PART I

The Blue Growth Sectors

1

Aquaculture

Tamás Bardócz[1,*], Henrice Jansen[4], Junning Cai[2], José Aguilar-Manjarrez[4], Sara Barrento[3], Shane A. Hunter[1] and Marnix Poelman[4]

[1]AquaBioTech Group, Malta
[2]UN Food and Agricultural Organisation
[3]Swansea University, Wales
[4]Wageningen Marine Research, The Netherlands
[*]Corresponding Author

1.1 Introduction

As the world population is growing and poverty is gradually being alleviated, the world is searching for new sources of protein in order to guarantee food security. Aquaculture has been identified as a sector with high potential for increased protein production without excessive burdens on the ecosystem. Predictions by OECD-FAO for fish and seafood production and trade (OECD/FAO 2016) indicate that future growth in seafood production will originate from aquaculture. Although 70% of the globe consists of water, aquaculture cannot be practised everywhere; it requires a unique set of natural, social and economic resources which must be used wisely if development of the sector is to be sustainable. In the EU and around the globe, the availability of areas suitable for aquaculture is becoming a major problem for the development and expansion of the sector. Care must be taken in the management of existing aquaculture facilities and the setting up of new production sites to ensure that there are appropriate environmental characteristics and that good water quality is maintained. Additionally, the consequences of social interactions and the appropriation of marine, coastal and inland resources must be well understood. In this chapter, we outline the status of this industry and discuss the key issues and opportunities. Firstly, we define what we mean by marine aquaculture.

Definitions

1. EU definition: 'aquaculture' means the rearing or cultivation of aquatic organisms using techniques designed to increase the production of the organisms in question beyond the natural capacity of the environment, where the organisms remain the property of a natural or legal person throughout the rearing and culture stage, up to and including harvesting; (REGULATION (EU) No 1380/2013)
2. FAO definition: Aquaculture is the farming of aquatic organisms including fish, molluscs, crustaceans and aquatic plants. Farming implies some sort of intervention in the rearing process to enhance production, such as regular stocking, feeding, protection from predators, etc. Farming also implies individual or corporate ownership of the stock being cultivated, the planning, development and operation of aquaculture systems, sites, facilities and practices, and the production and transport.[1]
3. According to FAO glossary of aquaculture, mariculture is cultivation, management and harvesting of marine organisms in the sea, in specially constructed rearing facilities e.g. cages, pens and long-lines. For the purpose of FAO statistics, mariculture refers to cultivation of the end product in seawater even though earlier stages in the life cycle of the concerned aquatic organisms may be cultured in brackish water or freshwater or captured from the wild. This term is interchangeable with marine aquaculture.

1.1.1 General Overview of the Sector

The Food and Agriculture Organization of the United Nations (FAO) produces regular authoritative statistical reports and publicly available databases (FishStatJ) on aquaculture sectors and subsectors, which include production volumes and values. This data is drawn on in this section, and refer the reader to their reports for further information (FAO, 2016). While world freshwater aquaculture and mariculture had similar growth rates over the past decade and each accounted for about half of the total aquaculture production, their species composition differs significantly. Freshwater aquaculture has been concentrated on finfish, while aquatic plants and shellfish (including Crustaceans and molluscs) were dominant in mariculture (Figure 1.1). For freshwater production, highest farm-gate value (production value calculated by using the on-farm, whole fish prices) is reported for fish production

[1]FAO Tech. Guidelines for Responsible Fisheries (5):40p. Rome, FAO.

($\sim$80%) matching the largest production sector, while in mariculture the largest production sector (aquatic plants) only contribute marginally to the total farm-gate values. Freshwater carps, tilapia and catfish are globally the most important aquaculture species in terms of both volume and value. These are generally low-value fishes for domestic consumption, providing low-cost animal protein to ordinary consumers, but tilapia and some catfish species (e.g. Pangasius) have become increasingly popular global commodities. Marine shrimp and salmon are major commodities in international seafood trade, and are two high-valued species. Marine perch-like fishes (e.g. seabass, seabreams, groupers) do not belong to the top-10 of most important species in terms of volume but are among the top-10 in terms of value.

Aquaculture production is now fully comparable to capture fisheries landings when measured by volume of output on global scale. World aquaculture production of fish accounted for 44.1 percent of total production (including for non-food uses) from capture fisheries and aquaculture in 2014, up from 42.1 percent in 2012 and 31.1 percent in 2004 (FAO, 2016) From 2014 the total aquaculture production surpassed capture fisheries for human consumption and it is expected that by 2025 aquaculture production will be larger in volume than the capture fisheries. (OECD/FAO 2016.). According to the latest OECD – FAO forecasts (OECD/FAO 2016) expanding aquaculture production will remain amongst the fastest growing food sectors with a 3% annual growth rate, which is however significantly lower than the annual growth rate of 5.6% experienced in the previous decade. This slowdown in expansion will mainly be due to restrictions caused by environmental impacts of production and competition from other users of water and coastal spaces (World Bank. 2013). For example, aquaculture farming along coasts, lakes or rivers can conflict with urban development or tourism. This can create problems related to water quality and scarcity and push aquaculture expansion into less optimal production locations and consequently increasing costs, this is therefore encouraging the industry to seek innovative technologies and partnerships to maintain existing production costs.

Asian countries will remain the main producers with a share of 89% of total production in 2025, but Aquaculture will also show an impressive increase in developed countries, growing 26% during the same period. In Africa, the capacity building activities of the last decade and local policies promoting aquaculture also will raise the recent 1.7 million tonnes to 2.2 million tonnes.

The product groups listed in Table 1.1 are cultured by using various technologies, influenced by the environment and determining the social,

Table 1.1 Volume of main product groups in the various culture environments in 2015 (brackish water production is included in the marine environment.)

Product (in Thousands of Tons)	Freshwater Aquaculture	Mariculture/Marine Aquaculture	Aquaculture Total
Finfish	44,108	7,800	51,907
Crustacean	2,857	4,495	7,351
Molluscs	284	16,148	16,432
Aquatic plants	90	29,273	29,363
Other aquatic animals and products	523	427	950
Total	47,861	58,143	106,004

Data from: © FAO – FishStatJ 2017 March.

economic and environmental sustainability of the production. The majority of freshwater fish are carp produced in Asia (37.5 million tons) in pond based systems, thus ensuring the local protein supply for underdeveloped regions. Asian countries produce the majority of mariculture farmed species which are mainly extractive species such as molluscs (e.g. mussels and oysters) and aquatic plants (e.g. seaweeds). Products from marine aquaculture also have an important role in the food supply and application of aquaculture technologies to different (new) species in marine areas have a potential to supplement the global shortage in capture fisheries.

