The drivers of fisheries and aquaculture production in the EU

Deliverable No. D4.2

SUSFANS DELIVERABLES

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The role of seafood is complex in sustainable and nutritious diets. Production from capture fisheries is limited whereas seafood from aquaculture is seen as the most promising food production systems for the future. In this report, data on EU seafood production is provided, as well as a review of indirect and direct drivers for seafood production in the EU. Several plausible directions for improved sustainability of seafood production in EU FNS are identified. Furthermore, metrics for environmental assessment of seafood in relation to EU policies on reduced environmental impacts are suggested.

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Overview of WP4 driver deliverables

Generally, WP4 aims to develop a system understanding of the drivers of and prepare, collect and deliver the data for assessing FNS and its sustainability at the level of primary agricultural and fisheries production.

Within WP4, the deliverables D4.1 (drivers of livestock production in the EU), D4.2 (drivers of fisheries and aquaculture production in the EU), D4.4 (preliminary report on the drivers of crop production in the EU) and D4.5 (final report on the drivers of crop production in the EU) provide:

- An analysis of the drivers of livestock production in the EU;
- An analysis of the drivers of seafood production in the EU;
- An analysis of the drivers of crop production in the EU.

Table 1 gives an overview of the WP4 driver reports.

Table 1 Overview of WP4 driver deliverables

Production system	Methodology	Deliverable
Livestock	Qualitative analysis	D4.1
Seafood	Qualitative analysis	D4.2
Crops	Qualitative/quantitative analysis	D4.4 (preliminary deliverable)
Crops	Quantitative analysis	D4.5 (final deliverable, due in March 2017)

Generally, primary agricultural production is not only affected by economic factors, but highly depends on biophysical factors as well. The economic aspects and, partly, their interplay with biophysical factors are part of the modelling work within the SUSFANS toolbox. The WP4 driver deliverables provide a basic understanding of the multi-disciplinary production system. Since economic factors are covered in the SUSFANS toolbox and the scenario work, emphasis is thereby put on biophysical and technology developments. A general introduction to the concept of drivers in primary production and drivers in the context of production economics is given in the appendix of each of the deliverables.

Table **2** shows the different foci of the individual drivers in the SUSFANS conceptual framework (CF) (Zurek et al. 2016) and each of the WP4 driver deliverables. Relevant for the WP4 driver deliverables are the indirect drivers that affect the whole food system and the direct drivers for producers. Indirect food system drivers considered in the CF are economic developments, population dynamics, technological change, agriculture and trade policies, environmental issues, and culture and lifestyle choices. Direct drivers for producers according to the CF are the regulatory environment, input and farm gate prices, contract opportunities, natural resource availability, available technology and producer and farm characteristics. The appendix provides a more detailed comparison of the drivers technological change and available technology.

Table 2 Different foci between WP4 driver deliverables and the CF

Driver	CF (D1.1)	Livestock (D4.1)	Seafood (D4.2)	Crop (D4.4)
Indirect drivers				
Economic development	-Summarized by growth in GDP -Impact on consumption, consumer and producer prices, wages in food sector -Market power and imperfect competition	-Summarized by growth in GDP -Development of livestock production	-Societal drivers affecting seafood prices -Macro- and microeconomics of EU seafood production	-Refers to CF (D1.1)
Population dynamics	-Population growth (in developing countries) -Demographic changes -Composition of diets	-Population growth (in developing countries) -Demographic changes -Composition of diets	-Demo-graphics and expected effects on seafood demand	-Refers to CF (D1.1)
Technological change	-Innovation -Technology development -Competition for land from emerging biotechnology	-Progress in feeding technology -Progress in breeding	-Historical development and the interplay between farmed and fished seafood -Technical innovations in society enabling growth	-Public and private research (breeding, fertilizer and plant protection, machinery)
Agriculture and trade policies	-Impacts on prices and diets -Price transmission	-Specific crop policies between EU and other countries	-Fishing policies between EU and other countries	-Specific crop policies between EU and other countries

