Gracilaria* spp. production.

Gracilaria dura is produced in two facilities in A Coruña, Galicia; while *Gracilariopsis longissimi* and *Codium vermilara* are produced in one facility in A Coruña, Galicia

Only three microalgae species have been produced in the ecoregion in Spain since 2017 and reported in the statistics. Those species are (*Isochrysis galbana*, *Nannochloropsis gaditana* and *Tetraselmis chuii*) all of them produced in A Coruña, Galicia, and *N. gaditana* and *T. chuii* also in Cádiz, Andalusia. The site in Andalusia grows microalgae in photobioreactors in land-based facilities using recirculating aquaculture systems (RAS).

3 Production over time

Lead by Fiz da Costa and Bastien Sadoul

Data sources

All plots shown here are derived from industry surveys performed at the national level and account for production in tonnes and value of on-grown products sold by producers. For hatchery, production information is provided in the specific sections below.

3.1 France

The French government oversees an annual survey of aquaculture activities since 2018. This Aquaculture Survey is the only annual statistical source providing a longitudinal monitoring of aquaculture production. Administrative data available from sources such as maritime concessions (licensing) and accreditations do not inform on the real composition of the sector. Beyond information provision, the Aquaculture statistical survey supplies crucial data to comply with the European Data Collection Framework. Produced by the French Bureau of Environmental and Forestry Structural Statistics, the data aims to enumerate freshwater and saltwater aquaculture enterprises, estimating annual sales production in quantity and value and assessing employment in number and full-time equivalents. Data collection primarily occurs online, with potential supplementation via telephone or paper questionnaires, subcontracted to a private company (BVA group). Information is annually summarized in reports available at (https://agreste.agriculture.gouv.fr). The geographical scope is the entire France, and the survey is conducted annually. Analysis on the subregion BoBICAO was performed by specifically extracting information from the survey results. It is important to note that some information was aggregated between species to present them without revealing confidential information of aquaculture enterprises.

3.2 Spain

Spanish data for this section were extracted from two sources. The main source was the Survey of Aquaculture Establishments, a statistical operation that is included in the National Statistical Plan for the 2021–2024 period (PEN 2021–2024,https://www.mapa.gob.es/es/estadistica/temas/estadisticas-pesqueras). The data collection method is described in detail in a report defining the methodology for the collection of aquaculture production data in Spain (https://www.mapa.gob.es/es/estadistica). The results are provided in tables which include data on the number of establishments, the quantity and value of their production in the study year, the number of hours worked in the establishment production in the study year, and the number of workers who have carried out the work. Production values are reported as the value expressed in euros and the quantity of sold products (from the farm), expressed in kilograms. In this Aquaculture overview production data reported refers to the final phase of culture (on-grown to commercial size). For the year 2017 and 2022, and any other data gaps, data were extracted from the information gathered by the National Sea Harvest Advisory Board (JACUMAR, https://www.mapa.gob.es/es/pesca), who collects data from the competent authorities in each region of the country.

3.3 Portugal

Aquaculture statistics are under the responsibility of Statistics Portugal and the Directorate-General for Natural Resources, Safety and Maritime Services, as the delegated authority of Statistics in Portugal. These institutions annually present the Fishery Statistics compendium, within their technical cooperation aiming at the production and dissemination of the official fishery statistics, where aquaculture statistics are included. Information on statistics is available online since 1969 (https://www.ine.pt/xportal). Data from shellfish culture parks were first reported in 1971, whereas statistics on aquaculture production were first reported in 1989.

The Directorate-General for Natural Resources, Safety and Maritime Services (DGRM) in collaboration with the Portuguese Agency for Environment (APA - Agência Portuguesa do Ambiente) participated on the development of a geoportal with the location of the different aquaculture facilities distributed along the Portuguese coast, including some information about the facility (e.g. Title for Aquaculture Activity (TAA) number, name, type of production system, rearing medium, exploitation regime, species produced) (https://webgis.dgrm.mm.gov.pt/portal).

3.4 Total production of on-grown product over time (Ecoregion level)

In 2021, the aquaculture sector within the ecoregion achieved a total production of 310 000 t, valued at 775 million euros. The dynamic of the production is very unpredictable with strong annual variations in both volume and economic value (Figure 3.1 and 3.2). In the ecoregion, production can be separated in four main group of species: shellfish, by far, and historically, the most produced in both tonnage and economic value, followed by finfish, crustacean and algae. Only crustaceans in Spain (in tonnes) and shellfish and finfish production in Portugal (both in tonnes and value) show a clear increase since 2010. In contrast, other types of aquaculture production have mostly stagnated (Figures 3.1 and 3.2). Spain leads the ecoregion in production volume, contributing 220 000 t, but ranks second in economic value behind France (Figure 3.3). In the ecoregion, shellfish, particularly from France, dominate the production, accounting for nearly 75% of the total economic value (Figure 3.3).

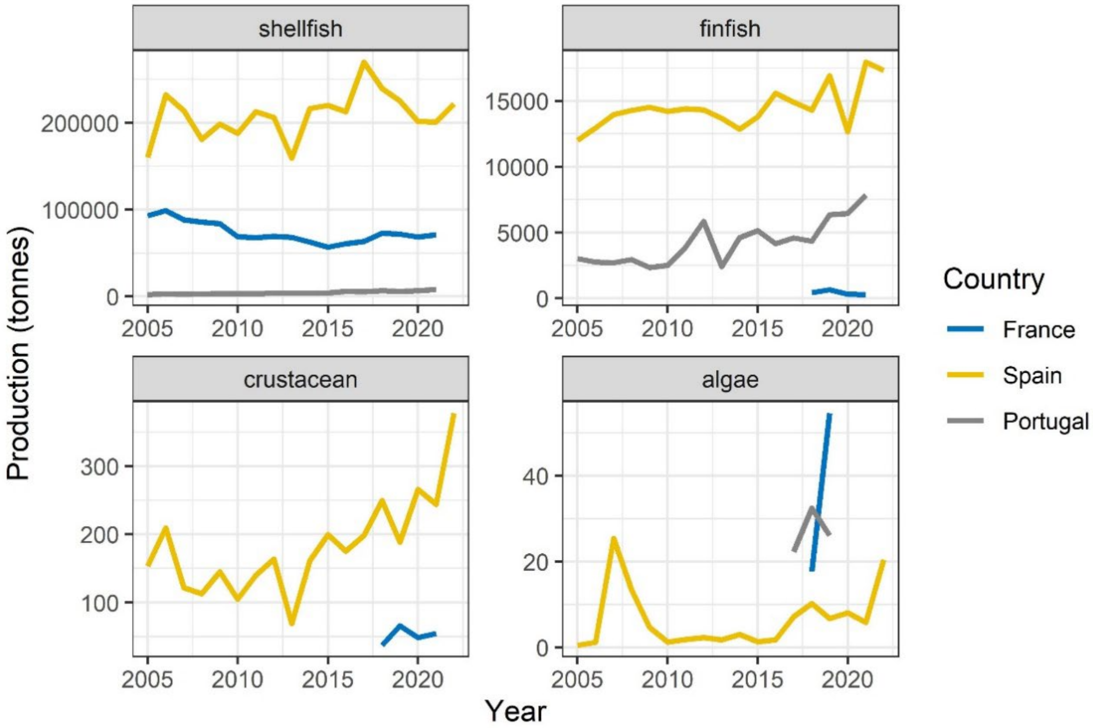

Figure 3.1. Time-series (2005–2021/2022) of aquaculture production for the Bay of Biscay and the Iberian Coast ecoregion, differentiated by major taxonomic grouping (shellfish, finfish, crustacean and algae) per country (STECF, 2023; INE 2023).

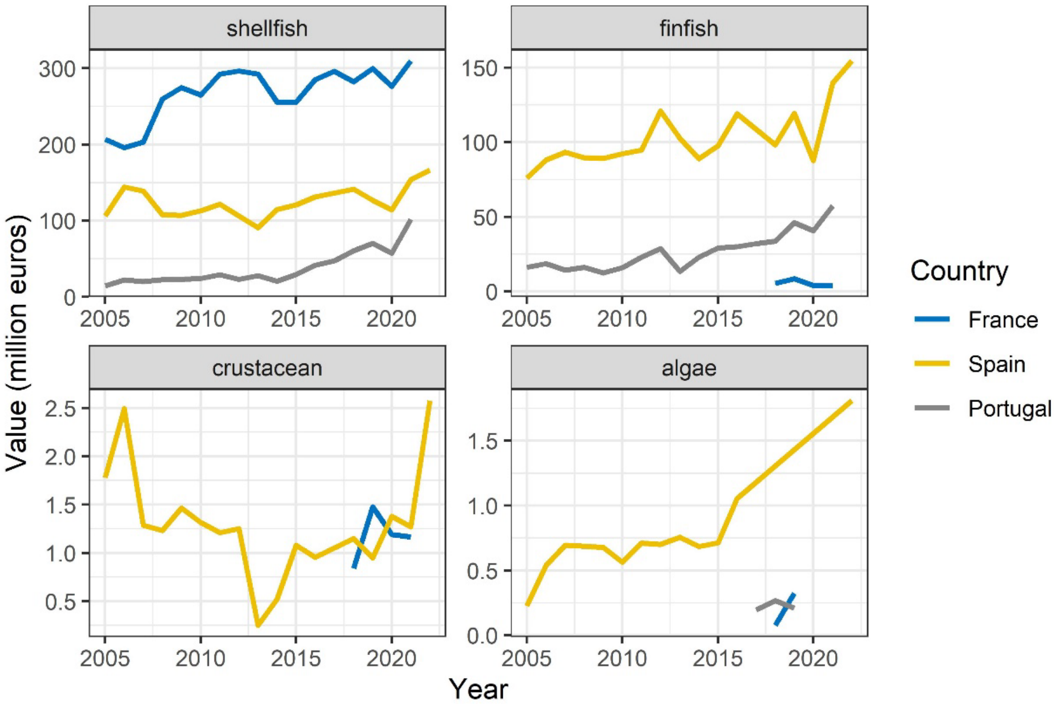

Figure 3.2 Time-series (2005–2021/2022) of aquaculture production value in million euros of on-grown sold product, differentiated by major taxonomic grouping (shellfish, finfish, crustacean and algae) in the Bay of Biscay and the Iberian Coast ecoregion per country, as declared by producers (STECF 2023).

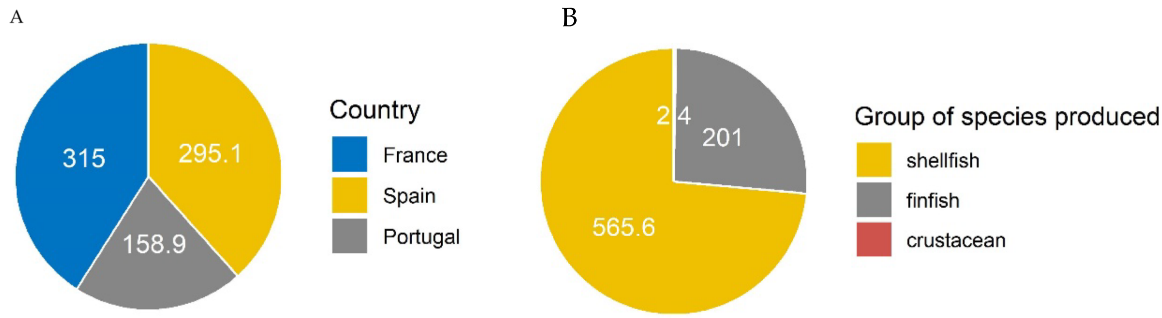

Figure 3.3 Value produced (in million euros) of on-grown sold product in 2021 in the ecoregion by country (A) or group of species (B). The value for the production of crustacean is 24 million EUR. The value for the production of algae in not available for all countries in 2021, so was this group of species was not illustrated, but production is neglectable compared to the rest (STECF 2023, Agreste 2022).

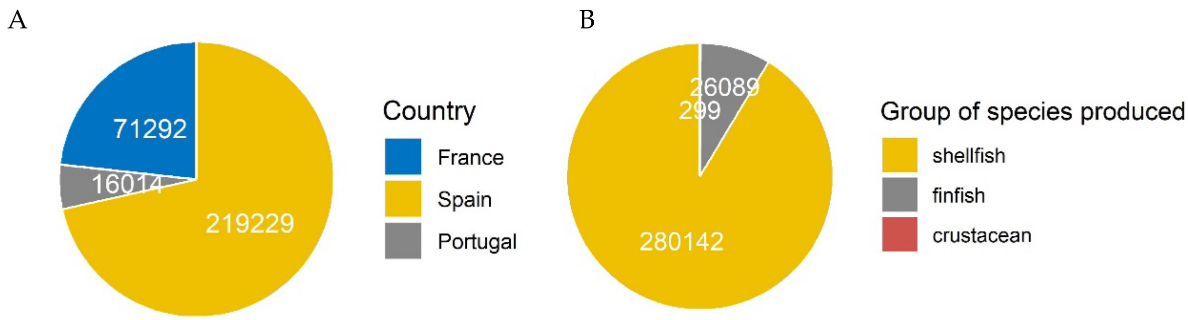

Figure 3.4 Volume produced (tonnes of on-grown product in 2021 in the ecoregion by country (A) or group of species (B). (The value for the production of crustacean is 299 tonnes). The value for the production of algae in not available for all countries in 2021, however production is low and, therefore, not included (STECF, 2023; INE, 2023; Agreste 20222).

France – general observations

French aquaculture in the BoBICAO region is largely dominated by shellfish production which reached around 100 000 t in the 2000s. The pacific oyster, *Magallana gigas*, is the most produced species with 69% of the total production in 2021, followed by the mussel, Mytilus edulis, which accounts for 27.6% of the production. Since the 2000s, the shellfish production is slowly decreasing to reach in 2021 71 000 t, mostly because of a shrinking in oyster production. The mussel production has stagnated over the same period. Other productions are neglectable with only 300 t of finfish on grown and 55 t of crustacean in 2021. The aquaculture sector over the period recorded has never shown an increase in the production on the contrary to neighbour countries of the ecoregion (see below). For France, only the economic value produced by shellfish production is growing on the record period reaching over 300 million euros produced in 2021, despite the reduction in volume produced.

Spain – general observations

The Spanish aquaculture production within the ecoregion has been quite stable since the start of the records in 2002 until 2022, with an average production of 223 500 t during the period and ranging from 172 343 t in 2005 to 284 997 t in 2017. Production value within the Spanish part of BoBICAO region followed an increasing trend from 207 million euros in 2002 to 284 million euros in 2022. In terms of production quantities in tonnes, shellfish represents the main group of species cultivated in the Spanish coast of the ecoregion (more than 90% for the time-series between 2002 and 2022), followed by finfishes (less than 10%). By contrast, the value of production in euros in 2022 is quite similar for shellfish (51%) and finfishes (48%). Mussel is the main shell-fish species produced in terms of quantity in tonnes (>98%) and value in euros (>75%) during the time-series. The main finfish species in production quantity (tonnes) and value (euros) in 2022 were the turbot (52–53%) and sea bass (33–35%).

Portugal – general observations

The aquaculture sector developed at slow pace since 1989 until the first decade of the 21st century, with production volumes remaining below 10 000 tonnes. From 2010 onwards, aquaculture production grew faster to reach a production volume of 17 900 tonnes in 2021, exhibiting a 10% increase per year since 2015. According to last report (INE, 2023) shellfish and fish are the group of organisms produced in marine aquaculture, where shellfish represent 54% of the marine production volume whereas fish 46%. In terms of value, shellfish represents 63% of the total value of marine aquaculture (16 1194.76 k€), whereas fish represent 36%. Shellfish was most of the times the group most produced within the time-series (from >80% before 1995, to 60–55% thereafter), except for the period within 2004 and 2007 when fish were produced, marginally, in higher quantities (ca. 55%). In terms of value a significant increase of shellfish value was observed since the early statistic reports, where 88% of marine production value around 12%.

The first statistics for Portuguese aquaculture were reported in 1989, with a production volume of 8 449 tonnes with a corresponding value of over 3 million euros (637 million ESCUDOS; INE, 1989). Marine aquaculture represented 88.4% of the total production volume, representing 25% of the total national value bivalves (clams, oysters) and fish (gilthead sea bream) production volume were respectively 87,9% and 0.5 % of the total production volume. However, bivalves represented 12.3% of the total value whereas fish represented 8.4%.

Conventional aquaculture farms consisted of extensive or semi-intensive systems, typically situated in wetland areas. They have faced increasing enforcement on environmental protection laws, which limited their intensification and increased production (Ramalho and Dinis, 2010). In addition, the harsh marine conditions along the west Atlantic coast have postponed the implementation of offshore structures for intensive production. Government measures to support aquaculture development (e.g. specific funding programs, maritime spatial planning) and new technological solutions have contributed over the last years to promote aquaculture production.

The number of active units with aquaculture production in transitional and marine waters was 1156, occupying an area of 1 955 ha (INE, 2023). The active units correspond almost exclusively to on-growing units, where bivalves culture parks represented the larger number (1 097; 95.2%) occupying an area around 565.4 ha, followed by tanks/ponds (38; 3.3%) and floating structures (17; 1.5%), respectively occupying an area of 442.6 and 863.0 hectares (INE, 2023).

3.5 Finfish

France

Marine finfish on-grown production in the French part of the ecoregion varies between 293 and 636 t produced annually between 2018 and 2021. This represents only around 10% of the total marine finfish production in France. In the French part of the ecoregion, there is only one producer of marine trout (*Oncorhynchus mykiss*) and one producer of sole (*Solea senegalensis*). Despite having the longest coastline in the ecoregion, France never developed finfish on-grown production to a significant level, far behind the other two countries of the ecoregion. The production of turbot has significantly decreased over the last years and there was no production of turbot (*Scophthalmus maximus*) in 2023.

Spain

On-grown production of marine finfish in Spain totalize 17 953 t produced. The production is dominated by turbot (*Scophthalmus maximus*), sea bass (*Dicentrachus labrax*) and sea bream (*Sparus aurata*), with peaks around 9 200 t, 7 300 t and 4 300 t, respectively. Turbot farming started in Galicia in 1983 and there were sixteen active licensed sites in 2022. Sea bass production in the ecoregion may be overestimated as there are 30 production facilities in the ecoregion and four facilities in the Mediterranean coast of Andalusia and production statistics cannot be differentiated among them. The same situation is also found for sea bream statistics, which may be overestimated due to the presence of 30 facilities within the ecoregion and three in the Mediterranean coast of Andalusia.

Other cultured finfish in the ecoregion in Spain, ranked in descending order by annual production, including Senegalese sole (*Solea senegalensis*) records that started in 2005 in Galicia with a production of only 7.5 t. It had increased significantly until 2013, when it reached 409 t. The highest point of the time-series was recorded in 2022 with a production of 1 179 t, which represented a value of more than 15.2 million euros.

Atlantic bluefin tuna (*Thunnus thynnus*) production in tonnes has been recorded from 2002 until 2020, with high variations between years and with a peak in 2018 of 1 178 t. The highest value achieved was 9 million euros in 2012.

The production of the blackspot sea bream (*Pagellus bogaraveo*) was produced between 2002 and 2019. Its production quantities were quite stable, with a mean production of 148.6 t, reaching 245 t in 2011. Except for 2002 and 2003, production value remained stagnant around a mean value of 1.39 million euros per year.

There are records of on-growing production of the thick lip grey mullet (*Chelon labrosus*) available for the period 2002–2016. It varied from 81 to 176 t and a value of 0.2 and 0.83 million euros.

The pollack (*Pollachius pollachius*) was only produced between 2005 and 2009. Its production reached 39 t in 2007 and a value of 124 766 euros.

Other species of marine finfish reported in the statistics are European eel (*Anguilla anguilla*), meagre (*Argyrosomus regius*), spotted sea bass (*Dicentrarchus punctatus*), white sea bream (*Diplodus sargus*), mullet (*Mugil spp*.), Greater amberjack (*Seriola dumerili*), Big-scale sand smelt (*Atherina boyeri*) and European sole (*Solea solea*).

Portugal

Finfish represents 44% of the total marine aquaculture production based on data collected in 2021 (INE, 2023). Finfish production has tripled since 2010 to reach 7842 t in 2021. The main marine fish species produced are turbot (*Scophthalmus maximus*), gilthead sea bream (*Sparus aurata*), sea bass (*Dicentrachus labrax*) and Senegalese sole (*Solea senegalensis*), with production volume of 3 538 t, 3 090 t, 953 t, 327 t respectively in 2021 (INE, 2023). In 2021 the value from marine fish production represented 57 million euros.

Turbot production, first reported in 1995 (35 t) has increased significantly to reach more than 4 000 t in 2012 (INE, 2013). From this year onward production volume has fluctuated between 2 300 and 3 600 t. In 2021 production volume was 3 538 t for a value above 30 million euros.

The production volume for sea bream and sea bass exhibited a similar pattern of variation during the last two decades, with gilthead sea bream being generally produced in higher volumes than sea bass. Gilthead sea bream production volume increased steadily until 2000, and until 2007 values stabilized between 1 500 t and 1 900 t. Thereafter a strong decrease was observed, resulting in a second plateau between 2011 and 2018, where values oscillated within 800 t and 1 000 t. Afterwards a sharp increase in production was observed reaching over 3 000 t in 2021, with a value of 17,5 million euros. Sea bass production over time was characterized by a steady increase until 2003, reaching values near 1 500 t that were oscillated around the same level until 2006. Thereafter a sharp decrease dropped production to 444 t in 2009, and values were maintained around 500 t until 2016. From 2017 onwards fluctuation was variable, but from 2019 production was around 900 t.

Between 1989 and 2011 sole production volumes fluctuated between 4 and 14 t. In 2012 production increased by a factor 10 and from this moment onwards, production volume increased with a mean annual value of 157 t/year. The knowledge driven research contributed to improve Senegalese sole productivity, with the development of specific feeds and adopting RAS in intensive regime among others. In 2021 production volume was 327 t, trade volume was 186 t and value of 3.6 million euros.

Meagre (*Argyrosomus regius*) production varied significantly these last two decades, with a peak of 63 t in 2016, but has then decreased to reach 0 t in 2020 (INE, 2007, 2017, 2022).

Other fish species have been tested to diversify aquaculture production, like Sparidae species (e.g. *Diplodus spp.*), but production volumes remain below 3 t.

3.5.1 Hatchery production for on-growing

France

France has an historical expertise in production of fingerling of sea bass, sea bream and turbot. However, only the production of sea bass and sea bream is now significant over the last few years. Only one farm in the ecoregion remains. Based on information provided by the only remaining fingerling producer, we can estimate that fingerling (mainly sea bass and sea bream) production reached 80–90 million annually, 80% of which are exported. However, this activity represents the largest value and employment of finfish aquaculture in the French part of the ecoregion which reached 4 million euros in 2020 and 106 full time jobs.

Spain

Spanish statistics do not report the number of hatchlings for each species. However, information about the number and value of juveniles produced are reported. In 2022, the greatest number of juveniles reported was for sea bass (17 million), followed by *Senegalese sole* (14 million), turbot (nearly 13 million) and sea bream (11 million). Few greater amberjack, *Seriola dumerili*, juveniles are produced in hatcheries.

Blackspot sea bream, *Pagellus bogaraveo*, juveniles were produced in hatcheries for several years, but the cultivation of this species ended in 2019.

Pollack juveniles (*Pollachius pollachius*) were produced in hatcheries in 2005, but since then no other juveniles were reported and on-growing of this species was finished in 2009.

Restoration projects have resulted in the release of hatchery-raised juveniles of brill, common sole, wedge sole, sea bream, meagre and greater amberjack between 2005 and 2015 on the Atlantic coast of Andalusia. Between 2008 and 2010 the Galician government released 20 000 juveniles of turbot.

Portugal

In the ecoregion there are only two flatfish hatcheries (turbot and Senegalese sole). Due to the crisis of 2008 the two hatcheries that existed for sea bream and sea bass were closed. Therefore, most of the production of sea bass, gilthead sea bream and meagre depend on imported juveniles.

3.5.2 Wild production input to aquaculture

France

There is no growth of wild-caught fish reported in the ecoregion for France.

Spain

Bluefin tuna (*Thunnus thynnus*) production data has been reported in aquaculture statistics from 2002 to 2020. From 2011 until 2020 average production was around 690 t per year, peaking at 78 t in 2018. Statistics only reported value to from 2002 to 2016, reaching a maximum value of 9.1 million euros in 2012.

European eel (*Anguilla anguilla*) production depends on the capture of wild eels since reproduction in captivity is not yet mastered. Aquaculture production for this species records started in 2002, reaching a maximum of 106 and 0.87 million euros in 2006, and decreasing progressively until 2018, the last year with production data available.

Portugal

In the South of Portugal two firms work in bluefin tuna fattening. These fish are conveyed to a principal pool, through a complex system of nets, where they are kept for a maximum of six months. Tuna fish are fed daily with frozen pelagic fishes until a desired fattening level is attained. According to International Commission for the Conservation of Atlantic Tunas (ICCAT) fattening consists of when mature individuals (<30 kg) are reared for a shorter period of time (generally between 4.72 and 9 months). During 2005 and 2009 statistics on bluefin tuna were reported as aquaculture production, but afterwards those values were omitted from aquaculture statistics. Both operations are monitored by ICCAT.

Mullet juveniles are naturally recruited into earth ponds where they are grown under extensive or semi-intensive regime. Production volume contributes to total aquaculture production, with values oscillating between 1 to 4 tonnes.

3.6 Molluscs

3.6.1 On-grown production

France

Oyster on-grown production, mainly *Magallana gigas*, is the main farmed species in the ecoregion with a production in 2021 of 49 611 t. The total volume produced is steadily decreasing since 1996 when oyster production reached more than 90 000 t. The value produced by oyster production is increasing to reach 255.8 million euros in 2021, representing 81% of the total value.

Mussel on-grown production is the second largest in volume and value in the French ecoregion with 14.6% of the value and 27,6% of total volume in 2021. Production can be considered stable since 1980 despite high interannual variability.

The production of cockles, *Cerastoderma spp.*, is also an important production with around 1 200 t produced annually since the late 1980's. Fluctuations of the production are however important, ranging from 0 to 2 280 tons over the last 30 years.

Historically, France produces manila clams, *Ruditapes philippinarum,* after having imported the species in the 70's. In the late 80's the production crashed because of the Brown Ring Disease due to the *Vibrio tapetis*, initially called *Vibrio P1.* Production has fluctuated between 350 and 600 t over the last 10 years.

Finally, the production of flat oyster, *Ostrea edulis*, represents now 387 t of production, for 2.9 million euros of value. The species used to be much more produced, with a peak in 1 961 at 9 843 t. However, ongoing disease outbreaks associated with two parasites, *Marteilia* and *Bonamia*, have negatively impacted production.

Spain

Mussel (*Mytilus galloprovincialis*) production is quite stable during the production series 2002–2022 with an average production of around 205 000 t per year, reaching up to 266 900 t in 2017. Value of production is also stable at around 105 million euros per year, ranging from 74 to 151 million euros.

Pacific oyster (*Magallana gigas*) production peaked in 2004 at 1 397 t, but since then production has decreased to 786 tons in 2022. The production value is 2.0 million euros in 2022. Organic Pacific oyster production was reported in Andalusia in 2018 and Asturias in 2019.

The highest production value recorded for European flat oyster (*Ostrea edulis*) was 4 573 t in 2002, and since then it has progressively decreased to 237 t in 2022. Value followed the same decreasing trend than production quantities, ranging from 19.5 million euros in 2002 to 1.4 million euros in 2022.

Among clam's species, Manila clam (*Ruditapes philippinarum*) is the species with the highest production within the Spanish part of the ecoregion. Its production reached 6 276 t in 2011, but since then it has decreased to quantities below 1 000 tons, reaching 718 t in 2022. In 2022 the total value of Manila clam produced in the ecoregion (Spain) was 7.1 million euros.

Production of the pullet carpet shell (*Venerupis corrugata*) showed a decreasing trend from 2002 to 2022, with a production peak in 2013 at 324 t. Current production was estimated in 2022 at 124 t with a value of 1.5 million euros. The grooved carpet shell (*Ruditapes decussatus*) followed the same decreasing trend that the pullet carpet shell, with a maximum of production in 2003 of 248 t and a progressive decrease to 31 t in 2022 (0.9 million euros value).

Cockle (*Cerastoderma edule*) production in Spain between 2005 and 2022 experienced great variation, with low values of only 3 t in 2005 and peaks of production of more than 1 000 t in 2007, 2008 and 2016. In 2022, the reported aquaculture production was 404 t with a value of 2.4 million euros.

Other species have slight productions such as the Queen scallop (*Aequipecten opercularis*), the Variegated scallop (*Mimachlamys varia*) and Great Atlantic scallop (*Pecten maximus*).

Portugal

Shellfish aquaculture production reached over 9 000 tons in 2021 and then represented 53,5% of the total aquaculture production, and a value of over 100 million euros. Clams and oysters are the most valuable species, ensuring 58.6% of the total value.

Shellfish production fluctuated between 2 500 and 4 000 tons between 1995 and 2012, but since 2013 shellfish production has increased at an average of 7.4%.year^{-1}.

Clams are the most produced species of shellfish. Production volumes have increased since 1990, with strong fluctuations between 1 500 and 3 000 t in the first decade of the 21st century. Since 2016, production volume has increased to almost 4000 t. The volume trade in 2021 was 5 650.8 t and value of 91 360 653 euros.

Mussels' production was maintained below 500 t between 1990 and 2012, followed by a sharp increase in 2013 to 1 500 t. Production values were rather stable the following years, fluctuating between 1 200 and 1 700 t, to increase to over 3 000 t in 2021. The trade volume in 2021 was 1884 tons with a value 2,1 million euros.

Oyster production fluctuated between 500 to 1 200 t between 1995 and 2017. In 2018, a production of 3 500 tons was reported followed by a decrease of similar magnitude in 2019, and the highly variable pattern was maintained with a yield of 2 293 t in 2021. The most produced oyster species is *Magallana gigas* representing around 70% of the oyster production. The rest of the production is supported mainly by *Crassostrea angulata* which became significant in 2009. Statistics on *Ostrea edulis* production were irregular and below 2% in 2017.

Cockle production volume fluctuated between 0 and 450 t these last 30 years. In 2021, 238 t were traded with a value of 0.5 million euros.

3.6.2 Hatchery production for on-growing

France

There are 8 to 10 active hatcheries of oyster spat in the French ecoregion. They mainly produce pacific oyster spats, with an economic value generated of 22 million euros in 2021. Spat are sold at different sizes ranging from 800 µm to 8 mm, and sometimes up to 25 mm when they are pre-grown. The total estimated quantity sold in the ecoregion is 2 973 T. The French part of the ecoregion also holds hatcheries of other shellfish species, mostly clams, which generated 3.7 million euros for 489 T sold in 2021.

Spain

Currently, there are only three active hatcheries in Spain. They mainly produce clams, the pullet carpet shell (*Venerupis corrugata*) and Manila clam (*Ruditapes philippinarum*). In 2022, around 60 million spat for each clam species was reported. One of the hatcheries produces every year some batches of flat oyster, but this production is not always included in the statistics.

Portugal

There is only one active hatchery for pullet carpet shell in Portugal. This hatchery is private and for the moment produces seeds to satisfy the growing phase.

3.6.3 Hatchery production for environmental stocking

Statistics and other data sources often include data of hatchery production for the restocking of natural beds carried out by research projects or other initiatives carried out by research centres of governmental hatcheries from national or regional administrations.

France

No planned and controlled restocking programs exist currently in France, except for the Atlantic salmon, *Salmo salar*, or the European sturgeon, *Acipenser sturio*, with annual release of juveniles in the river which are then reaching the ocean for maturation. Over two million salmons are released annually in the rivers of the ecoregion by three non-profit organizations. In parallel, around 700 000 sturgeons are released in the ecoregion.

Spain

There is hatchery production for restocking of pullet carpet shell (*V. corrugata*), grooved carpet shell (*R. decussatus*), Manila clam (*R. philippinarum*) and arched razor shell (*Ensis magnus*) in recent years.

Projects in the last 15 years released juveniles for restocking of pullet carpet shell (*V. corrugata*), grooved carpet shell (*R. decussatus*), Manila clam (*R. philippinarum*), banded carpet shell (*Polititapes rhomboides*), variegated scallop (*Mimachlamys varia*), arched razor shell (*E. magnus*), sword razor shell (*Ensis siliqua*), European razor clam (*Solen marginatus*) and truncate donax (*Donax trunculus*) (OESA-Fundación Biodiversidad, 2018).

In Galicia, production issues of hatcheries, mainly for clams have had an affect on the level of production of these species over time.

Portugal

No planned and controlled restocking programs exist currently in Portugal.

3.6.4 Wild production input to aquaculture

France

Mussels spat is collected from the wild using collecting ropes. While some are used directly by the same company for on-growing, spat can also be sold, and this represents a 2.6 million euros trade in 2021 for 410 t of spat.

For oysters, mainly *Magallana gigas*, the same methods are in practice and in 2021 this produced a 2.1-million-euro trade for 139.9 t. However, there has been a clear reduction in the market over the last year, with 417.3 t sold in 2018.

For cockles, juveniles are collected from the wild using dredge.

There are a number of other shellfish species grown in France at much lower volume. Their total production represents 77.5 T produced in 2021 and an economic value of 830 000 euros.

Spain

Mussel spat is collected either from rocks in the natural environment or collecting ropes, for later transfer to dropper lines on rafts. For an annual mussel harvest of 250 000 t, seed requirements are estimated at around 7 000 t per year.

Part of the clam seed comes from hatcheries, but there is also collection from natural beds. Pullet carpet shell and Manila clam juvenile production in hatcheries were 62.5 and 59.4 million units in 2022, respectively.

Cockle, Queen scallop, the Variegated scallop and Great Atlantic scallop seed come from natural beds.

3.7 Crustaceans

3.7.1 On-grown production

France

In the ecoregion, the Kuruma prawn, has been more and more produced in oyster ponds over the last years, often in combination with oyster on-growing. In 2021, 54.7 T of shrimps were produced for a 1.2 million euros market.

Spain

Except for the white leg shrimp (*Penaeus vannamei*), all crustacean species in Spain are produced using semi-intensive or extensive culture methods.

Atlantic ditch shrimp (*Palaemon varians*) is the main crustacean species produced to commercial size in Spain. There are records from 2013 until 2022 and its production has progressively increased until reaching 343 t in 2022, with a value of 1.7 million euros. The second crustacean species in terms of current production is the Kuruma prawn (*Penaeus japonicus)*, which is included in records of production since 2002. Kuruma prawn production in 2022 was 26 t with a value of 0.86 million euros.

Common prawn (*Palaemon serratus*) and palaemon shrimps (Palaemon spp.) were produced until 2014 and 2016 respectively and their production peaked at 132 t and 183 t, respectively.

Caramote prawn (*Penaeus kerathurus*) has been produced since 2010 until now (the last record is 2022), exhibiting production quantities below 2.5 t per year.

Portugal

Between 1989 and 1994 one firm was producing prawns, *Peneaus japonicas,* in earth ponds in a semi-intensive regime. A production peak of 22 t was reported in 1991 followed by a sharp decline until production ceased in 1993, due to financial aspects but also for legal aspects related to exotic species.