1.1.2 Marine Aquaculture as a Blue Growth Sector

In this book, the focus is on the mariculture technologies having a potential for combination with other Blue Growth industries. According to the distance from the coastline and characteristics of marine aquaculture activities; coastal, off the coast and offshore mariculture (or marine aquaculture) subsectors can be distinguished, where coastal and off the coast can be considered also as nearshore (Table 1.2):

1. **Coastal and off the coast marine fish culture**: Fish farming activities less than 3 km from the shore using various technologies also including flow-through and recirculation systems but mostly apply the open floating cage net technology. In Europe Atlantic salmon, Sea bream and Sea bass are the fish species produced in the largest quantity in marine cage aquaculture systems.
2. **Coastal and off the coast farming of molluscs and crustaceans**: Crustacean production is mostly inland or on shore pond based farming and because of the required technology, there are only very limited

opportunities to move the production to offshore farms (lobster cultures). Mussels and oysters are produced in large volume (Figure 1.1) using various techniques and molluscs cultures are considered as the most promising candidates for aquaculture on offshore energy platforms (Wever et al., 2015).

3. **Coastal and off the coast production of aquatic plants** (macro and micro): While off coast micro algae production is still in experimental stage, the production of seaweed is a well-established off the coast technology having a potential to be moved further offshore and combined with other offshore activities.
4. **Coastal and off the coast Integrated Multi-Trophic Aquaculture systems (IMTA)**: The basic concept of IMTA is the farming of several species at different trophic levels, that is, species that occupy distinct positions in a food chain. This allows one species' uneaten feed and wastes, nutrients and by-products to be recaptured and converted into fertilizer, feed and energy for the other crops (Chopin, 2012). As an example we can combine the cultivation of fed species (finfish or shrimp) with inorganic extractive species (seaweeds or aquatic plants) and organic extractive species (oysters, mussels and other invertebrates).
5. **Offshore mariculture or offshore marine aquaculture**: Adopting the FAO definition, offshore mariculture is classified as existing or potential activities where the distance of the production unit is more than 2 km from the coast. These are within continental shelf zones and possibly

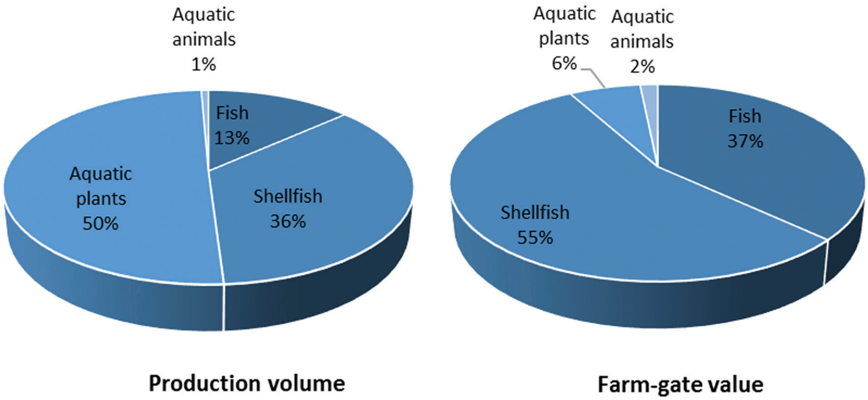

Figure 1.1 Relative Production volume (left) and Farm-gate value (right) by species type in 2014 for the Marine culture environment at a global level (data from FAO FishSTATJ).

Table 1.2 General criteria for defining coastal, off-the-coast and offshore mariculture. 1 Hs = significant wave height, a standard oceanographic term, approximately equal to the average of the highest one-third of the waves

Parameters	Coastal Mariculture	Off the Coast Mariculture	Offshore Mariculture
Location/ hydrography	<500 m from the coast <10 m depth at low tide within sight usually sheltered	500 m to 3 km from the coast 10–50 m depth at low tide often within sight somewhat sheltered	>2 km generally within continental shelf zones, possibly open ocean >50 m depth
Environment	Hs1 usually <1 m short-period winds localized coastal currents possibly strong tidal streams	Hs <3–4 m localized coastal currents some tidal streams	Hs 5 m or more, regularly 2–3 m oceanic swells variable wind periods possibly less localized current effect
Access	100% accessible landing possible at all times	>90% accessible on at least once daily basis landing usually possible	usually >80% accessible landing may be possible, periodic, e.g. every 3–10 days
Operation	manual involvement, feeding, monitoring and more	some automated operations, e.g. feeding, monitoring and more	remote operations, automated feeding, distance monitoring, system function
Exposure	sheltered	partly exposed (e.g. >90° exposed)	exposed (e.g. >180°)

Source: Lovatelli et al., 2013.

open ocean areas. The economic interest of offshore mariculture is today primarily related to finfish (Lovatelli et al. 2013), but from a technological point of view, seaweed and molluscs production have good opportunities for offshore farming. Offshore finfish farming has a specific technology using submersible floating cages and automatized feeding system paired with remote monitoring.

1.2 Sector Industry Structure and Lifecycle

The concept of business lifecycle (sometimes referred to as product lifecycle) is well established in economics. Influenced by Darwinian theories, Alfred Marshal considered how industries and firms were not in a steady state and appeared to evolve over time (Kerr and Johnson 2015.) As aquaculture moves offshore there will be important lessons to be learnt from existing installations and companies. Studying existing businesses provides the opportunity to see how barriers to growth were overcome in the past and learn lessons for future Blue Growth. This lifecycle analysis is especially useful to define the lifecycle stage of different aquaculture subsectors which helps to identify the benefits of each subsectors when they are combined with other Blue Growth industries. Life cycle description of the subsectors are summarised in the Table 1.3 according to the characteristics of life stages by Kerr and Johnson and the production and economic data of the subsectors. Based on the description of Table 1.3 the life cycle stage of the most relevant aquaculture subsectors are identified in Table 1.4.

Investigating these results from a business development point of view, it can be seen that aquaculture subsectors in different life stages could benefit from combinations with other Blue Growth sectors in various ways. Mature subsectors like salmon and sea bass, sea bream production are considerably limited by the available marine space. Investments in the combination of fish farming with other industries using off the coast and offshore areas could support the mature aquaculture subsectors to get licenses and increase their production.

Subsectors in the growth stage are in the process of increasing their capacity and reduce production costs. Mussel production in certain areas as well as organic fish production could benefit significantly from investments in combined coastal and off the coast platforms.