	between agricultural policies and consumer food prices -Price impacts through trade policies on commodity prices limited, highest effect on diets through general liberalization and economic growth -Impact of trade policies on price volatility -Effects on land use -Sanitary and phytosanitary regulations	-Food policies -Trade policies	-Food policies, trade barriers and regulations related to seafood -Beyond-EU regulatory environment of relevance to seafood production	-Food policies -Trade policies -Relevant sanitary and phytosanitary regulations
Environmental issues	-Climate change impacts on crop and livestock sectors -Soil carbon sequestration -Reduction of emissions from land use and carbon sequestration in biomass -Biomass production for energy uses -Energy prices	-Global environmental impact of livestock production. Competition for land between feed and food production	-Environmental pressures of seafood production -Effects on seafood production from changing environment	-Climate change
Culture and lifestyle choices	-Nutrition intake and changing dietary behaviours	-demand for livestock products over the years	-Consumer preferences related to seafood	-Specific trends in crop consumption

	-Undernourishment, malnourishment and human health		consumption	
Direct drivers				
Regulatory environment	-Common Agricultural Policy (CAP) of the EU -Common Fisheries Policy (CFP) of the EU -Different directives (e.g. water framework directive, Marine Strategy Framework Directive) -Food safety and related standards	-EU legislations and policies affecting livestock production	-EU legislations and policies affecting seafood production	-EU cereals regime -EU oilseeds regime -Fruits and vegetable policies
Input and farm gate prices	-Interplay supply and demand -Relation input and output prices -Input costs -Producer prices	-Trend in livestock prices	-General economic data on EU seafood production	-Input prices refer to CF (D1.1) -Trends in crop prices
Contract opportunities	-Contract farming as part of vertical integration -Relevance of contract farming in different production systems	-Relevance of contract farming in different production systems	-Hinders for aquaculture growth -Outsourcing of activities	-Refers to CF (D1.1)
Natural resource	-Determines feasibility of	-Impact of current	-Production	-Environmental

availability	primary production -Includes land, climate, soils, water, fish stocks	production levels on scare resources e.g. land use and future availability.	capacity and current status of capture fisheries -The role for aquaculture related to general resource availability (e.g. seafood per capita, feed)	setting on farm, refers to CF (D1.1)
Available technology	-Technology adoption & diffusion -Technology usage -Total factor productivity	-Feeding and breeding technologies are adapted in e.g. diet formulations	-Science and management behind current production -Difference in technology between individual enterprises, e.g. farmers' knowledge, skipper effect -Status of production systems and technical progress needed -Production efficiency incl. by-	-Management

			product utilization	
Producer and farm characteristics	-Personal attitudes, values and goals, experiences, social influences -Path dependencies through existing farm characteristics and farm structure -Vessel characteristics and fleet structure -Effect of socio-economic characteristics on risk aversion and management decisions	- type of farms - number of farms - animal numbers per farm	-Seafood production characteristics in the EU (technology, knowledge, prices and costs)	-Refers to CF (D1.1)

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1 Introduction

Achieving sustainable production and consumption of food represents a multifaceted challenge (Foley et al. 2011). The nutritional dimensions include both undernourishment and obesity; environmental aspects include food waste, climate change, biodiversity loss, water depletion and more. Some issues are aligned, such as some environmentally less sustainable food commodities also imply higher health risks (Tilman and Clark 2014). Other aspects are more complex, such as the role of seafood in human nutrition and environmental sustainability.

Seafood is generally a healthy alternative in a diet, even if some species from certain fishing areas may cause health risks due to contaminants (Gerber et al. 2012). At present, seafood accounts for approximately 17% of the global population's intake of animal protein and nearly 7% of all protein consumed (FAO 2016). Seafood also serves as an important source of minerals (including calcium, iodine, zinc, iron and selenium), contain all essential amino acids, provides essential fats (e.g. long-chain omega-3 fatty acids) and vitamins (D, A and B). Dietary advices in developed countries accordingly often recommend eating more seafood and vegetables and less beef (Thurstan and Roberts 2014).