The harvest of Atlantic ditch shrimp, *Palaemon varians*, is recruited naturally into earthen ponds and contributes to aquaculture production statistics since 2005. Volumes harvested increased from 1.1 t in 2005 to 20.8 t in 2018, followed by a decrease in 2021 to 2.8 t.

3.7.2 Hatchery production for on-growing and environmental stocking

The hatchery production of crustaceans is limited in the ecoregion with some in Spain where the white leg shrimp is produced in an inland hatchery and juvenile European lobsters where produced and released for restocking between 2008 and 2010. No hatcheries for Portuguese crustacean aquaculture exist and only two hatcheries are operational in France, one of which dominates the market.

3.8 Seaweed and microalgae

France

Very few companies produce macroalgae in the ecoregion. There was a maximum of six companies in 2020 with a production reaching 54.6 t in 2019. Species produced are *Undaria pinnatifida, ulva* sp., *Saccharina latissima* and *Palmaria palmata.*

Spain

Statistics do not always allow determination of the farmed species. The species cultivated include *Codium tomentosum*, *Codium vermilara, Gracilaria spp., Gracilaria coriacea, Gracilaropsis longissimi, Gracilaria dura, Laminaria spp., Ulva lactuca, Ulva rigida* and *Undaria pinnatifida*, with current production at 19 t.

Three species of microalgae (*Isochrysis galbana*, *Nannochloropsis gaditana* and *Tetraselmis chuii*) are reported in the statistics from 2017 until now, with a production in 2022 at 1.5 t.

Portugal

Seaweed production volumes were reported between 2017 and 2019. Green seaweed increased from 28 to 43 t, whereas red seaweed from 1.2 to 1.7 t. From 2020 onwards statistics are not available, related with law enforcement on data protection when the number of farms is lower than three and/or when values are lower than one tonne per year.

At least two microalgae companies exist, but production values are not reported. It might be related with law enforcement on data protection when the number of farms is lower than three and/or when values are lower than 1 tonne per year as aquaculture production.

3.9 Other marine invertebrates

France

Few other marine invertebrates have been tested in the french part of the ecoregion. One producers of purple sea urchin, *Paracentrotus lividus*, has produced up to 6 t annually from 2006 to 2016. Currently, a facility produces blow lugworms, *Arenicola marina*, for biopharmaceutical purposes.

Spain

Small quantities of the worm *Marphysa sanguinea* have been produced in one facility from 2010 until 2021, peaking in 2015 at 0.3 t.

The green abalone was produced in one facility from 2017 until 2019, with a production peaking at 4.9 t in 2019.

There are records in 2020 of stony sea urchin (*Paracentrotus lividus*) juvenile production for on-growing and in 2022 production was recorded for both on-growing and restocking. In the last 15 years several projects have released stony sea urchin juveniles for restocking.

Common octopus, *Octopus vulgaris*, is on-grown in cages. Its culture is based on the capture of juveniles that are fed to reach commercial size. There are records of production from 2002 until 2018, exhibiting a peak of production in 2008 at 30 T. There is not any commercial hatchery operating in Spain. There is one experimental private centre from a commercial company trying to develop octopus production in hatcheries in the ecoregion and the same company is planning a commercial hatchery in the Canary Islands, outside the ecoregion.

4 Policy and Legal Foundation for aquaculture

Lead by Rosa Chapela, Rui Oliveira, José A. Pérez Agúndez

4.1 Introduction: Framing the context of the Bay of Biscay and Iberian cost legal framework for aquaculture

This chapter aims to explore aquaculture legislation and policies in France, Spain, and Portugal within the broader context of European aquaculture policy. One of the main common challenges in this ecoregion is related to legal aspects especially concerning the high administrative burden (European Court of Auditors, 2023) which often hampers or delays the execution of aquaculture activities, the receipt of funds or public aids for their promotion, and consequently, contributes to the development of the blue economy in the region through aquaculture. Good governance in aquaculture, which involves effective legislation, ensuring legal certainty for aquaculture promoters and investors, supports a favourable operating environment, and enhances social acceptance of the sector, addressing societal challenges and opportunities.

We will begin by examining the common challenges in the ecoregion's context that pertain to ensuring good governance in aquaculture. This involves providing aquaculture promoters with an understanding of environmental legislation and procedures, environmental impact assessment, food safety standards, and, notably, licensing procedures. Unlike biological, oceanographic, or economic aspects that may vary based on specific country or regional characteristics, the legal aspects of aquaculture exhibit common elements among the three countries due to applicable European legislation. Subsequently, each country within the ecoregion, leveraging its exclusive competencies in aquaculture, develops a legal framework tailored to its legal or judicial culture.

We will also examine why, having an appropriate legal framework is crucial in this ecoregion, as it is in other regions where aquaculture is practised. Additionally, we will highlight the key legal and administrative aspects specific to of each country that can serve as exemplary practices for others and identify the challenges faced by this ecoregion regarding legal frameworks. For these proposes, we will delve into governance, which encompasses more than just the administrative management of the activity; it involves a range of public and private interactions aimed at addressing societal issues and capitalizing on societal opportunities (IUCN, 2009).

In the Bay of Biscay and Iberian Coast ecoregion, multi-tiered governance often leads to complex procedural requirements that can hinder the growth and development of aquaculture. Consequently, the regulatory landscape is characterized by an intricate interplay of diverse administrative roles, that need a continuous adaptation to technological innovations and economic growth.

Aquaculture is highly regulated because it plays a critical role in food production and operates in coastal and maritime zones, public or public domain, requiring adherence to quality standards and environmental protection rules. However, is widely recognized that aquaculture also holds significant potential for job creation and food supply in this ecoregion, where aquaculture plays a very crucial role in both social and economic dimensions, sharing common challenges in terms of legislation that justify this analysis. Many of these challenges or their potential solutions are found in European policies or strategies, making it often unavoidable to reference a broader framework than that of the ecoregion.

Such is the level of importance of administrative regulation that cases of aquaculture promoters relocating from Galicia, Spain, to Portugal or France have occurred in this same ecoregion, as seen in the cultivation of sole and turbot[3]. However, it is expected that with the new regulation and maritime spatial planning, along with the streamlining of procedures in Spain and the Galician region, procedures and legal frameworks in this ecoregion will be aligned, and aquaculture development will be uniform and driven by the blue economy in the Atlantic.

These two areas of activity in aquaculture involve a multitude of regulations and legislation that often complicate the process of granting and/or renewing licenses. Examples include matters related to food and food safety, prevention and control of diseases, Hazard Analysis and Critical Control Points (HACCP), traceability, labelling, organic production, licensing, license renewal, Environmental Impact Assessments (EIA), landscape regulations, etc. On the other hand, governments are responsible for establishing standards for environmental management and adopting regulations and laws to enforce compliance with these standards, regulating diseases, escapes, animal welfare, production and waste management, and other environmental requirements. All these transversal aspects make aquaculture a highly regulated sector compared to other food sectors.

The new green wave in this ecoregion aquaculture framework

The European Union has witnessed significant developments in aquaculture policies and governance in recent years. Initiatives such as the "Food from Oceans" document and the EU Green Deal have spurred actions towards promoting sustainable aquaculture and addressing challenges in the sector. Key recommendations have emphasized the importance of low-trophic aquaculture, focusing on species like algae and systems such as IMTA (European Commission, SAPEA, 2017). The Farm to Fork (F2F) Strategy under the EU Green Deal further advocates for sustainable practices and the promotion of low-trophic species aquaculture (European Commission, 2020).

The Common Fisheries Policy reform in 2013 introduced the Multiannual National Strategic Plans for Aquaculture to improve coordination between EU policies and Member States' competencies. This governance system, which applies to the three countries in the ecoregion, encourages Member States to implement strategic plans and facilitates the exchange of best practices, aligning with EU objectives for sustainable aquaculture development. The recent European Maritime, Fisheries and Aquaculture Fund[4] and the new Strategic Guidelines for aquaculture aim to provide financial support and strategic direction to enhance competitiveness, resilience, and sustainability in the EU aquaculture sector. These guidelines emphasize areas such as access to water and suitable spaces, reducing administrative burdens, improving environmental performance, addressing climate change, and focusing on health and animal welfare (European Commission, 2021).

The national aquaculture plans or strategies in France, Spain and Portugal are uniformly aligned with these challenges and objectives, aiming for a collectively stronger and more competitive aquaculture sector across Europe. This alignment results in a broadly consistent legal framework among the European Union countries, thereby ensuring equitable conditions for all members.

[3] https://www.laopinioncoruna.es/galicia/2016/03/13/firmas-acuicolas-galicia-producir-paises-24524154.html.

[4] Regulation 2021/1139 establishing the European Maritime, Fisheries and Aquaculture Fund and amending Regulation (EU) 2017/1004) promotes the financing of measures aligned with community aquaculture strategies, thus attempting to achieve greater coherence in the sustainable development of European aquaculture. The support provided to aquaculture initiatives through the EMFAF will be consistent with the National Multiannual Aquaculture Plans (article 27 of the EMFAF).

4.2 EU Policies and Legal Frameworks in the France-Spain-Portugal Ecoregion

Many of the legal regulations and strategies approved in the EU are directly or indirectly applicable in the three countries of the ecoregion. Before delving into how these regulations have been transposed or adapted into their legal systems, it is appropriate to introduce, as a general framework for Europe, legislation regarding MSP, environmental law, food safety, and organic aquaculture.

4.2.1 Integrating Aquaculture into the EU's Maritime Spatial Planning Policy Framework

Beyond the recognized benefits of the Directive 2014/89/EU, establishing a framework for maritime spatial planning (MSP), and its contribution to sustainable and reconciliatory development of various activities in maritime areas, this Directive can contribute simplifying the administrative procedures for obtaining licenses, one of the most hindering aspects of aquaculture development in the Ecoregion.

In many cases, especially in maritime areas, the process of granting licenses is prolonged, discouraging aquaculture investors. This is due to the involvement of multiple administrations in these maritime areas, each having a say in future establishment of marine aquaculture: maritime transport, tourism, navigation, fishing, ports, heritage, defence, public domain, environment, etc. If all these administrations have previously and collectively provided their opinions when a maritime area is designated for aquaculture, the administrative procedures for granting licenses should be much more streamlined and quicker.

Undoubtedly, the existence of zones or areas officially declared of interest for marine aquaculture can help to simplify the red tape and bureaucracy with the administration, offering greater legal security to aquaculture promoters. They will know in which areas they can carry out their activity without any future uncertainty telling them to cease operations because another greater interest demands that occupation. The MSP Directive itself acknowledges that the management of maritime spaces will create “confidence and certainty for investors provided through maritime spatial planning” (Recital nº 5 and 9).

The aquaculture location in specific areas would mean that an aquaculture agency will monitor those areas for aquaculture, all the permits and environmental impact assessments and other requirements from other administrations have been already provided to recognize that area as for aquaculture. Moreover, the Maritime Spatial Planning (MSP) Directive and the rules and plans of the Member States that transpose it ensure that aquaculture will have a reserved space in those Member States and the directive refers to aquaculture as the first activity, uses and interest that those plans may include (art. 8.2) and among their objectives (Chapela *et al.*, 2022).

> **“Through their maritime spatial plans, Member States shall aim to contribute to the sustainable development of energy sectors at sea, of maritime transport, and of the fisheries and aquaculture sectors, and to the preservation, protection and improvement of the environment, including resilience to climate change impacts”. (art. 5)**

As we will see in the sections on the legislation of each state of the ecoregion, the Member States must develop their maritime spatial planning in which they must establish the priority areas for aquaculture.

4.2.1.1 Environmental legislation

Although environmental issues and aquaculture are extensively addressed in Chapter 6, the affect of European environmental legislation on the aquaculture industry must be acknowledged in this context. The sector interacts and must comply with numerous European regulations, particularly environmental ones, including the Environmental Impact Assessment Directives, Natura 2000, Birds Directive, Water Framework Directive (WFD), and Marine Strategy Framework Directive (MSFD). These directives, especially the MSFD and WFD, focus on water quality protection.

The WFD, replacing older directives, aims to protect and restore water bodies to support aquatic life, mandating that all inland and coastal waters achieve good status. The MSFD, meanwhile, seeks to maintain good environmental status in maritime waters by 2020, with a broader scope than the WFD, including larger assessment scales[5].

Aquaculture must comply with these directives, implemented through national legislation. The MSFD is particularly significant for ensuring the environmental sustainability of aquaculture, addressing impacts like the introduction of non-indigenous species, nutrient and contaminant release, and potential wildlife disturbances.

The directives promote practices beneficial for both environmental protection and aquaculture development, such as Integrated Multi-Trophic Aquaculture (IMTA), which can improve seawater quality.

It is worth highlighting that the European Commission, in its document on the Guidance Document on Aquaculture and Natura 2000 (European Commission, 2018), establishes the compatibility of aquaculture activities with the preservation of the natural values of the Natura Network areas[6].

4.2.1.2 Food safety in the European Union legal framework

The EU has established a comprehensive set of food safety and health regulations for aquaculture products, aligned with the Farm to Fork Strategy and the FAO's Code of Conduct for Responsible Fisheries, art. 4.9,7 (FAO, 1995). These regulations aim to protect consumer health and ensure product quality. Key elements include the implementation of Hazard Analysis and Critical Control Points (HACCP) systems, comprehensive traceability, and adherence to quality standards.

The cornerstone of EU food law is Regulation 178/2002, which established the European Food Safety Authority (EFSA) and set the framework for food safety procedures. This law emphasizes quality management and process-oriented controls along the entire food chain, from production to consumption, and mandates traceability for all food, feed, and ingredients[7].

Specific regulations under this framework include Regulation (EC) No 852/2004 on food hygiene, which requires food business operators to meet hygiene standards at all production stages and implement HACCP principles. Regulation 853/2004 sets specific hygiene rules for food of animal origin and outlines requirements for identification marking and specific cases for certain aquatic

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[5] Directive 2008/56/EC of the European Parliament and of the Council of 17 June 2008 establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive).

[6] In Spain, according to data from the National Strategic Plan for Aquaculture 2021-2027, there are 2,902 establishments located in the Natura 2000 network, across 111 areas.

[7] REGULATION (EC) No 178/2002 of the European Parliament and of the Council of 28 January 2002 laying down the general principles and requirements of food law, establishing the European Food Safety Authority and laying down procedures in matters of food safety, art. 3.1.

animals. Regulation 854/2004 establishes rules for official controls on animal products intended for human consumption.

Additionally, Directive 2006/88 addresses animal health in aquaculture, focusing on the prevention and control of diseases, with amendments for further disease control. This directive categorizes diseases into exotic and non-exotic, with strict controls on the movement and importation of aquatic animals based on their health status.

Overall, the EU's legislative framework, applicable in this ecoregion, ensures the health and safety of aquaculture products through stringent control measures, disease management, and quality assurance protocols.

4.2.1.3 Specific EU regulation on organic aquaculture

The European Union, through its Farm to Fork and Biodiversity Strategies, aims to significantly increase organic aquaculture, including seaweed production, by 2030. To achieve this, a robust regulatory framework is essential. European organic aquaculture regulations, continually updated to reflect the sector's evolution, aim to provide clear rules for organic animal and seaweed production, ensuring uniform application across member states.

Regulation 710/2009 was a key development, being the first to specifically address organic aquaculture, including seaweed. It sets standards for seaweed culture, emphasizing the use of natural nutrients and integration into polyculture systems. EU regulations cover various aspects of organic aquaculture, such as stocking densities, water quality, respect for biodiversity, and restrictions on artificial spawning and feed sources. Special provisions are made for bivalve mollusc and seaweed production.

A significant update occurred with Regulation (EU) 2018/848, effective from January 2022, replacing the initial organic production regulation. This regulation aims to standardize organic production and labelling rules within the EU and in trade with third countries, requiring non-EU producers to comply with EU standards. The regulation introduces "group certification" for small-scale producers, facilitating their access to international markets and reducing inspection and certification costs (Idowu, 2020). This is particularly beneficial for small seaweed and aquaculture producers.

The regulation also acknowledges the unique nature of macroalgae aquaculture. Since seaweed naturally obtains nutrients from the sea, most seaweed can be considered organic. However, hatchery-based seaweed aquaculture might not always meet these criteria. Additionally, the regulation recognizes the concept of polyculture systems in aquaculture, allowing for the cultivation of multiple species within the same unit, enhancing sustainability and ecological balance.

4.3 Aquaculture legal Framework in Spain

Aquaculture in Spain is a long-standing tradition, as corroborated by the data on species and volume cultivated presented in chapters one and two of this document, placing this country among the top in Europe in terms of mollusc farming. This activity, which began in the 1950s and expanded into various types of aquaculture in the 1980s, has been supported by a legislative framework that has evolved step by step alongside the development of the aquaculture industry. The legislative production in Spain has been overwhelming, and perhaps it is in recent years when the legislation is no longer keeping pace with the technological evolution that aquaculture is experiencing. But efforts have been made in Andalusia, Galicia, and the Basque Country to try to accommodate new forms of aquaculture to their geography, traditions, and socio-economic aspects, as evidenced by their Strategic Aquaculture Plans.

In Spain, the system of competencies in aquaculture is further complicated because, in this decentralized State with Autonomous Communities, the competencies in aquaculture fall to these regional entities[8]. Additionally, unlike the fishing activity, this main rule does not set geographical limits on the exercise of this activity. Therefore, according to Spanish constitutional rules, the Autonomous Communities are competent in regulating everything related to aquaculture, even in territorial seas, beyond internal waters. However, there are several pieces of legislation applying to aquaculture (sanitary, environmental, sectoral, health, market, etc.) both from central government and from other decision-making bodies in the regions, or even from European legislation. Due to the overlapping of some competencies that would affect aquaculture, the conflicts caused for the lack of coordination in some cases, or the over-regulated scenario in others, usually result in the stagnation of aquaculture (Chapela *et al*., 2022).

In this situation, and before the Autonomous Communities exercised their competencies in aquaculture, the Spanish state published what can be called the first law on low trophic aquaculture with the Law 59/1969, on Shellfish Management, becoming the first law that generally regulates this sector for the entire national scope. It meant the transformation from an extractive activity for shellfish to the cultivation, especially for cockles, clams and mussels (Chapela, 2002). Lately, Spain published a more comprehensive Law 23/1984, 25 July on marine aquaculture. Soon, the Autonomous Communities reacted by exercising their powers, publishing their own laws on fishing and aquaculture. Galicia was the first and the most productive in terms of regulations for aquaculture in its various forms and spaces, with the Law for marine aquaculture 15/1985.

Now, aquaculture in Galicia is regulated by Law 11/2008, 3 December on fishing[9], a law that jointly addresses the fisheries and the aquaculture activity. Since that year, aquaculture has not been regulated individually in a specific text, but rather jointly with fishing in all these regions. This probably means that during the 1980s, public authorities wanted to reflect in the law what an authentic aquaculture boom was in those years, then relaxing to merge with fishing on a law that sometimes does not correspond to the technological advancements in aquaculture[10]. This new Law on fishing in Galicia has a complete chapter for aquaculture and its permits and monitoring of this activity.

As the main producer of aquaculture in Spain, the Autonomous Community of Galicia has taken the lead in regulation aquaculture in greater detail. This has been achieved through the laws along with regulations, that are tailored to different types of aquaculture and the specific areas where the activities are carried out:

a) Aquaculture in the maritime zone is regulated by Decree 406/1996, of 7 November, approving the Regulation of Marine Aquaculture cages in Galician waters.;
b) Aquaculture in the terrestrial zone: Decree 274/2003, of 4 June, regulating the procedure for obtaining permission and granting activity for aquaculture establishments and auxiliary aquaculture facilities in terrestrial areas.

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[8] According to the Spanish Constitution in its Article 148, aquaculture is an activity of exclusive competence for the Autonomous Communities.

[9] This law was modified by Law 1/2009 of 15 June on amendments to Law 11/2008 of 3 December on fishing in Galicia. (Official Journal of Galicia DOG No. 116, of 16 June) and Law 6/2009 of 11 December on amendments to Law 11/2008 of 3 December on fishing in Galicia. (Official Gazette of Galicia DOG No. 243, of December 15).

[10] This region tried to approve the first Aquaculture Act in 2016 in Spain, however surprisingly the draft bill has been temporarily retired and will be discussed again. The reasons for not approving this law should be found in the social license of aquaculture in Galicia. This Galician Regional Government's draft law on aquaculture has triggered concern and growing opposition across the region among members of the public and industries using the same zones as aquaculture, mainly some artisanal fishing sector and mussel producers.

Similar steps are being taken in Andalucía as well. Andalucía, the southern part of this ecoregion was the following region developing a strong legal framework for aquaculture. The Law 1/2002, 4 April, for planning, promoting and monitor fisheries and aquaculture. After approving a Strategy for the Development of Marine Aquaculture in Andalusia (Junta de Andalucía, 2014 b), this region decided to create its own legal framework for marine aquaculture, primarily aimed at simplifying administrative procedures and facilitating access to licenses for aquaculture promoters, thus, the Decree 58/2017 of 18 April regulates the marine aquaculture in Andalusia in depth. And this region continues to support aquaculture through a New Aquaculture Strategy aiming at enhancing and providing greater support to this activity. This includes maritime spatial zoning for aquaculture and streamlining the administrative procedures, thereby offering more legal certainty to aquaculture promoters (Junta de Andalucía, 2022).

Asturias has a law that also jointly regulates fishing and aquaculture, Law 2/1993, of 29 October, on Maritime Fishing in Inland Waters and the Exploitation of Marine Resources and includes a chapter on marine aquaculture. The Asturias law presents a simpler regulation, focused on marine cultivation in general in public domain areas, its licenses, concession procedures, causes of extinction, and inspection.

The Basque Country, on the Cantabrian coast of the Iberian basin, also regulates aquaculture in its 6/1998 Fishing Law. This Law delimits the content to marine cultivation, some principal rules about the licenses or permits, their termination, the declaration of areas of aquaculture interest by the Basque government, and an innovative section on the cultivation and harvesting of algae that will require an exploitation plan.

More recently, the Law of 1/2021, of Fisheries, Shellfish Gathering and Aquaculture of Cantabria, devotes a greater number of articles to aquaculture and goes into somewhat more detail than its neighbouring Autonomous Communities in regulating the procedure for granting licenses, and regulates experimental aquaculture authorizations. This law, being the most recent, is the only one that has explicitly included a reference to the scope of regional competencies beyond internal waters: to the territorial sea and the Exclusive Economic Zone, which is valid for all autonomous communities in Spain:

> **The regulations related to aquaculture are applicable to aquaculture activities carried out throughout the territory of Cantabria, in the maritime-terrestrial zone, in the internal maritime waters, in the territorial sea, and in the Exclusive Economic Zone off the coast of Cantabria (art. 2, c).**

Despite the different legal regulations for aquaculture, Spain has approved an Aquaculture Plan following the guidelines of the European Aquaculture Strategy and linked to the European funds from the EMFF. Thus, the document "Spain's Contribution to the Strategic Guidelines for a More Sustainable and Competitive EU Aquaculture 2021–2030" (MAPA, SGP, 2022), from the Ministry of Agriculture, Fisheries, and Food has developed its strategic planning with the collaboration of all the Autonomous Communities, trying to integrate common regulations and procedures for Spain. In addition to this, these Autonomous Communities have developed their own strategic plans, which are nowadays integrated into Spanish Plan for Aquaculture[11].

A notable example of good practice in institutional and administrative coordination in Spain is the establishment of the National Advisory Board of Marine Aquaculture (JACUMAR) created by the Law 23/1984 on marine aquaculture. This board serves as a stable mechanism for collaborative efforts and plays a foundational role in enhancing cooperation among administrations, sectoral organizations, and other stakeholders involved in aquaculture. JACUMAR, led by the

[11] This is the case of Galician, Andalucian and Basque Country regional aquaculture strategic Plans.

Spanish Ministry of Fisheries, includes the General Director of each Autonomous Community with responsibilities in aquaculture as advisory members (MAPA, 20023). Within this framework, they developed the Strategic Aquaculture Plan 2020–2030 for Spain. This advisory Body in Spain plays a crucial role in specific areas where the coordination between regions like Galicia, Asturias and Andalucía is needed especially when it comes to the development of the Marine Spatial Plan for Aquaculture. This was done in a highly coordinated manner with all Autonomous communities, which had a very positive effect on the final proposal agreed (European Commission, 2024).

4.3.1 Aquaculture Licensing Procedures in Spain

With some minor differences, the five regions in Spain that are part of this ecoregion, follow similar procedures for granting aquaculture permits. In this document, a synthesis of them is presented emphasizing the most relevant differences that contribute as good practices to simplify procedures and expedite processes.

Despite having exclusive competence to grant aquaculture permits, if this activity is carried out on public domain or state land, then they need a permit or a prior report from the holder of that space, which is the State Administration. This remains the case unless the State Administration decentralizes the management of said public domain to the Autonomous Communities, as has happened in some other parts of Spain like Catalonia or Andalusia. Therefore, any occupation in those areas for aquaculture needs an additional license or concession by Central or Spanish authorities according to the Spanish Law of Coasts 22/1988, and the Decree 1471/89, developing the Law of Coasts. The combination of both regional and national competences, results in complications and red tape when granting aquaculture licences, making this procedure for licence granting extremely complex and often results in legal vulnerability of the promoter (Chapela *et al.*, 2022).

the issue of licenses has been and continues to be one of the major problems hindering the development of aquaculture in Spain, even paralysing it in some places. It must be acknowledged that the administrations and public authorities have made great efforts to simplify procedures. Even the Constitutional Court has ruled on the nature of the State's concession to occupy the public domain, eventually admitting that a binding report from the Ministry of Environment would be sufficient to expedite the processes. Today, the issue of overlapping competences, which led to a duplication of concessions, has been resolved with the binding report of the Ministry responsible for the management of the coasts and the public domain and the aquaculture permit is granted by the regional administration.

In addition to the administration that holds the public domain and the administration granting the license for aquaculture, there are usually up to ten public administrations or authorities that can be involved in this process, as they need to issue their report or feedback to the management authority that grants aquaculture licenses. These include transportation, defence, environment, heritage or tourism. This leads to a complex procedure, as showed in Figure 4.1 present in the Spanish Aquaculture Strategy.

Briefly, the procedure begins with the application by the promoter, which is normally managed by the competent administration in aquaculture in the autonomous community. This administration will, in turn, be responsible for collecting other licenses or reports from different administrations, which can vary depending on the type of aquaculture establishment:

- Authorization for the occupation of public domain;
- Discharge authorization;
- Environmental authorization;

- Reports from entities in Defence, Fisheries, Tourism, Maritime Captaincy, Territorial Planning, Provincial Delegations, Cultural Heritage, Municipalities, and others, as appropriate;
- Buoy marking in the maritime zone.

Generally, it is necessary to present a report on economic and technical feasibility as well as an environmental assessment report, where applicable. In Spain, according to Law 21/2013 on environmental assessment, all intensive aquaculture facilities with a production capacity exceeding 500 tons/year must undergo a simplified environmental assessment.

The Ministry of Agriculture, Fisheries, and Food in Spain has made available on its website the procedures for obtaining authorization for aquaculture farms in each autonomous community. These guidelines serve as a reference for all relevant stakeholders[12].

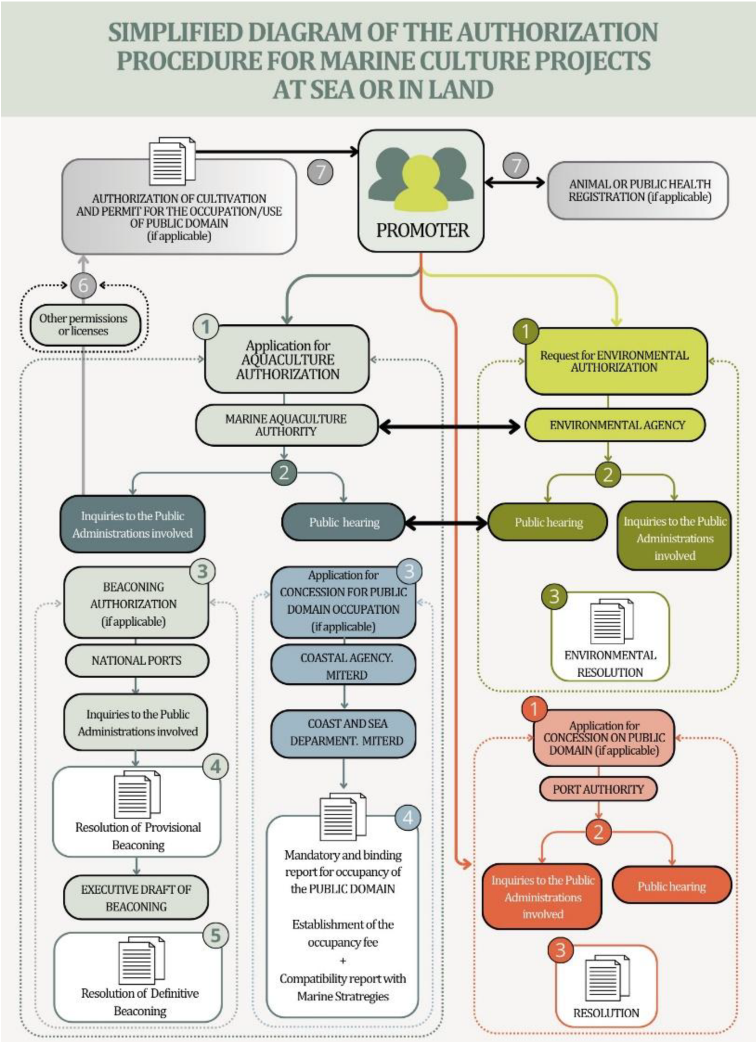

Figure 4.1 Simplified outline of the aquaculture permits authorization procedure. Translation based on the outline provided by the SGP-MAPA document in S'ain's Contribution to the Strategic Guidelines for Aquaculture, 2022.

This is a complex procedure that "on average can last almost 30 months and, in some circumstances, can be significantly prolonged" (MAPA, SGP, 2022), despite efforts to simplify by

[12] Spain's procedures for the authorisation of aquaculture farming in the different Autonomous Communities (last updated in 2022). General Secretariat for Fisheries of the Ministry of Agriculture, Fisheries and Food: https://www.mapa.gob.es/es/pesca/temas/acuicultura/datospracticos/gestion-administrativa/default.aspx.

establishing one-stop offices, reducing red tape, training public managers. However, the long duration of these procedures continues to be an obstacle to the development of the activity in Spain.

The legal frameworks in Galicia and Andalusia aim to simplify licensing procedures through streamlined legislation and better coordination tools among all the agencies and public authorities involved. The Andalusian Decree 58/2017 sets a maximum deadline of 6 months to issue the license in public domain. When aquaculture activities are developed on private properties, the deadline for resolution is two months. To achieve this administrative simplification and facilitate access to licenses and suitable spaces for aquaculture companies, Andalusia approved a specific law for the improvement and simplification of regulations to promote productive activities in Andalusia, including aquaculture (Decree-Law 2/2020, March 9). This regulation centralized the processing of activity and public domain occupation permits under a single authority in the region, subject to prior review by the State Administration.

In addition to simplifying administrative procedures, some administrations, such as the Galician government, have declared aquaculture a public interest activity through the resolution of 26 May 2011, and more recently, Law 4/2023, of 6 July, on the planning and integrated management of the Galician coast, also confers this strategic character to aquaculture on the coast. This designation provides greater protection for this activity by the authorities, both in terms of granting licenses and in establishing areas for aquaculture along the coast by giving it certain priority and improving the legal security to promoters.

The permit for aquaculture in Spain is issued for 10 years and might be extended to periods of a further 10 until a 30-year maximum. Generally, licenses can be transferred along with the facility, always with prior authorization from the administration. Similarly, they can be inherited if previously communicated to the competent body. In the case of maritime concessions in Galicia and Asturias, there is a preference for producer organizations and fishing guilds in the granting of the concession.

To facilitate the introduction of new aquaculture systems or the incorporation of new species, both autonomous communities, Galicia and Andalusia, which consider aquaculture as a strategic activity in their economies, regulate experimental authorization. These are temporary concessions that in Galicia will have a duration of five years and in Andalusia specifically for "new crops, innovative projects, or those without previous experience in the region," thus leaving the door open to new species or cultivation systems that want to experiment in Andalusia.

4.3.2 The Environmental Impact Assessment in Spain

Only specific types of aquaculture in Spain is subject to an environmental impact assessments (EIAs). Prior to the enactment of Law 21/2013 on Environmental Impact Assessment in Spain, regions had diverse regulations regarding EIAs, resulting in a heterogeneous situation with 17 different types of EIAs. This Spanish law standardized terminology and established common criteria for all regions of the country. While Spain develops the basic regulations, regions have the flexibility to introduce strictly necessary modifications to address their particularities (Ruiz de Apocada, 2018).

The competent body for issuing the environmental impact statement is the environmental authority in each region or Autonomous Communities, which is distinct from the authority issuing aquaculture permits. This environmental authority conducts a technical analysis of the file after the public information period and formulates the Environmental Impact Statement.

The law classifies environmental impact procedures according to the type of project: a regular evaluation procedure for projects of greater impact, although it does not specifically mention aquaculture (Annex I). In contrast, Annex II contains the Simplified Evaluation for projects with less significant environmental effects, including intensive aquaculture facilities when the production capacity exceeding 500 tonnes per year. In this case, the procedure is shorter.

The aquaculture promoter submits the environmental impact application to the agency that will grant the aquaculture license or the processing body. This agency verifies the information and forwards it to the competent environmental authority, which conducts a public information process for the environmental impact study. Within a period of three months, it will issue the environmental impact statement, authorizing or not authorizing the activity and establishing the necessary environmental requirements, if applicable.

If the project requires an environmental impact statement, once the public information period is completed, the file will be forwarded to the environmental authority as established in the corresponding regulations. (Article 11 of Galician Decree 274/2003, regulating the procedure for obtaining the permit and granting of activity for aquaculture establishments and aquaculture support facilities on land).

4.3.3 Maritime spatial planning and aquaculture

Some regions in Spain tried to reduce the procedures and improve their efficiency by designing coastal-zone planning for aquaculture, most of them defined as “interested zones for aquaculture” as it was described in the Law 23/1985 of Aquaculture, as “those zones that for its optimum conditions for aquaculture needs official protection”. Galicia has created polygons at sea for mussel aquaculture in rafts (bateas) (Decree 406/1996, regulation for marine cage aquaculture in Galician waters). Galicia has also published a Sectoral Plan for Aquaculture to establish suitable zones inland and in coastal zones in 2005 and replaced it with a new Aquaculture Plan in 2008. Within the framework of Directive 2014/89, Spain has approved the POEM, Marine Spatial Planning, agreed upon by all the coastal Autonomous Communities to delineate spaces for different activities along the coast, and the aquaculture among them[13]. In the case of Galicia, its entire coast has been declared as having potential for aquaculture, demonstrating the interest in this activity and its protection or priority over other possible activities that aim to establish themselves on the Galician coast, such as offshore wind farms. Galician government is developing the MARPLAN a decision-making tool to establish areas for maritime aquaculture to identify and quantify the socio-economic value of mollusc production in the Galician estuaries. This tool will assist aquaculture managers in making informed decisions regarding the allocation of zones and polygons aquaculture compared to other activities, while also promoting reconciliation with them[14].