Offshore fish farming has only just started and can thus be classified as development or embryonic stage in the selected regions. Combination with other BG industries that are already in the mature and growth stage could facilitate the technology transfer of offshore technologies to aquaculture. There is also potential for the more mature industries to facilitate the investments in offshore aquaculture sectors.

1.3 Market

1.3.1 Products and Trade Flows in the World

The expansion of seafood consumption and thereby aquaculture production has dramatically changed the major seafood trade pathways (FAO 2016). Salmon and trout products have increased market share over a number of years and now represent the largest single commodity by value in the fish

Table 1.3 Analysis of business life cycle stages (Kerr and Johnson 2015) of aquaculture sub-sectors

Sub-sector	Demand/ Products	Technology/ Manufacturing	Trade/ Competition	Key Success Factors	Finance/ Investment
Coastal and off the coast marine fish culture	Stable mass market for salmon, sea bream and sea bass, customer knowledge is high. Branding phase emerging markets for species and products.	Well diffused technical knowhow, available marine space is one of the main limitation. Overcapacity in the Mediterranean. New EU regulation on organic aquaculture, innovations for new species.	Production shifts to less developed countries. Price competition; customers focus. New entries with new technologies for niche markets.	Cost efficiency achieved mainly through scale and driving down input costs. Technology innovations are still important. New production areas have to be opened.	Bank finance and institutional investments are common. R&D grants for new species and technologies.
Coastal and off the coast farming of molluscs and crustaceans	Stable market for molluscs (mussels, oysters). Emerging markets for abalone. Crustaceans market is large but highly dependent on global economy (Asia).	Hatchery is still a limiting factor. Diseases and natural events Structures need to be better prepared for storms. Production of new crustacean species is difficult.	The market for both crustaceans and molluscs can suffer major shifts depending on extreme weather events, food safety regulations of individual countries.	New communication streams are being used to inform consumers about the advantages of eating extractive species. Sustainability of the production methods is getting more important.	In Europe, the main investments are made mainly by existing producers in marketing, and combination of farming and tourism. New investors from BG industries are needed.

Coastal and off the coast production of aquatic plants (macro and micro algae/seaweed)	Stable, but growing market for different species of sea weeds. Product specification is oriented to added value products (compounds).	Technology in place is usually relatively low tech., and based on manual labour. Off the coast technology for micro algae production is in the experimental phase.	Seaweed trade and market in Asia is huge, but very little in Europe. Micro algae has an emerging market as raw material for food, health, chemical and biofuel products.	Technology innovations are needed to guarantee high crop quality and cost-effective production and processing. Product cost price is the main current bottleneck.	R&D grants and EU or governmental funding in Europe.
Coastal and off the coast Integrated Multi-Trophic Aquaculture systems	No specific demand, as this is a production system and not a particular product.	Technology is available but needs to be developed and adapted to different environments and market trends.	High value markets, niche markets concerned with sustainability. Difficult to compete with low price products.	Communication channels, marketing tools and education are key factors to develop IMTA. Market diversification.	Dependent on subsidies (EMFF aqua-environmental measures) and joint ventures between companies producing complementary products (e.g. fish and seaweed).
Offshore mariculture	Well known products with high demand are the main target species (e.g. Atlantic salmon). No specific market yet.	Technology is available, but innovations through technology transfer are needed to reduce the costs and solve some problems.	Only a few producer countries and companies. Competition with the coastal and off the coast production.	Main driving force is the easier licensing. R&D work to reduce OPEX and CAPEX costs.	Only investments in large capacities can be economically feasible. The high CAPEX costs requires investors. Bank finance, share issue. Institutional investors. Corporate partners, merger.

Table 1.4 Life cycle stage of the sub-sectors

Sub Sector	Life Cycle Stage	Justification of the Development Stage (Including Regional Variations)
Coastal and off the coast marine fish culture	Growth and Mature stage	Salmon, sea bass, sea bream in the MATURE stage. Organic aquaculture and new species in the GROWTH stage.
Coastal and off the coast farming of molluscs and crustaceans	Life cycle stage depends on the species and region. Embryonic to Mature stage	Production conditions in moderate climates are investigated for biomass production optimisation. R&D on the most suitable technical approaches is done. To support this action, prototypes and pilot sites have been installed at certain areas (Norway, Portugal, Netherlands, Germany, Ireland, etc). Coastal molluscs culture is in the Mature stage as well as the crustacean (shrimp) culture in Asia. While lobsters farming in Europe is at a – development/embryonic stage. Bottom cultivation of blue mussels in the Netherlands is a sector in stage in growth stage, while suspended cultivation of spat collectors is embryonic stage.
Off shore production of aquatic plants (macro algae)	Embryonic to growth stage	Seaweed, macro algae production in Asia, worldwide and coastal micro algae production is in a GROWTH stage. Others in Development or Embryonic stage. Production conditions in moderate climates are investigated for biomass production optimisation. R&D on the most suitable technical approaches is done. To support this action, prototypes and pilot sites have been installed at certain areas (Norway, Portugal, Netherlands, Germany, Ireland, etc).

Coastal production of aquatic plants (macro algae)	Embryonic to growth stage	Production in moderate climates is currently in its first commercial stage. This is generally following previous wild harvesting activities. Production in Asia and tropical conditions is in its expansion stage. Development of sea weed culture areal is still increasing.
Coastal and off the coast production of aquatic plants (micro algae)	Development to Embryonic stage	Microalgae cultures under offshore conditions are in R&D stage, some prototypes have been installed. The developments are currently inhibited by productivity and thus economics of the production methods. Further development needed to optimise technologies.
Coastal and off the coast Integrated Multi-Trophic Aquaculture systems	Development/Embryonic stage	Mostly still in the pilot scale in Europe, only a few farms use the technology.
Offshore mariculture	Development/Embryonic stage	Companies in the Caribbean (for cobia) and in the Atlantic region (Atlantic salmon) use the offshore technologies. However, these businesses are in the embryonic stage already, there is high need for new technical solutions. Offshore fish farming in the Mediterranean and in the Baltic region is still in the development stage focusing on the research and pilot testing.

trade (16.6% of the world trade in 2013), this is clear evidence of the impact of aquaculture on the market. The majority of salmonids are exported from a limited number of countries which have a suitable natural environment for salmon farming (Norway, Chile, Canada), mostly to high-income countries although China also accounted for 4.4 percent of world salmon import in 2011. Shrimps and prawns are high value seafood commodities and are mostly exported from developing countries to developed countries. Trade data indicates that most shrimp import in EU comprises warm-water species which originate mostly from aquaculture. International trade of molluscs (excluding cephalopods) is more disperse among countries although China holds a strong position in both import and export of molluscs.