However, there are issues to be solved for seafood to take a more leading role in sustainable diets. Seafood production is today based either on capture fisheries, which is the only large-scale food production based on a wild, natural resource, or from aquaculture, today accounting for half of the consumed seafood volume. Production volume from capture fisheries is limited. It has not increased for decades and there is little room for expansion, with only 10% of stocks considered to be under-utilized (FAO 2016). Overexploited species have impaired production capacity, with varied recovery time depending on life history and management effectiveness. Furthermore, present seafood consumption in the EU is based on a globally unequal sharing of a common resource; the EU, together with the US and Japan, dominate by far the appropriation of supply from capture fisheries (Swartz et al. 2010a). This is the result of fish resources having a high economic value; countries with undernourishment, which are more dependent on local seafood resources for protein and micronutrients, are therefore net exporters of seafood to developed countries (Smith et al. 2010; Brunner et al. 2012; Black et al. 2013). To meet the growing global demand for seafood, aquaculture production has shown a remarkable rate of increase (FAO 2014), and generally seen as a sustainable option in future diets (Godfray et al. 2010). Unfortunately, consumers in more wealthy countries have a high preference for farming of carnivorous species (Cambell and Pauly 2013) leading to larger than necessary footprints due to their high protein requirement in feed.

Key components of food security are stability of supply and accessibility. Fully strengthening food and nutrition security (FNS) in the EU thus requires a transition towards a diet that operates within the planet's capacity, and supports sustainable food consumption and production from a global equity perspective (Golden et al. 2016; Foley et al. 2011; Rockström et al. 2009). To gauge the policy reforms needed for this major societal challenge it is vital to identify how food production and nutritional health in developed countries can be better aligned, neither compromising environment sustainability, nor nutrition in developing countries.

From the complexity of seafood production and consumption – being the most traded food commodity, having vast different environmental sustainability, being essential in countries with undernourishment but being exported to developed countries where it is being promoted as a healthy choice (FAO 2014) – this report intends to illustrate the role seafood can play in healthy and sustainable diets in the EU.

1.1 Aim

The overall objective of this report is to provide insight into the links between policy-production-supply for seafood and identify improvement options and obstacles for more sustainable FNS related to seafood with focus on the EU.

The study focus on drivers from the EU seafood producer perspective and how FNS related to seafood could be strengthened. This is done by i) compilation of data related to the seafood production system actors and activities today; ii) literature review on drivers related to seafood; iii) discussion on environmental variables and metrics for assessing seafood FNS in the EU within the SUSFANS framework (Rutten et al. forthcoming) and which case studies that would be of interest to identify improvement potentials.

2 Material and methods

The structure of the report is as follows:

1. Description of current seafood production in the EU in volume and value,
2. Indirect drivers, here focused on global aspects of seafood production and external drivers affecting EU seafood production systems,
3. Direct drivers, those more directly related to EU seafood producers such as EU regulations,
4. Discussion on how drivers are related to each other (positive and negative feedbacks), metrics needed to assess FNS for seafood and case studies of interest to identify more sustainable FNS in the EU.

The report is based on literature review and data on EU (the present 28 countries) seafood production and trade compiled from European Market Observatory for Fisheries and Aquaculture Products (EUMOFA). The data presented is from the year 2013 (the latest available data for capture fishery production) and is presented as the same commodity groups and main commercial species as defined by EUMOFA (EUMOFA 2016). The EUMOFA commodity group name “Bivalves and other molluscs and aquatic invertebrates” was however shortened to “Bivalves” in this report. From this, an improved understanding of the interplay between various drivers and response in terms of supply, resource use and environmental pressures of seafood production is sought for.

The definition of drivers is based on the agreed SUSFANS Conceptual Framework for Assessing EU Sustainable FNS (Figure 1). Emphasis is put on direct drivers related to the production side. In short, this framework categorizes indirect drivers as those related to general trends in society, i.e. affecting the whole food system (such as economic development, population dynamics, and culture and lifestyle choices). Direct drivers are those more closely linked to producers (such as the regulatory environment, input and farm gate prices, contract opportunities, natural resource availability, available technology and producer and farm characteristics). A specific introduction to rationale behind definition of the drivers specific to the seafood producers relative to crop and live-stock production are found in Appendix A.