The case of installing ocean energy systems through wind turbines is currently significant on the Spanish North Atlantic coast, affecting Galicia and Asturias, the North Atlantic Marine Demarcation, where the fishing and aquaculture sectors oppose the controversial creation of offshore wind farms outlined in the POEM. We are facing a controversial case with significant implications for a large part of the maritime-industrial sector in Spain. Indeed, fishing sectors traditionally established in Galicia and some NGOs have expressed their rejection and concern regarding the planning of these offshore wind energy projects[15]. Law 41/2010, of 29 December, on

[13] Royal Decree 150/2023, of February 28, which approves the maritime space management plans of the five Spanish marine demarcations (POEM).

[14] This decision-making tool is being developed during the writing of this chapter. https://www.xunta.gal/es/notas-de-prensa/-/nova/85695/cetmar-disena-una-nueva-herramienta-apoyo-toma-decisiones-ordenacion-espacial.

[15] Fishermen from Galicia and Asturias created the Platform in defence of fishing and marine ecosystems after the signing of the *Burela Manifesto*, promoted by the National Federation of Cofradías of Spain for the defence of ecosystems, fishing

protection of the marine environment, establishes that in the planning of the marine environment, an "adaptive management of human activities" must be followed. This will be applied following the precautionary principle and the ecosystem approach, and "taking into account scientific knowledge, to ensure that the combined pressure of these activities is maintained at levels compatible with achieving a good environmental status" (art. 4). In addition, the Royal Decree 363/2017, of 8 April, establishes a framework for maritime spatial planning. It emphasizes that in determining maritime spatial planning, "the peculiarities of marine demarcations, as well as relevant existing and future activities and uses and their impacts on the environment, especially on protected species and areas, and resources, must be duly considered. Interactions between land and sea must also be considered (art. 4.5).

Therefore, it would be of interest to address clearly and effectively in a spatial planning document the maritime and maritime-terrestrial areas where aquaculture can be developed in peaceful coexistence with other activities or without negatively affecting other economic interests.

In the southern part of the ecoregion, the Andalusian government has released a document that identifies suitable areas for Marine Aquaculture development. This document contains spatial, environmental, and sectorial information aimed at assessing the potential of areas for aquaculture. It categorizes zones as "suitable" for aquaculture and includes 'suitable areas with limitations,' which have lower potential for aquaculture. This publication corresponds to the 5th Stage of a project whose overarching goal is to identify suitable areas for the organized expansion of aquaculture along the Andalusian coast. This assessment takes into account inherent cultivation factors, existing uses, activities, and occupations, as well as the conservation of environmental values in the identified areas (Junta de Andalucía, 2014).

The purpose of this document is to provide information to the relevant administrations responsible for authorizing marine aquaculture and to potential new investors. It aids in selecting the optimal location for aquaculture spaces, considering environmental, technical, and administrative criteria. Furthermore, it ensures long-term legal security for companies operating in the sector.

The Andalusian aquaculture strategy itself stipulates that these areas will need to be reviewed and aligned with the provisions of the Marine Spatial Planning Plan (POEM) approved by Spanish government. In the case of Andalucía, the future development of the aquaculture sector has culminated in a Proposal for Spatial Planning in the South Atlantic Demarcation, illustrating the zones of future uses that have been studied and delimited within the framework of the work carried out by the regional administration. These zones have been included in the inventory of future uses of said planning. According to this proposal within the Spanish POEM, marine aquaculture production in Andalusia could exceed 14 000 tonnes in the coming years, showcasing aquaculture production diversity (MTERD, 2023).

4.4 Aquaculture Legal Framework in Portugal[16]

4.4.1 Aquaculture licensing procedures in Portugal

The legal regime for the installation and exploitation of culture establishments in marine, transition and inland waters is defined by Decree-Law No. 40/2017, of 4 April. This Decree-Law

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and better management of spaces for offshore wind power in coexistence with fishing and other activities in the seas, https://www.fncp.eu/wp-content/uploads/2022/07/NP-Manifiesto-de-Burela-Julio.pdf.

[16] Part of the content of this chapter originates from the work carried out within the framework of the AquaVitae project "New species, processes and products contributing to increased production and improved sustainability in emerging

declares in its Preamble, among different measures, "the purpose of launching an offshore aquaculture program, to resume aquaculture semi-intensive and extensive use of bivalves in estuaries, and to support the studied introduction of new species".

This legislation also encompasses associated facilities situated on privately owned land, state-owned domains (both private and public), as well as those under local authorities, including public water bodies.

Assuming that licensing procedures could be a barrier in aquaculture development, this Decree-Law specifically aims to allow "greater speed and agility in the treatment of processes associated with this productive sector". This regulation is a consequence of the provisions of the Strategic Plan for Portuguese Aquaculture, 2014–2020 in line with the European Strategic Guidelines for Aquaculture. This Plan, among other legal issues, prioritized:

"the adaptation of the legislation that covers the licensing of the use of the water domain and […] the simplification of procedures and definition of elements to be submitted by economic agents; creation of an electronic platform for the submission, analysis, and processing of licensing processes for aquaculture establishments"17.

The simplification process of aquaculture licensing is already implemented, as stated in the new Strategic Plan for Portuguese Aquaculture 2023–2030[18], occurring on the electronic platforms, ePortugal (https://eportugal.gov.pt/) and Bmar -Electronic Sea Counter (https://www.bmar.pt/), for the submission, analysis, and processing of licensing for aquaculture establishments in inland waters and in marine waters, including transitional ones, respectively.

It's worth noting that the Directorate-General for Natural Resources, Safety, and Maritime Services (DGRM) serves as the central coordinating authority for the processes involved in setting up and managing facilities in marine and transitional waters, along with their associated counterparts.

However, this new plan, recognizing the progress made in Portugal in the field of digitalization and simplification of procedures, envisages new actions to be implemented to further improve the aquaculture licensing process and to continue the improvement processes. For example, with the development of a licensing procedure guide to reduce the licensing period and to disseminate it among promoters. The design of active aquaculture zones and areas with potential for aquaculture will be represented on the e-aquaculture portal, with the goal to reduce the licensing period to 90 days by 2030, excluding the periods necessary for Environmental Impact Assessment or Environmental Impact Studies.

Licences to establish and operate a marine aquaculture facility are granted by DGRM (National Body for Marine Resources, art. 4º), after consultation and approval from APA (Portuguese Agency of the Environment). Approval from other public authorities may be required for specific cases or locations, this includes ICNF (National Institute for the Conservation of Nature and Forests), the competent port authority, and Autoridade Marítima Nacional (Nacional Maritime Authority), in cases where the facility is located within their jurisdiction. In addition, Instituto Português do Mar e da Atmosfera (National Institute for the Sea and Atmosphere), and Direção-Geral de Alimentação e Veterinária (State Veterinary and Food Administration) as stated in art.

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low trophic, and existing low and high trophic aquaculture value chains in the Atlantic". The Deliverable 8.1 analysed the legal frameworks of Spain, Portugal, Germany, Brazil, and South Africa, focusing on Long-Term Agreements (LTAs).

[17] Strategic Plan for Portuguese Aquaculture, 2014-2020, Ministry of Agriculture and Sea, Portuguese Government. Link.

[18] Plano Estratégico para a Aquicultura Portuguesa 2021-2030; DGRM (Direcçao Geral de Recursos Naturais, Segurança e Servizos Marítimos) https://mar2020.blob.core.windows.net/mar2020/2022/10/PT_PEA_2021_2030.pdf.

6º. This is a one-stop-shop process starting with an online application submitted to DGRM[19]. During the technical analysis of the requests, all the authorities competent in the matter are consulted and, if all the entities give a favourable opinion, the aquaculture licence is issued.

In cases where the licence is requested for an area of public domain information on the applicant identity, production area, production system, species, etc., will be advertised at DGRM´s webpage, competent port authority, and relevant municipality and parish council. If there is no objection by any other party (person or company) within the legally established time frame the licence may be granted to the applicant (if all other requirements are met). On the other hand, if there is another party interested in doing the same, then a competition will be held.

DGRM typically processes applications and makes decisions within 3 months. This timeline can vary, especially if there is competing interest in a project or if an environmental impact assessment is necessary. For a quicker licensing process, applications should be complete with all required documents. Incomplete applications will delay the process, as additional information is needed (information from DGRM). In some instances, the general licensing process can take up to a year (Chapela *et al.*, 2022).

The government has introduced the Blue Licensing system as part of the Simplex+ 2016 program, aimed at simplifying and speeding up aquaculture licensing. This system allows for applications in predefined areas and promises a 3-month processing time. However, most licenses are still issued through the general licensing system (information from DGRM).

A license (Título de Atividade Aquícola - TAA) details the species to be produced, their quantities, and the production regime, typically valid for up to 25 years. Under general licensing, this can be reduced to 10 years if deemed necessary, while Blue Licensing allows for renewal up to a total of 50 years. If a producer wishes to add a new species not included in their original TAA, they must apply to DGRM. Approval of this request leads to an update of the TAA, but if denied, a new application is required[20]. Each TAA has a unique code that simplifies the licensing and monitoring process of aquaculture establishments.

The Portuguese legal framework covers the production of various native species, including fish, molluscs, echinoderms, tunicates, and algae. It allows for the production of multiple species at the same facility under one license, opening the door for Integrated Multi-Trophic Aquaculture (IMTA) systems.

4.4.2 The Environmental Impact Assessment in Portugal

The regulatory framework for Environmental Impact Assessment (EIA) (DL 151-B/2013, in its current wording) describes two scenarios in which an aquaculture project intending to apply the intensive regime may under an EIA process. Extensive and semi-intensive establishments are exempt from the EIA.

The establishments situated in sensitive areas or those meeting the specified criteria in Annex II are obligated to undergo an EIA. According to Article 1, paragraph 3 b) iii), establishments characterized in Annex II may also undergo EIAs, irrespective of the thresholds. This determination is made through a case-by-case evaluation conducted by the licensing authority (DGRM), in consultation with the EIA authority (APA – Agência Portuguesa do Ambiente or CCDR – Comissão de Coordenação e Desenvolvimento Regional). In such instances, these entities evaluate whether the project's location, size, or nature is likely to have a significant impact on the environment.

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[19] https://www.bmar.pt/BMAR_Geral/faces/userauth/LoginX.xhtml?ssoOrigApp=BMAR_Geral.

[20] https://eportugal.gov.pt/fichas-de-encuadramento/aquicultura

Decree-Law no. 151-B/2013, describes the criteria for selection for EIA, like its location, and potential affect, governing the assessment of likely significant affect, are outlined in Annex III of that legislation (table 4.1).

Table 4.1 Criteria for EIA application (Source: DL 151-B/2013, in its current wording)

Fish farming in estuarine or similar systems or lagoon systems:	Project characteristics:
Area ≥5 ha or production ≥ 200 t/year; or area ≥2 ha or production ≥ 80 tonnes/year if, together with similar pre-existing units, less than 1 km apart, gives rise to an area ≥5 ha or production ≥200 t/year Floating structures: Production ≥200 tonnes/year, or production ≥80 tonnes/year if, together with similar pre-existing units, less than 1 kilometre apart, gives rise to production ≥200 tonnes/year.	a) Project size; b) Cumulative effects in relation to other projects; c) Use of natural resources; d) Waste generation; e) Pollution and nuisance caused; f) Risk of accidents, taking into account in particular the substances or technologies used.
Marine fish farming:	**Location of projects, in particular:**
Production ≥1000 t/year, in coastal waters, or, production ≥5000 t/year, in territorial waters.	a) The affectation of land use; b) The relative richness, quality and regeneration capacity of the area's natural resources; c) The absorption capacity of the natural environment, with particular attention to the following areas: i) Wetlands; ii) Coastal zones; iii) Ocean areas; iv) Mountain and forest areas; v) Nature reserves and parks; vi) Classified or protected areas, special protection areas, according to legislation; vii) Areas where the environmental quality standards set by national legislation have already been exceeded; viii) Areas of high population density; ix) Historically, culturally or archaeologically important landscapes.

As per the guidelines outlined in Annex IV of the legislation, individuals or entities undergoing an Environmental Impact Assessment are required to furnish a project overview, an account of the project's location, and a comprehensive evaluation of its potential affects. The determination regarding the EIA must be finalized prior to the issuance of the license.

4.4.3 Maritime spatial planning and aquaculture in Portugal

The Decree-Law Decreto-Lei n.º 309/93 imposed, for the coastal and shoreline area of the mainland, the elaboration of Coastal zone Management Plans (POOC). Despite not being embodied in a binding legal instrument, this plan, by virtue of Decree-Law no. 38/2015, of 12 March, in its current wording, came to be considered as the reference situation for the management of the national maritime space and for the issuance of titles of private use until the approval of this current Plan.

Following the Directive 2014/89 guidelines, Portugal approved the PSOEM, the National Maritime Spatial Planning Situation Plan for the Mainland subdivision, the Madeira subdivision and the Extended Continental Shelf subdivision, approved by Council of Ministers Resolution 203-A/2019[21]. The PSOEM defines spaces for different maritime activities, including aquaculture, along the coast of the mentioned regions. This plan classifies existing aquaculture zones and potential aquaculture zones, and for this purpose, it envisages a series of conditions for the classification of these potential zones, including depth, location outside the protected area, impact on Vulnerable Marine Ecosystems, dredging zones, fishing zones, etc. The document is accompanied by maps showing the aquaculture zones. This Plan includes the existing Aquaculture production zones (APAs) and the new ones. The APAs have defined environmental carrying capacities and can also define what type of aquaculture activity might be used in that area. The PSOEM includes also three zones for multipurpose platforms where marine aquaculture could be developed.

The Maritime Spatial Situation Plan (MSSP) aims to promote the compatibility between competing uses or activities. It aims to contribute to better and greater economic use of the marine environment and to minimize the impacts of human activities on the marine environment[22].

4.5 Aquaculture Legal Framework in France

The regulation of the aquaculture sector in France relies on two pillars: one related to licensing and the other concerning health control and marketing of seafood products.

4.5.1 Aquaculture licensing procedures in France

The conditions for the occupation of the maritime public domain (MPD) are defined by Decree 83-228 of 22 March 1983, establishing the authorization regime for marine culture operations, amended in 1987, which introduced the management of aquaculture activities by production basin under a co-management system between the Administration and professional representatives. Subsequently, the amendment to the decree in 2009 stipulates the development of sectoral management plans at the level of the country's administrative departments.

At the regional level, local planning documents for aquaculture regulation define, by production basin, the rules for the occupation of maritime domain and their use for shellfish production (types and densities of cultures, minimum and maximum sizes held by an operator, concession values, etc.). Marine Culture Commissions handle license allocation and, more broadly, proposals for management rules at the production basin level. These are defined by the Rural and Maritime Fisheries Code [Regulatory Part (Articles D111-1 to R958-33)], which describes the composition and co-management systems between professionals and the Administration, with the advisory participation of other stakeholders (Article D914-4).

The Plan Aquacultures of the Future 2021-2027, submitted as the Multi-annual National Strategic Plan for the development of sustainable Aquaculture, according to the Strategic EU Guidelines, establishes as first strategic lines the access to water and the simplification of administrative procedures.

Simplifying fish-farming procedures is crucial to this Plan. Once annual production reaches 20 tons, fish farms fall under a regime requiring authorization and environmental assessment. These processes can be complex and time-consuming, often discouraging project leaders. To

[21] https://diariodarepublica.pt/dr/detalhe/resolucao-conselho-ministros/203-a-2019-127659203

[22] https://webgis.dgrm.mm.gov.pt/portal/apps/webappviewer/index.html?id=9ea76f6fe4ca463a8ced196e30fcc2e1

address this, proposed modifications to regulations governing fish farms aim to streamline administrative procedures, allowing smoother sector development while maintaining high environmental standards. A task force comprising industry representatives, technical institutions, and government authorities was formed to tackle this challenge. As a result, measures were adopted to revise authorization thresholds and establish a simplified registration scheme for fish farms producing between 20 and 100 tons. This will streamline processes and reduce costs for producers[23].

An innovative element established by the Plan, unlike some of the plans of the Member States, is the promotion of IMTA. Although some French companies already practise it, IMTA continues to be the subject of studies to optimize flows between different trophic levels and economic viability. Additionally, the Plan highlights the need for regulations that consider the particularities of this technique to promote its development.

The plan includes several measures to modify aquaculture regulatory developments to simplify licensing administrative procedures, demonstrating that this remains a problem to be addressed.

On the health front, European regulations frame the marketing of aquaculture animals to prevent the spread of pathogens or toxins. In France, European Regulation (EU) 2016/429 regarding animal health legislation was transposed into national law by Ordinance No. 2021-1370 of 20 October 2021.

4.5.2 The Environmental Impact Assessment in France

In accordance with European regulations (European Directive 2001/42 of 27 June 2001) and its transposition into French law by articles R. 122-4 and R122-17 of the Environment Code, new applications for aquaculture facilities and the plans of aquaculture management at French Department administrative scales must comply with environmental assessment procedures. Fish-farming enterprises, for those producing between 5 and 20 tons, are required to make a declaration under the Classified Facilities for Environmental Protection (ICPE) and obtain prior authorization for production levels exceeding 20 tons. This regulation is governed by Book V of the Environmental Code and concerns enterprises that may pose risks of pollution and nuisances to residents. In addition, this environmental assessment regime also covers Natura 2000 impacts, in order to verify the compatibility of an aquaculture activity with the conservation objectives of Natura 2000 sites.

This environmental assessment must take into account all regulatory frameworks that are subject to environmental protection measures, such as the Water Framework Directive, local water management plants, the Marine Environment Framework Directive or territorial management directives (“Directives Territoriales d'Aménagement”). There no specificities relying to EIA procedures at this ecoregional level.

4.5.3 Maritime spatial planning and aquaculture in France

France has been one of the pioneer countries in coastal management and regulation, striving to reconcile traditional and economic uses with other activities, as well as with the protection of the coastal and marine environment. In fact, the Law No. 86-2 of 3 January 1986, concerning the planning, protection, and development of the coastline, constitutes a mandatory reference in the legal framework for coastal planning, spatial planning, and the reservation of areas for activities inherently linked to the proximity of the sea. The legislator, aiming to address the competing

[23] Plan aquacultures d’avenir 2021-2027; https://www.mer.gouv.fr/sites/default/files/2022-03/.pdf

interests on the coast, establishes a hierarchy of traditional activities, including marine farming activities, shellfish farming, or coastal fishing, alongside more recent ones. Marine aquaculture and its more traditional version of shellfish farming receive extreme care in the Law, to the extent of safeguarding aquaculture from others that coexist with it, such as the construction of marinas, which may negatively affect it. Article 21, concerning the concession for the construction of a marina, warns that, if necessary, its granting may be conditioned by the obligation to rebuild an area of artificial beach or an "equivalent shellfish or aquaculture potential to what will have been destroyed by the construction works." Similar protection is derived from the limitation or prohibition of extracting materials as soon as they may endanger beaches, dunes, and the "natural deposits of living shellfish and marine farming operations" (Article 24). The Coastal Law also ensures that the aquaculture business sector is represented and participates in the development of "master plans and land use plans for coastal municipalities," through the Regional Sections of Shellfish (Conchyliculture) Farming, thus securing the interests of aquaculture professionals in coastal planning (Article 8).

Now, the Law No. 2016-1087 of 8 August 2016, for the reconquest of biodiversity, nature, and landscapes ensures, through its article 123, the introduction of a specific Article L 219-5-1 dedicated to maritime space planning in the Environmental Code. This planning is defined as "the process by which the State analyses and organizes human activities at sea from an ecological, economic, and social perspective" (Art. L. 219-5-1 of the Environmental Code)[24]. This planning is done by ecoregion according to a national framework. France has chosen to build a joint approach to implement maritime spatial planning and the Marine Strategy Framework Directive (Directive 2008/56/EC), aiming to reconcile support for the sustainable development of a "blue economy" with the preservation of the marine and coastal environment. Planning at the scale of each ecoregion is described in the Strategic Ecoregion Documents (DSF in French acronym as “Document Stratégique de Façade”) that includes a strategic component and an action plan to achieve the goals set in this planning. The Regional Plans for the Development of Marine Aquaculture introduced by the Law on the modernization of agriculture and fisheries of 27 July 2010, Article L. 923-1 of the Rural and Maritime Fisheries Code list marine areas potentially suitable for reservation for the development of marine aquaculture. This planning must be compatible with this general governance framework. Thus, Article L. 219-4 of the Environmental Code defines the opposability regime of the “DSF”, within which the Regional Plans for the Development of Marine Aquaculture are included.

The Plan Aquacultures of the Future 2021–2027 establishes as objectives in this area:

- Conservation of existing sites for aquaculture
- Enriching the Geolittoral aquaculture portal: Ensuring that aquaculture is considered in the revision of planning documents; Provide for the possibility of shellfish and seaweed farming farms within offshore wind farms, in conjunction with the strategic façade documents (DFS); Integrate the objective of aquaculture development within the Water Development and Management Plans (SAGE/SDAGE) (Plan aquaculture d’avenir).

This map is expected to be available during the DSF review in 2024. Local urban planning and territorial coherence schemes must be compatible with this map, allowing for the reservation of sufficient areas for production and preserving others for future developments, especially in areas with high competition for access to the sea. This map of aquaculture vocations will become the new-shared Regional Plans for the Development of Marine Aquaculture (SRDAM) at the

[24] Art. L. 2194.I. Must be compatible with, or made compatible with, the objectives and provisions of the strategic document for the coastal area or maritime basin: "3. Schemes for the development of the sea; "4. Regional schemes for the development of marine aquaculture provided for in Article L. 923-11 of the Rural and Maritime Fisheries Code.

regional level. To improve the mapping of suitable sites for aquaculture, a feasibility study of national systems determining the best possible locations for aquaculture (MEAP) was conducted in 2017. This resulted in the creation of a cartographic web portal as part of the MTES marine and coastal data portal called Géolittoral. This portal, known as the Aquaculture Portal, provides information on marine aquaculture sites but does not include continental aquaculture sites. However, additional modelling tools are being developed, including MOCAA (Ifremer-DGAMPA) to predict the environmental impact of different types of aquaculture crops (Callier *et al.*, 2023).

4.6 Conclusions

The European Commission, through successive Aquaculture Strategic Guidelines and the National Aquaculture Plans of each Member State has contributed to homogenizing legislation to some extent in the ecoregion. The coordination mechanism, as governance system between MS and European Commission, is the key element to address the main legal aquaculture constraints. This has led to the simplification of licensing procedures by establishing processing agencies and setting maximum deadlines for license resolution. It has also established coordination systems among different agencies involved in these administrative procedures, as seen in France, Spain, and Portugal, aiming to reduce the resolution time of procedures and contribute to the development of aquaculture.

The MS of this ecoregion have developed marine zoning policy to organize these areas with special attention to aquaculture among other blue economy activities. By declaring potential aquaculture zones for the future and accounting for them alongside other activities, it helps highlight the role of this activity in the ecoregion and particularly its social reputation. In many cases, citizens' opposition to aquaculture stems from the "not in my backyard" principle, environmental concerns, and aesthetic considerations. Therefore, the planning of marine spaces and the designation of suitable areas for aquaculture will contribute not only to streamlining administrative procedures and license issuance but also to improving public perception. This will recognize the need for spaces dedicated to aquaculture, thereby enhancing the social acceptance and understanding of this vital activity within the ecoregion.

The potential of aquaculture the Bay of Biscay and Iberian Coast is undoubtedly undeniable, with the support of the EU and its funding, but we must not forget the latest report from the EU Court of Auditors pointing out that despite increased EU funding and all the EU aquaculture policy, the aquaculture production is stagnated and with unclear results. Some key strategies for the environment did not consider aquaculture properly. Moreover, spatial planning and licensing procedures still hampered the growth of the aquaculture sector (European Court of Auditors, 2023), which is even more striking, especially now that aquaculture is receiving support from the European Union, Parliament, and Commission in the form of regulations and assistance.

This is still evident today as one of the main barriers to the development of marine aquaculture in the ecoregion, specifically along its Atlantic facade with great potential for the development of this sustainable activity for the production of marine food, especially given the fact that the EU imports 70 % of the fish it consumes (EUMOFA, 2024) and aquaculture is presented as a present and future alternative.

In many cases, technological advancements in aquaculture outpace the relevant legislation. Public authorities often struggle to keep up with the rapid development of the aquaculture sector, and as a result, many of these technological innovations cannot be implemented due to the absence of a supportive legal framework. Therefore, it is crucial to enhance the training and knowledge of civil servants and policymakers responsible for managing aquaculture. By doing so, they can more effectively adapt to changes and approve or amend regulations to facilitate access to this activity, ensuring that legislative frameworks are responsive and conducive to the evolving needs of the aquaculture industry.

In this sense, aquaculture is still facing many challenges in relation to technologies, climate change, disease control, and its adaptation to new legal frameworks, as for example in terms of new aquaculture technology systems (e.g. Recirculated Aquaculture System - RAS, oceanic sea cages), Integrated Multi-Trophic Aquaculture (IMTA).

5 Management Frameworks

Contribution Laura Ribeiro, José Perez

5.1 Aquaculture Health and Food Safety Regulations

ICES (2022) communicated that the majority of food safety and animal health legislation governing the management of fish health on shellfish and finfish farms in the Celtic Seas ecoregion derives primarily from EU legislation. The same is true for the Bay of Biscay and Iberian Coast ecosystem. The overall aims of the legislation for all jurisdictions are similar, outlining parameters for the prevention and control of aquatic animal diseases and requiring operators of all aquaculture establishments to be approved by or authorized by the competent authority. They outline monitoring programmes for listed notifiable diseases and other aquatic diseases of national importance. To this end, a number of notifiable diseases are routinely monitored for in both finfish and shellfish. All establishments must operate in accordance with an approved biosecurity measures plan, which is generally developed by the business and regulator, with the latter possibly providing guidelines on how this should be created and in line with larger strategies. Operators in all jurisdictions are subject to a number of licence or authorization conditions, which may include generic conditions such as mandatory record keeping of movements on/off a site to facilitate disease tracing as well as specific conditions that may be site- or species-specific.

Portugal

National laws are designed primarily to transpose EU legislation, to this end, the following national legislation cover animal health and food safety directives:

- Decree-Law nº152/ 2009 of 2 July 2009 – Transposition of Directive 2006/88/CE of 24 October 2006 into national legislation.
- Decree-Law nº63/2013 of 10 May 2013 - First amendment of Decree-Law nº 152/2009 of July 2, which establishes the zoo-sanitary requirements applicable to aquaculture animals and derived products. It transposes Commission Implementing Directive 2012/31/EU of 25 October 2012.
- Decree-Law nº 169/2014 of 6 November 2014 - Second amendment to Decree-Law no. 152/2009, of 2 July 2009, transposing Commission Implementing Directive nº 2014/22/EU, of 13 February 2014, with regard to infectious salmon anaemia.
- Regulation (EU) No. 2017/625 of 15 March, establishes general rules relating to official controls and other official activities aimed at ensuring the application of food and feed legislation and rules on animal health and welfare, plant health and plant protection products.
- Directive 2006/88/CE of 24 October 2006 - On animal health requirements for aquaculture animals and products thereof, and on the prevention and control of certain diseases in aquatic animals; No longer in force since 20/04/2021, being replaced by Regulation (EU) 2016/429 of the European Parliament and of the Council of 9 March 2016 on transmissible animal diseases and amending and repealing certain acts in the area of animal health.
- Implementing Regulation (EU) 2019/627 of 15 March 2019 establishing uniform practical arrangements for carrying out official controls on products of animal origin intended for human consumption, in accordance with Regulation (EU) 2017/625 of the European Parliament and of the Council, and amending Commission Regulation (EC) No 2074/2005 as regards official controls.

- Carrying out official controls is without prejudice to the main legal responsibility of food business operators to ensure the safety of foodstuffs, as set out in Regulation (EC) No. 178/2002 January 28, 2002.
- Decree-Law No. 113/2006 of 12 June 12 aims to ensure the execution and guarantee compliance, in the national legal system, with the obligations arising from the Regulations (EC) No. 852/2004 and No. 853/2004, of 29 April, namely through the creation of a sanctioning framework for infringements of the rules contained in these regulations.
- Commission Implementing Regulation (EU) 2019/627 of 15 March 2019 laying down uniform practical arrangements for the performance of official controls on products of animal origin intended for human consumption in accordance with Regulation (EU) 2017/625 of the European Parliament and of the Council and amending Commission Regulation (EC) No 2074/2005 as regards official controls (Text with EEA relevance.) In force, consolidated version in 09/01/2023.
- Commission Implementing Regulation (EU) 2019/627 of 15 March 2019 laying down uniform practical arrangements for the performance of official controls on products of animal origin intended for human consumption in accordance with Regulation (EU) 2017/625 of the European Parliament and of the Council and amending Commission Regulation (EC) No 2074/2005 as regards official controls (Text with EEA relevance.). Consolidated version in 09/01/2023.
- Regulation (EC) No 853/2004 of the European Parliament and of the Council of 29 April 2004 laying down specific hygiene rules for food of animal origin. Consolidated version in 15/02/2023.
- EU Commission Regulation (EU) No 786/2013 of 16 August 2013 Amending Annex III to Regulation (EC) No 853/2004 of the European Parliament and of the Council as Regards the Permitted Limits of Yessotoxins in Live Bivalve Molluscs.

Chemical contamination

- Commission Regulation (EC) No 1881/2006 of 19 December 2006 - setting maximum levels for certain contaminants in foodstuffs (Text with EEA relevance). Commission Regulation (EU) 2023/915 of 25 April 2023 on maximum levels for certain contaminants in food and repealing Regulation (EC) No 1881/2006 (Text with EEA relevance). In force consolidate version in 10/08/2023.

France

Sanitary and animal health regulations in France

- Regulation (EC) no. 853/2004 concerning specific hygiene rules for food of animal origin. In Annex III, Section VII sets out the rules that apply to live bivalve molluscs from production to dispatch and marketing.
- Regulation (EC) no. 854/2004 concerning specific rules for the organization of official controls on products of animal origin intended for human consumption (Annex II on live mollusc bivalves covers control of the classification of production areas and control of relaying).
- The latest amendments to Annex II of Regulation (EC) no. 854/2004 concerning certain requirements for live bivalve molluscs, have been set out in a new regulation (EU) no. 2285/2015. This introduces a 20% tolerance for results of E. coli.
- Decree n°2012–1220 of 31 October 2012, amending the provisions relating to the sanitary conditions for the production and marketing of live shellfish and updating the regulatory part of the code of rural and maritime fisheries relating to the production and marketing of live shellfish.
- Decree of 6 November 2013 relating to the classification, monitoring and sanitary management of production areas and relaying areas for live shellfish.

- Council Directive 2006/88/EC of 24 October 2006 covers animal health requirements for aquaculture animals and products, and the prevention and control of certain diseases in aquatic animals. This European directive led to the consequent amendment of French law (Code rural) by Decree no. 2008-1141 and the promulgation of a decree on November 4, 2008 (bearing the same title as the European directive).

5.2 Monitoring and Management

Within the general framework of European food law, it is up to member states to ensure the implementation of food, animal health and animal welfare legislation, as well as to verify compliance with relevant requirements thereof by operators at all stages of processing, production, transformation, and distribution. For this purpose, official controls are organized as National Animal Health Plan.

In Portugal, according to the Regulatory Decree No. 31/2012 of 13 March, the General Directorate of Food and Veterinary (DGAV – Direção Geral de Alimentação e Veterinária) is responsible for defining, implementing and evaluating food safety, animal protection and animal health, plant protection and plant health policies, being invested with the functions of national veterinary and phytosanitary health authority and authority responsible for managing the food safety system.

The National Animal Health Plan includes surveillance of aquatic organisms. In the last report on Animal Health for the period between 2016 and 2021, the number of aquaculture facilities controlled (marine and freshwater, under intensive, semi-intensive or extensive regime) varied from 67 to 74. The official controls are for Viral haemorrhagic septicaemia (VHS) and Infectious haematopoietic necrosis (IHN) diseases. The species controlled were turbot, trout and other marine fish species, respectively 5.4.

Results from 32.4 facilities, and 62.2% of the total facilities, analysed in 2021 were negative for the notifiable diseases. Nonetheless, some facilities were classified under surveillance, for turbot one out of four, and for trout one out of 24.

The notifiable diseases for shellfish are *Bonamia ostreae* in European flat oyster and *Marteilia refringens* in European flat oyster and mussels. The sampling effort increased between 2016 and 2021 (site and number of samples). Negative results were obtained for oysters both *B. ostreae* and *M. refringens*. Mussels tested positive for *M. refringens,* for the reported period, with the incidence of infected mussels decreasing from 100% to 32% of the total mussels analysed.

The Portuguese monitoring program for shellfish safety, under the responsibility of the Portuguese Institute for the Sea and Atmosphere, was implemented in 1986. Currently, the Portuguese monitoring programme comprises 40 classified shellfish-producing areas divided into 13 offshore production areas and 27 estuarine and lagoon areas (https://www.ipma.pt/pt/bivalves/), analysing microbiological, metal and biotoxin hazards (Braga *et al*., 2023). The monitoring program of shellfish production areas underwent a considerable improvement between 2011 and 2020, with an increase in the number of tested samples and their representativeness (Braga *et al*., 2023).

In France, there are monitoring frameworks for phytoplankton (REPHY) and phycotoxins (REPHYTOX), in addition to microbiology in shellfish (REMI) and chemical contaminants (ROCCH) as they relate to seafood produced via aquaculture operations in French coastal areas (Lemoine et al., 2018). Governed under EU and National legislation, the monitored parameters represent those likely to present a risk to human health. Sampling is carried out at specified frequency and analysis is carried out at accredited laboratories and overseen by the National Reference Laboratory (https://envlit.ifremer.fr/Surveillance-du-littoral).

REPHY and REPHYTOX.

The development of phytoplankton (abundance, biodiversity and biogeographic distribution) depends on the conditions it finds light, temperature, nutrients, interactions with other living organisms present, etc. Its observation in coastal areas provides valuable information on the state of the masses. water, on the health of ecosystems and on the health risk linked to toxins. Ifremer (France) has deployed two networks, REPHY and REPHYTOX, to observe phytoplankton and monitor phycotoxins in French coastal areas (Lemoine *et al.*, 2018).

REPHY (network for observation and monitoring of phytoplankton and hydrology in coastal waters: phytoplankton in water).
REPHYTOX (monitoring network for phycotoxins in marine organisms: toxins (produced by phytoplankton in shellfish)).

The objective of the REPHYTOX network is health, with the detection and monitoring of regulated toxins likely to accumulate in marine consumer products, in particular bivalve molluscs from production areas (shellfish farming and fishing). The toxins regulated at European level belong to three families:

- lipophilic toxins including diarrheal toxins (DSP), produced in particular by Dinophysis phytoplankton. They can cause rapid onset digestive disorders in the consumer, most often not serious;
- paralytic toxins (PSP) produced by Alexandrium phytoplankton. They can cause rapid onset, potentially serious, sometimes fatal neurological disorders in the consumer;
- amnesia toxins (ASP), produced by Pseudo-nitzschia phytoplankton. They can cause neurological disorders in the consumer that are generally rapid in onset, potentially serious, and sometimes fatal.