1.3.2 Market Trends, Prices and a View of Future Demand in the EU

Although aquaculture in the European Union is very diverse with production spread across more than 100 species categories, a limited number of species dominate. In 2014, 1,275,902 tonnes total aquaculture production comprised (EUMOFA online query): 35.7% Mytilus mussels (455,079 tonnes), 14.8% Atlantic salmon (189,476 tonnes), 13.6% other salmonids (mainly rainbow trout, 185,663 tonnes), 7.1% oysters (91,460 tonnes), 6.2% carp (79,994 tonnes), 11.7% Sea bass and Sea bream (149,317 tonnes together). Although the reported harvest from freshwater appears to be small relative to harvest from seawater and brackish water, it must be recognised that Atlantic salmon (and other salmonids harvested from seawater) are initially reared in freshwater and freshwater species are also reared in brackish and seawater (large trout).

Five Member States dominate EU-28 aquaculture (Figure 1.3), accounting for 75% of production (Spain: 266,594 tonnes; United Kingdom: 205,594 tonnes; France: 205,107 tonnes; Italy: ca. 160,000 tonnes; Greece: 108,852 tonnes). The relative importance of the different aquaculture sectors varies between Member States, e.g.:

- Molluscs dominate production (>60% of national tonnage) in Spain, France, Netherlands and Ireland;
- Atlantic salmon and other salmonids (mainly rainbow trout) dominate in the UK, Denmark, Finland, Sweden, Slovakia, Slovenia and Estonia;
- Marine finfish (including seabass and seabream) dominate in Greece, Malta and Cyprus;
- Freshwater finfish (including carp) dominate in Germany, Poland, Czech Republic, Hungary, Romania, Lithuania and Latvia.

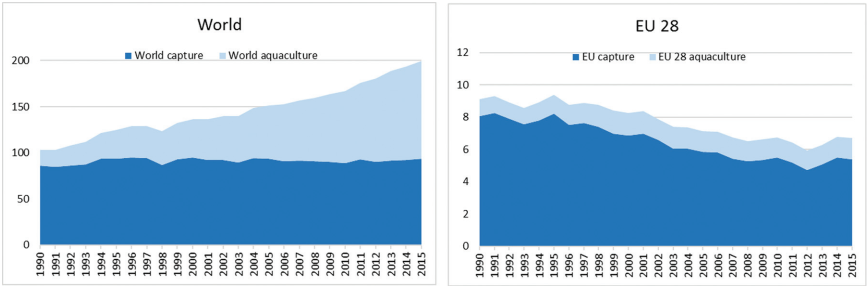

Figure 1.2 Development of Aquaculture production (in million tonnes) in the world (left) and European Union (right) indicating that the EU does not follow the high growth rates as displayed in other parts of the world (data from FishStatJ 2017 March).

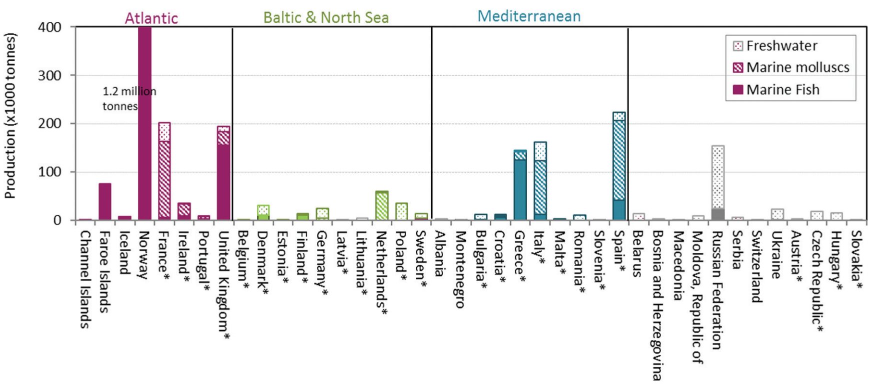

Figure 1.3 Marine aquaculture production in the Europe in 2015 specified for each Maribe basin and divided per production type (Marine finfish, Marine shellfish, Freshwater). *indicates if member state is part of the EU-28. (Data from: FishStat FAO).

The aquaculture production in the EU (Figure 1.2) has stagnated for many years in terms of the total production volume where the increases in salmonid (Atlantic salmon, large trout) and mussel production have been cancelled out by reductions in production of eels and other freshwater fish.

According to the predictions of aquaculture development in the period 2016–2025 (OECD/FAO 2016), developing countries will consolidate their position as lead aquaculture producers, with a share of almost 95% of global aquaculture production. The latest trends and forecast studies also justify the 28% increase until 2025 in Europe, however the majority of this growth still expected from the salmon aquaculture of Norway. Numerous studies indicate a considerable increase of aquaculture production in the European Union.

Lane et al. (2014) projected a faster growth rate of aquaculture in the European Union than the OECD/FAO forecast for Europe estimating a total increase of 772,000 tonnes (+56%) in volume from 2010 to 2030 with a corresponding value increase of 2.7 billion euros and requiring an additional 395,000 tonnes of feeds.

The latest production trend estimations for the European Union can be calculated from the data of the Multiannual National Aquaculture Plans prepared by each member states as a strategy for the use of the European Maritime and Fisheries Fund. The common structure of the plans required an estimation of the impact of EU funds on the production and the estimated projection for EU aquaculture volume in 2020 is expected to increase by about 300,000 tonnes (25%) to a total of more than 1.5 million tonnes.

The European Aquaculture Technology and Innovation Platform (EATIP) provides a forecast for the whole of Europe in a vision document (EATiP 2012) predicting that by the year 2030, European aquaculture will provide annually 4.5 million tons of sustainable food products (recent production is 3 million tonnes), worth 14 billion euros, and supporting more than 150,000 direct jobs.

1.3.3 Market Trends, Prices and Supply & Demand Gaps

The European Union is a major consumption market of seafood products in the world with 13,8 million tonnes representing EUR 49,3 billion in 2015 (EUMOFA 2016).