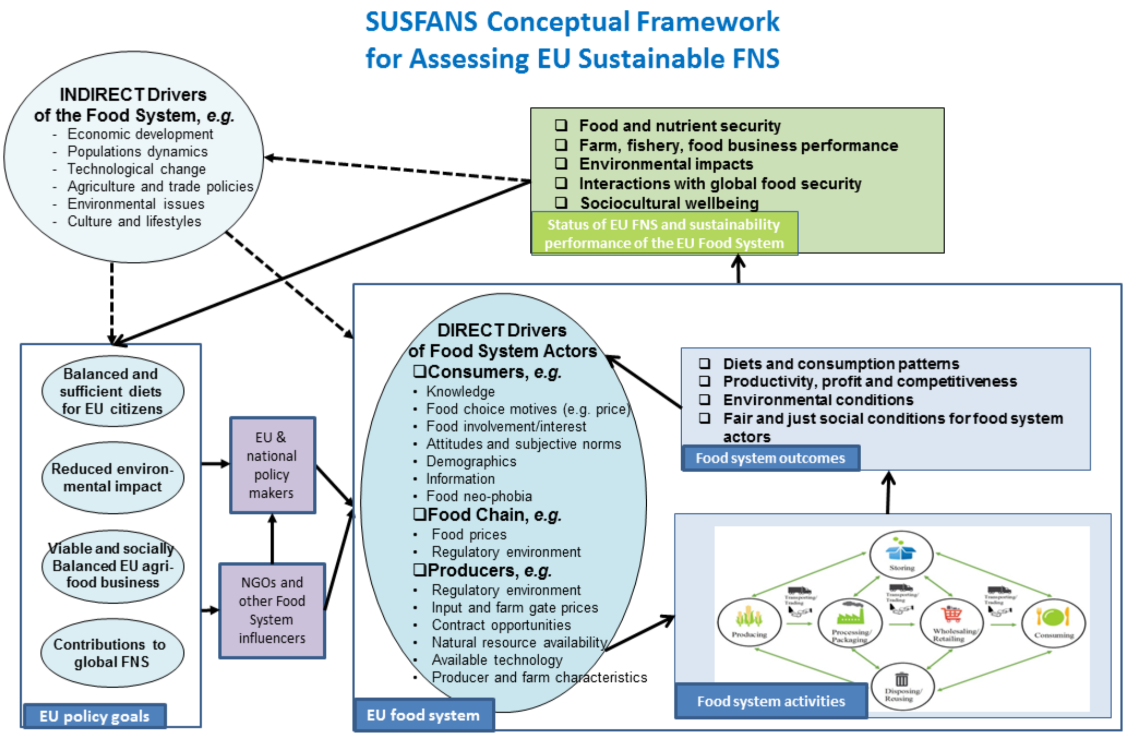


Figure 1 SUSFANS Conceptual Framework for Assessing EU Sustainable Food and Nutrition Security (FNS). From Zurek et al. (2016).

Corresponding analysis of direct drivers of the food chain within the SUSFANS project are found in Van der Velde (forthcoming) and for consumption in (e.g. Bouwman et al. 2016, Irz et al. 2016, Marette et al. 2016). For crop production, see Zimmermann and Latka (2016), and for livestock production van Zanten and de Boer (2016).

3 EU seafood production and consumption

3.1 Fishing fleet capacity

European fishing vessels comprise 2% of the global fishing fleet (FAO 2016). Still, in terms of fishing effort (expressed as total engine power and the number of fishing days in a year, kilowatt days), Europe dominates the global fishing effort, closely followed by Asia (Anticamara et al. 2011).