REMI:

The REMI monitoring framework ensures health surveillance and classification of shellfish production areas, based on the enumeration of *Escherichia coli* (E. coli). This monitoring aims to estimate the microbiological quality of shellfish production areas and to detect and monitor unusual episodes of contamination.

ROCHH:

The list of monitored contaminants is available on Ifremer website (https://envlit.ifremer.fr/Surveillance-du-littoral/Contaminants-chimiques/Contaminants-suivis) and include Heavy metals, Pesticides and Industrial pollutants. The monitoring protocols are detailed in AQUAREF (2015)

The production zones are classified A, B and C, depending on criteria for the classification of production zones (based on REMI and ROCHH monitoring).

6 Ecosystem/Environment Interactions

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Interactions between aquaculture and ecosystems are governed by the cultured species (type of species, production stage, trophic level, fed vs. unfed species), the method of culture (land-based vs. coastal, pond vs. open-water system), the location (intertidal vs. subtidal) and the type of production (fish cages/land-based/RAS and shellfish Longline/bouchot/parcs/bags/bateas). It also depends on farming practices, including the density of the production, the amount of feed provided (Intensive vs. semi-intensive vs. extensive culture) and the "receiving" ecosystems (Aubin *et al.*, 2019). Throughout the BoBIC ecoregion, the main cultured species within the marine environments (see chapters 2 and 3) are bivalves (*M. gigas, Mytilus edulis, Mytilus galloprovincialis, Ruditapes philippinarium, Ruditapes decussatus*) and finfish (*Scophtalmus maximus*, *Dicentrachus labrax*, Gilthead sea bream and *Sparus aurata).*

The present chapter will not cover all aquaculture-ecosystems interactions as a number of reports have already considered these and provided a synthesis of aquaculture interactions (e.g. WGEIA 2022 report). This Chapter will focus on the interactions that we considered, as an expert group, as particularly relevant to the BoBIC region, considering farmed species and published studies. Interactions must be considered from two perspectives: the impact of the aquaculture on the environment (e.g. waste production). The impact of the environment on aquaculture (contaminant, welfare, disease, stress, among others).

6.1 Impact of aquaculture on ecosystems

6.1.1 Finfish farming

The impact of finfish farming at farm and ecosystem scales has been well documented and include the effects related to feed production, the release of nutrients into the environment (solid waste and dissolved nutrients) and, the release of treatments/pollutants, genetic introgression (from escapees). Finfish production in the BoBIC ecoregion is relatively small compared to other ecoregions. The total production of finfish is approximately 26 088 T per year (17 953 T in Spain in 2021, 7842 in Portugal in 2021 and 293 T in France in 2021). In comparison, the production is ten times higher in the Celtic Seas ecoregion (200 000 T) and 54 times higher in the Norwegian sea ecoregion (at 1.4 million T).

6.1.1.1 Feed

On a global scale, main impacts of fish farming are linked to the ingredients needed for production of feed. Fish feed is composed of terrestrial and marine ingredients with impacts on ecosystems in other regions of the world. The production of marine ingredients (fishoil and fishmeal) typically involves harvesting large quantities of wild fish, which can lead to overfishing and depletion of some fish stocks (Corten *et al.*, 2017). This is concerning for small, pelagic fish species, usually harvested for aquaculture feed, that are a critical part of the ocean's food chain. Also, most of these fish are of human-grade (Cashion *et al.*, 2017), and therefore aquaculture feeding is in competition with direct human nutrition, especially in Africa, in sub-Saharan countries (Corten *et al.*, 2017; Thiao and Bunting, 2022). Yet, increasing efforts are made to reduce pressure on wild stocks by improving feed composition and feed conversion ratio. The emblematic example of this reduction is the formulation of feed for salmon which used, in the 90s, 80% of marine ingredients, it is now around 22% (Aas *et al.*, 2022). In parallel, fishmeal and oil are increasingly obtained from by-products of fisheries. As a consequence of all these efforts, the quantity of fish required to produce 1 kg of fed marine finfish is estimated at 0.94 kg (In supplementary table 3 of Koch *et al.* 2020) (NB: there is a variation in the percentage of each component (and/or the fish species and stock of harvested fish used to manufacture the feeds) depending on the prices of raw materials). Therefore, for the BoBIC ecoregion, it can be estimated that the annual production of approx. 26 000 tons of fish required 24 440 tons of wild fish. Yet, this is only a gross approximation, which can greatly vary depending on the species, the production practices, the environmental conditions, and the price of ingredients. For marine species, studies on the potential of alternative ingredients (including algae, insects, etc.) are in progress (see Le Gouvello and Simard, 2017). Concerning terrestrial ingredients, we can report general environmental impacts related to classic crop production such as land-use, freshwater use, and Greenhouse gas release. Terrestrial food ingredients represent the major source of these global scale impacts for fed marine finfish production (Gephart *et al.*, 2021). Since shellfish and algae productions are not fed, these environmental impacts do not apply. The vast majority of aquaculture production in the ecoregion is therefore not concerned by these impacts.

6.1.1.2 Nutrient wastes

At the farm level, the release of faeces, uneaten feed and dissolved waste may induce organic enrichment around finfish production and may decrease water quality and induce modification of benthic and pelagic ecosystems (Hargarve, 2005). Fish waste includes particulate organic matter (i.e. faeces, uneaten feed) and dissolved inorganic nutrients (fish excretion). Particulate organic matter may accumulate under fish cages and induce organic enrichment with local impact on the sediment biogeochemical characteristics of the sediment (anoxia, increase of H2S), and modification of the benthic community diversity, abundance and structure. Nearfield impacts have been well studied and are measurable, however far-field effects are less studied and more difficult to measure. In coastal areas under pressure from multiple activities, it is difficult to determine the contribution of nutrients from finfish farming to systems that are already nutrient enriched.

- In France, on the French Atlantic coast, the fish-farm production is low (see Chapter 2). Only four finfish farms are located in this ecoregion including 3 land-based systems: Environmental Impact Assessments are carried out although no publications are available.
- Few references are available regarding nutrient waste estimation and revalorization of wastes and sub-products in the Spanish Atlantic coast. Fraga-Corral *et al.*, (2022) selected the Galician coast as a case study. The authors analyse the production data and the generation of waste and by-products and, concluded that a bio-economy model should be adopted for their reuse and to reduce their negative environmental impact. As far as we know, aquaculture companies in Spain carry out Environmental Impact Assessments, but the results are confidential. In Galicia guides for the realization of environmental monitoring plans for marine cultures in floating cages and land-based fish farms installed on the coasts of Galicia are published (https://mar.xunta.gal/es/el-sector/acuicultura).
- In Portugal, along the Atlantic coast (western and south) the majority of marine finfish aquaculture is located in the ecoregion. There are several land-based finfish aquacultures in earth ponds within the lagoons (Ria de Aveiro, Sado Estuary, Ria de Alvor and Ria Formosa) under a semi-intensive regime. Two intensive land-based fish farms are located in Praia da Tocha and south of the Praia de Mira, responsible for 45% of the total marine fish production in 2021. Finfish production in cages also exists in Sines and in the South of Portugal. Fish farms in transitional waters are generally located close to areas of good water renewal, with high water exchange rates with oceanic water, to ensure an appropriate and healthy production. Furthermore, due to their privileged location, the

potential impact of the fish-farming effluents is reduced by dilution with clean coastal or oceanic waters.

6.1.1.3 Mitigation: fallowing, and Integrated multi-trophic aquaculture

The main strategies to mitigate the impact of fish waste on the environment are:

1. proper selection of production sites based on the evaluation of the carrying capacity of the ecosystem,
2. fallowing i.e. halting the production for a variable period of at least several months moving the farm to a different location (Zhulay *et al*., 2015),
3. improving the feed conversion ratio (by improvement of feed composition, selection program) and
4. better management practices, such as the use and development of innovative farming systems such as recirculating aquaculture system (RAS) and integrated multi-trophic aquaculture (IMTA) to improve the treatment and valorisation of waste.

Fallowing is a practice to assist recovery of the environment and to protect the farmed specimens from potential pathogens by moving the farm somewhere else without the threat. It is obligatory in some countries such as Norway (Zhulay *et al*., 2015), but it has not officially been implemented in the BoBIC area. In Spain for example, while the 2014 APROMAR report (APROMAR, 2014) recommended its implementation, it is not mentioned in the 2022 report (APROMAR, 2022). In Portugal, shellfish farmers themselves implement fallowing, especially for clams in certain lagoon areas with low water renewal and low oxygenation. The procedure consists of mixing new sand with the existing sediment and stop using that area for a couple of months. RAS could be a mitigation of many of these impacts – but may still present a risk (i.e. point source of pollution).

Integrated multi-trophic aquaculture (IMTA) refers to the combination of species from different trophic levels in the same culture system (Chopin and Robinson, 2004). IMTA, in addition to diversifying species in culture, can be designed to improve environmental sustainability of fish farming, increase profitability and be a source of employment in coastal regions. Few IMTA systems are commercially effective in the BoBIC region but, many projects are testing IMTA pilots both in open and inland waters (see chapter 9).

Some examples of commercial IMTA:

- In France (see Chapter 2):
  - one marine finfish hatchery on-land uses a series of a dozen of downstream ponds to allow sedimentation of particulate waste and the culture of macroalgae that benefit from the dissolved waste. This system allows to effectively mitigate the waste of the hatchery.
  - many producers of pacific oysters in ponds have diversified their production by adding Kuruma prawn (*Penaeus japonicus)* in the ponds in summer. The prawns eat the macrobenthos in the sediment and allow the resuspension of organic matter which can benefit the oysters. The association favours oyster's growth and allows the production of additional biomass, often without feeding the shrimps.
  - A fishfarm producing fingerling including a system combining land-based finfish farm producing 50 million fingerlings in 2018: sea bass (*Dicentrarchus labrax*), sea bream (*Sparus aurata*) and meagre (*Argyrosomus regius*) (Ferme Marine du Douet in Oleron Islands) and 11 t of *Ulva rigida* in 13 lagoons of 500 m² and 1,8 m depth.
- In Spain (see trials described in Chapter 9)
- In Portugal: ALGAPLUS (see Chapter 2)

6.1.1.4 Disease interactions

"Most, if not all, farmed fish diseases come from pathogens existing in wild populations. Aquaculture activities, however, create conditions (e.g. high stocking levels) conducive to pathogen transmission and disease. Stocking with hatchery-reared fish or aquaculture escapees can affect disease dynamics in wild populations. The close contact between farmed and wild fish may readily lead to pathogen exchange (Peeler and Murray, 2004)" (in a review Cidad *et al.,* 2018, MEDAID). Many diseases in farmed fish are diseases initially found in wild populations. However, aquaculture practices, such as dense stocking, enhance the likelihood of diseases spreading. Interactions between farmed fish and wild animals can change the dynamics of disease among wild fish populations. Indeed, due to the close proximity between farmed and wild species or because of escapees, there is a high risk of exchanging pathogens between them (Peeler and Murray, 2004).

A viral epidemiological study of wild fish around the Gulf of Cadiz (southwestern Iberian Peninsula) by Moreno *et al*., 2014 focused on infectious pancreatic necrosis virus (IPNV), viral hemorrhagic septicemia virus (VHSV), and viral nervous necrosis virus (VNNV) and found isolated incidences in wild fish in the San Pedro River mouth and in near oceanic locations. Among the segmented viruses that most severely impact fish aquaculture, IPNV especially affects salmonid aquaculture, mainly Atlantic salmon (*Salmo salar*) and rainbow trout (*Oncorhynchus mykiss*) species, with lethality rates that can reach up to 90% in fry and postsmolt stock (Valero and Cuesta, 2022).

The critical incidence of fish NNV (family Nodaviridae, genus Betanodavirus) is expanding, with a wide range of farmed and wild affected species and a worldwide geographical distribution. One of the most affected regions is the Mediterranean area, where NNV affects two of the main aquaculture fish species, the European sea bass and the gilthead sea bream which are also farmed in the BoBIC region. Therefore, this virus is one of the most threatening and studied during the last three decades since it can reach complete losses of production at larval and juvenile stages (Valero and Cuesta, 2022)

Official disease surveillance in Spain is carried out by the competent authorities of the Autonomous Communities (CCAA). These have developed specific surveillance programs in accordance with the sampling plans and diagnostic methods established in the Commission Implementing Decision (EU) (2015/1554). Coordination is exercised by MAPA (Ministry of Agriculture, Fisheries and Food).

6.1.1.5 Escapes and genetic impact

Fish escape events have been reported for a number of fish species cultured worldwide (Arechavala-Lopez *et al*., 2018). There are two forms of escapees: "fish escape" can be defined as a single or a group of fish that make their way out of the net-pen, "escape through spawning" refers to the release of viable, fertilized eggs spawned by farmed fish inside sea cages (Arechavala-Lopez *et al.,* 2018).

The impact of escapees from aquaculture is of general concern for the sustainability of natural resources (Prado *et al.,* 2018). Fish escaping from sea cage aquaculture may induce potential genetic effects through interbreeding with wild populations, ecological effects through predation, or competition and the transfer of diseases to wild fish. Escapes also represent an important economic loss for the sector. According to Arechvala-Lopez *et al*., (2018), knowledge of the effects of escaped fish on the ecosystem is limited to Atlantic salmon (*Salmo salar*) and Atlantic cod (*Gadus morhua*).

In the BoBICAO ecoregion, land-based aquaculture of turbot started 40 years ago with low risk of escapees but the use of farmed turbot to enhance wild stocks along the Northeast Atlantic coasts in the last decades will likely have increased the risk to wild populations (Prado *et al.,* 2018). In the framework of the EU project AquaTrace (The development of tools for tracing and evaluating the genetic impact of fish from aquaculture 2012–2016), the genetic introgression in wild populations of turbot Scophthalmus maximus has been studied. Prado *et al.,* (2018) developed Single nucleotide polymorphism tools to monitor turbot of farmed ancestry in the wild. The study reported a notable proportion of fish of farmed ancestry in the wild (15.5%), mainly in the North Sea, where restocking activities have taken place, determining genetic introgression in wild populations. Conversely, effects of land-based aquaculture appear negligible. The authors indicate that this introgression might represent a risk for the turbot population, considering the lower fitness of farmed individuals.

Genimpact, a European network (2006–2007) focused on the evaluation of the genetic impact of aquaculture activities on native populations, provided a summary of the genetic effects of domestication, culture and breeding of fish and shellfish, and their impacts on wild populations as well as the monitoring tools for evaluation of genetic impact of aquaculture activities on wild populations, predictive tools and management options. As for turbot, according to Danancher and García-Vázquez (2007), escapes are not common in land-based facilities (most companies produce turbot in this type of facility), but no further data are provided.

Prevent-Escape, a pan-European project funded by the EU carried out between 2009–2012, provided recommendations and guidelines for aquaculture technologies and operational strategies to reduce escape events, including indicators to differentiate between escaped and wild fish (external appearance, morphometry, fatty acids profiles and trace elements in scales). A project co-financed by the European Fisheries Fund and the Spanish Biodiversity Foundation, called ESCA-FEP, offered guidelines for prevention of fish escapes (Izquierdo-Gomez *et al*., 2014a) and defined recapture plans to mitigate their impact and reduce the economic loss of aquaculture companies (Izquierdo-Gómez *et al*., 2014b). Some of the outputs of the Prevent-Escape and ESCA-PEP are presented in the review by Arechavala-Lopez *et al*. (2018). In this paper, a review of the potential interactions, risks and consequences, of Sea Bream and Sea Bass escapes is provided in the Table below).

In addition, the project “Global change Resilience in Aquaculture” (GLORiA and GLORiA2) aims to provide solutions regarding the adaptation to climate change including extreme events that may cause damage to aquaculture facilities and increase the risk of escapees. In this project, methods are also developed to better identify the origin of the fish: farm-raised fish, wild or escapees (analysis of antibiotics in fish, deep learning image). To underpin the importance of this project it is noted that Storm Gloria (in January 2020), with waves up to 14 m high, ravaged most marine net-pen facilities and between 60 and 70% of Spanish finfish production was impacted (APROMAR, 2021; De Alfonso *et al*., 2021). Millions of fish perished and/or escaped, with considerable socio-economic and ecological implications.

Table 6.1 Summary of the reviewed literature on the implications and risks of genetic, ecological and socio-economic interactions of sea bream (Br) and sea bass (Bs) escapees at different geographic areas. H: hypothesis; S: suggested; D: demonstrated

Interactions	Implications and risks	Sps.	Geographic area/s	H	Author/s.
Ecological	Dispersion, competition, predation	Br	W-Mediterranean	D/S	Arechavala-Lopez et al., 2012a
		Br	C-Mediterranean	D/S	Šegvić-Bubić et al., 2017b
		Bs	W-Mediterranean	D/S	Arechavala-Lopez et al., 2014a
	Establishment/local-absent sps.	Br	CE-Atlantic	D/S	González-Lorenzo et al., 2005
		Bs	CE-Atlantic	D/S	Toledo-Guedes et al., 2009,2012
		Bs	CE-Atlantic	D	Toledo-Guedes et al., 2014a,b
		Bs	CE-Atlantic	D/S	Ramirez et al., 2015
	Pathogens transmission	Br	W-Mediterranean	S	Arechavala-Lopez et al., 2012a
		Bs	W-Mediterranean	S	Arechavala-Lopez et al., 2011
		Bs	CE-Atlantic	S	Toledo-Guedes et al., 2012
		Br, Bs	Mediterranean Sea	S	Arechavala-Lopez et al., 2013a
	Interbreed, hybridization, etc.	Br	C-Mediterranean	S	De Innocentiis et al., 2004
		Br	Mediterranean and NE-Atlantic	S	Miggiano et al., 2005
		Br	C-Mediterranean	S	Šegvić-Bubić et al., 2011a
		Br	C-Mediterranean and NE-Atlantic	S	Franchini et al., 2012
		Br	C-Mediterranean	D	Šegvić-Bubić et al., 2014
		Bs	Mediterranean	S	Bahri-Sfar et al., 2005
		Bs	Mediterranean and NE-Atlantic	S	Haffray et al., 2006
		Bs	E-Mediterranean	S	Brown et al., 2015
		Bs	C-Mediterranean	D	Šegvić-Bubić et al., 2017a
	Gametes/eggs escapes	Br	E-Mediterranean	S	Dimitriou et al., 2007
		Br	C-Mediterranean	S	Šegvić-Bubić et al., 2011a
		Br	C-Mediterranean	S	Franchini et al., 2012
		Br	E-Mediterranean	D	Somarakis et al., 2013
Socioeconomic	Farm economic losses	Br, Bs	Mediterranean	D	Jackson et al., 2014
	Impacts on fish/mussel farms	Br	C-Mediterranean	D	Šegvić-Bubić et al., 2011b
	Interactions with fisheries	Br	E-Mediterranean	D	Dimitriou et al., 2007
		Br	W-Mediterranean	D	Arechavala-Lopez et al., 2012a,2018
		Br	W-Mediterranean	D	Izquierdo-Gómez et al., 2014,2017
		Br	W-Mediterranean	S	Izquierdo-Gómez et al., 2016
		Bs	W-Mediterranean	D	Arechavala-Lopez et al., 2011,2018
		Bs	CE-Atlantic	D	Toledo-Guedes et al., 2014a,b

6.1.1.6 Changing of habitats /impacts of habitat uses

In Portugal, the expansion of semi-intensive fish farming in earthen ponds is usually carried out in old, abandoned salt pans (*salinas*), which impacts the natural capital and this priority habitat for the conservation of avifauna. It might have an important impact on wading birds that use the salt pans for feeding or refuge during high tides. Nevertheless, there are large areas abandoned and degraded in transitional waters and coastal lagoons (e.g. Sousa *et al.*, 2020) that could be re-naturalised. Part of these areas could be reused for salt production or converted for fish production. The same happens in southern Spain where earthen pond culture is also common (see 2.2.1).

6.1.1.7 Ecological Carrying Capacity

The concept of carrying capacity has emerged as a flexible framework to operationalize the ecosystem approach to aquaculture (Weitzman and Filgueira, 2019). Carrying capacity can be defined as the magnitude of aquaculture activity that can be supported without leading to "unacceptable changes" in ecological process, species, populations, or communities in the environment (Filgueira *et al.*, 2015). The flexibility of the concept in the definition of metrics and thresholds to define "unacceptable changes" allows the inclusion of different perspectives in its application. While the most common application of carrying capacity in aquaculture is related to ecological aspects, the concept has also been applied to evaluate production, social, and physical carrying capacities (McKindsey *et al.*, 2006). Further, other concepts commonly applied to aquaculture management, such as assimilative capacity, i.e. the capacity of the system to assimilate organic loading without compromising the delivery of goods and services (Tett *et al.*, 2011), could fit within the general definition of carrying capacity, and it is particularly relevant to finfish aquaculture. The concept of carrying capacity becomes a powerful tool for bay-scale assessments of aquaculture sustainability as it can incorporate the potential cumulative effects of multiple farms. One farm can have a reduced impact on the environment, but several farms may have a significant impact, with eutrophication risk increased. For the evaluation of the impact of additional farms in a restricted area long-term monitoring and ecosystem modelling are essential. The global carrying capacity of the system must be evaluated.

Despite the broader recognition of the concept in policies, the use of carrying capacity to grant aquaculture sites and to study broader ecological effects is limited for finfish aquaculture in the Bay of Biscay and the Iberian Coast ecoregion. The use of carrying capacity as a potential management tool is most prominent in the scientific literature rather than in policies and regulations for this region.

In Spain, the central government indicates that carrying capacity studies are needed for aquaculture planning; however, they defer to the precautionary principle and monitoring as an alternative due to the complexity of estimating carrying capacity (Fisher *et al.*, 2023). The relevance of the concept is recognized by provincial policies, e.g. Andalusia, Galicia (FOESA, 2015).

In France, the MOCAA project funded by Ifremer and the Ministry developed a modelling tool to evaluate the assimilative capacity of site for fish farming. Case studies on the BoBIC region are included in this study to validate the tool (Callier *et al*., 2022).

In Portugal, the carrying capacity of semiartificial lagoons for extensive fish production, in Ria Formosa, has been estimated. Their carrying capacity can be increased by raising the water renewal and improving the environmental quality (Gamito, 1997). Later, using a trophic model, the carrying capacity of a similar semiartificial lagoon, a water reservoir of a sea bream farming pond, was estimated using a trophic model (Gamito and Erzini, 2005). Further trophic model exploration showed that the intensification of fish production increases the carrying capacity of the ponds, fuelled by the artificial feed introduced into the system, and the energy spent in water pumping for increasing water renewal and aeration (Gamito *et al*., 2020).

Ria Formosa was also modelled to explore the interactions of inshore and offshore aquaculture (Ferreira *et al*., 2012, 2014). The authors used a set of joint models (hydrodynamic and ecological) to explore the potential spread of diseases and for optimization of stocking density, pointing to a better performance in IMTA with gilthead sea bream and mussel culture compared to mussel culture alone. The limited number of ecological carrying capacity studies and assessments for fish compared to bivalves (see below) is related to the reliance of bivalves on natural food resources at the bay-scale (Weitzman and Filgueira, 2019). Contrarily, one of the major ecological effects of finfish aquaculture is organic deposition at the farm-scale, which can be explored with local measurements or models.

The joint impact of several fish or bivalve farms in a restricted area such as an estuary or a coastal lagoon must be evaluated. One fish farm can have a low negative impact on the environment, but several farms may have a significant impact, with eutrophication risk increased. For the evaluation of the impact of an extra farm in a restricted area long-term monitoring and ecosystem modelling are essential, and the ecological carrying capacity of the global estuarine or coastal system must be evaluated. For example, Ferreira *et al*. (2014) highlights the need for an ecosystem approach to aquaculture and proposed an integrated model for aquaculture production, pathogen interaction, and environmental effects (Ferreira *et al*., 2021).

6.1.2 Shellfish farming

At farm and ecosystem scale, shellfish farming may induce several pressures on the environment:

- Fall-off under structures - Longline and raft culture.
- Biodeposit production may increase sedimentation rates and modify benthic ecosystem characteristics (sediment, infaunal community) (McKindsey *et al.*, 2011).
- Hydrodynamic changes.

- Phytoplankton removal, top–down control of eutrophication.
- Zooplankton removal, top–down control of plankton.
- Pathogens.
- Overfishing of natural seed stocks.
- Interaction with wild species (Callier *et al.,* 2018).
- Effects on sensitive habitat/spawning areas.
- Treatment: chemical used to treat the structure, antifouling.
- plastic issue (impact on finfish +shellfish) and contribution of Aquaculture to plastic
- Biogenic acidification, shellfish emit CO^2 in the seawater through respiration and calcification and remove (bi)carbonate ions, potentially leading to seawater acidification and CO^2 degassing in the atmosphere. That is also true for finfish or any other animal production in the sea.
- Acidification / carbon removal. Through respiration, high density shellfish production may acidify the coastal waters while shellfish growth may remove carbonate from the system.
- Changes on habitat uses.
- Effect of antibiotics (hatcheries bivalve) leading to increased bacterial resistance near shellfish hatcheries. Shellfish hatcheries using antibiotics may act as a potential source of antibiotic residues and resistant bacteria to the aquatic environment (Dubert *et al.,* 2017).
- Chemical used in structures in shellfish culture.
- Aquaculture as a source of plastics and microplastics – some data from PT in relation to MP in shellfish and originating in land (run-off)- any publication/report).
- impacts on sensitive areas and habitats (seagrass).
- Shading, with effects particularly on photosensitive species.

Some specifics pressures are more detailed below:

6.1.2.1 Effects on habitats

Some shellfish farms in the north of Portugal produce oysters in old salt ponds, contributing to their maintenance There are, however, conflicts between extensive shellfish culture in intertidal bottoms and natural habitats, such as the destruction of seagrass beds and sandbanks (Mateus *et al.,* 2016). The shellfish farmers remove the seagrass, such as *Zostera noltii*, from the sediment and add gravel to improve oxygenation and water circulation in the sediment (Carvalho, 2006; Guimarães *et al.,* 2012). The farmers also change the natural sandy banks for shellfish culture, damaging the wild benthic invertebrate communities. The water circulation through the tidal channels might be changed due to the addition of coarse sediments in the clams' culture bed, reducing the lagoons' water renewal with oceanic water. To prevent erosion of the clams' beds borders, barriers of old nets, rests of oysters' bags and other plastic materials are placed along the tidal channels (Figure 6.1). These barriers function as artificial reefs for the settlement of hard substratum macroinvertebrates, such as mussels and oysters, increasing at the end the local biodiversity nearby the shellfish farm that, however, have reduced several ecosystem services provided by the *Zostera* beds and sandy banks.

Figure 6.1 Ria Formosa lagoon (southern Portugal): Example of a clam's culture bed (right side of the image), protected by a barrier of old oyster bags and other debris from the tidal channel, to prevent erosion.

In France, the presence of bouchots and trestles may prevent erosion by attenuating current (Sornin, 1982). The use of old salt ponds (Amanieu, 1973) for oyster production contribute to maintain and a good supply of salt water, essential to maintaining the lagoon habitat and anthropized marshes which are buffer zones in the event of submersion (e.g. Shepard *et al.*, 2011; Spalding *et al.,* 2014).

6.1.2.2 Production and Ecological Carrying capacity

The concept of carrying capacity has mainly been applied to study the environmental interactions of shellfish aquaculture, particularly in relation to the potential effects of the farmed biomass on phytoplankton populations.

In Spain, studies in the early 1970s pioneered the use of the trophic relationship between phytoplankton and filter-feeders to optimize mussel production in Galician Rías at the bay-scale; however, these studies focused on production rather than ecological carrying capacity (e.g. Tenore *et al.,* 1985). Similarly, the depletion of seston and phytoplankton at the raft-scale in Ría de Ares-Betanzos has been used to evaluate the potential effects of food depletion on bivalve performance but the findings were also contextualized around ecological carrying capacity (Duarte *et al*., 2008; Cranford *et al*., 2014). Trophic web modelling has been used to estimate the ecological and production carrying capacity of Ría de Arousa, an extensive mussel cultivation area (Outeiro *et al*., 2018).

In France, carrying capacity studies were carried out in the Pertuis Charentais and Marennes Oléron Bay in the 90's (Bacher 1993, Raillard *et al.,* 1994, Bacher *et al.,* 1998) and resulted in the development of modelling tools to estimate the production carrying capacity of shellfish systems. More recently, ecosystem modelling to assess the impact of rearing density, environment variability and mortality on oyster production has been developed (Cugier *et al.,* 2022). In this paper, a three-dimensional hydrodynamic model, primary production and individual growth estimates are used to predict oyster growth and production in Bourgneuf Bay (French Atlantic coast). Scenarios were tested to compare the effects of aquaculture practices and environment variability and mortality (Cugier *et al*., 2022).

In Portugal, bivalve production in intertidal areas and estuarine waters has been the focus of several carrying capacity studies concerning bivalve aquaculture. Production might exceed the carrying capacity of the system since the bivalves filter all the water and remove the available phytoplankton and POM (Ferreira *et al.,* 2018). Their feeding, therefore, can have an impact on other filter-feeder wild organisms of the ecosystem, as well as a negative impact on the individual growth rates of the farmed bivalves themselves, as food availability could be the limiting factor for maximizing growth of introduced organisms. Their growth might be reduced and, the bivalves can become more fragile and susceptible to parasitic infections or other illnesses. Ria Formosa in southern Portugal, is the main region for bivalve production, mainly clams (*Ruditapes decussata*) and oysters (*Magallana gigas*). Recently, oyster production has been gaining ground in the Ria Formosa, to the detriment of clam farmers, which are losing income, leading producers to abandon clam production or convert the activity, or even produce both species together. The joint production of oysters (in tables or bags above the sediment) and clams can have a negative effect on clam growth since oysters might absorb the phytoplankton and POM available leaving few for the clams that lay on the bottom. These interactions need to be investigated and tested and the total carrying capacity of the ecosystem needs to be evaluated.

Similar to the studies in Spain, farm-scale models have been used to optimize bivalve production, in which the implications for ecological carrying capacity have been stated (Ferreira *et al.*, 2009). At the ecosystem-level, the effects of dredging and clam biomass on Ría de Formosa were simulated by mathematical modelling indicating that aquaculture was exploited close to the carrying capacity of the system (Duarte *et al.*, 2007). As stated above, a large modelling initiative was carried out to explore the aquaculture environment interactions of IMTA in Ría de Formosa, which included several bivalve species and types of culture, benthic and suspended (Ferreira *et al*., 2012, 2014).

6.2 Impact of the environment on aquaculture (all species)

6.2.1 Water quality – Ecological status

Water bodies used for marine aquaculture production are subject to multiple sources of contamination, which may impact their microbiological or chemical quality. Sources of contamination can be of human origin: agriculture (livestock effluents, chemical treatments of crops), collective or individual sanitation, transport, and industries (contaminant discharges into water); or of natural origin: wildlife or natural soil erosion. Water quality might therefore vary according to environmental conditions, and human activities, and can alter the correct development of aquaculture activities. This is particularly true for shellfish, which filter water for nourishment, and therefore concentrate micro-organisms and certain chemical molecules present in the water.

- In Portugal, for transitional waters (TW - estuaries and coastal lagoons) a high percentage of Portugal's area was classified as being in moderate ecological status (76%), with only 18% of the area with good ecological status. In contrast, coastal areas presented 83% of the area in good or high ecological status[25].
- For future consideration, similar assessment could be done for Spain and France. WFD status and aquaculture production could be linked for all three countries[26].

[25] (https://water.europa.eu/marine/countries-and-regional-seas/country-profiles/portugal, assessed December 2023).

[26] https://water.europa.eu/marine/countries-and-regional-seas/country-profiles.

6.2.2 Impact of pathogens on shellfish farming

Shellfish production is regularly affected by degradation of water quality leading to regulation forbidding the selling of products. This is for example the case during norovirus outbreaks which tend to follow seasonal patterns, with a higher prevalence typically observed in colder months, particularly during winter and early spring. This coincides with peak times for norovirus infections among humans, increasing the likelihood of contamination entering marine and estuarine environments.

In France, since 2008, Pacific oyster has been affected by episodes of massive and recurrent mortality triggered by the presence of viral infectious agents (such as Herpes virus OsHV-1 μVar) in conjunction with environmental factors (i.e. rise in temperature). (Fleury *et al.*, 2022) This viral infection induces a decrease in antimicrobial defences as well as a modification of its microbiota. This process leads to a secondary infection by potentially pathogenic opportunistic bacteria, which multiply rapidly causing irreversible tissue damage leading to the death of the animal. At the same time and although less documented, mortality also affects the numerous wild stocks present on the French coast. Oyster farming industry relies on natural spatfall collection and hatchery. This collect is practised in several oyster farming basins (Chapter 2), Bassin d'Arcachon was providing between 60 and 70% of the 4 billion needed for the production (e.g. Maurer *et al.*, 2009a; Auby *et al.*, 2012) followed by Pertuis Charentais (e.g. Geay and Bouquet, 2009). Now, oyster natural spatfall production has declined markedly with hatcheries now supplying 50–70% of the oyster spat production. Mussel production rely solely on natural spatfall production (https://agreste.agriculture.gouv.fr/agreste-web).

Natural spatfall recruitment is highly variable from year-to-year and therefore unpredictable. This context has motivated the implementation of monitoring networks at the national scale to measure the health status of cultivated and wild oyster populations, during the entire life cycle of the species (reproduction, larval ecology, recruitment, growth, survival) (Fleury *et al*., 2022).

In the 2022 ECOSCOPA report, authors were able to analyse the effect of an increased in temperature from climate change on a local scale. The main results obtained during this 2021 campaign indicate that, in terms of environmental factors, this year was part of the general trend of global warming, but in a more moderate way than in previous years (Fleury *et al.*, 2022). At the level of the network sites, 2021 is a continuation of recent years with an average thermal anomaly higher than normal by +0.5°C, which results mainly from a strong anomaly from winter: temperatures of seawater exceeded normal levels, but late in summer. In terms of phytoplankton inputs, phytoplankton concentrations were fairly normal. The reproduction and egg-laying phases took place at a "normal" period, allowing a supply of larvae within normal limits, except for the Bourgneuf Bay site, for which concentrations of young larvae were low. Given the variable temperatures that were just within the norms in the different basins, the spat collection was relatively heterogeneous depending on the sectors, very good on certain sites, almost zero on others. After a long period of high mortality, the spat mortalities observed for 2021 were very low for the first time (except for the Bay of Veys and Marennes-Oléron sites).