It is the largest importer of seafood products, absorbing 24% of total world exchanges in value. Seafood consumption per capita in the EU seems to have reached a plateau after a decade of dynamic growth. The consumption per capita in 2015 was 25,5 kg which is 1 kg more than it was in 2013. The increase in the consumption was more significant for farmed products (+6%) than for fisheries products (+2,7%), but the consumption in the EU market is still dominated by products originating from fishing activities (75% of total). Tuna, cod and salmon are the main species consumed in the EU in volume. Shrimps are the first imported species in value ahead of salmon, tuna and cod. Seafood consumption varies a lot from one Member State to the other. Northern Member States are more focused on processed fish (frozen, smoked) while Southern Member States still favour fresh products and devote a larger part of household expenditures to fish. Central and Eastern European countries are below the EU average but register increase in consumption (EUMOFA 2017). The data of the detailed EU wide consumer survey showed, that the per capita consumption trend (in kg) is slightly negative, while the per capita real expenditure (in Purchasing Power Parities which was calculated by multiplying the EU28 expenditure in real terms in EUR with the volume indices of real expenditure per capita (for fish)) trend is basically flat. (EUMOFA 2017). This widening gap between the two indicators supposes an increase in the consumption of high value products (high quality fresh products, processed products). Of course, these average figures hide the different situation in member states and while for example, the average unit value increased in the Central and Eastern European countries, in the most Mediterranean countries this value decreased.

In 2015 Atlantic salmon was the most consumed aquaculture product in the EU reaching 2.09 kg/capita/year consumption showing 9% and 38% increase from 2013 and 2005, respectively. The main producer of this species in Europe is Norway, selling the half of its yearly 1.3 million tons production (FEAP Production Report 2007–2015) to Europe. The second largest producer is the UK with 186 thousand tons mainly from Scotland. The main production area for this species is the Atlantic Ocean where all production countries continuously increase their production and looking for innovative technologies to support this raise.

In the Baltic region fish production in the marine environment is less developed and the main produced species is the large trout (>1.2 kg). The biggest producers of large trout using the marine cage technology are Denmark (10,500 t), Sweden (9436 t) and Finland (12,500 t) and according to their EMFF Operational Programs all countries want to increase its aquaculture production.

The fish production in the Mediterranean is dominated by the sea bass and sea bream production mainly in coastal and off the coast cages. The main producer countries are Greece (93,000 t) and Turkey (142,000 t) competing with each other for the leading producer position and for the markets (FEAP Production Report 2007–2015).

EU self-sufficiency for seafood (i.e. the production relative to its internal consumption) increased from 44,5% to 47,5% during 2013–2014, but to keep up with the rise of the internal demand needed an increase of catches and production as well. While the EU covers fully its needs for small pelagics (and even produces surpluses) it is increasingly and highly dependent on external sourcing for groundfish, salmonids and tuna. In terms of the aquaculture products the self-sufficiency is much lower and only 10% of the total EU seafood consumption (13 million tonnes) is currently come from EU aquaculture (1.3 million tonnes). These statistics suggests that demand is greater than supply and there is great potential to expand aquaculture production in the EU to meet the demand, improve food security and improve the economy.

1.4 Working Environment

1.4.1 Economic Indicators for the Aquaculture Sector in the EU

In the EU, aquaculture production is an important economic activity in many coastal and inland regions (COM 2012a), often providing employment in marginal and remote areas. The sustainable development of European aquaculture has been identified as a priority under reforms of the Common Fisheries Policies (CFP) to strengthen long term food security (EU 2013). These regulations require actions to improve the competitiveness of the sector, whilst ensuring its long term environmental, economic and social sustainability. Aquaculture has thereby been identified as one of five value chains that can deliver sustainable growth and jobs within the blue economy (COM 2012b).

Reliable data on key economic indicators are difficult to obtain for the aquaculture sector in all the 28 Member States, but the latest report of Scientific, Technical and Economic Committee for Fisheries (STECF 2016) provide a good overview. While the countries participated in the report indicated more than 12,000 enterprises, the study estimated that the total number of companies with aquaculture as their main activity in the EU-28 is between 14 and 15 thousand. In 2014 the majority (90%) of the companies were micro-enterprises (with less than 10 employees) and tend to be family owned. Micro-enterprises are usually small scale rather than large companies using capital intensive methods. The number of enterprises with more than 10 employees has increased from 1040 in 2012 to 1230 in 2014. The reported data displays an employment of about 69 700 people in 2014, but the study estimates that EU-28 aquaculture sector directly employs around 80,000 people. The EU aquaculture sector has an important component of part-time work which is due to the importance of the shellfish sector that has a significant percentage of part-time and seasonal work. Women accounted for the 24% of the EU aquaculture sector employments, but only 19% when measured in FTE. There is a lot of variability within the salaries paid in each country and subsector, varying from 3,300 Euros per year in Bulgaria to 72,100 Euros per year in Denmark.

EU aquaculture sector provided about €1 596 billion in Gross Value Added (GVA) in 2014. This is an increase of 14% from the €1 294 billion reported in 2012. EBIT (Earnings Before Interest and Taxes or Operating

Profit) data from 19 countries (excluding Poland) show that the EU aquaculture sector was more profitable in 2014 with a reported total EBIT of €402 million, which is an increase of 24% from the €324 million reported in 2012.

1.4.2 Driving Forces and Limitations of Aquaculture Sector

The majority of global aquaculture production is concentrated in developing countries, in particular in Asia, while aquaculture development in more developed countries and especially in the European Union is relatively stagnant. This partly due to a range of governance challenges, regulatory framework and the scarcity of suitable locations. The main constrains of aquaculture development in the EU-28 countries are often listed as the followings (Lane et al. 2014):

- Fierce and often unequal competition with third countries that brings market prices down. Fish farmers association in the EU says that the strict regulation often creates a sloped playing field for third countries having for example less stringent environmental or food security regulation.
- High labour and capital costs and administrative burdens slow down investments in the sector.
- Lack of understanding of the spatial needs and infrastructure for the industry among the planning authorities.

The annual growth rate of the world aquaculture in the next decade is expected to be 2.5% (FAO/OECD), which is significantly lower than the growth rate of 5.6% p.a. experienced in the previous decade. Driving forces of aquaculture growth on a global level are (Guillen & Motova 2013, Lane et al. 2014):

- Overfished and decreasing wild fish stocks, while the demand for fish is growing
- Aquaculture is more efficient in terms of freshwater use and energy than other animal production sectors.
- The availability of marine space for aquaculture is larger than availability of agricultural land
- Technology development makes aquaculture more and more profitable.

Limitations of aquaculture growth on a global level:

- Dependency on and availability of sustainable fish meal sources
- Direct environmental interactions: pollutions, predators, diseases, algal blooms

- Poor husbandry practices: use of antibiotics, antifungal, herbicides ...
- Consumers attitudes and trends
- Deterioration of the quality of water bodies suitable for aquaculture

1.4.3 Regulatory Framework of Marine Aquaculture in the European Union

Aquaculture is an integral part of the reformed Common Fisheries Policy (CFP) (REGULATION (EU) No 1380/2013). The basic regulations define aquaculture as an important economic and food supply industry and encourage the development of the sector. Aquaculture has thereby been identified as one of five value chains that can deliver sustainable growth and jobs within the blue economy (COM 2012b). The Commission published Strategic Guidelines for the Sustainable Development of EU aquaculture (COM 2013a) which highlighted four priority areas to unlock the potential of the sector: i) simplification of administrative procedures, ii) co-ordinated spatial planning, iii) competitiveness and, iv) a level playing field. Using these guidelines, Member States (MS) has developed or are now developing multiannual national plans for the development of sustainable aquaculture.

One of the main tool to achieve the goals of the CFP is the European Maritime and Fisheries Fund (EMFF) which is one of the five European Structural and Investment (ESI) Funds which complement each other and seek to promote a growth and job based recovery in Europe. The EMFF regulation (REGULATION (EU) No 508/2014) lay down the principal rules how this fund is used to co-finance projects, along with national funding. Each country is allocated a share of the total 5.7 billion Euro Fund budget, based on the size of its fishing, aquaculture and processing industry. Member states then draws up an operational programme (OP), saying how it intends to spend the money. Once the Commission approves this programme, it is up to the national authorities to decide which projects will be funded. Recently, Member States are submitting their OPs to the commission and preparing their national legislation and system for the distribution of the fund. The regulations allow aquaculture investments to be supported with a maximum funding rate of 50% of the total investment.

The development of sustainable aquaculture is dependent on clean, healthy and productive marine and fresh waters. A prerequisite for sustainable aquaculture activities is compliance with the relevant EU Legislation. The Water Framework Directive (WFD) (Directive 2000/60/EC) and the Marine Strategy Framework Directive (MSFD) (Directive 2008/56/EC) aim to protect and enhance aquatic environments and ensure that the uses to which they are put are sustainable in the long term. All mariculture activities in the Member States has to be carried out in line with the common regulation of MSFD to minimise the risk of the introduction of non-indigenous species (NIS), to keep under limits the amount of discharged nutrients, organic matter, contaminants including pesticides and litter. New aquaculture technologies also have to reduce the disturbance to wildlife, and the possibility for escape of farmed fish. However, the magnitude of these impacts from aquaculture in comparison with impacts from other sources (e.g. agricultural runoff) are not known, aquaculture, alongside all other sectors, will need to reduce impacts in order to reach Good Environmental Status (GES) under MSFD. The role of the MSFD is becoming increasingly important to ensure that aquaculture activities provide long-term environmental sustainability.

1.5 Innovation

1.5.1 Innovation Trends in Coastal and Off the Coast Marine Aquaculture Subsectors

To identify the innovation trends in the aquaculture the mapping of the research needs of the sector can provide a good indication of the main directions. EFARO, the European Fisheries and Aquaculture Research Organisations, identified the following "game changer" technical and scientific topics enabling a European aquaculture vision to happen (EFARO 2017): 1) Develop sustainable fish feeds based on aquaculture ingredients, 2) Diversification of activities, 3) Breeding: Development of breeding programmes for the production of robust animals, 4) Seaweed Production and Value Chains: Innovation and optimization of seaweed products and processes, 5) Develop research on aquaculture productions associations and the integration of aquaculture productions with other productions or service productions, 6) Bivalve production: Innovation and optimization of shellfish products.

Marine and freshwater aquaculture is already an efficient user of land and freshwater while also has a lower carbon footprint than the production of terrestrial animals, but due to its dependence on plant products such as soy in the feed, aquaculture still uses a considerable amount of these limited resources. Therefore, exploring new or alternative feed resources and production sites along with the necessary technology and delivery systems are urgently needed.

EFARO members also launched the Cooperation in Fisheries, Aquaculture and Seafood Processing (COFASP ERA-NET) to develop and strengthen the coordination of national and regional research programmes. The COFASP Strategic Research Agenda identified the following topics to be of importance for future development of aquaculture as a whole: 1) Market demand (species that can be cost effectively produced), 2) Organic aquaculture (lower the production costs relative to conventional methods), 3) Technology development (Recirculation facilities & multi-trophic aquaculture), 4) Species enhancement (Aquatic animal health and welfare, and Breeding Programmes) (COFASP 2016). The ERA-NET COFASP collects and analyses a list of projects on aquaculture, fisheries and seafood processing funded at European/national level and maintain a database available at http://www.projectsdatabase.cofasp.eu. Recently a total of 1203 aquaculture research projects can be found in the database with €816 million total funding. From these projects 28 have activities to develop offshore aquaculture. Many of the projects funded focussed technological development, but environmental impact studies are also listed. The recent and planned future calls within the H2020 program have a significant focus on multi-use possibilities to make better use of marine space and resources.

1.5.2 Recent Technology and Expected New Technologies in Offshore Mariculture, Opportunities and Challenges

Sturrock et al. (2008) identified offshore aquaculture and IMTA as emerging technologies supporting the European aquaculture development. The current development of mariculture of species such as Atlantic salmon, Sea bream and European seabass and experimental/pilot farming of other species such as cobia (*Rachycentron canandum*) and amberjacks (*Seriola spp.*) provides excellent and promising technological advances for moving marine aquaculture farther offshore. However, the economic viability of offshore mariculture is a major challenge and better technologies still need to be developed. There are also concerns about the availability of capital for investments in research and development (R&D) and for the development of commercial farms. Moreover, there is no clear candidate species of finfish available that has proved both economic and physiological feasibility for offshore production and, while species of shellfish and aquatic plants are better identified, the economic viability of their production is still questionable. A transition from coastal to off-the-coast and offshore mariculture will demand the development of new or suitably adapted technologies throughout the value chain, with obvious scientific challenges. This is what is needed if global seafood supply is to be increased in a way that minimizes impacts on benthic and pelagic ecosystems as demanded by society. One of the main driving force of aquaculture innovations recently is the so called “green licensing” system of the Norwegian salmon industry. Norwegian governments have publicly declared that further growth is impossible until the problems of sea lice, escapes and pollution have been solved or, at least, considerably reduced. Since the salmon farming companies have shown that they have the capacity and market access for an increase of production, the government opened up new salmon farming licenses subject to strict environmental criteria mainly on sea lice, escape risk and other environmental factors known as “Green Licenses” (Hersoug 2015). The interest is still very high for the valuable available licenses and the requested new technological solutions encouraged other marine and offshore industries like shipbuilding and offshore oil and gas to bring in their experience to the aquaculture industry and team up with aquaculture companies. Of course, the large salmon farming companies like SalMar AS (www.salmar.no) and Marine Harvest AS (marineharvest.com) also invested in innovation and developed their own technological solutions to fulfil the requirements of green licenses. SalMar is more focused on the offshore production and invested in Ocean Farm-1 full scale pilot facility, a 110m wide cage system under a floating platform also hosting the feed barge, control room and maintenance facilities.