6.2.3 Persistence of antibiotic resistant Vibrio spp. in shellfish hatcheries

The main supply of seed for farming bivalves comes from hatcheries. The main bottleneck in the bivalve production process are pathogenic species belonging to the genus *Vibrio* which may lead to disease outbreaks causing the entire loss of larval batches in hatcheries (Dubert *et al*., 2016a). Dubert *et al*. (2017) published an extensive review of the recently characterized Vibrio species associated with disease of bivalves during early stages of development. Antimicrobial agents have routinely been applied to water to treat and prevent disease in hatcheries, particularly during the first stages of bivalve development (Prado *et al.*, 2014). Therefore, this extensive use of antibiotics may trigger the development of resistant bacteria, which can transmit quickly resistance genes in the hatchery environment by horizontal transfer mechanisms (Miranda *et al.*, 2013). Antibiotic treatments limit the bacterial diversity and promote the rapid development and persistence of resistant vibrio *spp.*, most of them with pathogenic potential, as observed with bacterial strains isolated from a Spanish bivalve hatchery (Dubert *et al.*, 2016b). In addition to that, those shellfish hatcheries using antibiotics may act as a potential source of antibiotic residues and resistant bacteria to the aquatic environment (Dubert *et al.*, 2017).

6.2.4 Predation

Predation is a major problem for some productions, especially in open water and in ponds. The most direct impact of predation on marine aquaculture is the loss of stock. Predators such as birds, fish, and crustaceans can consume a significant portion of the farmed species, leading to direct economic losses for producers. For example, birds like cormorants and herons are known to prey on fish in ponds and nets, while sea bream and sea stars can be a problem for bivalves' productions. They are known to prey on a variety of bivalves and can cause significant losses if they invade aquaculture areas. To prevent birds' predation in fish farms in earthen ponds, these are usually covered by nets. The culture of molluscs in bags also prevents or reduces predation by birds, fish, and larger crabs.

6.2.5 Effect of climate change on aquaculture

In the past years, the North Atlantic water temperature has risen to unprecedented values (Kuhlbrodt *et al.*, 2024). This temperature changes affects the aquaculture production. For example, in the EPPO experimental station (located in the Ria Formosa, in southern Portugal), summer temperature in fishponds rose to more than 28^{o}C for several days. These temperatures might be a limiting factor for the majority of species produced in Portugal. In fact, for meagre (*Argyrosomus regius*) and sea bass (*Dicentrarchus labrax*) 28^{o}C or above are temperatures out of the reproduction limit for the species (Mosqueira *et al.*, 2022). According to Mosqueira et al., the ideal temperature for the gilthead bream (*Sparus aurata*) lies between 22 and 26^{o}C and higher temperatures are cause of stress. Furthermore, with temperature rise, the amount of dissolved oxygen decreases, and the degradation of the water quality accelerates, which imposes additional management measures to sustain the production, such as more aeration or even ejection of compressed air or oxygen. Although the ocean water temperature near the coast in southern Portugal usually does not exceed 24^{o}C, the water temperature in earthen ponds of 1 or 2 m deep can exceed 30^{o}C for several days. The situation can worsen during neap tides, when there is a lower water renewal rate inside the ponds and outside, in the shallow waters of the estuaries or coastal lagoons. Therefore, the outside water temperature can also remain too high, without the possibility of lowering the inside water temperature in the ponds.

6.2.6 Emerging issues and contaminants of concern

Well known and documented environmental pollutants that may influence aquaculture practices include heavy metals, fertilizers, pesticides, Persistent Organic Pollutants (POPs), micro- and nanoplastics, and the so-called emerging contaminants, which are being detected worldwide with increasing frequency and in higher amounts in aquatic systems, displaying strong spatial and temporal quantitative and qualitative variations (Deycard *et al.*, 2014; Laroche *et al.*, 2014;

Borja *et al*.; 2019, Mendoza *et al*., 2020; Masia *et al*., 2021; Solaun *et al*., 2021; Basurko *et al*., 2022; Rosas *et al*., 2022; Bilbao-Kareaga *et al*., 2023; Mauffret *et al*., 2023; Zorita *et al*., 2023).

These compounds will not only influence the wildlife but also the health and welfare of farmed organisms bred in those waters. Emerging contaminants include human and veterinary medicines (such as antibiotics, anti-inflammatory drugs, beta-blockers, hormones and antidepressants), recreational drugs, caffeine, nicotine, hygienic products (scrubbings, soaps, triclosan) and sun-blockers, among many others. They are relevant not only because they may influence the health of aquatic organisms and induce resistances to some of the treatments, but also because they influence their behaviour, including that of bivalves and fish. These are so marked that behavioural modifications have been proposed as early biological warning systems for the presence of pollutants in the environment (Bae and Park, 2014, see also Laroche *et al*., 2014 for responses of European flounder in different waters of the Bay of Biscay) and in aquaculture (Eguiraun *et al*., 2014; Eguiraun and Martinez, 2023 a, b). Furthermore, contaminant-induced behavioural modifications in aquaculture settings have the potential to influence the welfare and yield in aquaculture settings (Eguiraun and Martinez, 2023 a, b).

The presence and quantity of heavy metals are regularly monitored in different zones of the Bay of Biscay through the Spanish Mussel Watch program (Besada *et al*., 2014). Not surprisingly, the program identified industrial and the more densely populated areas both as primary sources of contaminants and the most polluted zones. Cu, Zn and as concentrations presented fairly uniform geographical distributions while Hg and Pb levels were higher in mussels from the Cantabrian Sea region as a result of historical anthropogenic activities. Cd, on the other hand, appeared to be more affected by natural processes on the Northwest Atlantic coast than by human activity.

Deycard *et al*. (2014) documented the contribution of urban wastewater of As, Cd, Cu, Cr, Ni, Pb and Zn to the Girone Estuary (France) and remarked the relevance of the weather, in particular, short, intense summer rainstorms, in increasing the levels of these elements. However, while heavy metal contamination of farmed shellfish and algae may be largely due to the environmental levels of the contaminants and may be severely affected by weather events, the levels in farmed finfish would be highly dependent on the composition of the feed, which is regulated by the European Food Law (EC,2002).

6.2.6.1 Microplastics and microfibers

Worldwide there is a rising awareness of plastic litter and the impacts it might have regarding food safety and aquatic environment. Global plastic production and use was over 320 million tonnes in 2015, and it is expected to exceed 1 billion tonnes by 2050 due to the growing market demand for plastic products.

Plastic is a general term for a range of polymer materials with different properties, when mixed with different additives to enhance their performance (e.g. plasticizers, ultraviolet stabilizers, antioxidants, flame retardants,) (FAO, 2017). The five types of plastics that dominate the global production are: polyethylene, polypropylene, polyvinylchloride, polystyrene, and polyethylene terephthalate (GESAMP, 2015).

Microplastics (MP), particles smaller than 5mm, can originate in manufacturing (e.g. cosmetics, calibration) or from the abrasion, degradation, and physical breakdown of macroplastics from different sectors of activity, including aquaculture itself given that the aquaculture sector uses different types of plastics in their daily routines. The resistance, durability, ease of moulding and lightness of plastic material are some of the characteristics that explain the strong and widespread implementation of this material in the sector, especially in marine aquaculture where the environment is more corrosive (e.g. sun exposure, salinity, hydrodynamics).

Identifying the contribution from the large variety of human activities to microplastic litter is extremely difficult, but estimates indicate that 74% of the 12.2 million tonnes of plastic ending in the marine environment annually have land-based origin (Eunomia, 2016). Scarce information exists regarding the contribution of the aquaculture sector to microplastic litter but estimates from a Norwegian study considers that microplastics generated from abrasion in an aquaculture unit to be in the range of few kilograms (Sundt *et al*., 2014, in Huntington, 2019). However, since the aquaculture sector is pressured to increase production, it is expected that the contribution will increase, thus monitoring and good practices to minimize plastic litter must be implemented.

The smaller size of these particles raises questions in regard to food safety, since these tiny particles (or even lower, nanoparticles <1 µm) can be ingested by different aquatic organisms in the foodweb, and if accumulated in tissues, present hazards for consumers.

When ingested MP accumulation in tissues have been described to affect cellular structures and interfere with biological pathways. Some authors indicate that MP induce physical disruption of an inert particle, and others highlight the adsorption potential of these small particles of aquatic pollutants.

Shellfish are filter-feeders therefore are more exposed to MP. Shellfish's whole-body soft tissue is totally ingested compared to fish, where muscle is the portion consumed, posing higher concerns for consumer's food safety.

Not only microplastics but also microfibers are relevant ubiquitous environmental pollutants (Mendoza *et al.,* 2020; Basurko *et al.,* 2022; Rosas *et al.,* 2022; Bilbao-Kareaga *et al.,* 2023) and have been found in edible species, including European hake (Cabanilles, 2022), eel (Menendez et al., 2022) and mussels (Reguera, 2019; Masia *et al.,* 2022) whose physiological, particularly large-term, effects are still under investigation. Some authors, consider the southeast Bay of Biscay, particularly the French waters, a hot spot for plastic accumulations (see Basurko *et al*., 2022, who measured 28% microplastic, 26% mesoplastics and 46% macroplastics) that may originate in the southwest Iberia and extend (Rosas *et al.,* 2022). In addition, Mendoza et al. (2020) identified maritime ports and areas related to fishing activities as sources of macroplastics and probably microplastics as well (Masia *et al.,* 2011). As is the case for other contaminants, there is a strong spatial and temporal variability of the microplastic distribution in the Bay of Biscay. Some studies indicate that European shellfish consumers are expected to ingest up to 11 000 plastic particles per year (Barcelo and Knepper, 2019).

In Portugal, two studies assessed the incidence of MP (e.g. shape, size colour) in different shellfish species, reared in different structures and from different areas of the country (Botelho *et al*., 2023, Ribeiro *et al*., 2023). One study carried out for one year in the Aveiro lagoon, mussels (*Mytilus galloprovincialis*) and cockles (*Cerastoderma edule*), respectively from rocky substratum and sandy sediments, were periodically collected. In mussels the concentrations varied between 0.77–4.3 MP g^{-1}, whereas for cockles varied between 0.81–5.1 MP g^{-1} (Botelho *et al*., 2023). For both species lower values were observed in January, which according to authors is related to bivalves' lower filtering rate due to lower winter temperatures. The types of plastics and colours were a mixture that differed throughout the year.

The other study evaluated the concentration of MP in different species (*M. gigas*, *Ruditapes decussata*, *Mytilus galloprovincialis*) cultured under different systems along the Portuguese coast, both in spring and autumn (Ribeiro *et al*., 2023). Oysters reared in tables at Ria de Aveiro Lagoon, Sado estuary and floating structures in earth pond (in IMTA - Integrated Multitrophic aquaculture - regime) exhibited values below 0.4 MP.g-1 and below 0.1 MP.g-1, respectively in spring and autumn. Clams reared in culture parks in Ria Formosa lagoon exhibited an increase in the number of MP between spring and autumn, from 0.2 MP.g-1 in spring to – 1 MP.g-1 to 0.64. MP concentrations in mussels reared in longlines off the coast were 0.8 and 0.5 MP.g^{-1}, respectively in spring and autumn. Overall, concentrations were lower or equal to 1 MP. g^{-1} soft tissue.

In addition to microplastics, microfiber pollution is also ubiquitous and found in shorelines all over the world Browne *et al.*, (2011) whose work suggested that a significant source of microfibers comes from sewage waters as a consequence of cloth washing. Interestingly, Masia *et al.*, (2019) found microfibers to be more abundant than microplastics in sand samples from the Bay of Biscay. The physiological effects of micro- and nano-plastics and fibres themselves are still under investigation, but it has been shown that microplastics can be carriers of micro-organisms including antibiotic-resistant pathogenic bacteria (Pham *et al.*, 2021; Yang *et al.*, 2023) and therefore constitute a serious hazard for farmed and wild organisms.

Regarding the presence of emerging chemical contaminants, the European Water Framework Directive (WFD; EC, 2000) establishes a list of chemicals that must be monitored and kept under certain established Environmental Quality Standards (EQS) to maintain a satisfactory surface water status. In addition, some substances have been listed as deserving further monitoring and regulation (EC, 2015, 2018). The "Watch List" includes hormones, antibiotics, anti-inflammatory drugs, pesticides, antioxidants and UV-filters. Their presence has been recorded in the waters of the Bay of Biscay (Mijangos *et al.*, 2018; Solaun *et al.*, 2021). The values detected by Mijangos *et al.* (2018) for the period February 2016 to February 2017 in wastewater treatment plants (WWTP) into estuaries of the Basque Country, were similar to those detected in Europe wide surveys of WWTPs and they displayed local, depth-related and seasonal variations. The latter could be related to seasonal mobility patterns of the population in the corresponding areas, for instance, in towns that significantly increase their population for the holiday seasons (i.e. Górliz-Plentzia, Spain). Harbour activities were also identified as a noteworthy source of contaminants. A more recent study limited to the presence of contaminants listed in the European watch list has been published by Solaun *et al.* (2021) who sampled three wastewater locations in the Basque country (Galindo, Gernika and Oiartzun) and 5 points associated with receiving waters. As in the study by Mijangos *et al.* (2018), the concentration in the wastewaters was higher than in the receiving waters and there were temporal variations. Six of the 19 compounds analysed exceeded their predicted no-effect concentrations in receiving waters.

6.2.6.2 Effect of climate change on environmental pollutants

In addition to influencing the water temperature and salinity (Borja *et al.*, 2019), climate change also affects the type and amounts of pollutants in the waters. Although increased water temperatures exerts a stress on wild and farmed aquatic species and the presence of faecal contaminants in the water jeopardize the safety of aquaculture products, we have not been able to find data on how the changing environmental conditions might have impacted the aquaculture production in 2023 and previous years; we believe the temperature-increase will influence the frequency and type of pathogenic micro-organisms that will challenge the farming industry. Borja *et al.* (2019) considered global warming and its unpredictable effects on the total ecosystem one of the factors that may compromise the status of the Bay of Biscay.

6.3 Ecosystem services

In the last 20 years, the Ecosystem Services (ES) concept has gained important visibility in environmental research and policymaking. ES has been defined as the "benefits that people obtain from ecosystems" (MEA, 2005) and the "direct and indirect contribution of ecosystems to human well-being" (TEEB, 2010), supporting all domains of human society, from individual survival to the development of the global economy.

In the EU context, aquaculture is one of the five maritime economic activities prioritized in the Blue Growth Strategy (European Commission, 2017) and linking marine/coastal ES with the different blue economy sectors is key to accomplish a sustainable blue growth (Lillebø *et al*., 2017). Furthermore, United Nations Sustainable Development Goals (SDG) for 2030 acknowledges that sustainable aquaculture can contribute to support the sustainable use and conservation of oceans, seas and marine resources (SDG 14 – life below water) and offer ample opportunities to reduce hunger and foster well-being (SDG 2 – zero hunger; SDG 3 – good health and well-being).

As any other human activity, aquaculture evolves within complex environmental, social, economic and cultural contexts, with each one of them having particular effects worth describing explicitly and systematically. Aquaculture is an interconnected part of the ecosystem in which it occurs and can provide ES far beyond the provision of food and recognizing the positive effects of certain modes of aquaculture is paramount (Custodio *et al*., 2021). Given aquaculture's rapid expansion and intensification worldwide, reframing aquaculture trade-offs analysis through the lens of an ES framework can provide a novel and comprehensive analytical matrix of interactions with its multidimensional context, stimulate science-based Ecosystem Based Management and promote sustainable solutions (Custodio *et al*., 2022).

Table 6.2. Examples of aquaculture Ecosystem Services.

Type of ecosystem services	Examples of services
Provisioning services	Direct food provision (e.g. aquatic plants and animals)
	Indirect food provision (e.g. boosts fisheries by providing habitat and organic enrichment for wild species)
	Other non-food products (e.g. agar, carrageenan, bivalve shells, ornamental fish)
	Medicinal resources (e.g. extracts from algae and marine invertebrates)
Regulation and maintenance services	Bioremediation and water filtration (e.g. filter-feeders, bottom feeders and algae)
	Wave attenuation/coastal protection (e.g. offshore mussel farms, oyster reefs)
	Carbon sequestration and storage (e.g. bivalves and algae)
	Buffer for ocean acidification (e.g. algae)
	Sediments stabilization (e.g. constructed wetlands)
	Habitat provision (e.g. pseudo-reserves around farms)
Cultural services	Spiritual and physical connection with marine/aquatic environments (e.g. coastal communities, natural reserves)
	Cultural symbols (e.g. Koi carp aquaculture)
	Sense of place (e.g. employment opportunities, gender equity)
	Livelihood (e.g. alternative activity for fishing communities)
	Tourism and recreation (e.g. ecotourism, food tourism, sport fishing)
	Education (e.g. education-oriented activities)
	Research (e.g. pilot-scale experiments)

A recent global review conducted by Custodio *et al*. (2021) found that, in general, it seems that certain types of aquaculture negatively impact overall ES delivery (e.g. intensive mangrove shrimp farming in Asia), yet certain modes of production (e.g. integrated multi-trophic aquaculture) and cultured species (e.g. algae and certain bivalves) can have a positive impact on ES, not only improving provisioning services but also regulation and maintenance services and, potentially, cultural services. Some types of aquaculture are potentially more impactful on the supply of ES than others due to their high energy needs and ecological risk. Both fish- and shrimp farming are usually on top of the list, as they are typically fed with artificial feeds, which promote externalities (e.g. sourcing fishmeal from fisheries) and nutrient pollution and pose greater a threat to local biodiversity due to, for example, escapees, disease and chemical inputs.

Regarding production systems design, Integrated Multi-Trophic Aquaculture (IMTA) has been endorsed by scientists as a more sustainable mode of aquaculture than intensive monocultures, as that practice is capable of enhancing multiple ES. In IMTA, nutrients wasted on artificially fed cultures (e.g. fish, shrimp), in both particulate and dissolved forms, are redirected to downstream trophic levels to nourish extractive species. Bottom feeders (e.g. sea cucumber, polychaeta) and filter-feeders (e.g. bivalves) feed on the wasted particulate fraction and other extractive species, such as seaweeds and macrophytes, utilize the dissolved nutrients for growth. Such system mimics natural trophic interactions, benefiting from ES supported by certain aquatic species to create a more sustainable and productive environment. Walton *et al*. (2015) assessed the potential ES delivered by sustainable aquaculture systems in wetlands from Doñana National Park, Spain, and concluded that properly designed dual-purpose farms could provide a suitable environment for ecological synergies. Moreover, a review on the status of semi-intensive and extensive aquaculture in Southern European countries suggested that developing IMTA in degraded wetlands would potentially benefit stakeholders and improve ES in those areas (Anras *et al*., 2010).

7 Social and Economic Context

Lead by Francis O'Beirn, Jorge Ramos, José Perez, Sebastian Villasante

In 2020, the EU aquaculture sector received 1.2 million tonnes in sales volume and €3.9 billion in turnover. The importance of this ecoregion in terms of European aquaculture production is highlighted in STECF (2023) wherein the majority of the value of aquaculture production is identified as occurring in Spain (24%) and France (21%). In economic value, France had the highest turnover at 22%, followed by Spain at 15%. While some of these statistics might be derived from outside the Ecoregion, i.e. the northern coast of France and the Mediterranean coast of Spain, the ecoregion still likely accounts for a large proportion of these values. It is important to note that the majority of aquaculture output from this region is derived from marine-based ventures concentrated in inshore intertidal and shallow subtidal areas. Furthermore, the importance of the shellfish sector is considered high, especially as it primarily consists of small family owned enterprises with a strong historical connection to the specific areas which plays an important role in terms of social acceptance. This chapter discusses the structure of the aquaculture sector within various sectors and subregions (countries) and considers its importance in terms of employment, among other aspects.

7.1 Portugal

In 2021, total production from aquaculture in mainland Portugal represented just 1.6% of the total production in Europe. In that year, around 17 900 tonnes of live weight were produced. Aquaculture sales generated a revenue of 162.8 million euros (INE, 2022). The main taxa produced essentially belonged to bivalves and fish. Shellfish is the primary component of Portuguese aquaculture production, representing 57% of the total produced and 63% in terms of value (MRAG, 2021). Clams, mussels and oysters represent around 97.8% of the molluscs produced. When considering fish, there are essentially four main species: turbot, sea bream, and sea bass.

7.1.1 Economic context

National importance of the aquaculture industry

Most of the aquaculture sector in Portugal involves small producers, the vast majority related to the production of bivalves in *viveiros* (i.e. plots of sandy-muddy land located in tidal marshes). In these bivalve plots, producers pay an eventually renewable 10-year leasing fee to the state (i.e. a public domain occupancy fee). There are also small fish production companies on an extensive or semi-intensive basis, producing mainly sea bream and sea bass. These companies are essentially located in the Central region of the country, and south in the Sado River estuary and the Algarve region. Regarding the production of fish at sea - namely sea bass and sea bream -, there are several constraints that have not allowed large production (e.g. high hydrodynamic seawaters).

From 2009 until 2016 in the central area of the Portuguese mainland coast there was also production of turbot by a large company. Later, after 2017 the infrastructures have been considered a national interest project (PIN). The production is essentially to export to European countries (Spain, France, Italy, Netherlands, and Germany). In 2021 this firm produced 3 200 tons of turbot and obtained 28 million euros in revenue.

In the last 15 years, some other medium-sized companies have also emerged in the aquaculture sector. These companies are essentially involved in the production of fish and mussels in offshore systems.

Until 2011, Portuguese aquaculture production was less than 10 000 tons per year. From 2009 onwards, turbot began to be produced on a larger scale, almost quadrupling its quantity compared to 2008, and with production reaching a maximum of 4 406 tons in 2012. From 2013 onwards, mussel production increased considerably. In 2021 there were two species with production of more than 3 500 tons (clams and turbot) and two other species with production of more than 3 000 tons (bream and mussels).

The value of the aquaculture industry

Clams and oysters are traditionally the main cultivated bivalves with records dating back to the 1950s. The main production areas are the Ria Formosa, Ria de Alvor, Ria de Aveiro, Sado Estuary and Lagoa de Albufeira. More recently, from 2008 onwards - when offshore production areas were delimited - mussels also began to be produced on a large-scale (Ramos *et al.*, 2015). During 2013 there was a large increase in mussel production (1 547 tons), almost exclusively offshore the Algarve region. Offshore the central area of the Algarve there were years of high production and was certified as sustainable for the mussel species (*Mytilus galloprovincialis*) in 2014. Offshore the westernmost part of the Algarve and Vicentine coast, mussel production continues at a steady state. In 2020, following proposals for new mussel aquaculture projects off the Sagres area, there was opposition from several stakeholders.

In general, there has been a gradual decrease in the number of establishments licensed for aquaculture production accompanied by a gradual increase in the quantity produced. This is a sign of new entrants with capacity to produce at a larger scale and a larger number of exits from small-scale producers (bivalve *viveiros* and extensive production fish farmers).

The estimated value of aquaculture production for the year 2014 was around 50.3 million euros. In 2018 this value almost doubled, reaching close to 100 million euros. Since then, this value has always been above that figure.

7.1.2 Employment

Shellfish related jobs

Employment in aquaculture has been decreasing slightly in recent years. However, the importance of clam and oyster aquaculture is recognized as a generator of economic wealth and employment. Many jobs consist of bivalve plot producers (a.k.a. *viveiristas*) who lease their plot to the State for a period of 10 years. These *viveiros* are essentially located in areas such as the Ria Formosa, the Ria de Alvor and the Ria de Aveiro to produce clams and oysters. There are support infrastructures that help bivalve producers to yield high quality bivalves (purification plants locally known as *depuradoras*), and thus facilitate and open channels for the flow of their products to other markets (Spain and France essentially).

In the Tagus River estuary, Ria Formosa and other intertidal areas there is also informal employment linked to the capture of bivalves (clams and oysters). They are essentially people who collect in the saltmarsh areas that are open access. The harvesting of Japanese clams *Ruditapes philippinarum* in the Tagus estuary is prohibited (Mamede *et al.*, 2022). However, until May 2021 there were some informal shellfish farmers who had no difficulty selling to a few buyers. Japanese clams could yield 4–5 euros/kg for the gatherer under these circumstances. It was reported by authorities that the capture and dispatch of these bivalves without depuration for human consumption is a public health problem, as there is a high risk of contamination by toxins (de Pablo *et al.*, 2022).

Regional impacts of the aquaculture industry

For jobs related to fish production, there are some semi-intensive or intensive production units in the centre and north of Portugal. These are the units that generate the most specialized jobs, some of them employing people with high academic qualifications. They essentially produce flatfish such as turbot and Senegalese sole. There are other small-scale production units that mainly produce sea bream and sea bass, in areas further along the coast. In the central and northern interior of the country there are family businesses (i.e. SMEs) producing trout. In 2020, the total number of employees in the aquaculture industry was estimated at 1 262 persons and 987 FTE, from which only 154 are women.

Production units

At the end of 2021, there were 1 252 licensed aquaculture establishments for inland, marine and transitional waters, 20 fewer units than in 2020, a balance generated by the reduction of 14 tanks and nine nurseries, offset by the licensing of three additional floating ones. The number of hatchery units remained the same as in the previous year. In terms of total licensed area, there was an increase of 19.5%, which resulted in an increase in the average size of around 21%, reaching 2.40 hectares per aquaculture establishment (1.98 hectares in 2020) (EP-INE, 2022).

7.2 Spain

Spain is one of the most important producers of marine aquaculture species within the EU. Overall, the sector produced 276 600 Tonnes of product in 2020 with an estimated value of €517.4 million (STECF, 2023). The two sectors considered most important on the Atlantic coast of the ecoregion are shellfish sector (mostly raft culture of mussels) and the production of turbot in tanks on land.

Production

The production in 2020 was mainly related to marine aquaculture (fish and shellfish), which together represent more than 94% of the quantities produced, while only 6% in freshwater aquaculture. Marine aquaculture is mainly represented by shellfish and around 18% of that total production is marine fish. The relevance to shellfish production total production has remained stable around 75–81% between 2017–2020 (STECF, 2023).

Within shellfish aquaculture, the species with the greatest activity in Spanish aquaculture in terms of production is the mussel (*Mytilus galloprovincialis*). Mussel production, which is very stable, is around 225 000 tonnes per year. Although more than 95% of Spanish mussel production is in Galicia, there are four other producing regions (Catalonia, Andalusia, Valencia and the Balearic Islands). This production, however, translates to only 18.4% of overall economic value. The production of mussels is influenced heavily by market prices but also by natural phenomena such as harmful algal blooms, poor growth rate and poor mussel recruitment. The potential impact on climate related factors will greatly influence performance of this sector, for example, the almost exclusive reliance on natural seed settlement in this sector is a major risk to future projections (Avdelas *et al.*, 2021).

The second most relevant species in shellfish aquaculture is the oyster. Mainly two types of oysters are cultivated, the flat oyster (*Ostrea edulis*) and the Japanese oyster (*Magallana gigas*). Although their production is much lower than that of mussels, this species represents an important group of molluscs in economic terms. In addition to the others, clam culture is also a representative group within shellfish production. The most cultivated species are the fine clam (*Ruditapes decussatus*), the slimy clam (*Venerupis pullastra*) and the Japanese clam (*Ruditapes philippinarum*), which can be cultivated in cultivation parks or in natural beds.

The main species in marine fish production were sea bass, sea bream and turbot. While the production of sea bass and sea bream is concentrated in the Mediterranean area, that of turbot is only located in Galicia, since the turbot aquaculture companies in Cantabria and Asturias ceased their activity in previous years. When talking about marine fish, sea bass is the main harvested species in Spain, with 22 765 tonnes in 2020, with a total value of 144.1 million euros. Sea bream is the fourth marine fish cultivated in Spain, 6 458 tonnes in 2020, valued at 12.5 million euros. These two species represented more than 31% of the total aquaculture production value in 2020. Sea bream and sea bass production is concentrated in the Mediterranean coast, but these species are also produced in the Canary Islands and in the Atlantic coast of Andalusia (STECF, 2023).

Another important species is Atlantic bluefin tuna, with a total production in 2020 of 8913 tonnes, valued 133 million euros. This species has experienced a 73% growth in production between 2017 and 2020. Moreover, this is one of the species with the highest price per unit, representing 3% of the total volume of the total production of the industry, but accounting for 23% of the total value of production. Turbot, with 6 963 tonnes, is the third most important species for marine aquaculture in Spain. The impact of COVID-19 has had a negative effect on the production of this species, which has decreased its production by 15% with respect to 2019, after presenting a sustained trend in its production during the last four years. The rainbow trout is the main freshwater species in Spain. Its production takes place inland around all the regions of the country. Total production achieved 15 806 tonnes in 2020 with a value of 52 million euros (STECF, 2023).

Regarding aquatic plants, production has stagnated between 9–11 tonnes between 2017 and 2020. In Spain, production is evenly distributed between microalgae and macroalgae cultivation. Regarding microalgae cultivation, its production is carried out in companies, spread throughout the Spanish geography, dedicated to its production mainly using fotobioreactors.

Industry structure and employment

Considering official data from the Spanish Government (MAPA), in 2020, 5 102 aquaculture establishments were in operation in Spain, meaning a reduction of 160 establishments compared to 2019. Currently, within the ecoregion, there are 3 979 aquaculture establishments listed as in operation (Aquaculture Viewer- Spain). In 2020, the total number of employees in the aquaculture industry was estimated at 12 500, of which approx. 9 800 (3 941 FTE) were located in the ecoregion. In 2017, the proportion of females in the workforce was 26 % with the majority (75%) over the age of 40 years. Furthermore, there was 3 030 were skilled workers, 1 846 unskilled workers, 639 technicians with higher or medium degrees, 263 administrative staff and 118 people with other professional categories. As for the distribution of work by gender, in 2020 the trend whereby men (74%) occupy most jobs and FTE (81%) continues.

7.3 France

Main context of the French aquaculture (including this related area)

Marine aquaculture in France extends across all its maritime territories. While there's a diversity of production systems associated with shellfish farming and fish farming, the production relies on a limited number of cultivated species: oysters and mussels for shellfish farming, and sea bass, sea bream, turbot, meagre, salmon, sole, and sturgeon for fish farming. Nationally, shellfish farming represents 91% of the turnover and 95% of employment (full-time equivalent). In 2021, there were a total of 2 328 companies specialized in shellfish farming (2 294) and 34 in fish farming (Agreste Survey, 2023). That same year, the total production of French marine aquaculture animals amounted to nearly 157 000 tons, with around 5 600 related to fish farming and the rest composed of approximately 81 000 tons of oysters, 66 000 tons of mussels, and 2 200 tons of other shellfish (Agreste, 2020 and 2021). In terms of value added, shellfish farming is characterized by higher value-added rates compared to fish farming. In 2020, the value added created by shellfish farming amounted to 390 million euros compared to 18.7 million euros for marine fish farming.

The shellfish farming sector in France is mainly composed of small businesses. 80% of the companies employ fewer than five full-time equivalent employees (FTE). In contrast, fish farming companies mostly involve larger enterprises with more than 20 FTE.

The overall dynamics of the sector show a downward production trend with a total loss of 20% in tonnage between 2008 and 2021. Shellfish-farming businesses have been impacted in recent years by episodes of increased mortality resulting in losses of marketable biomass in farming. The production levels of oysters and mussels have not been able to reach those recorded in the early 2000s, which were around 180 000 tons annually. Regarding fish farming, the stagnation of production around 5 000 tons per year (which is even a lower production level compared with the 6 000 tons produced in the mid-90s) (Dosdat *et al*., 1997), across all species, shows the sector's difficulties in growing within a context of competition and international market opening, conflicts over the use of maritime species, and limited social acceptability, which greatly restricts access to new production areas. With a total production of about 375 tons per year, seaweed farming remains a marginal branch of the sector in France but represents one of the main producers in Europe.

7.4 Global picture of aquaculture in the Bay of Biscay

The aquaculture landscape in the Bay of Biscay and the Iberian Coast ecoregion is a microcosm of the national industry, sharing common drivers and challenges with other ecoregions. Oyster farming remains a dominant activity. Innovation and technological advancements, particularly in fish farming, are leading to diversification, integrated multi-trophic aquaculture (IMTA), and exploration of new farming spaces. However, the sector is largely dominated by shellfish and mainly oyster farming. The small number of fish farms in the area means that detailed descriptive statistics are not possible due to confidentiality constraints.

The French shellfish activity is geographically segmented into "shellfish-farming regions", which are administrative subdivisions for the governance of the sector. The Bay of Biscay area is hosting four of them, corresponding to Southern Brittany, Pays de la Loire, Poitou Charente and Aquitaine. Although practices and métiers are homogeneous throughout the regions, they do have their own specific characteristics. The species cultivated are more varied in Southern Brittany, where in addition to pacific oysters (*Magallana gigas*) and mussels *(Mytilus edulis)*, flat oysters, cockles and clams are also produced. This region is also diversified in terms of cultivation types, with oysters grown on the foreshore in bags put on fixed rafts, on the ground and also in deep water. Mussel production is dominated by bouchots. In the Loire Atlantique region, mussels are cultivated either on lines or in bouchots. Oysters are mainly produced in bags on rafts, as is also the case in Poitou Charente and Aquitaine regions.

Oyster farming is by far the dominant activity across the whole of the Bay of Biscay and is almost exclusive to Aquitaine. In Pays de la Loire, mussel farming is proportionally more important than in other regions. There are also more mixed enterprises producing both oysters and mussels in this region. In general, the métiers are rather segmented, as cultivation practices are specific to each species.

The production business is often combined with trading activities, which allows access to the final consumer market via sanitary certification for the sale of live animals' safety. For small and medium-sized companies, this allows them to sell directly to markets, thereby increasing their profit margins particularly in the event of economic difficulties (as in the case of mass mortality episodes). Large oyster companies and mussel growers mainly sell their products via large distribution platforms or directly to supermarkets. Brittany is the region with the largest proportion of pure producers who sell to other producers.

Marennes-Oléron, in the Poitou Charente region, is the largest oyster basin in France. It is renowned for its spat collection, which, along with the Arcachon basin in Aquitaine, is used to supply natural spat to a large number of local companies. Since the advent of hatcheries, the supply of spat has been split half and half between natural and hatchery spat, mainly triploid. In addition, this production basin is also important for the production of oysters matured in marshes, which provides a significant adding value to the oyster production.

The sector is characterized by small family run shellfish businesses, highlighting the industry's socio-economic fabric. Environmental considerations are paramount, with a wide range of issues to address. Development expectations from both administrative bodies and professionals are high, often colliding with the hurdles of social acceptability and space scarcity. Offshore aquaculture emerges as a potential frontier, possibly synergizing with wind farms, embodying new opportunities and complexities.

Sector employment figures in the Bay of Biscay

The structure of the aquaculture sector in the Bay of Biscay follows the same pattern as at the national level, with a predominant weight of shellfish farming, primarily oyster farming. This ecoregion contains one of the largest oyster production and commercialization basins in Europe. The entire Bay of Biscay coastline hosted 1 355 shellfish-farming businesses in 2021, nearly half of which are located in the Marennes Oléron basin. They employ 12 216 workers, 60% of whom are temporary in 2021. This work is equivalent to a total of 5 081 FTE.

Sales of adult animals for consumption account for the bulk of the trade, with around 58 500 tons of oysters sold for a value of 303 million euros, 23 500 tons of mussels for a value of 53.5 million euros, and 1 500 tons of other shellfish for a value of 7.8 million euros, (Agreste). Nearly 25 000 tons of adult oysters produced by Bay of Biscay companies are sold to other professionals. This represents around 5 000 tons of mussels and 1 000 tons of other shellfish.

8 Interaction of environmental, economic and social drivers

Lead by Jose Perez and Sebastian Villasante

8.1 Interaction of environmental drivers

Aquaculture is intimately tied to environmental conditions and exhibits sensitivities to climate hazards. This relationship works both ways. Production systems are likely to have both positive and negative effects on ecosystems, and at the same time, products resulting from aquaculture depend on environmental quality.

Shellfish farmers grapple with deteriorating operating conditions linked to environmental issues which have consequences for cultured animals in terms of growth, mortality and recruitment. These environmental factors result from multiple factors including climate change leading to droughts, the increase of water temperature or water acidification, abrupt changes in salinity, microbiologic or chemical pollution and contamination from harmful algal blooms. Changes to local biodiversity equilibria can also cause new predation threats that lead to economic losses. All these disruptions are likely to bring about changes in production cycles, which are conditioned by seasonality processes and can modify economic risks. For instance, in oyster farming, income is highly concentrated during specific times of the year, such as Christmas and summer period since ecoregion has important touristic destinations.

Viral contamination of cultivated shellfish can also affect businesses, particularly in the case of heavy rainfall events likely to overflow sewage networks and treatment plants. The detection of noroviruses in shellfish, responsible for gastroenteritis, led to commercial bans in production basins along the Atlantic coast (Arcachon, Vendée, Loire Atlantique) at the end of 2023. This concern has also emerged in Galicia in recent decades (Polo *et al.,* 2015; Romalde *et al.,* 2018). These watershed contaminant processes also involve bacterial pathogens. Similar situations occurred in Portugal, although official reports are still not available.

Parasites are also responsible for production losses with significant socio-economic impacts. Besides leading to heavy mortalities *Perkinsus olensis*, can also affect the natural reproductive capacity of clams cultivated offshore, affecting recruitment.

Environmental impacts triggered by aquaculture production are significant, with waste management of metals, organics, and plastics being a concern, alongside the abandonment of oyster beds that can lead to ecological and economic repercussions. For example, a survey conducted in Charentes Maritimes, as part of the CODEMAR project, recently analysed the plastic pollution from marine aquaculture. The results indicated that three quarters of new entrants to the industry lose material at sea. Although the individual loss rate is low, the cumulative volume of plastic waste generated by the sector is substantial.

Unused or abandoned oyster beds may give rise to desolate habitats incurring considerable expenses for restoration. Beyond the financial implications for the shellfish sector, the challenge encompasses the need to monitor biomass levels concerning the trophic support capacity of shellfish ponds. The shellfish sector must also consider biomass monitoring relative to the carrying capacity of ponds. Contrasting regional approaches in places like Charente-Maritime, which suggests reducing stocking density, stand in sharp contrast to national plans aiming to increase production. At the same time there is growing pressure to consider ways to reduce carbon footprint in the production process.

Ensuring water quality remains critical, especially as the majority of shellfish areas are classified under category B (based on the Regulation (EU) No 2015/2285, this requires mandatory purification before the expedition for final markets), facing issues like harmful algal blooms and chemical pollutants from agriculture. This is also the case for the Spanish and Portuguese sector, mainly shellfish aquaculture which needs to be purified when shellfish comes from areas classified as B (the case for all Galician waters) and harmful algal blooms which impose the closure of harvesting for shellfish sector.

These issues reflect the delicate balance the aquaculture sector must maintain with the environment, highlighting the need for sustainable practices and careful management of resources to mitigate impacts and safeguard the industry's future.

8.2 Interaction of economic drivers

In the interplay of economic drivers within the aquaculture sector, the industry stands at the crossroads of societal expectations and economic ambitions. As it navigates the Blue Economy framework, its objective is to maintain high standards of economic and environmental performance. The sector seeks to balance growth with environmental stewardship and social responsibility, aiming to enhance the attractiveness of the profession. By increasing the added value of aquaculture products, it strives to remain competitive against imports from low-cost countries while ensuring the social acceptability of its products. For example, in France, the industry aims to rectify the structural deficit in the mussel market and return oyster production to pre-mortality crisis levels. Mussel culture in Galicia (NW Spain) has evolved over the last 40 years and among other adaptations producers has increased the proportion of small mussels to meet market demand affecting mussels culture cycles and profitability of the mussel industry (Labarta and Fernán-dez-Reiriz, 2019). Portugal aims to increase aquaculture production to 25 tonnes/year until 2030, based on offshore production and RAS production, as a result of the investments on R&D projects, technological innovations, and highly qualified human resources

8.3 Interaction of social drivers

The aquaculture sector navigates complex social dynamics. Public perception often challenges new projects, with the industry facing hurdles in gaining social acceptability. Conflicts over the use of marine and freshwater spaces and the difficulty in obtaining necessary production licenses, especially for fish farming, are prevalent issues. This necessitates strategic communication and awareness efforts to foster public understanding and support. Effective planning is crucial, including careful site selection and management of resource use conflicts, to align with social drivers and ensure the sustainable growth of aquaculture. In Spain, the level of social acceptance of aquaculture has been analysed from the point of view of carrying capacity (Ruiz-Chico *et al.*, 2020) as a tool to achieve societal sustainability. The authors conducted surveys in six coastal provinces in Spain and respondents gave higher priority to socio-economic objectives than to environmental ones.

Strategies for aquaculture in the area are poised to tackle several key challenges. The simplification of administrative procedures is critical to facilitate smoother operations and encourage growth. Marine spatial planning is another priority, ensuring the sustainable use of maritime spaces, alongside social acceptability. Ensuring animal health and welfare is also high in the priority list, as is improving environmental performance, particularly in the face of climate change. Driving innovation, improving data collection, and fostering transparent communication are also strategic priorities to propel the industry forward sustainably.

Concerning social drivers and bottlenecks of aquaculture development, several works in the literature address the social dimensions of aquaculture particularly focusing on the conflicts with other different users in the ecoregion (Gesche *et al*., 2015, Pérez Agúndez *et al*., 2022). The nature of these conflicts is diverse. We can distinguish between conflicts associated with claims from third-party users against aquaculture. These conflicts generally involve: (1) competition for shared spaces with other activities; this is the case for interactions with fisheries, both professional and recreational, and with various recreational nautical and touristic activities, (2) opposition from environmental NGOs or local residents for various reasons, such as ecosystem and landscape preservation. A second type of conflictual interaction concerns aquaculture claims against other users. The origins of these disputes lie in the use of common resources, or concerns about water quality degradation.

The Bay of Biscay has witnessed several conflicts associated with these types listed. Examples include conflicts between shellfish farming and agriculture arising from the competition for freshwater resources in the Marennes-Oléron basin, particularly during summer period. Additionally, complaints from oyster farmers in the Arcachon basin have arisen due to deteriorating water quality, leading to sanitary closures or disruption of production cycles (Rivaud and Cazals, 2013). Numerous other conflicts have been documented along the French Atlantic coast in previous decades (Borel, 1997) involving fishers, recreational and tourist activities, environmental NGOs or local residents. However, this type of conflict can also be found in more recent times (Mille, D., and Blachier, P., 2009; Moulin, 2022). While the historic usage rights held by shellfish farmers are a guarantee of the sector's legitimacy among other users, tensions tend to escalate when expanding the areas accessible to shellfish companies or introducing new activities such as offshore aquaculture or fish cage culture systems.

Although no conflicts have been reported for Portugal until now, potential risk exists due to the larger number of users of maritime common space. It is expected that the plan developed for the National Maritime Spatial Planning Situation (PSOEM, 2019), contributes to minimize potential conflicts.

Even if aquaculture production systems based on low trophic levels could represent a better social perception due to lower environmental impact, issues of social acceptability are linked to various factors that are also economic and social in nature, including the questioning, by some citizens, of participatory democracy as deployed in the field (Kermagoret and Frangoudes, 2021).

9 Future projections and emerging threats and opportunities

Lead by Fabrice Pernet; contribution by Iciar Martinez and Harkaitz Eguiraun

9.1 Emerging threats

Climate change and other constraints will undoubtedly challenge future growth of marine aquaculture (Froehlich *et al.*, 2018). The Bay of Biscay is no exception to this reality. Ocean warming, acidification and deoxygenation, shifts in precipitation regime, changing ocean productivity and circulation patterns and increasing occurrence of extreme climatic events are some of the stressors that will influence the potential of marine aquaculture production worldwide (FAO, 2018; IPCC, 2019; IPCC, 2023). The Bay of Biscay is no exception to this reality (Costoya *et al.*, 2015; Borja *et al.*, 2019; Chust *et al.*, 2022). Here are some general impacts that are direct or indirect consequences of climate changes.

Ocean warming and marine heatwaves

Climate change leads to an increase in sea surface temperatures and enhance the probabilities of marine heatwave, i.e. a prolonged period of unusually warm water temperatures in the ocean (Hobday *et al.*, 2016). Sea surface temperatures in the Bay of Biscay have been warming at a rate of 0.26 ± 0.03°C per decade from 1982 to 2014, with the most pronounced warming during April-June and September-November (Costoya *et al.*, 2015). Additionally, the warm season has lengthened by roughly one month over the past three decades, accompanied by a rise in the occurrence of extreme hot sea surface temperature (Costoya *et al.*, 2015). This long-term trend will affect the distribution and behavior of marine species, including those targeted by aquaculture. Species indeed follow their thermal niche, and their performance (growth, survival, reproduction) depends on temperature. Seawater warming is already occurring and shifts in reproductive phenology or population distribution range have already been reported. One of the most striking examples is the case of the Pacific oyster *Crassostrea gigas*. Initially introduced to the southern coast of France in the 1970s, it has since expanded its range northward, reaching the southern coast of Norway thanks to global warming (Thomas *et al.*, 2015). Beyond changes in the biogeographic distribution of aquaculture species, marine heatwave can also induce unusual stress, abnormal mortality and reduced growth rate.

Ocean Acidification

As the oceans absorb more carbon dioxide from the atmosphere, they become more acidic. This can have detrimental effects on shell-forming organisms, such as molluscs and certain types of plankton, which are important components of the marine foodweb (Kroeker *et al.*, 2013; Wittmann and Pörtner, 2013; Leung *et al.*, 2022). This can disrupt the growth and development of shell-forming organisms like oysters and mussels, impacting their production in aquaculture systems (Gazeau *et al.*, 2013).

Overall, ocean acidification is monitored worldwide since the late 1980s using a combination of ship-based measurements, buoy networks, coastal monitoring stations, and international collaborations to track changes in seawater chemistry and better understand the global implications of this phenomenon. The rate of acidification varies between regions and within each region. Overall, time-series show covering periods of more than 15 years show a decrease of around 0.017–0.027 pH units per decade (Kwiatkowski *et al.*, 2020). There is currently no reliable estimate of acidification trends for the Bay of Biscay. However, according to IPCC, future pH in the Bay of Biscay is expected to decrease of -0,0023 to -0,0035 yr^{-1} under RCP 4.5 and RCP 8.5 respectively (McGovern *et al.*, 2022). Considering these trends, 60% of the bottom waters of shelf area of the Greater North Sea, Celtic Seas, Bay of Biscay and Iberian Coast (OSPAR Regions II, III and IV) will become undersaturated with respect to aragonite by 2100 under RCP 8.5, which may threaten shellfish aquaculture in these areas (McGovern *et al.*, 2022).

As part of the CocoriCO$_2$ research project supported by EMFF between 2020 to 2023, France established a comprehensive pH monitoring network across mollusc farming regions including 5 sites within the Bay of Biscay. This monitoring network revealed extreme and sporadic episodes of acidification within shellfish farms (Petton *et al.*, 2023). These occurrences already pose threats to shellfish populations, with potential exacerbation in future.

Deoxygenation

Deoxygenation is on the rise across coastal and open oceanic regions, predominantly driven by ocean warming and nutrient run-off from land (Diaz and Rosenberg, 2008; Breitburg *et al.*, 2018). Projections indicate that this trend will persist, with the ocean experiencing ongoing oxygen depletion as global warming progresses. The ramifications of oxygen loss within marine environments are far-reaching, encompassing diminished biodiversity, alterations in species distributions, potential displacement or depletion of fisheries resources, shifts in biogeochemical cycling, and the likelihood of mass mortalities. Despite these potential effects on ecosystems supporting fisheries, the consequences of climate changes on dissolved oxygen in the coastal ocean are still poorly documented.

Model simulation suggested that several areas of the Northwest European continental shelves, including the Bay of Biscay, would be vulnerable to deoxygenation (Ciavatta *et al.*, 2016). A high frequency monitoring of the Vilaine Bay along the Atlantic coast of France revealed recurrent deoxygenations and even hypoxia in bottom waters (Ratmaya *et al.*, 2022) as also observed in the Gironde estuary (France) (Dubosq *et al.*, 2022). Deoxygenation is an emerging issue in this ecosystem of a great economic interest. A better understanding of dissolved oxygen dynamics though long-term and continuous *in situ* monitoring is required.

Sea Level Rise

According to IPCC, global mean sea level increased by 0.20 m between 1901 and 2018. Global sea levels could further rise by about 0.63 to 1.01 meters by the end of the 21st century compared to 1995–2014 levels under SSP5/RCP8.5 with high regional variability (IPCC, 2023). (Chust *et al.*, 2010)

The impact of sea level rise on aquaculture is significant, with inundation of coastal facilities, damage to infrastructure such as ponds, cages, and hatcheries, disruption of production, and financial losses being among the most notable consequences. Rising sea levels can lead to the intrusion of saltwater into coastal aquifers, contaminating freshwater sources used in aquaculture operations. Elevated salinity levels can negatively affect the health and growth of aquatic species, particularly those adapted to lower salinity levels. As a consequence of the retreat of coastlines due to sea level rise, aquaculture farms may lose valuable land for expansion or relocation. This loss of space can limit the industry's ability to adapt to changing environmental conditions and meet growing demand for seafood. Higher sea levels can exacerbate coastal erosion, undermining aquaculture infrastructure and causing shoreline instability. This can necessitate the implementation of costly measures such as shoreline protection or relocation of facilities to more stable areas. Finally, changes in coastal habitats and water quality resulting from sea level rise can alter the distribution and abundance of aquaculture species. Some species may thrive in new conditions, while others may struggle to adapt, leading to shifts in farming practices and product availability. Overall, sea level rise poses significant challenges to the sustainability and viability of coastal aquaculture operations, necessitating proactive adaptation strategies and careful management to mitigate its impacts.

Change in precipitation level

Climate change is resulting in alterations to precipitation patterns, leading to longer and more frequent episodes of drought in Western Europe (Dai, 2011). The drought that occurred in France during summer of 2022 (which continues to the present in the south of the country) is a clear manifestation of ongoing climate change (Faranda *et al.*, 2023). Drought has the effect of limiting the supply of nutrient salts (mainly nitrogen and phosphorus) and consequently primary production and the growth of primary consumers like shellfish.

Disease outbreak

Climate change can promote the growth and spread of pathogens and parasites, increasing the risk of disease outbreaks among aquaculture stocks (Harvell *et al.*, 1999; Burge *et al.*, 2014; Lafferty *et al.*, 2015). This can result in significant economic losses for aquaculture operations. Temperature is the most well-studied climate-related driver of marine disease because it profoundly influences host and pathogen metabolism. Although there are reports of the exacerbating effects of temperature on the risk of disease, it is difficult to attribute a causal link between climate change and the occurrence of disease. However, the general assumption that a warmer world is a sicker world is not always true. Disease outbreaks are influenced by complex interactions of factors involving hosts, pathogens and environmental conditions, some of which may overshadow the effects of climate change itself (Lafferty, 2009).

Harmful algal blooms

Global climate change (warming, acidification and deoxygenation) can also contribute to the proliferation of harmful algal blooms (HABs) (Gobler, 2020). These blooms can produce toxins that are harmful to aquaculture species, posing health risks to both aquatic organisms and consumers.

9.2 Adaptation to climate change

To adapt to climate change, there are three main options available (Pernet and Browman, 2021). First, it's imperative to anticipate the biogeographical shifts in species distribution. Species are naturally distributed across geographic areas where environmental conditions align with their physiological requirements. Any alterations in these conditions due to climate change can potentially disrupt the suitability of certain areas for aquaculture production. As a result, it's anticipated that some production may relocate to environments that remain favourable for longer durations. For instance, the open sea, with its greater resilience and stability in terms of temperature and pH compared to the coastal zone, may become a more viable option for aquaculture. Additionally, there's growing interest in developing land-based recirculating aquaculture systems (RAS) where environmental parameters are tightly controlled. However, transitioning to these alternatives would necessitate significant industry-wide changes, likely appealing to only a minority of producers initially.

The second option is to select animals that are tolerant of climate change. It is therefore necessary to select traits of interest that are heritable, that is to say transmissible between generations, then develop genetic selection plans while maintaining genetic diversity (Reid et al., 2019). The foundations for such plans need further developments.

Finally, the third option is to promote ecosystem conservation, restoration or remediation strategies though nature-based solutions to foster resilience to climate change stressors. Among NBS, vegetation though seaweed aquaculture is a promising area (Duarte *et al.*, 2017; Gattuso *et al.*, 2018). Through photosynthesis, seaweed decrease acidity, increase calcium carbonate saturation levels and oxygen concentration during the day, which, under future acidified/deoxygenated conditions, may provide a temporary refuge for shellfish. These three options are not mutually exclusive and should be considered together.

9.3 Reinforcing monitoring programs

Monitoring programs assist in the assessment of how climate change affects aquaculture systems, including changes in water temperature, acidity, oxygen levels, nutrient and phytoplankton, diseases and other anthropogenic stressors like contaminants. This understanding allows for the implementation of adaptive management practices to mitigate risks and enhance resilience.

Regular monitoring of environmental parameters allows aquaculture operators to detect changes at an early stage, such as shifts in water quality or disease outbreaks. This allows for timely responses to mitigate negative impacts. Monitoring data can inform aquaculture management decisions, such as adjusting stocking densities, feed formulations, or site selection, to optimize production efficiency and minimize environmental impacts.

Monitoring programs can help ensure compliance with environmental regulations and sustainability standards, providing evidence of responsible aquaculture practices and promoting consumer confidence in seafood products.

In conclusion, monitoring programs represent an invaluable instrument for the implementation of adaptive management in aquaculture. They facilitate the anticipation and response to the challenges posed by climate change, while simultaneously promoting the implementation of sustainable production practices.

9.4 Other anthropogenic stressors

The monitoring of heavy metals particularly, but not restricted to, Hg and Pb deserve continuing monitoring programs to assess their evolution in the Bay of Biscay, either using analytical biochemical methods (Borja *et al*., 2019; Besada *et al*., 2014) or by implementing Early Biological Warning Systems and monitoring the behaviour of selected species (Bae and Park, 2014; Eguiraun and Martinez, 2023 a, b).

Similarly, monitoring of emerging contaminants and their spatial and temporal variations should also be implemented by national and international plans. Solaun *et al*. (2021) recommend performing regular monitoring focusing on the most populated areas and removing from the list of compounds to monitor those whose concentration does not exceed their PNEC values. This recommendation is intended to spare screening expenses and efforts. However, the amount and type of compounds will vary spatial and temporarily and the fact that a given compound has not been detected for some time is not a predictor for its future levels. Therefore, they should not be completely eliminated from the list. Similarly, non-targeted screenings for unexpected compounds should be performed regularly. In addition, the locations to be monitored should not be limited to populated and industrial (harbours, refineries, gas platforms etc.) areas, but also rural areas where pesticides, fertilizers, purines and related compounds may originate.

In the managing of microplastics, the initiation of BlueWWater, a recently granted 3-year European project (https://cetmar.org/bluewwater/) is noteworthy. The project is aiming to reduce the emission of microplastics and pollutants to the marine environment in the waters between Galicia and Northern Portugal. The aim of the project is to improve the quality of Galician and Portuguese river, transition and coastal water masses through the control, monitoring and evaluation of emissions of microplastics and emerging contaminants to the aquatic environment. Given the relevance of the aquaculture industry in this region, the results of this project will be of high value to evaluate and managing the influence of regular and emerging contaminants in the farmed organisms. In addition to the monitoring of microplastics and microfibers, antibiotic-resistant and pathogenic bacteria often carried by them (Pham *et al.,* 2021; Yang *et al.*, 2023) that therefore constitute a potential and serious health hazard for farmed organisms, should also be monitored.

In addition, the European project Nettag+ (https://nettagplus.eu/) is a three-year project aiming to PREVENT, AVOID and MITIGATE the environmentally harmful impacts of marine litter in European ports, actively contributing to the European Commission Mission "Restore our ocean and waters by 2030".

Finally, Rapid Alert and Contingency Systems following accidents should be strictly followed and, whenever necessary, improved.

Recommendations

To ensure high quality aquaculture production, that is in agreement with the recommendations proposed by other authors (in particular those of Borja *et al.,* 2019) we propose the following steps to be taken: (1) reducing/eliminating the sources of contaminants by using, whenever possible, alternative safer materials and medicines; (2) improving sewage and discharge water purification systems to eliminate contaminants from industrial, hospital, household and any other type of effluents; (3) the improved sewage systems must be able to cope with periods of unusually heavy rains; (4) efficient non-targeted and targeted (of the most relevant pollutants) monitoring programs; (5) respecting and improving the Rapid Alert Systems that the responsible authorities should follow quickly and strictly to minimize the dangers caused by undesirable spillages, (6) setting up of early biological warning systems to estimate the real effect of the naturally found mixtures of contaminants on selected and relevant model organisms, and (7) establish trustworthy, official channels to keep a close contact with aquaculture facilities to inform them about the status of the relevant waters.

9.5 IMTA systems as a strategy to improve environmental sustainability

Many projects tested IMTA pilots both in open and inland waters. Some examples of pilot IMTA:

- In Portugal, semi-intensive aquaculture in earthen ponds is common in coastal lagoons and estuaries, the impact of the effluents is reduced using settlement ponds (Hubert *et al.*, 2006, Carvalho *et al.*, 2009). The evolution from monoculture to Integrated Multi-Trophic Aquaculture (IMTA) has resulted in the removal of excess nutrients and detritus (Cunha *et al.,* 2019, Gamito *et al.,* 2020). In IMTA, extractive species such as macroalgae reduced the concentration of nutrients, while detritivore macroinvertebrates reduced the amount of POM in the sediment and in the effluents, improving the overall health of the ecosystem.
- As part of the Seacase project (2007–2010), 6 independent case studies were presented to demonstrate the feasibility for productivity enhancement in coastal extensive or/and semi-intensive aquaculture in Southern Europe under sound environmental conditions. These included production of juveniles in extensive or semi-extensive conditions, extensive and semi-intensive polyculture in earthen ponds, an intensive-extensive integrated land-based system, extensive production in valliculture, and integrated management of marine extensive ponds and lagoons for a sustainable eel fishery.

- IMTA-Effect (2016-2019) (Integrated Multi Trophic Aquaculture for EFFiciency and Environmental ConservaTion) was funded by EU ERANET COFASP (www.cofasp.eu) with partners from France and Portugal. "It associated nine partners from public research and private companies, in six countries. The project aimed to develop IMTA strategies for fish farmers to develop new production systems being efficient, economically attractive, robust, and environmentally friendly. For this purpose, the project aims to provide scientific references on the nutrient and energy efficiency gains generated by associating different aquatic species of different levels in the foodweb".
- In France, the EPURVAL2 project (2017–2021) (https://www.europe-en-france.gouv.fr/fr/projets/epurval-2-mise-en-place-de-sites-pilotes-pour-lepuration-et-la-valorisation-des-effluents-de) tested different IMTA systems including a system combining land-based finfish farm producing 50 million fingerlings in 2018: sea bass (*Dicentrarchus labrax*), sea bream (*Sparus aurata*) and meager (*Argyrosomus regius*) (Ferme Marine du Douet in Oleron Islands) and 11 t of *Ulva rigida* production in 13 lagoons of 500 m² and 1,8 m depth.
- In France, the European Integrate project extension (2022–2023) testing the association of flatoyster and sea cucumbers (*Holothuria forskali*) with exceptional growth of sea cucumbers.
- In France, the European SIMTAP project (2019–2022) tested the association in successive ponds, with one for the production of gilthead sea bream, followed by two of an association of oysters and shrimps, one with an association of clam and shrimps, and one with *ulva*.
- In Spain, a project funded by JACUMAR was launched in 2007. The overall objective was "to evaluate the application of integrated multi-trophic farming systems in aquaculture in Spain.". The goals were to improve the environmental management of farms and to promote the economic bolstering of companies by diversifying their production. Six regions with diverse conditions for farming were considered. A report is available for the Galician region (Guerrero and Cremades, 2012) and describe case studies in the BoBIC region including:
  - Integrated farming of macroalgae in fish cages in the ria of Muros and Noia (A Coruña): The experiment was conducted in turbot rearing cages (MARCULTURA, S.A., company) located in the ria of Muros and Noia (A Coruña), farmed with the macroalgae *Saccharina latissima*. No significant benefit of the integration of macroalgae due to the high level of nutrients in the Galician rias was observed. The presence of macroalgae near fish could reduce light radiation while increasing sedimentation and recruitment processes that may lead to increase in fouling, which could be a problem. They also conclude that the benefit of these polycultures should be evaluated both in terms of the improvement in quality of the marine environment and the increase and diversification of total aquaculture production.
  - Open sea farming of the edible seaweed *S. latissima* associated with floating mussel rafts was tested in the rias of Ares and Betanzos (A Coruña). The analysis of isotopic abundance (15N ratio) in *S. latissima* indicated that the macroalgae assimilate forms of nitrogen excreted by organisms at a greater trophic level, probably mussels (Pérez Camacho, 1992).

Biofiltration of solids from the effluent of a turbot farming plant, in a closed circuit, with filtering molluscs (clam and oyster), suspension feeding invertebrates (anemone) and food macroalgae (*S. latissima* and *Ulva spp.*) in O Grove (*Pontevedra*). This study indicated that the system was able to maintain various commercial species, and high ammonia concentration in fish and mollusc tanks decreased as it passed through the algae. They measured the increase in the biomass of molluscs (from 2 to 29 kg in a period of 10 months) and algae (*S. latissima*, and *Ulva spp.*) and concluded that it would be feasible to optimize an IMTA system on land, combining fish/anemone/polychaetes/molluscs/macroalgae, to generate a diversification of production and a substantial improvement in the management of suspended solids and in the quality of effluent discharged into the sea.

10 Reference list

Aas, T.S., Åsgård, T., Ytrestøyl, T. (2022) Utilization of feed resources in the production of Atlantic salmon (Salmo salar) in Norway: an update for 2022. Aquac. Rep. 26, https://doi.org/10.1016/j.aqrep.2022.101316.

Agreste 2021, Recensement agricole 2021. https://agreste.agriculture.gouv.fr/agreste-web/download/publication/publie/Chd2105/cd2021-5_Aqua2019.pdf.

Anras L, Boglione C, Cataudella S, Dinis MT, Livi S, Makridis P *et al*. (2010) The current status of extensive and semi-intensive aquaculture practices in Southern Europe. Aquaculture Europe 35: 12–16.

APROMAR (2014) La acuicultura en España. https://apromar.es/wp-content/uploads/2022/01/Informe-ACUICULTURA-2014.pdf.

APROMAR (2022) Aquaculture in Spain 2022. https://apromar.es/wp-content/uploads/2022/10/Aquaculture-in-Spain-2022_APROMAR.pdf.f.

APROMAR (2023) Aquaculture in Spain https://apromar.es/wp-content/uploads/2023/10/Aquaculture_in_Spain_2023_APROMAR.pdf.

AQUAREF - Opérations d'échantillonnage en milieu marin dans le cadre des programmes de surveillance DCE (matrices : eau, sédiment et biote) - Recommandations techniques – Edition 2015.

Aquaculture Viewer- Spain - https://servicio.pesca.mapama.es/acuivisor/.

Arechavala-Lopez P., Toledo-Guedes K., Izquierdo-Gomez D., Šegvić-Bubić T. & Sanchez-Jerez P. (2018) Implications of Sea Bream and Sea Bass Escapes for Sustainable Aquaculture Management: A Review of Interactions, Risks and Consequences, Reviews in Fisheries Science & Aquaculture, 26:2, 214-234, https://doi.org/10.1080/23308249.2017.1384789.

Aubin Joel, Callier Myriam, Rey-Valette Helene, Mathe Syndhia, Wilfart Aurelie, Legendre Marc, Slembrouck Jacques, Caruso Domenico, Chia Eduardo, Masson Gerard, Blancheton Jean-Paul, Ediwarman , Haryadi Joni, Prihadi Tri Heru, Casaca Jorge De Matos, Tamassia Sergio T. J., Tocqueville Aurelien, Fontaine Pascal (2019). Implementing ecological intensification in fish farming: definition and principles from contrasting experiences. Reviews In Aquaculture, 11(1), 149-167. Publisher's official version: https://doi.org/10.1111/raq.12231 , Open Access version : https://archimer.ifremer.fr/doc/00484/59570/

Aubin Joël, Caroline Fontaine, Myriam Callier, Emmanuelle Roque d'Orbcastel. Blue mussel (*Mytilus* edulis) bouchot culture in Mont-St Michel Bay: potential mitigation effects on climate change and eutrophication. International Journal of Life Cycle Assessment, 2018, 23 (5), pp.1030-1041. 10.1007/s11367-017-1403-y.

Avdelas, L., Avdic-Mravlje, E., Borges Marques, A.C., Cano, S., Capelle, J.J., Carvalho, N., Cozzolino, M., Dennis, J., Ellis, T., Fernández Polanco, J.M., Guillen, J., Lasner, T., Le Bihan, V., Llorente, I., Mol, A., Nicheva, S., Nielsen, R., van Oostenbrugge, H., Villasante, S., Visnic, S., Zhelev, K. and Asche, F. (2021), The decline of mussel aquaculture in the European Union: causes, economic impacts and opportunities. Rev. Aquacult., 13: 91-118. https://doi.org/10.1111/raq.12465.

Bacher C. (1993) Use of an ecosystem model for the assessment of the influence of cultivated oysters (*M. gigas*) of the nitrogen cycling in the Marennes-Oleron Bay (Ifremer report)

Bacher Cédric, Johanna Balle-Beganton, Julien Neveu, Harold Rethoret, Françoise Vernier, Paul Bordenave, Rémi Mongruel, José Perez (2010) Modeling freshwater uses in coastal areas – the case of Pertuis Charentais (France). International Environmental Modelling and Software Society (iEMSs) 2010 International Congress on Environmental Modelling and Software Modelling for Environment's Sake, Fifth Biennial Meeting, Ottawa, Canada.

Bacher, Duarte, Ferreira, Heral and O. Raillard (1998) Assessment and comparison of the Marennes Oleron Bay (France) and Carlingford Lough (Ireland) carrying capacity with ecosystem models. Aquatic Ecology 31: 379–394, 1998 Production Carrying capacity (model based on physical transport and deposited matter).

Bae, M.-J.; Park, Y.-S. (2014) Biological early warning system based on the responses of aquatic organisms to disturbances: A review. Sci. Total. Environ., 466-467: 635-649. https://doi.org/10.1016/j.scitotenv.2013.07.075.

Barcelo D., Knepper, T. (2019) Analysis, fate and effects of microplastics in the environment: Preface to article collection. Trends in Analytical Chemistry 121, 115671. https://doi.org/10.1016/j.trac.2019.115671.

Basurko, O.C., Ruiz, I., Rubio, A., Beldarrain, B., Kukul, D., Cózar, A., Galli, M., Destang, T., Larreta, J. (2022) The coastal waters of the south-east Bay of Biscay a dead-end for neustonic plastics. Marine Pollution Bulletin, 181, art. no. 113881. https://doi.org/10.1016/j.marpolbul.2022.113881.

Besada V, Sericano JL, Schultze F. (2014) An assessment of two decades of trace metals monitoring in wild mussels from the Northwest Atlantic and Cantabrian coastal areas of Spain, 1991-2011. Env. Int., 71: 1-12. doi: 10.1016/j.envint.2014.05.024.

Bhagat, J., Zang, L., Nishimura, N., Shimada, Y., (2022) Application of omics approaches for assessing microplastic and nanoplastic toxicity in fish and seafood species, Trends in Analytical Chemistry, 154, 116674, https://doi.org/10.1016/j.trac.2022.116674.

Bilbao J., Muñiz O., Revilla M., Rodríguez J. G., Laza-Martínez A., Seoane S. (2020) Suitability of two areas of the Basque coast to sustain shellfish aquaculture according to both the presence of potentially toxic phytoplankton and the biotoxins regulated by the European Union. Regional Studies in Marine Science (36): 101279. https://doi.org/10.1016/j.rsma.2020.101279.

Bilbao-Kareaga, A., Menendez, D., Peón, P., Ardura, A., Garcia-Vazquez, E. (2023) Microplastics in jellifying algae in the Bay of Biscay. Implications for consumers' health. Algal Res., 72: 103080. http://dx.doi.org/10.1016/j.algal.2023.103080.

Borel, G. (1997). Les conflits d'usage liés aux mutations de l'aquaculture marine sur le littoral atlantique français: l'exemple du Finistère/Resource-use conflicts linked to changes in marine aquaculture on the French Atlantic coast: the example of Finistère. Cahiers Nantais, 47(1), 92-100.

Borja, A., Amouroux, D., Anschutz, P., Gómez-Gesteira, M., Uyarra, M.C., Valdés, L. (2019) Chapter 5 - The Bay of Biscay. In: World Seas: An Environmental Evaluation. 2nd Edition, Editor: Charles Sheppard, Academic Press. Pages 113-152. https://doi.org/10.1016/B978-0-12-805068-2.00006-1.

Botelho M.J., Vale C., Marques F., Moreirinha C., Costa S.T., Guilhermino L., Joaquim S., et al.), Rudnitskaya A. (2023) One-year variation in quantity and properties of microplastics in mussels (*Mytilus galloprovincialis*) and cockles (*Cerastoderma edule*) from Aveiro lagoon. Environmental Pollution, 333 , art. no. 121949. https://doi.org/10.1016/j.envpol.2023.121949.

Braga, A.C.; Rodrigues, S.M.; Lourenço, H.M.; Costa, P.R.; Pedro, S. Bivalve Shellfish Safety in Portugal: Variability of Faecal Levels, Metal Contaminants and Marine Biotoxins during the Last Decade (2011–2020). Toxins 2023, 15, 91. https://doi.org/10.3390/ toxins15020091.

Brausch, J.M.; Connors, K.A.; Brooks, B.W.; Rand, G.M. (2012) Human pharmaceuticals in the aquatic environment: A review of recent toxicological studies and considerations for toxicity testing. Rev. Environ. Contam. Toxicol., 218: 1-99. https://doi.org/10.1007/978-1-4614-3137-4_1.

Breitburg, D., Levin, L. A., Oschlies, A., Grégoire, M., Chavez, F. P., Conley, D. J., Garçon, V., Gilbert, D., Gutiérrez, D., Isensee, K., Jacinto, G. S., Limburg, K. E., Montes, I., Naqvi, S. W. A., Pitcher, G. C., Rabalais, N. N., Roman, M. R., Rose, K. A., Seibel, B. A., Telszewski, M., Yasuhara, M., and Zhang, J. 2018. Declining oxygen in the global ocean and coastal waters. Science, 359: eaam7240.doi:10.1126/science.aam7240

Browne, M.A., Crump, P., Niven, S.J., Teuten, E., Tonkin, A., Galloway, T., Thompson, R. (2011) Accumulation of microplastic on shorelines worldwide: Sources and Sinks. Env. Sci. Technol, 45: 9175-9179. https://doi.org/10.1021/es201811s.