1.6 Investment

Investments in aquaculture stem from the sector itself, from private investment funds or investors and from public sources. The investment environment of the EU aquaculture sector can be characterized as follows.

- The Future Expectations Indicator (FEI) indicates whether the industry in a sector is investing more than the depreciation of their current assets. According to a recent research (STECF 2016) FEI in 2014 for 19 EU countries for the whole aquaculture sector (freshwater and marine) was negative at 5.8% while net investments in marine aquaculture increased by 16% from 2013–2014.
- The figures of fast growth of the sector in certain areas and increasing needs for aquaculture products attracts numerous private investors. While we will not recommend specific funds, some examples of

funds that specifically invest in aquaculture include: Oceanis Partners, A-Spark Good Ventures, Watershed Capital Group, Fish 2.0.

Public investments are mostly linked to the European Maritime and Fisheries Fund (EMFF), which is the EU financial instrument to support Common Fisheries Policy (CFP) implementation. The Commission is keen to use the opportunities presented by EMFF to boost aquaculture growth. It therefore requires Member States to produce Multiannual National Plans (MANPs) outlining how each member state intend to foster growth in the aquaculture industry. Each country is allocated a share of the total 5.7 billion Euro Fund budget, based on the size of its fishing, aquaculture and processing industry. The MANPs will provide information on how each member state will allocate the funds to stimulate sustainable aquaculture (Figure 1.4), including a prediction of the expected growth of the sector. Under priority 2 of the national operational programme the following objectives can be funded:

- support for technological development, innovation and knowledge transfer;
- the enhancement of the competitiveness and viability of aquaculture enterprises, including the improvement of safety and working conditions, in particular of SMEs;
- the protection and restoration of aquatic biodiversity and the enhancement of ecosystems related to aquaculture and the promotion of resource-efficient aquaculture;

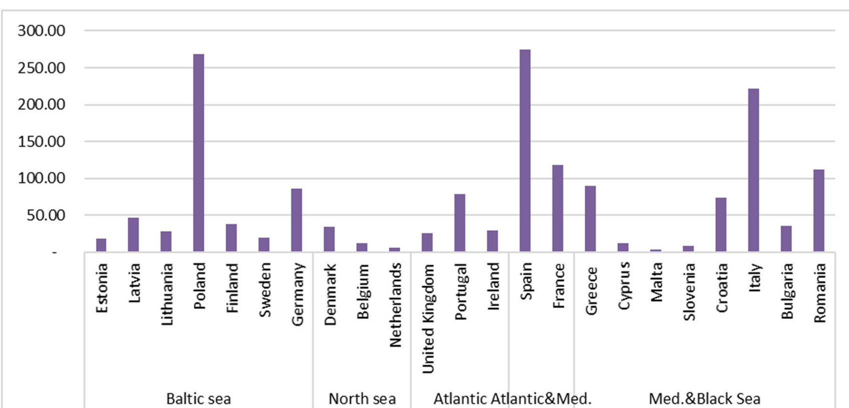

Figure 1.4 Allocated EMFF funding (million €) for aquaculture investments in EU member states with marine aquaculture production for the 2014–2020 period.

Source: Operational Programs of listed countries.

- the promotion of aquaculture having a high level of environmental protection, and the promotion of animal health and welfare and of public health and safety;
- professional training, skills and lifelong learning.

The sum of funding budgets between 2014–2020 consisting of national and EU contributions for promoting environmentally sustainable, resource efficient, innovative, competitive and knowledge based aquaculture is €1.7 billion allowing at least €3.4 billion supported investments in European Aquaculture (http://ec.europa.eu/fisheries/cfp/emff/index_en.htm). Good access to information on the economics of offshore mariculture can help would-be investors and coastal States in developing economically feasible technologies for offshore mariculture. Member government actions are also needed to create conditions for increased investment in mariculture and to allocate funds for R&D, including funding demonstration and pre-commercial projects for a variety of species. Governments should also encourage international cooperation and technology transfer among stakeholders.

1.7 Uncertainties and Concluding Remarks

Marine aquaculture is a well-developed industry in the Atlantic and Mediterranean regions while it is under development in Baltic, North Sea and Black sea regions. The sector is dominated by the fish production sector in terms of the value, but this subsector also needs higher investment and operating costs. In terms of environmental interactions, seaweed and mollusc aquaculture is considered to have a positive impact on the marine environment.

The most limiting uncertainties of the marine aquaculture sector are:

- Lack of available marine space for aquaculture production and different licensing strategy of coastal countries.
- Availability and price fluctuation of fish meal which is still an important ingredient of the fish feed.
- Even though numerous promising offshore aquaculture technologies have been developed in the last years, none of them was tested yet for commercial scale production.

In spite of these uncertainties, the recent technology and socio-economic developments in the sector can provide good opportunities for the investment in offshore aquaculture in Europe. The main driving force of offshore production is to release the pressure from coastal areas which often have special nature values and can't provide more space for the expected growth of production. However offshore development is between the development and embryonic stage of business lifecycle, there are strong interests from government, institutions and commercial sectors to explore and develop offshore potential. These developments require large investments that can only be realized by large industries or with the support of external investment (private or governmental subsidies). The recent known attempts for offshore aquaculture development shows that the high market value of Atlantic salmon and increasing demand for salmon products has encouraged the existing large producers and other large companies having experience in other marine industries (shipping, oil) to invest in offshore salmon production projects.

Even though cultivation of shellfish or seaweeds may be better adapted to offshore conditions, the market value does not (yet) guarantee a profitable business case, while their minimal environmental impact on coastal areas does not force these technologies to move offshore. Seaweed and shellfish production can have an important role in offshore aquaculture by reducing the nutrient discharge of fish production in IMTA systems.

It is expected that a rapid growth in offshore aquaculture production will be triggered when the feasibility of large scale production will be demonstrated with the profitable business cases (economy of scale) of the recent projects. This growth stage will also require a next level in technical engineering of aquaculture (structures, remote sensing, safety at sea are important issues) which will facilitate the combination of aquaculture with other, mature, offshore industries.