Burge, C. A., Mark Eakin, C., Friedman, C. S., Froelich, B., Hershberger, P. K., Hofmann, E. E., Petes, L. E., Prager, K. C., Weil, E., Willis, B. L., Ford, S. E., and Harvell, C. D. 2014. Climate Change Influences on Marine Infectious Diseases: Implications for Management and Society. Annual Review of Marine Science, 6: 249-277.10.1146/annurev-marine-010213-135029.

Cabanilles, P., Acle, S., Arias, A., Masiá, P., Ardura, A., Garcia-Vazquez, E. (2022) Microplastics Risk into a Three-Link Food Chain Inside European Hake. Diversity, 14: 308. https://doi.org/10.3390/d14050308.

Callier Myriam, Byron Carrie J., Bengtson David A., Cranford Peter J., Cross Stephen F., Focken Ulfert, Jansen Henrice M., Kamermans Pauline, Kiessling Anders, Landry Thomas, O'Beirn Francis, Petersson Erik, Rheault Robert B., Strand Oivind, Sundell Kristina, Svasand Terje, Wikfors Gary H., McKindsey Christopher W. (2018). Attraction and repulsion of mobile wild organisms to finfish and shellfish aquaculture: a review. Reviews In Aquaculture, 10(4), 924-949. Publisher's official version: https://doi.org/10.1111/raq.12208

Callier Myriam, Fiandrino Annie, Laugier Thierry, Triplet Sebastien, Geoffroy Thibault, Le Grand Louis, Chary Killian, Falguiere Jean-Claude, Ubertini Martin, Merou Nicolas (2023). Modelling ecosystem assimilation capacity for a sustainable aquaculture in France: the MOCAA project. ASC 2023 - ICES Annual Science Conference 2023. 11–14 September 2023 Bilbao, Spain.

Cardoso C., Almeida J., Coelho I., Delgado I., Gomes R., Quintã R., Bandarra N.M., Afonso C. 2023. Farming a wild seaweed and changes to its composition, bioactivity, and bioaccessibility: The Saccorhiza polyschides case study. Aquaculture (566): 739217, https://doi.org/10.1016/j.aquaculture.2022.739217.

Carvalho, S; Falcão, M; *et al* 2009 Benthic dynamics within a land-based semi-intensive aquaculture fish farm The importance of settlement ponds. Aquacult Int 17: 571-587.

Carvalho, S; Moura, A; Sprung, M. 2006 Ecological implications of removing seagrass beds (*Zostera noltii*) for bivalve aquaculture in Southern Portugal. Cah. Biol. Mar. 47: 321-329.

Chapela Rosa., El Régimen Jurídico de la Acuicultura Marina, Marcial Pons, Madrid, 2002.

Chapela, Rosa, *et al* (2022) "Report on Current policy frameworks for aquaculture"; AquaVitae project, Deliverable 8.1 page. 25; https://aquavitaeproject.eu

Chapela, Rosa: Enabling good governance in aquaculture. Regional Aquaculture Conference, GFCM, FAO, Bari 2014.

Charria, G., Lazure, P., Le Cann, B., Serpette, A., Reverdin, G., Louazel,S., Batifoulier, F., Dumas, F., Pichon, A., Morel, Y. (2013) Surface layer circulation derived from Lagrangian drifters in the Bay of Biscay. J. Marine Sys., 109–110: S60-S76. doi.org/10.1016/j.jmarsys.2011.09.015.

Chu, Y., Wang, C., Park, J., Lader, P., 2020. Review of cage and containment tank designs for offshore fish farming. Aquaculture 734928.

Chust, G., Caballero, A., Marcos, M., Liria, P., Hernández, C., and Borja, Á. 2010. Regional scenarios of sea level rise and impacts on Basque (Bay of Biscay) coastal habitats, throughout the 21st century. Estuarine, Coastal and Shelf Science, 87: 113-124.https://doi.org/10.1016/j.ecss.2009.12.021.

Chust, G., González, M., Fontán, A., Revilla, M., Alvarez, P., Santos, M., Cotano, U., Chifflet, M., Borja, A., Muxika, I., Sagarminaga, Y., Caballero, A., de Santiago, I., Epelde, I., Liria, P., Ibaibarriaga, L., Garnier, R., Franco, J., Villarino, E., Irigoien, X., Fernandes-Salvador, J. A., Uriarte, A., Esteban, X., Orue-Echevarria, D., Figueira, T., and Uriarte, A. 2022. Climate regime shifts and biodiversity redistribution in the Bay of Biscay. Science of the Total Environment, 803: 149622.https://doi.org/10.1016/j.scitotenv.2021.149622

Ciavatta, S., Kay, S., Saux-Picart, S., Butenschön, M., and Allen, J. 2016. Decadal reanalysis of biogeochemical indicators and fluxes in the North West European shelf-sea ecosystem. Journal of Geophysical Research: Oceans, 121: 1824-1845

Cidad Maite, Peral Irene, Ramos Saioa, Basurco Bernardo, López-Francos Antonio, Muniesa Ana, Cavallo Marianna, Perez Jose, Aguilera Cristóbal, Furones Dolors, Reverté Carmen, Sanjuan-Vilaplana Anna, Edgar Brun, Dverdal Jansen Mona, Tavornpanich Saraya, Raux Pascal, Baraibar Díez Elisa, Cobo Angel, Fernández Polanco José Manuel, Llorente García Ignacio, Fernández Sánchez José Luis, Luna García Manuel, Luna Sotorrio Ladislao, Odriozola Zamanillo María, Gulzari Benan, Janssen Kasper, Komen Hans (2018). Assessment of Mediterranean Aquaculture Sustainability. Deliverable 1.2 of the Horizon 2020 project MedAID (GA number 727315), published in the project website on 21.12.2018. https://archimer.ifremer.fr/doc/00515/62630/.

Costoya, X., deCastro, M., Gómez-Gesteira, M., and Santos, F. 2015. Changes in sea surface temperature seasonality in the Bay of Biscay over the last decades (1982–2014). Journal of Marine Systems, 150: 91-101.https://doi.org/10.1016/j.jmarsys.2015.06.002.

Cranford, P. J., Duarte, P., Robinson, S. M., Fernández-Reiriz, M. J., & Labarta, U. (2014). Suspended particulate matter depletion and los modification inside mussel (Mytilus galloprovincialis) culture rafts in the Ría de Betanzos, Spain. Journal of experimental marine biology and ecology, 452, 70-81.

Cremades J., Freire O., Baamonde S., Salinas J.M. & Fuertes C. (2007) Nuevo método para el cultivo industrial de Laminaria saccharina (Laminariales, Phaeophyta) en las costas gallegas. Actas XI Congreso Nacional de Acuicultura, 1: 559-562.

Cunha ME, Quental-Ferreira H, Parejo A, Gamito S and others 2019. Understanding the individual role of fish, oyster, phytoplankton and macroalgae in the ecology of integrated production in earthen ponds. Aquaculture, 512: 734297.

Cyanopica, 2017. Boas práticas em cultivo de ostra – Algarve, APA, 50 pp.

Dai, A. 2011. Drought under global warming: a review. WIREs Climate Change, 2: 45-65. https://doi.org/10.1002/wcc.81.

Danancher D. and García-Vázquez E. (2007). Genetic effects of domestication, culture and breeding of fish and shellfish, and their impacts on wild populations. Turbot – Scophthalmus maximus. p 55-61, In: Svåsand T., Crosetti D., García-Vázquez E., Verspoor E. (eds). Genetic impact of aquaculture activities on native populations. Genimpact final scientifi c report (EU contract n. RICA-CT-2005-022802). http://genimpact.imr.no/.

Decree 83-228 of March 22, 1983, establishing the authorization regime for marine farming operations. [Accessed 27. October. 2023]. Available online: https://www.legifrance.gouv.fr/loda/id.

Decree 274/2003, of June 4, 2003, regulating the procedure for obtaining permits and activity concessions for aquaculture and auxiliary aquaculture establishments in the terrestrial zone. DOGA 110 (09-06-2003) Accessed 27. September. 2023]. Available online: https://vlex.es/vid/acuicultura-auxiliares-terrestre.

Decree-Law no. 151-B/2013. Environmental impact assessment (EIA). D.R. I Series. (31 -10- 2013) 6328-6354. [Accessed 13 October 2023]. Available online: https://diariodarepublica.pt/dr/detalhe/decreto-lei/151-b-2013-513863.

Decree-Law n.º 40/2017. Installation and operation of culture establishments in marine waters, including transitional waters, and in inland waters. D.R. I Series. 67 (04 -04-2017) 1712-1724. [Accessed 22. June. 2023]. Consolidated version available online: https://diariodarepublica.pt/dr/legislacao-consolidada/decreto-lei/2017-107468888.

Directive 2001/42/EC of the European Parliament and of the Council of 27 June 2001 on the assessment of the effects of certain plans and programmes on the environment. (OJ, L197) [Accessed 27. October. 2023]. Available online: https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=celex%3A32001L0042.

de Pablo, H., Sobrinho, J., Garaboa-Paz, D., Fonteles, C., Neves, R., & Gaspar, M. B. (2022). The influence of the river discharge on residence time, exposure time and integrated water fractions for the tagus estuary (Portugal). Frontiers in Marine Science, 8, 734814. https://doi.org/10.3389/fmars.2021.734814.

Deycard, V.N., Schäfer, J., Blanc, G., Coynel, A., Petit, J.C.J., Lanceleur, L., Dutruch, L., Bossy, C., Ventura, A. (2014) Contributions and potential impacts of seven priority substances (As, Cd, Cu, Cr, Ni, Pb, and Zn) to a major European Estuary (Gironde Estuary, France) from urban wastewater. Mar. Chem., 167: 123-134. https://doi.org/10.1016/j.marchem.2014.05.005.

Diaz, R. J., and Rosenberg, R. 2008. Spreading Dead Zones and Consequences for Marine Ecosystems. Science, 321: 926-929.10.1126/science.1156401.

Dosdat Antoine, Gaignon Jean-Louis, Fuchs Jacques, Harache Yves, Lacroix Denis, Paquotte Philippe, Thouard Emmanuel (1997). La pisciculture marine en France. Note ʻde synthèse DRV/RAID 97. .

Duarte, C. M., Wu, J., Xiao, X., Bruhn, A., and Krause-Jensen, D. 2017. Can Seaweed Farming Play a Role in Climate Change Mitigation and Adaptation? Frontiers in Marine Science, 4.10.3389/fmars.2017.00100

Duarte, P., Azevedo, B., Ribeiro, C., Pereira, A., Falcão, M., Serpa, D., Reia, J. (2007). Management oriented mathematical modelling of Ria Formosa (South Portugal). Transitional Waters Monographs, 1(1), 13-51.

Duarte, P., Labarta, U., & Fernández-Reiriz, M. J. (2008). Modelling local food depletion effects in mussel rafts of Galician Rias. Aquaculture, 274(2-4), 300-312.

Dubert J, Nelson DR, Spinard EJ, Kessner L, Gomez-Chiarri M, da Costa F, Prado S, Barja JL (2016[a]). Following the infection process of vibriosis in Manila clam (Ruditapes philippinarum) larvae through GFP-tagged pathogenic Vibrio species. J. Invertebr. Pathol. 133, 27–33. Doi: 10.1016/j.jip.2015.11.008.

Dubert, J., Barja, J. L., & Romalde, J. L. (2017). New insights into pathogenic Vibrios affecting bivalves in hatcheries: present and future prospects. Frontiers in Microbiology, 8, 762. https://doi.org/10.3389/fmicb.2017.00762.

Dubert, J., Osorio, C. R., Prado, S., & Barja, J. L. (2016). Persistence of antibiotic resistant Vibrio spp. in shellfish hatchery environment. Microbial ecology, 72, 851-860. https://doi.org/10.1007/s00248-015-0705-5.

Dubosq, N., Schmidt, S., Sudre, J., Rigaud, S., Lamarque, B., Danilo, M., Grémare, A., and Deflandre, B. 2022. First observations of seasonal bottom water deoxygenation off the Gironde estuary (Bay of Biscay, North East Atlantic). Frontiers in Marine Science, 9.10.3389/fmars.2022.1006453.

EC, 2000. Directive 2000/60/EC of the European Parliament and of the council of 23 October 2000 establishing a framework for community action in the field of water policy. Official Journal of the European Union, L 327, 1–72. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32000L0060.

EC, 2015. Commission implementing decision (EU) 2015/495 of 20 March 2015 establishing a watch list of substances for union-wide monitoring in the field of water policypursuant to directive 2008/105/EC of the European Parliament and of the council (notified under document C(2015) 1756). Official Journal of the European Union, L 78, 40–42. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32015D0495.

EC, 2018. Commission implementing decision (EU) 2018/840 of 5 June 2018 establishing a watch list of substances for union-wide monitoring in the field of water policy pursuant to directive 2008/105/EC of the European Parliament and of the council and repealing commission implementing decision (EU) 2015/495 (notified under document C(2018) 3362). Official Journal of the European Union, L 141, 9–12. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018D0840.

EEA 2015. Spatial analysis of marine protected area networks in Europe's seas. EEA Technical report No 17/2015.

Eguiraun, H.; López-De-Ipiña, K.; Martinez, I. (2014) Application of entropy and fractal dimension analyses to the pattern recognition of contaminated fish responses in aquaculture. Entropy, 16, 6133–6151. https://doi.org/10.3390/e16116133.

Eguiraun, H.; Martinez, I. (2023a) Entropy and fractal techniques for monitoring fish behaviour and welfare in aquacultural precision fish farming—A review. Entropy, 25, 559. https://doi.org/10.3390/e25040559.

Eguiraun, H.; Martinez, I. (2023b) Non-linear analyses of fish behaviours in response to aquatic environmental pollutants—A Review. Fishes, 8, 311. https://doi.org/ 10.3390/fishes8060311.

Ellis, R. P., Urbina, M. A., and Wilson, R. W. 2017. Lessons from two high CO2 worlds – future oceans and intensive aquaculture. Global Change Biology, 23: 2141-2148.10.1111/gcb.13515.

EP-INE (2022). Instituto Nacional de Estatística. Estatísticas da Pesca 2021. Lisboa, Portugal. Accessed October 08, 2023, through the site: https://www.ine.pt/xportal/xmain?xpid=INE&xpgid=ine_publicacoes&PUBLICACOESpub_boui=280980687&PUBLICACOEStema=00&PUBLICACOESmodo=2.

European Commission (2009), Communication from the Commission to the European Parliament and the Council: Building a sustainable future for aquaculture: A new impetus for the Strategy for the Sustainable Development of European Aquaculture, Brussels, 8.4.2009, COM (2009) 162 final.

European Commission (2012). Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee of the Regions: Blue Growth opportunities for marine and maritime sustainable growth. COM/2012/0494 final.

European Commission (2017), Directorate-General for Research and Innovation, Group of Chief Scientifc Advisors, *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*; Publications Office, 2017, p. 31; https://data.europa.eu/doi/10.2777/66235.

European Commission (2017). Report on the Blue Growth Strategy: towards more sustainable growth and jobs in the blue economy. SWD (2017) 128 final.

European Commission (2018) Guidance document on aquaculture activities in the context of the Natura 2000 Network, European Commission, 2018.

European Commission (2019). The European Green Deal. Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions; Brussels, 11.12.2019 COM (2019) 640 final.

European Commission (2020); Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. *A Farm to Fork Strategy for a fair, healthy and environmentally friendly food system.* Brussels, 20.5.2020. COM (2020) 381 final.

European Commission (2024): Commission Staff Working Document Implementing the Strategic Guidelines for EU aquaculture Regulatory and administrative framework for aquaculture, SWD(2024) 95 final.

European Commission (2021): Communication on strategic guidelines for a more sustainable and competitive EU aquaculture for the period 2021-2030 – COM (2021) 236 final.

European Court of Auditors (2014): "The effectiveness of European Fisheries Fund Support for aquaculture, Special Report, num. 10, 2014.

European Court of Auditors (2023): "EU aquaculture policy: Stagnating production and unclear results despite increased EU funding" Special Report 25/2023.

European Parliament (2018) Resolution of 12 June 2018 on "Towards a sustainable and competitive European aquaculture sector: current status and future challenges"; Committee on Fisheries, 2018.

EUSeaMap 2023 Broad-Scale Predictive Habitat Map for Europe.

FAO (1995), Code of Conduct for Responsible Fisheries, Roma, FAO, 1995ICES. 2022. Workshop on the Celtic Seas Ecoregion Aquaculture Overview (WKCSAO). ICES Scientific Reports. 04:57. 126 pp. http://doi.org/10.17895/ices.pub.21221882.

FAO. 2018. Impacts of Climate Change on Fisheries and Aquaculture: Synthesis of Current Knowledge, Adaptation and Mitigation Options. 627 pp.

Faranda, D., Pascale, S., and Bulut, B. 2023. Persistent anticyclonic conditions and climate change exacerbated the exceptional 2022 European-Mediterranean drought. Environmental Research Letters, 18: 034030.10.1088/1748-9326/acbc37.

Fendall, L.S., Sewell, M.A. (2009) Contributing to marine pollution by washing your face: Microplastics in facial cleansers. Mar. Poll. Bull., 58: 1225-1228. https://doi.org/10.1016/j.marpolbul.2009.04.025.

Ferreira JG, Corner RA, Moore H, Service M, Rheault R. 2018. Ecological carrying capacity for shellfish aquaculture—sustainability of naturally occurring filter-feeders and cultivated bivalves. J. Shellfish Res. 37, 709–726.

Ferreira JG, Taylor NGH, Cubillo A, Lencart-Silva J, Pastres P, Bergh O, Guilder J. 2021. An integrated model for aquaculture production, pathogen interaction, and environmental effects. Aquaculture 536.

Ferreira, J. G., Saurel, C., e Silva, J. L., Nunes, J. P., & Vazquez, F. (2014). Modelling of interactions between inshore and offshore aquaculture. Aquaculture, 426, 154-164.

Ferreira, J. G., Saurel, C., Nunes, J. P., Ramos, L., Silva, J. D. L. E., Vazquez, F.& Rocha, M. (2012). Framework for Ria Formosa water quality, aquaculture, and resource development. ISBN: 978-972-99923-3-9.

Ferreira, J. G., Sequeira, A., Hawkins, A. J. S., Newton, A., Nickell, T. D., Pastres, R., ... & Bricker, S. B. (2009). Analysis of coastal and offshore aquaculture: application of the FARM model to multiple systems and shellfish species. Aquaculture, 289(1-2), 32-41.

Figueras et al. (2007) Biología y cultivo del mejillón (*Mytilus galloprovincialis*) en Galicia (2007). Consejo Superior de Investigaciones Científicas (España) Eds. Figueras Huerta, Antonio; Cáceres-Martínez, J. ISBN: 978-84-00-0526-1 http://hdl.handle.net/10261/104143

Filgueira, R., Comeau, L. A., Guyondet, T., McKindsey, C. W., & Byron, C. J. (2015). Modelling carrying capacity of bivalve aquaculture: a review of definitions and methods. Fisheries and Oceans Canada, Ecosystems and Oceans Science.

Flassch and Leborgne ICES 1992.

Fleury E., Petton S., Benabdelmouna A., Corporeau C., Pouvreau S. et coll. (2022) Observatoire national du cycle de vie de l'huître creuse en France. Rapport annuel 2021. Convention DPMA 2021 – Ifremer.

Fleury Elodie, Petton Sébastien, Benabdelmouna Abdellah, Pouvreau Stephane, (coord.) (2023). Observatoire national du cycle de vie de l'huître creuse en France. Rapport annuel ECOSCOPA 2022. R.INT.BREST RBE/PFOM/PI 2023-1 . https://archimer.ifremer.fr/doc/00840/95240/.

Froehlich, H. E., Gentry, R. R., and Halpern, B. S. 2018. Global change in marine aquaculture production potential under climate change. Nature Ecology & Evolution, 2: 1745-1750.10.1038/s41559-018-0669-1

FOESA (2015) Plan Estratégico Plurianual de la Acuicultura Española (2014-2020). Documento de Planificaciones Estratégicas Autonómicas. Ministerio de Agricultura y Medio Ambiente. https://www.mapa.gob.es/es/pesca/temas/acuicultura/315_PLANES_AUTONOMICOS_PEAE_MAR_2015_tcm30-77596.pdf.

Following the infection process of vibriosis in Manila clam (*Ruditapes philippinarum*) larvae through GFP-tagged pathogenic Vibrio species. J Invertebr Pathol 133:27–33. https://doi.org/10.1016/j.jip.2015.11.008.

Fraga-Corral M., Ronza P., Garcia-Oliveira P., Pereira A.G., Losada A.P., Prieto M.A., Quiroga M.I., Simal-Gandara J. 2022. Aquaculture as a circular bio-economy model with Galicia as a study case: How to transform waste into revalorized by-products. Trends in Food Science & Technology (119): 23-35, https://doi.org/10.1016/j.tifs.2021.11.026.

Freitas, J. R., Salinas Morrondo, J. M., & Cremades Ugarte, J. (2016). Saccharina latissima (Laminariales, Ochrophyta) farming in an industrial IMTA system in Galicia (Spain). Journal of applied phycology, 28, 377-385.

Gamito S, Quental-Ferreira H, Parejo A, Aubin J, Christensen V, Cunha ME. 2020 Integrated multi-trophic aquaculture systems: energy transfers and foodweb organization in coastal earthen ponds. Aquacult Environ Interact 12: 457-470.

Gamito, S. 1997. Sustainable management of a coastal lagoonal system (Ria Formosa, Portugal): An ecological model for extensive aquaculture. International Journal of Salt Lake Research 6:145-173.

Gamito, S., & Erzini, K. 2005. Trophic foodweb and ecosystem attributes of a water reservoir of the Ria Formosa (south Portugal). Ecological Modelling, 181(4), 509-520.

Gattuso, J.-P., Magnan, A. K., Bopp, L., Cheung, W. W. L., Duarte, C. M., Hinkel, J., Mcleod, E., Micheli, F., Oschlies, A., Williamson, P., Billé, R., Chalastani, V. I., Gates, R. D., Irisson, J.-O., Middelburg, J. J., Pörtner, H.-O., and Rau, G. H. 2018. Ocean Solutions to Address Climate Change and Its Effects on Marine Ecosystems. Frontiers in Marine Science, 5.10.3389/fmars.2018.00337

Gavrilescu, M.; Demnerová, K.; Aamand, J.; Agathos, S.; Fava, F. (2015) Emerging pollutants in the environment: Present and future challenges in biomonitoring, ecological risks and bioremediation. New Biotechnol., 32, 147–156. https://doi.org/10.1016/j.nbt.2014.01.001.

Gazeau, F., Parker, L., Comeau, S., Gattuso, J.-P., O'Connor, W., Martin, S., Pörtner, H.-O., and Ross, P. 2013. Impacts of ocean acidification on marine shelled molluscs. Marine Biology, 160: 2207-2245.10.1007/s00227-013-2219-3

Gephart *et al*. 2021 10.1038/s41586-021-03889-2

Gobler, C. J. 2020. Climate Change and Harmful Algal Blooms: Insights and perspective. Harmful Algae, 91: 101731.https://doi.org/10.1016/j.hal.2019.101731.

Gomes M, Correia A, Pinto L, Sá C, Brotas V and Mateus M (2020) Coastal Water Quality in an Atlantic Sea Bass Farm Site (Sines, Portugal): A First Assessment. Front. Mar. Sci. 7:175. doi: 10.3389/fmars.2020.00175Guerra-Diaz, A. 2013. Clan Production and cultivation in Galicia (NW Spain): The role of hatcheries. In: Clam fisheries and aquaculture. (ed. da Costa, F.). Nova Science Publishers. New York. 255-272.

Guimarães MHME, Cunha AH, Nzinga RL, Marques JF. 2012. The distribution of seagrass (*Zostera noltii*) in the Ria Formosa lagoon system and the implications of clam farming on its conservation. Journal for Nature Conservation, 20: 30-40.

Hargrave, B.T. (Ed.), 2005. Environmental Effects of Marine Finfish Aquaculture, Handbook of Environmental Chemistry. Springer-Verlag, Berlin/ Heidelberg. https:// doi.org/10.1007/b12227.

Harvell, C. D., Kim, K., Burkholder, J. M., Colwell, R. R., Epstein, P. R., Grimes, D. J., Hofmann, E. E., Lipp, E. K., Osterhaus, A. D., Overstreet, R. M., Porter, J. W., Smith, G. W., and Vasta, G. R. 1999. Emerging marine diseases--climate links and anthropogenic factors. Science, 285: 1505-1510.10.1126/science.285.5433.1505.

Hobday, A. J., Alexander, L. V., Perkins, S. E., Smale, D. A., Straub, S. C., Oliver, E. C. J., Benthuysen, J. A., Burrows, M. T., Donat, M. G., Feng, M., Holbrook, N. J., Moore, P. J., Scannell, H. A., Sen Gupta, A., and Wernberg, T. 2016. A hierarchical approach to defining marine heatwaves. Progress in Oceanography, 141: 227-238. https://doi.org/10.1016/j.pocean.2015.12.014.

Holmer M., Hansen P.K., Karakassis I., Borg J.A. & Schembri P.J. (2008) Monitoring of environmental impacts of marine aquaculture. En: (Eds.), Aquaculture in the Ecosystem. Holmer M., Black K., Duarte C.M., Marbà N. & Karakassis I. Springer, pp. 47-85.

https://www.webofscience.com/wos/author/record/664046.

Hubert FN, Pellaud M, Gamito S. 2006 Environmental effects of marine fish pond culture in the Ria Formosa (Southern Portugal). Hydrobiologia, 555: 289-297.

ICES (2022) BoBIC Ecosystem Overview.

Idowu Caroline (2020): The new EU organic regulation is coming – are you ready?, Pen & Tec Consulting, August 2020, https://pentec-consulting.eu/the-new-eu-organic-regulation-is-coming-are-you-ready/.

INE & DGRM.

IPCC. 2019. IPCC Special Report on the Ocean and Cryosphere in a Changing Climate.

IPCC 2023. Summary for Policymakers. In Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, pp. 1-34. Ed. by H. Lee, and J. Romero. IPCC, Geneva, Switzerland.

IUCN Guidelines on Site Selection and Site Management on Aquaculture, 2009.

Izquierdo-Gomez, D., Fernandez-Jover, D., Sanchez-Jerez, P., Toledo-Guedes, K., Arechavala-Lopez, P., Forcada, A., & Valle-Pérez, C. (2014a). Guía de buenas prácticas para la gestión de escapes en acuicultura marina. Vol. I. Prevención.

Izquierdo-Gómez, D., Sánchez-Jerez, P., Fernández-Jover, D., Toledo-Guedes, K., Arechavala-López, P., Forcada-Almarcha, A., & Valle-Pérez, C. (2014b). Guía de buenas prácticas para la gestión de escapes en la acuicultura marina: Vol II. Mitigación. Proyecto ESCA-FEP, Fondo Europeo de Pesca. Ed. Oceanográfica, 32.

Junta de Andalucía (2014a), Localización de zonas idóneas para el desarrollo de la Acuicultura Marina en Andalucía (2014), Dirección General de Pesca y Acuicultura. Servicio de Ordenación de Recursos Pesqueros y Acuícolas, Junta de Andalucía, Sevilla, 2014. https://www.juntadeandalucia.es/servicios/publicaciones/detalle/77385.html#toc-informaci-n-general.

Junta de Andalucía (2014b), Estrategia Andaluza para el Desarrollo de la Acuicultura Marina, 2014-2020, https://www.juntadeandalucia.es/export/drupaljda/ESTRATEGIA_ANDALUZA_PARA_EL_DESARROLLO_DE_LA_ACUICULTURA_MARINA_2014-2020.pdf.

Junta de Andalucía (2014b), Nueva Estrategia de la Acuicultura Marina en Andalucía, 2021-2030, Consejería de Agricultura, Pesca, Agua y Desarrollo Rural, 2022, https://www.juntadeandalucia.es/sites/default/files/inline-files/2023/03/Estrategia_Acuicultura_2021_2030_0.pdf.

Kermagoret, C., & Frangoudes, K. (2021). Blue growth in the face of citizen protests: analyzing the participative democracy process through four case studies in Brittany (France). Revue internationale de psychosociologie et de gestion des comportements organisationnels, (69), 91-111.

Kock *et al*. 2020 https://doi.org/10.1016/j.aquaculture.2020.735474.

Krause Gesche, *et al*., (2015). A revolution without people? Closing the people-policy gap in aquaculture development. Aquaculture, 447, 44-55. Publisher's official version :https://doi.org/10.1016/j.aquaculture.2015.02.009, Open Access version: https://archimer.ifremer.fr/doc/00252/36301/.

Kroeker, K. J., Kordas, R. L., Crim, R., Hendriks, I. E., Ramajo, L., Singh, G. S., Duarte, C. M., and Gattuso, J.-P. 2013. Impacts of ocean acidification on marine organisms: quantifying sensitivities and interaction with warming. Global Change Biology, 19: 1884-1896.10.1111/gcb.12179.

Kuhlbrodt, T., Swaminathan, R., Ceppi, P., Wilder, T. 2024. A Glimpse into the Future The 2023 Ocean Temperature and Sea Ice Extremes in the Context of Longer-Term Climate Change. American Meteorological Society. https://doi.org/10.1175/BAMS-D-23-0209.1.

Kwiatkowski, L., *et al.,* (2020). Twenty-first century ocean warming, acidification, deoxygenation, and upper-ocean nutrient and primary production decline from CMIP6 model projections. Biogeosciences, 17: 3439-3470.10.5194/bg-17-3439-2020

Labarta, U., & Fernández-Reiriz, M. J. (2019). The Galician mussel industry: Innovation and changes in the last forty years. Ocean & coastal management, 167, 208-218.

Lafferty, K. D. 2009. The ecology of climate change and infectious diseases. Ecology, 90: 888-900. https://doi.org/10.1890/08-0079.1.

Lafferty, K. D., Harvell, C. D., Conrad, J. M., Friedman, C. S., Kent, M. L., Kuris, A. M., Powell, E. N., Rondeau, D., and Saksida, S. M. 2015. Infectious diseases affect marine fisheries and aquaculture economics. Annual Review of Marine Science, 7: 471-496.10.1146/annurev-marine-010814-015646

Laroche, J., *et al.,* (2013) Variation patterns in individual fish responses to chemical stress among estuaries, seasons and genders: The case of the European flounder (Platichthys flesus) in the Bay of Biscay. Env. Sci. Pollut. Res. 20: 738-748. https://doi.org/10.1007/s11356-012-1276-3.

Law 23/1984. Regulation and management of marine cultures. BOE-A-1984-14431 (25-06-1984). [Accessed 27. September. 2023]. [Accessed 27. September. 2023]. Available online: https://www.boe.es/buscar/doc.php?id=BOE-A-1984-14431.

Law no. 86-2 of January 3, 1986 on coastal development, protection and enhancement. [Accessed 27. October. 2023]. Available online: https://www.legifrance.gouv.fr/loda/id/JORFTEXT000000317531.

Law 21/2013. Environmental assessment. BOE-A-2013-12913 (09-12-2013). [Accessed 27. September. 2023]. Available online: https://www.boe.es/buscar/act.php?id=BOE-A-2013-12913.

Le Gouvello, R., et Simard, F. (eds.) (2017) Durabilité des aliments pour le poisson en aquaculture : Réflexions et recommandations sur les aspects technologiques, économiques, sociaux et environnementaux. Gland, Suisse : UICN, et Paris, France : Comité français de l'UICN. 296 pp.

Lemoine Maud, Durand Gaetane, Pilven Sophie (2018). The REPHY, an outstanding monitoring network: 30 years of data. ICHA2018 - 18th International Conference on Harmful Algae "From ecosystems to socio-ecosystems". 21-26 october 2018, Nantes, France. https://archimer.ifremer.fr/doc/00472/58411/.

Leung, J. Y. S., Zhang, S., and Connell, S. D. 2022. Is Ocean Acidification Really a Threat to Marine Calcifiers? A Systematic Review and Meta-Analysis of 980+ Studies Spanning Two Decades. Small, 18: 2107407.10.1002/smll.202107407.

Lillebø AL, Pita C, Garcia-Rodrigues J, Ramos S, Villasante S (2017) How can marine ecosystem services support the Blue Growth agenda? Marine Policy 81: 132–142.

Mamede, R., Santos, A., Diaz, S., da Silva, E. F., Patinha, C., Calado, R., & Ricardo, F. (2022). Elemental fingerprints of bivalve shells (Ruditapes decussatus and R. philippinarum) as natural tags to confirm their geographic origin and expose fraudulent trade practices. Food Control, 135, 108785. https://doi.org/10.1016/j.foodcont.2021.108785.

Macías JC, Aguado F, González N, Guerrero S, Estévez A, Valencia JM, Cremades J (2008) Acuicultura Integrada: desarrollo de experiencias de cultivos multitróficos en la costa española. In: Rey-Méndez M, Lodeiros C, Fernández Casal J, Guerra A (eds) Foro Ac. Rec. Mar. Rías Gal. 10, p 483–490 (in Spanish).

Masiá, P., Ardura, A., Gaitán, M., Gerber, S., Rayon-Viña, F., Garcia-Vazquez, E. (2021) Maritime ports and beach management as sources of coastal macro-, meso-, and microplastic pollution. Env. Sci. Pollut. Res., 28: 30722-30731. DOI: 10.1007/s11356-021-12821-0.

Masiá, P., Ardura, A., Garcia-Vazquez, E. (2019) Microplastics in special protected areas for migratory birds in the Bay of Biscay. Mar. Pollut. Bull., 146: 993-1001. https://doi.org/10.1016/j.marpolbul.2019.07.065.

Masiá, P., Ardura, A., Garcia-Vazquez, E. (2022) Microplastics in seafood: Relative input of Mytilus galloprovincialis and table salt in mussel dishes. Food Res. Int., 153: 110973. https://doi.org/10.1016/j.foodres.2022.110973.

Mateus, M., Almeida D., Simonson, W., Felgueiras, M., Banza, P. Batty, L. 2016. Conflictive uses of coastal areas: A case study in a southern European coastal lagoon (Ria de Alvor, Portugal). Ocean & Coastal Management, 132: 90-100.

Matos GS, Pereira SG, Genisheva ZA, Gomes AM, Teixeira JA, Rocha CMR. Advances in Extraction Methods to Recover Added-Value Compounds from Seaweeds: Sustainability and Functionality. Foods. 2021; 10(3):516. https://doi.org/10.3390/foods10030516.

Mauffret, A., Chouvelon, T., Wessel, N., Cresson, P., Bănaru, D., Baudrier, J., Bustamante, P., Chekri, R., Jitaru, P., Le Loc'h, F., Mialet, B., Vaccher, V., Harmelin-Vivien, M. (2023) Trace elements, dioxins and PCBs in different fish species and marine regions: Importance of the taxon and regional features. Env. Res., 216: 114624. https://doi.org/10.1016/j.envres.2022.114624.

McGovern, E., Schilder, J., Artioli, Y., Birchenough, S., Dupont, S., Findlay, H., Skjelvan, I., Skogen, M. D., Álvarez, M., Büsher, J. V., Chierici, M., Aagaard Christensen, J. P., Diaz, P. L., Grage, A., Gregor, L., Humphreys, M., Järnegren, J., Knockaert, M., Krakau, M., Nogueira, M., Ólafsdóttir, S. R., von Schuckmann, K., Carreiro-Silva, M., Stiasny, M., Walsham, P., Widdicombe, S., Gehlen, M., Chau, T. T. T., Chevallier, F., Savoye, N., Clark, J., Galli, G., Hordoir, R., and C., M. 2022. Ocean Acidification.

McKindsey Christopher W., Archambault Philippe, Callier Myriam, Olivier Frederic (2011). Influence of suspended and off-bottom mussel culture on the sea bottom and benthic habitats: a review. *Canadian Journal Of Zoology-revue Canadienne De Zoologie* , 89(7), 622-646 . Publisher's official version: https://doi.org/10.1139/Z11-037.

McKindsey, C. W., Thetmeyer, H., Landry, T., & Silvert, W. (2006). Review of recent carrying capacity models for bivalve culture and recommendations for research and management. Aquaculture, 261(2), 451-462.

MEA (2005) Ecosystems and Human Well-Being: Biodiversity Synthesis. World Resources Institute, Washington, DC.

Mendoza, A., Osa, J.L., Basurko, O.C., Rubio, A., Santos, M., Gago, J., Galgani, F., Peña-Rodriguez, C. (2020) Microplastics in the Bay of Biscay: An overview. Mar. Poll. Bull., 153: 110996. https://doi.org/10.1016/j.marpolbul.2020.110996.

Menéndez, D., Álvarez, A., Acle, S., Peón, P., Ardura, A., Garcia-Vazquez, E. (2022) Microplastics across biomes in diadromous species. Insights from the critically endangered Anguilla Anguilla. Env. Pollut., 305: 119277. https://doi.org/10.1016/j.envpol.2022.119277.

Mijangos, l., Ziarrusta, h., Ros, O., Kortazar, L., Fernandez, L.A., Olivares, M., Zuloaga, O., Prieto, A., Etxebarria, N. (2018) Occurrence of emerging pollutants in estuaries of the Basque Country: Analysis of sources and distribution, and assessment of the environmental risk. Water Res., 147: 152-163. https://doi.org/10.1016/j.watres.2018.09.033.

Mille, D., & Blachier, P. (2009). Les mutations conchylicoles sur la façade maritime de l'AGLIA. État des lieux et perspectives de développement. Rapport, CREAA.

Ministerio para la Transición Ecológica y el Reto Demográfico, MTERD, (2023). Planes de Ordenación del Espacio Marítimo, III. Diagnóstico: Demarcación Sudatlántica (Dirección General de la Costa y el Mar), 2023. https://www.miteco.gob.es/es/costas/temas/proteccion-medio-marino/ordenacion-del-espacio-maritimo.html.

Ministry of Agriculture, Fisheries and Food). SGP-MAPA (2022). Contribución de España a las Directrices estratégicas para una acuicultura de la UE más sostenible y competitiva 2021-2030. Secretaría General de pesca. Ministerio de Agricultura, Pesca y Alimentación, Madrid, España. 170 p.

Miranda, C., Rojas, R., Garrido, M., Geisse, J., and González, G. (2013). Role of shellfish hatchery as a reservoir of antimicrobial resistant bacteria. Mar. Pollut. Bull. 74, 334–343. doi: 10.1016/j.marpolbul.2013.06.032.

Mongruel R, Prou J, Ballé-Béganton J, Lample M, Vanhoutte-Brunier A, Réthoret H, Pérez Agúndez J, Vernier F, Bordenave P, Bacher C (2011) Modeling soft institutional change and the improvement of freshwater governance in the coastal zone. Ecol Soc 16(4):15. https://doi.org/10.5751/ES-04294-160415.

Moreno, P. *et al*. Surveillance of viruses in wild fish populations in areas around the Gulf of Cadiz (South Atlantic Iberian Peninsula). Appl. Environ. Microbiol. 80, 6560–6571 (2014).

Mosqueira M, Pombo A, Borges C, Brito AC, Zacarias N, Esteves R, Palma C. 2022. Potential for Coastal d Offshore Aquaculture in Portugal: Insights from Physico-Chemical and Oceanographic Conditions. Applied Sciences, 12.

MRAG (2021). Study on state-of-the-art scientific information on the impacts of aquaculture activities in Europe. Accessed October 08, 2023, through the site: https://op.europa.eu/en/publication-detail/-/publication/9dcce336-a5a5-11ec-83e1-01aa75ed71a1/language-en.

Morro, B., Davidson, K., Adams, T.P., Falconer, L., Holloway, M., Dale, A., Aleynik, D., Thies, P.R., Khalid, F., Hardwick, J., Smith, H., Gillibrand, P.A., Rey-Planellas, S., 2022. Offshore aquaculture of finfish: Big expectations at sea. Rev. Aquac. 14, 791–815. https://doi.org/10.1111/raq.12625.

National Strategic Plan for the Sustainable Development of Aquaculture (2018) (https://www.europe-en-france.gouv.fr/fr/ressources/plan-strategique-national-pour-le-developpement-des-aquacultures-durables-2020).

Nina Moulin. Analyse rétrospective de la gouvernance du socio-écosystème ostréicole du bassin de Marennes-Oléron: une approche par la mémoire des acteurs. Sciences du Vivant [q-bio]. 2022. dumas-03888648.

Ottinger et al. 2006 https://doi.org/10.1016/j.ocecoaman.2015.10.015.

Peeler, E.J., & Murray, A.G. (2004). Disease interaction between farmed and wild fish populations. J. Fish Biol., 65: 321–322.

Pérez Agúndez José A., Raux Pascal, Vieira Pak Manuela, Cavallo Marianna, Lancelot Loeiza (2022). Top-level institutional policies and their implementation at regional level − A difficult equation. The example of the social acceptability of aquaculture development in Malaga, Spain. Aquaculture Reports, 25, 101227 (10p.). Publisher's official version : https://doi.org/10.1016/j.aqrep.2022.101227 , Open Access version : https://archimer.ifremer.fr/doc/00780/89195/.

Pérez Camacho A., González R., Fuentes J., 1991. Mussel culture in Galicia (N.W. Spain). Aquaculture (94) 2–3: 263-278. https://doi.org/10.1016/0044-8486(91)90122-N.

Pérez R., Kaas R., Campello F., Arbault S. & Babaroux O. (1992) La culture des algues marines dans le monde. Service de la Documentation et des Plubications (SDP). Ifremer. Plouzane.

Pernet, F., and Browman, H. I. 2021. The future is now: marine aquaculture in the anthropocene. Ices Journal of Marine Science, 78: 315-322.10.1093/icesjms/fsaa248.

Peteiro C., Salinas J.M., Freire O & Fuertes C. (2006) Cultivation of the autoctonous seaweed Laminaria saccharina on the Galician Coast NW Spain): Production and features of the sporophytes for an annual and biennal harvest. Thalassas, 22: 45-53.

Petton, S., Pernet, et al., (2023). French coastal network for carbonate system monitoring: The CocoriCO2 dataset. Earth Syst. Sci. Data Discuss., 2023: 1-34.10.5194/essd-2023-445.

Pham, D.N., Clark, L., Li, M. (2021) Microplastics as hubs enriching antibiotic-resistant bacteria and pathogens in municipal activated sludge. J. Hazard. Mater. Lett., 2: 100014. https://doi.org/10.1016/j.hazl.2021.100014.

Polo, D., Varela, M. F., & Romalde, J. L. (2015). Detection and quantification of hepatitis A virus and norovirus in Spanish authorized shellfish harvesting areas. International journal of food microbiology, 193, 43-50.

Prado FD, Vera M, Hermida M, Blanco A. and others (2018) Tracing the genetic impact of farmed turbot Scophthalmus maximus on wild populations. Aquacult Environ Interact 10:447-463. https://doi.org/10.3354/aei00282.

Prado, S., Dubert, J., da Costa, F., Martínez-Patiño, D., and Barja, J. L. (2014). Vibrios in hatchery cultures of the razor clam, Solen marginatus (Pulteney). J. Fish. Dis. 37, 209–217. Doi: 10.1111/jfd.12098.

Raillard O., Ménesguen A. (1994) An ecosystem box model for estimating the carrying capacity of a macrotidal shellfish system. MEPS, 115(1–2), 117–130 *Production Carrying capacity (coupled physical and biological submodels into an ecological model).*

Ramos, J., Lino, P. G., Caetano, M., Pereira, F., Gaspar, M., & dos Santos, M. N. (2015). Perceived impact of offshore aquaculture area on small-scale fisheries: A fuzzy logic model approach. Fisheries research, 170, 217-227. https://doi.org/10.1016/j.fishres.2015.05.030.

Ratmaya, W., Laverman, A. M., Rabouille, C., Akbarzadeh, Z., Andrieux-Loyer, F., Barillé, L., Barillé, A.-L., Le Merrer, Y., and Souchu, P. 2022. Temporal and spatial variations in benthic nitrogen cycling in a temperate macro-tidal coastal ecosystem: Observation and modeling. Continental Shelf Research, 235: 104649.

Reguera, P., Viñas, L., Gago, J. (2019) Microplastics in wild mussels (Mytilus spp.) from the north coast of spain [Microplásticos en mejillones silvestres (Mytilus spp.) de la costa del norte de España]. Sci. Mar., 83: 337-347. DOI: https://doi.org/10.3989/scimar.04927.05A.

Regulation (EC) No 853/2004 of the European Parliament and of the Council of 29 April 2004 laying down specific hygiene rules for food of animal origin. (OJ, L 139) [Accessed 27. October. 2023]. Available online: https://eur-lex.europa.eu/legal-content/en/ALL/?uri=CELEX%3A32004R0853.

Regulation (EU) 2016/429 of the European Parliament and of the Council of 9 March 2016 on transmissible animal diseases and amending and repealing certain acts in the area of animal health (‘Animal Health Law’) (OJ, L84) [Accessed 27. October. 2023]. Available online: https://eur-lex.europa.eu/eli/reg/2016/429/oj.

Regulatory Part (Articles D111-1 to R958-33). Rural and Maritime Fishing Code. [Accessed 27. october. 2023]. Available online: https://www.legifrance.gouv.fr/codes/section_lc/LEGITEXT000006071367/LEGISCTA000006098287/2016-01-01/.

Reid, G. K., Gurney-Smith, H. J., Marcogliese, D. J., Knowler, D., Benfey, T., Garber, A. F., Forster, I., Chopin, T., Brewer-Dalton, K., Moccia, R. D., Flaherty, M., Smith, C. T., and De Silva, S. 2019. Climate change and aquaculture: considering biological response and resources. Aquaculture Environment Interactions, 11: 569-602

Relvas, P., and Barton, E. D. 2002. Mesoscale patterns in the Cape São Vicente (Iberian Peninsula) upwelling region, Journal of Geophysical Research Atmospheres, 107(C10), 3164. https://doi.org/10.1029/2000JC000456.

Ribeiro L., Soares F., Luna-Araujo R., Quental-Ferreira H., Pousão-Ferreira P., Nathan J., Cristina S., Fragoso B. (2023) Chapter 6. Microplásticos na aquacultura, o que sabemos? IN : Micro e Nanoplásticos: um Macroproblema Editores: Delminda Moura, Isabel Mendes, Jaime Aníbal, Ana Gomes. Doi: http://dx.doi.org/10.34623/tz6d-k552, Disponível em: http://hdl.handle.net/10400.1/19968Rivaud*, A., & Cazals, C. (2013). Quand la co-localisation contraint la coordination: l'apport du modèle 'exit-voice'à l'analyse des dynamiques territoriales. Revue d'économie régionale et urbaine, (4), 679-704.

Romalde, J. L., Rivadulla, E., Varela, M. F., & Barja, J. L. (2018). An overview of 20 years of studies on the prevalence of human enteric viruses in shellfish from Galicia, Spain. Journal of applied microbiology, 124(4), 943-957.

Rosas, E., Martins, F., Tosic, M., Janeiro, J., Mendonça, F., Mills, L. (2022) Pathways and Hot Spots of Floating and Submerged Microplastics in Atlantic Iberian Marine Waters: A Modelling Approach. J. Mar. Sci. Eng., 10: 1640. https://doi.org/10.3390/jmse10111640.

Royal Decree 1471/1989. General Regulations for the development and execution of Law 22/1988, of July 28, 1988, on Coasts. BOE-A-1989-29127 (01-12-1989). [Accessed 27. September. 2023]. Available online: https://www.boe.es/buscar/doc.php?id=BOE-A-1989-29127.

Rowley, A.F., Cross, M.E., Culloty, S.C., Lynch, S.A., Mackenzie, C.L., Morgan, E., O'Riordan, R.M., Robins, P.E., Smith, A.L., Thrupp, T.J., Vogan, C.L., Wootton, E.C., Malham, S.K. (2014) The potential impact of climate change on the infectious diseases of commercially important shellfish populations in the Irish Sea—a review, ICES J. Mar. Sci., 71: 741-759.https://doi.org/10.1093/icesjms/fst234.

Ruiz-Chico J, Biedma-Ferrer JM, Peña-Sánchez AR, Jiménez-García M. Social Acceptance of Aquaculture in Spain: An Instrument to Achieve Sustainability for Society. International Journal of Environmental Research and Public Health. 2020; 17(18):6628. https://doi.org/10.3390/ijerph17186628.

Ruiz de Apodaca Espinosa, Ángel: Régimen jurídico de la Evaluación de Impacto Ambiental de proyectos. Ambienta: la revista del Ministerio de Medio Ambiente, nº 123, 2018, pag. 84-97 https://www.mapa.gob.es/ministerio/pags/Biblioteca/Revistas/pdf%5FAM%2FPDF%5FAM%5FAmbienta%5F2018%5F123%5F84%5F97%2Epdf.

SAPEA, Science Advice for Policy by European Academies. (2017). Food from the oceans: how can more food and bio-mass be obtained from the oceans in a way that does not deprive future generations of their benefits? Berlin: SAPEA. doi:10.26356/foodfromtheoceans. https://scientificadvice.eu/advice/food-from-the-oceans/

Scientific, Technical and Economic Committee for Fisheries (STECF) 2013, The Economic Performance Report on the EU Aquaculture sector (STECF-13-29). 2013. Publications Office of the European Union, Luxembourg, EUR 26336 EN, JRC 86671, 383 pp.

Scientific, Technical and Economic Committee for Fisheries (STECF 2023), Economic Report on the EU aquaculture (STECF- 22-17). Nielsen, R., Virtanen, J. & Guillen, J. (editors). Publications Office of the European Union, Luxembourg, 2023, doi:10.2760/51391, JRC132648.

Solaun, O., Rodríguez,J.G., Menchaca, I., López-García, E., Martínez, E., Zonja, B., Postigo, C., López de Alda, M., Barceló, D., Borja, A., Manzanos, A., Larreta, J. (2021) Contaminants of emerging concern in the Basque coast (N Spain): Occurrence and risk assessment for a better monitoring and management decisions. Sci. Tot Environ., 765: 142765. https://doi.org/10.1016/j.scitotenv.2020.142765.

Solaun, O., Rodríguez,J.G., Menchaca, I., López-García, E., Martínez, E., Zonja, B., Postigo, C., López de Alda, M., Barceló, D., Borja, A., Manzanos, A., Larreta, J. (2021) Contaminants of emerging concern in the Basque coast (N Spain): Occurrence and risk assessment for a better monitoring and management decisions. Sci. Tot Environ., 765: 142765. https://doi.org/10.1016/j.scitotenv.2020.142765.

Sousa CAM, Cunha ME, Ribeiro L. 2020 Tracking 130 years of coastal wetland reclamation in Ria Formosa, Portugal: Opportunities for conservation and aquaculture. Land Use Policy 94.

Svåsand T., Crosetti D., García-Vázquez E., Verspoor E. (eds). (2007). Genetic impact of aquaculture activities on native populations. Genimpact final scientific report (EU contract n. RICA-CT-2005-022802). 176 p. http://genimpact.imr.no/.

Tacon A.G.J and Metian M. (2009) Fishing for Feed or Fishing for Food: Increasing Global Competition for Small Pelagic Forage Fish, Ambio, Vol. 38, No. 6 (Sep., 2009), pp. 294-302.

TEEB (2010) The Economics of Ecosystems and Biodiversity: Mainstreaming the Economics of Nature: A Synthesis of the Approach, Conclusions and Recommendations of TEEB. Available from: http://www.teebweb.org.

Tenore, K. R., Corral, J., Gonzalez, N., & Lopez-Jamar, E. (1985, July). Effects of intense mussel culture on food chain patterns and production in coastal Galicia, NW Spain. In Proceedings of the International Symposium on Utilization of Coastal Ecosystems: Planning, Pollution and Productivity. Rio Grande, Brazil (Vol. 1, pp. 321-328).

Tett, P., Portilla, E., Gillibrand, P. A., & Inall, M. (2011). Carrying and assimilative capacities: the ACExR-LESV model for sea-loch aquaculture. Aquaculture Research, 42, 51-67.

Thomas, Y., Pouvreau, S., Alunno-Bruscia, M., Barillé, L., Gohin, F., Bryère, P., and Gernez, P. 2015. Global change and climate-driven invasion of the Pacific oyster (Crassostrea gigas) along European coasts: a bioenergetics modelling approach. Journal of Biogeography.10.1111/jbi.12665.

Walton MEM, Vilas C, Canavate JP, Gonzalez-Ortegon E, Prieto A, van Bergeijk SA *et al*. (2015) A model for the future: ecosystem services provided by the aquaculture activities of Veta la Palma, Southern Spain. Aquaculture 448: 382–390.

Weitzman, J., & Filgueira, R. (2020). The evolution and application of carrying capacity in aquaculture: towards a research agenda. Reviews in Aquaculture, 12(3), 1297-1322.

Wittmann, A. C., and Pörtner, H.-O. 2013. Sensitivities of extant animal taxa to ocean acidification. Nature Climate Change, 3: 995-1001.10.1038/nclimate1982.

Yang W, Li Y, Boraschi D. (2023) Association between microorganisms and microplastics: How does it change the host-pathogen interaction and subsequent immune response? Int. J. Mol. Sci., 24:4065. doi: 10.3390/ijms24044065.

Zhulay, I., Reiss, K., Reiss, H (2015) Effects of aquaculture fallowing on the recovery of macrofauna communities, Marine Pollution Bulletin, 97: 381-390. https://doi.org/10.1016/j.marpolbul.2015.05.064.

Zorita, I., Solaun, O., Rodríguez, J.G., Larreta, J., Abad, E., Ábalos, M. (2023) Time series data (2008–2023) of polychlorinated dibenzo-p-dioxins, dibenzofurans and polychlorinated biphenyls in bivalves from Shellfish Production Areas of the Basque coast (SE Bay of Biscay). Data in Brief, 51, art. no. 109751. https://doi.org/10.1016/j.dib.2023.109751.

Annex 1: List of participants

Name	INSTITUTE	Country of institute
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Francis O'Beirn	Marine Institute	Ireland
Anne Cooper	ICES	Denmark
Ann Lisbeth Agnalt	IMR	Norway
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Laura Ribeiro	Instituto Português do Mar e da Atmosfera	Portugal
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Pedro Pousão	Portuguese Institute for the Ocean and Atmosphere (IPMA)	Portugal
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Rui Oliveira	Directorate-General for Natural Resources, Safety and Maritime Services	Portugal
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Anaël Delorme (statistics)	SSP/SDSAFA/BSSAF, SSP BP 32688 31326 CASTANET TOLOSAN CEDEX	

Annex 2: Resolutions

2022/WK/ASG01 Workshop on the Bay of Biscay and Iberian Coast ecoregion Aquaculture Overview (WKBoBICAO) chaired by Myriam Callier, France*, and Francis O'Beirn, Ireland*, will be established and meet (hybrid meeting) in Sète, France (Ifremer Station) in 3–5 October 2023 to:

a) Review and discuss the data and information collected for the Bay of Biscay and Iberian Coast ecoregion aquaculture overview, identify the gaps and agree next steps to complete the draft overview;

b) Collate datasets and resources for the aquaculture overview by completing the ICES Data Profiling Tool (https://www.ices.dk/data/tools/Pages/Data-profiler.aspx); and

c) Produce a workshop report detailing the conclusions of ToRs a and b. This report will serve as the foundation for the Bay of Biscay and Iberian Coast ecoregion aquaculture overview.

WKBoBICAO will report by January 2024 for the attention of the ACOM.

Supporting information

Priority	Aquaculture is a high-priority topic for ICES. ICES work on aquaculture is part of a wider portfolio of work that seeks to advance and share scientific understanding of marine ecosystems and the services they provide, and to use this knowledge to generate state-of-the-art advice for meeting conservation, management, and sustainability goals. The ICES Strategic Plan states: 'We will regularly publish, update, and disseminate overviews on the state of fisheries, aquaculture, and ecosystems in the ICES region, drawing as appropriate on analyses of human activities, pressures, and impacts, and incorporating social, cultural, and economic information.'
Scientific justification	The process of establishing ICES AOs was initiated in 2019, with: i) forming a core group consisting of representatives from ACOM leadership, SCICOM and Secretariat, and ii) agreeing on the directions and procedure of further work of the core group. The objectives AOs are to: i) synthesize regional and temporal information on aquaculture activities, practices and production of the cultured taxa; ii) consider environmental and socio-economic interactions of aquaculture activities and practices; iii) provide insights on cross-sectorial interactions of aquaculture; and, iv) consider future perspectives. The overview will have ten sections: 1) executive summary; 2) introduction; 3) description and location of marine aquaculture activities and practices; 4) production over time; 5) policy and legal foundation; 6) management frameworks; 7) ecosystem/environment interactions; 8) social and economic context; 9) interaction of environmental, economic and social drivers; and 10) future projections, and emerging threats and opportunities.
Resource requirements	There are already several confirmed experts (as suggested by ACOM members) from France, Spain and Portugal to agree to contribute to the work. The lead author of the Bay of Biscay and Iberian Coast ecoregion AO (Myriam Callier) has already started establishing contacts with these experts.
Participants	The WK will be attended by experts contributing to the Bay of Biscay and Iberian Coast ecoregion AO, as well as other interested scientists from ASG.
Secretariat facilities	Setting up conference calls.
Financial	No financial implications.
Linkages to advisory committees	Direct link to ACOM.
Linkages to other committees or groups	ASG, WGAGFA, WGECCA, WGOOA, WGPDMO, WGREIA, WGSEDA, WGSPA, WGEEL, WGSOCIAL, WGECON, SICCME, SIHD

Linkages to other organizations	DGMARE

Annex 3: Review of ICES Scientific Reports – Workshop on the Bay of Biscay and Iberian Coast Ecoregion Aquaculture Overview

Katherine Dunlop – Institute of Marine Research, Norway. April 2024

Matt Gubbins – Marine Scotland, Scotland. April 2024

Llucia Mascorda-Cabre – University of Plymouth, UK. April 2024

General review to overall report

Overall, the reviewers accept the report as a source of suitable and detailed information that could be used as the basis of ICES advice following the verification of some details as identified here below.

The review in its current format provides a comprehensive and informative review of the aquaculture ecoregion in focus. However, prior to publication several improvements need to be made in readability in several chapters and continuity between chapters to avoid repetition and improve the flow of the review. Of most concern is the unfished nature of some of the text in some chapters. Currently it is clear that that minimal collaboration was achieved between chapters. In some chapters, a large part of the text is given over to a review of general issues related to aquaculture globally which leaves less focus for addressing details of these aspects in the ecoregion.

It is a very long report with some very useful information and overview. However, there are some parts that I believe are not relevant to the overview and could be removed to make it more concise while others could be given a more aquaculture focus. There is a lack of references throughout the document which needs to be addressed and some updated to include more recent literature. In particular, information on effects and impacts of every type of aquaculture is lacking and that a more thorough literature review is needed to avoid biased arguments.

We appreciate that the review has involved a lot of effort from authors for which English is not a first language so as we have done our best to correct the language and improve readability. Some parts are written in note format and are unfinished and headings need to be used consistently throughout. Many paragraphs with single sentences which made the text disjointed and is not a correct writing style. Several parts of the text were difficult to understand (highlighted in yellow). Text has room for improvements in readability. Many parts read like a list and the use of tables and figures in some sections could improve this.

Section 4 is very long and rather than focusing on the ecoregion itself, is attempting to review the EU aquaculture policy thus, doing neither one or the other appropriately. Chapter 7 and 3 could be merged or structured differently to avoid so much repetition. Overall, the document needs to be thoroughly edited and some sections rewritten to improve readability and avoid repetition. Some sentences and paragraphs are unfinished which needs to be addressed.

Executive summary:

I believed this section is not finished as it needs to include a brief summary of the report.

A glossary of terms should be added.

Chapter 1

This Chapter provides some useful detail on the context of the ecoregion however, it is lacking in information compared to the Celtic Sea review. It needs more explicit linking to aquaculture making the information relevant. Particularly around the relevance of the specific oceanography which clearly lends itself to being a highly productive ecosystem suitable for farming certain shellfish species. The description of conservation areas seems quite general and lacking in details so more in-depth information on the extent to which the habitats and their protection designations are relevant to aquaculture developments is needed.

There is a lot of repetition and there is a need to be more specific to the task of the overview. Heading and sub-headings should be revised and updated. More information on emerging candidate species and production methods is needed. We provide some suggestions for improvement in text readability and the inclusion of map data. Figures need to be updated and better ones produced. References are missing and this must be addressed.

Chapter 2

It needs some formatting, restructuring and editing. There is specific country information missing and some better definitions needed, and the production systems and methodologies should be better described – there are some methods missing. Figures need updating in the section as well and headings and sub-headings revised as there is inconsistency issues. References are also missing, and some are too old while there are newer ones available. There is some repetition, unfinished sentences, contradictory and confusing parts, others are not relevant to the overview while other parts need more detailed information. Map figures should be improved to allow the reader to extract more information and legends with more detailed explanations are needed. All figures should be references within the text. Currently a large part of the map is of the Bay of Biscay while the aquaculture areas of interest are on the coast. For instance, some information is presented as a list and while a table of the most important species with production biomass for each country would be more appropriate.

Section 2.2 on cultivation methods is missing a lot of detail on aspects of culture such as harvesting, predator control, seeding techniques, use of hatcheries vs. wild-caught etc. None of the provided information is referenced.

Section 2.3 contains a lot of detail in text form, much of it by country. There is reference to multiple cultivation methods that are not referred to in any detail in section 2.2 and much of the information would be much better presented in the form of tables or maps. We have the impression there are some real issues disentangling some of the data from national or regional aggregates into the ecoregion, but if this could be done from the source data it would help the overall assessment.

Chapter 3

This Chapter starts with too much detail on production survey methodology and could just be referenced to the named survey reports. Headings and sub-headings should be checked and the order in which sections are put so the structure needs some editing. There is repetition of information from other sections but then there are sections missing and entire country/ies. Some parts are irrelevant to the overview so should be deleted to avoid confusion. This Chapter could benefit from the use of more figures and thorough editing (e.g. species in italics, consistency of terms and units, one sentence paragraphs). It is difficult to read and seems more in note form than a finished product (it sometimes reads like a list - see page 29).

The combined production trend plots are very nice – good work by the workshop to combine the national data to the ecoregion for this. Again much of the quantitative information is provided by text when tables might be more useful. List of species produced and facilities separate from information on production in different chapters. The text could be move concise and easier to read with these sections combined. Currently keeps returning to the same topic but at a slightly different angle. While there is repetition between Chapter 2 and 3, the same level of detail in the Celtic Sea Aquaculture overview is not achieved.

Chapter 4

This section has somehow confused the reviewers. It starts with some long text around principles and reasons for aquaculture governance and EU approach that are not particularly relevant to the ecoregion assessment. The text prior to 4.2.2 is all interesting but not really critical to an ecoregion assessment except to highlight that the same overarching European legislation applies equally to all jurisdictions in the ecoregion. If the BoBIC overview wants to include a review of EU aq strategies and policies, this section needs a lot more work to be done and a better literature review. If, on the contrary, it wants to introduce the topic of policy at EU level, to then properly explain the situation within the BoBIC ecoregion, it needs to be explicit, summarized and drastically reduced to focus on France, Spain and Portugal. In the country specific sections on legal frameworks there is some excellent relevant detail that provides the context for the authorizing environment for aquaculture in this ecoregion. The authors conclude that the complexity of this and in some countries slow pace of implementation are to blame for some of the stagnation of the sector. This is fine but the concluding recommendations should be looked at closely in the context of unsolicited ICES advice. We are nervous about such recommendations being associated with ICES advice. They are the sort of thing that might be recommended should we be asked about future changes required to strengthen a European aquaculture sector in the context of a growing Blue Economy but ICES hasn't been asked to do that. This is an overview. Instead, it might be worth highlighting these as issues experienced by the sector relevant to the ecoregion in the overview.

This Chapter's readability has improved, it is well written, organised, comprehensive and informative however, the entire section should be restructured and rewritten to focus on the ecoregion. References are needed throughout.

Chapter 5

Useful information here but it is unevenly distributed across the jurisdictions / countries and needs bringing together for context and relevance to the assessment. In particular the section on management regimes focuses on pathogen control in Portugal and biotoxin management in France (but nothing in Spain which has some of the best biotoxin management in the world). The scope of Section 5 seems narrow; What about other management frameworks than human health and health/welfare?

The title should reflect the section. There is too much use of list format and unfinished text in some parts. Figures need to be updated and legends added. All figures and tables should be mentioned within the text. It is very short compared to chapter 4.

Chapter 6

This section is well written but needs more work not only on the title itself but also on content. It needs tightened up with respect to linking the types of interactions discussed to the ecoregions. Where that is done it needs more attention to equitably representing the different regions in the assessment. Some areas are notably missing such as management of enteric microorganisms (a major issue for management) and biotoxins from section 6.2. The assessment is left without a real understanding of whether that is an issue for the ecoregion or not. Microplastic and climate change sections presents information that is more general to plastic impacts but less relevant to aquaculture, the authors should consider if this is relevant here.

Terms need to standardized throughout the text. Some references should be updated to more recent literature on the topic. There is repetition from other sections and missing information. Some sections need to be summarized to reduce the length and at the same time, more information on the impacts of farming is needed. This is a very long overview and needs to focus more on the BoBIC rather than reviewing issues.

Chapter 7

This Chapter contains some great relevant detail but much of it should appear in earlier sections on production detail, trends and relative importance of sectors and regions. It is well drafted and referenced but there seems to be repetition of what has been exposed in Chapter 2 and 3. Chapter 7 and 3 could be merged or structured differently to avoid so much repetition. Headings are different between each country. There is again parts that are not relevant. This section is well written so could be used in the introduction.

Chapter 8

This Chapter is a good piece of text, well written and synthesising the issues well. It represents a good summing of aspects of the report to date. However, there is some information missing for certain countries. What about the positive impacts that low-trophic aquaculture can have as habitat restoration or decreasing eutrophication? The difference between chapter 8 and 6 should be clearer: Interactionsvs.impacts. This section could be better referenced given some of the assertions in the section.

Chapter 9

This Chapter has clearly not been progressed, there is information missing, some threats and opportunities have been identified but not further developed and again there is a need to focus on the ecoregion. There is too much detail on contaminants but there are other threats and ways to improve aq sustainability practices. Are the recommendations really what ICES wants to portray? Are they already published by Angel Borja? They seem a restrictive set of recommendations given the scope of the overview and does an EO need recommendations anyway? Where are INNS threats and impacts addressed in the report?

This Chapter seems unfinished and still in note format in parts, there is repetition and some areas are difficult to understand. There's no need for so many subheading levels. It needs better explanation of findings from IMTA projects not just aims. IMTA has been discussed in several chapters and continuity between text can be much improved. Presentation of most important information should come in the earlier chapters and later chapters can refer to this.

There are a lot of references found within the text that are missing from the list.

Annex 4: ADGAO meeting minutes

13-16 May 2024

Hybrid meeting (ICES HQ Copenhagen and Teams)

Participants: Dounia Hamoutene (Canada), Myriam Callier (invited expert, WKBoBICAO chair), Francis O'Beirn (invited expert, WKBoBICAO chair), Neil Ruane (Ireland), Matthew J. Gubbins (invited expert, RG chair), Reinhold Hanel (Germany), Laura Ribeiro (Portugal), Henn Ojaveer (chair, ACOM vice chair), Michala Ovens and Anne Cooper (ICES Secretariat).

Declaration of conflict of interest: The group was informed of the ICES code of conduct and was asked to declare perceived, potential or real conflicts of interest. None of the participants declared any types of conflict of interest.

The ADG meeting started with a short introductory presentation by the ADGAO chair who introduced the ICES Advisory Framework, adoption of the agenda and suggested working procedure.

RGAO chair presented the main findings from reviewers and the WKCSAO chair responded to the major points raised by reviewers.

The ADG started work on the initial draft advice prepared in advance by the ADGAO chair, which was made available for the ADG members on 29 August. The initial draft advice was prepared based on the WKBoBICA draft report.

General comments made by the Review Group

The review in its current format provides a comprehensive and informative review of the aquaculture ecoregion in focus. However, prior to publication several improvements need to be made in readability in several chapters and continuity between chapters to avoid repetition and improve the flow of the review. Of most concern is the unfished nature of some of the text in some chapters. Currently it is clear that that minimal collaboration was achieved between chapters. In some chapters, a large part of the text is given over to a review of general issues related to aquaculture globally which leaves less focus for addressing details of these aspects in the ecoregion.

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Major decisions made / actions taken

Keep the following organism groups in the following order: shellfish, finfish, crustacea, other invertebrates, seaweeds, microalgae.

Aquaculture facilities maps were created for shellfish, finfish and algae (seaweeds and microalgae). These were added to the aquaculture facilities location and description section. The previous map for France was removed.

Production time series figures were redrawn with year 2005 as the start date.

ADG has requested France and Spain to provide more information for the management frameworks section, to balance the national information in that section.

Additional evidence was submitted to ADG by WKBoBICAO chairs during the meeting on future projections section. ADG decided to bring in some of the evidence to the draft advice.

Data/knowledge gaps table was populated with the ecoregion information and column added for the explaining the reasons of the gaps.

Annex 1 table containing the species names (common and Latin) was added.

The deadline for providing text edits is Monday, 20th May 17:00 CET. In case of spotting any major mistakes, all ADG members should be alerted.

Suggestions

Moving to interactive online advice would allow delivery of the fine-scale spatial aquaculture activities maps, which are available at least for some ecoregions.

Secretariat support during the EG meeting for creating ecoregion-level spatial maps for aquaculture activities would be needed.

Availability of the expertise on day-to-day industry operations at the EG meeting would be very beneficial.

Recommendations

Consider establishing ICES Data Call for collecting data for Aquaculture Overviews. This would likely need a workshop to agree on the type of data and unit reporting (action for ASG).

Socio-economy section should be strengthened by developing a common sub-structure to be followed by all ecoregions (action for HUDISG).