The recent state and future opportunities for combination of aquaculture with other maritime industries in different marine basins can be summarised as follows:

Basin	Summary	Opportunities and Justification
Atlantic	The Salmon industry in Norway and Scotland (UK) is in expansion looking for marine space for new production sites and new technologies.	The companies are motivated to find partners and share the marine space with other industries. Salmon aquaculture is in the mature stage and ready for feasible combinations.
Baltic/North Sea	Mussel and crustacean culture is relatively more important and considerable amount of national research was done to combine their production with offshore wind energy.	More than 1 billion € investment in aquaculture is planned in the region (according to the adopted OPs). There is also a high need for Blue Energy investments providing good base for combinations.

Mediterranean and Black sea	Sea bass and sea bream industry is very well developed and production of new species is also emerging. Mussel production in the Black sea region has a growing interest.	High interest to invest in combined offshore platforms in the region. To reduce the environmental impact of fish production there is opportunity to establish IMTA systems.

References

Aquaculture glossary: http://www.fao.org/faoterm/collection/aquaculture/en/

Aguilar-Manjarrez, J., Soto, D. and Brummett, R. (2017). Aquaculture zoning, site selection and area management under the ecosystem approach to aquaculture. Full document. Report ACS113536. Rome, FAO, and World Bank Group, Washington, DC. pp. 395. Available at: http://www.fao.org/3/a-i6992e.pdf

CEFAS (2014). Background information for sustainable aquaculture development, addressing environmental protection in particular: SUSAQ (Part 1), Cefas contract report <C6078>

Chopin, T., Cooper, J. A., Reid, G., Cross, S., Moore, C., (2012) Open-water integrated multi-trophic aquaculture: environmental biomitigation and economic diversification of fed aquaculture by extractive aquaculture. Reviews in Aquaculture, 4(4), 209–220. doi:10.1111/j.1753-5131.2012.01074.x

COFASP (2016) Strategic Research Agenda For Fisheries, Aquaculture and Seafood Processing – www.cofasp.eu

EFARO 2017 A vision on the future of European Aquaculture, IJmuiden, The Netherlands, May 2017 www.efaro.eu

EUMOFA (2016) The EU Fish Market, 2016 edition, European Commission – European Market Observatory for Fisheries and Aquaculture Products 2016.

EUMOFA (2017) EU Consumer Habits Regarding Fishery and Aquaculture Products – Final Report, European Commission – European Market Observatory for Fisheries and Aquaculture Products

European Commission (2014). Facts and figures on the Common Fisheries Policy – Basic statistical data – 2014 Edition, Luxembourg: Publications Office of the European Union 2014 – 44 p. – 14.8 × 21 cm ISBN 978-92-79-34192-2

FAO & World Bank. (2015). Aquaculture zoning, site selection and area management under the ecosystem approach to aquaculture. Policy brief.

Rome, FAO. Available at: http://www.fao.org/documents/card/en/c/4c777b3a-6afc-4475-bfc2-a51646471b0d/

FAO. 2016. The State of World Fisheries and Aquaculture 2016.; Contributing to food security and nutrition for all. Rome. 200 pp.

World Bank. 2013. Fish to 2030: prospects for fisheries and aquaculture. Agriculture and environmental services discussion paper; no. 3. Washington DC; World Bank Group. http://documents.worldbank.org/curated/en/458631468152376668/Fish-to-2030-prospects-for-fisheries-and-aquaculture

OECD/FAO (2016), "Fish and Seafood", in OECD-FAO Agricultural Outlook 2016–2025, OECD Publishing, Paris. DOI: http://dx.doi.org/10.1787/agr_outlook-2016-12-en

Helen Sturrock, Richard Newton, Susan Paffrath, John Bostock, James Muir, James Young, Anton Immink & Malcolm Dickson. Ilias Papatryfon (editor) (2008) Prospective Analysis of the Aquaculture Sector in the EU. PART 2: Characterisation of Emerging Aquaculture, Systems European Commission, Joint Research Centre, EUR Number: 23409 EN/2

Hersoug, B. (2015) The greening of Norwegian salmon production Maritime Studies (2015) 14:16 DOI 10.1186/s40152-015-0034-9

Kapetsky, J. M., Aguilar-Manjarrez, J., Jenness, J., (2013). A global assessment of potential for offshore mariculture development from a spatial perspective. FAO Fisheries and Aquaculture Technical Paper. No. 549. Rome, FAO. 181 pp. (also available at http://www.fao.org/docrep/017/i3100e/i3100e00.htm).

Kerr, S., Johnson, K., (2015) Identifying and Describing Business Lifecycle Stages, MARIBE Internal publication Version 1.1, Briefing paper prepared by ICIT Heriot-Watt University.

Lovatelli, A., Aguilar-Manjarrez, J., Soto, D., (Eds.) (2013). Expanding mariculture farther offshore – Technical, environmental, spatial and governance challenges. FAO Technical Workshop. 22–25 March 2010. Orbetello, Italy. FAO Fisheries and Aquaculture Proceedings No. 24. Rome, FAO. 73 pp. Includes a CD–ROM containing the full document (314 pp.). (also available at http://www.fao.org/docrep/018/i3092e/i3092e00.htm).

Lane, A., Hough, C., Bostock, J., (2014). The long-term economic and ecologic impact of larger sustainable aquaculture, Study for the European Parliament's Committee on Fisheries, European Union, 2014.

Meaden, G. J., Aguilar-Manjarrez, J., Corner, R. A., Ó Hagan, A. M., and Cardia, F. (2016). Marine spatial planning for enhanced fisheries and aquaculture sustainability its application in the Near East. FAO Fisheries and Aquaculture Technical Paper No. 604. Rome, FAO. Available at: http://www.fao.org/3/a-i6043e.pdf

Scientific, Technical and Economic Committee for Fisheries (STECF) 2016 – Economic Report of the EU Aquaculture Sector (EWG-16-12); Publications Office of the European Union, Luxembourg;

Soto, D., (2009). Integrated mariculture: a global review. FAO Fisheries and Aquaculture Technical Paper. No. 529. Rome, FAO. 2009. 183 pp. (also available at http://www.fao.org/docrep/012/i1092e/i1092e00.htm).

Wever, L., Krause, G., Buck, B. H., (2015) Lessons from stakeholder dialogues on marine aquaculture in offshore windfarms: perceived potentials, constraints and research gaps. Marine Policy 51:251–259.