The EU fishing fleet is highly diverse, with vessels ranging from less than six metres to more than 75 metres (Table 3). Total fishing capacity is under EU law forbidden to increase. The fleet has declined with 18% in number of vessels during the past decades (thus both in tonnage and engine power). The net profit margin has also increased from 2008 to being around 6% in 2011 (EU 2014). The EU fleet consists of vessels that are more or less active in fishing. Of the active vessels, 74% are defined as small-scale, 26% large-scale and less than 1% are distant-water vessels (STECF 2015). Italy and France dominate EU production in terms of engine power, but most EU vessels use passive gears such as nets and creels. Greece has the largest number of vessels (Table 4).

Table 3 EU fleet size (February 2014). Source: EU 2014.

Length (m)	Vessels (No.)	Gross tonnage	Engine power (kW)	Average age
0 - 6	28 198	23 385	352 894	27
6 - 12	45 946	162 730	2 287 848	24
12 - 18	6 955	159 505	986 749	25
18 - 24	3 330	249 700	886 491	22
24 - 30	1 729	243 883	642 124	20
30 - 36	579	139 979	311 268	22
36 - 45	433	172 689	409 750	17
45 - 60	109	93 235	164 607	19
60 - 75	76	130 994	225 899	16
>75	90	349 840	414 945	20
Total	**87 445**	**1 725 938**	**6 682 574**	**21**

Table 4 Fleet segments and fishing capacity for EU member states (Czech Republic, Luxembourg, Hungary, Romania and Austria have no fleet managed under the EU fisheries policy). Source: EU 2014.

Member state	No. of vessels	Share of EU total engine power (%)	Passive gears (%)	Trawlers (%)
Belgium	82	0.7	2	98
Bulgaria	2 053	0.9	94	6
Denmark	2 682	3.4	75	25
Germany	1 538	2.2	77	23
Estonia	1 443	0.7	93	7
Ireland	2 202	2.9	59	41
Greece	15 860	6.8	96	4
Spain	9 895	12.8	89	11
France	7 143	15.3	78	22
Croatia	7 621	6.2	87	13
Italy	12 698	15.2	70	30
Cyprus	894	0.6	99	1
Latvia	703	0.7	90	10
Lithuania	293	1.3	74	26
Malta	1 037	1.1	98	2
The Netherlands	848	5.0	31	69
Poland	832	1.2	80	20
Portugal	8 236	5.5	93	7
Romania	200	0.1	95	5
Slovenia	170	0.1	91	9
Finland	3 210	2.6	97	3
Sweden	1 390	2.5	81	19
United Kingdom	6 415	12.0	68	32
EU-28	**87 445**	**100**	**84**	**16**

3.2 Aquaculture production systems

The largest producer of farmed salmon in the EU is the UK, more specifically Scotland, where salmon is farmed in seawater cages along the coast (Munro and Wallace 2015). The largest production of farmed bivalves in the EU is Spain's farming of mussels, mainly taking place in Galicia where the mussels are grown on ropes suspended from rafts.

Farming of European seabass and Gilthead seabream is predominantly done in Greece and the Mediterranean by approximately 270 medium and large scale enterprises (STECF 2014). Most combine the production of the two species to adjust volumes according to demand and price.

In 2009, Denmark and the Netherlands dominated grow-out production volume of farmed seafood using re-circulating aquaculture systems (RAS); of the total approximately 25.5 thousand MT produced in these systems, the two countries stand for 92% (Martins et al. 2010).

3.3 Employment

Within the EU, seafood production in 2012-2013 employed over 170 thousand persons in fisheries, 73 thousand in aquaculture and 122 thousand in the processing sector, in full-time equivalents (FTE) (EU 2016a).

In relative terms, all Member State fishing fleets generate positive gross and net profit margins, with the exception for Belgium, the Netherlands and Poland who have negative net profit margins (STECF, 2015).

Basic data on EU aquaculture production (covering 20 member states) for 2012 provided by STECF (2014) states:

- The total number of enterprises in EU28 is estimated to be between 14 and 15 000.
- 90% of the enterprises in the aquaculture sector are micro-enterprises, employing less than 10 employees. However, production is also concentrated. Four countries produce 71% in volume and 70% in value of total EU production and larger enterprises (more than 10 employees) have increased in recent years.
- The number of FTE reported decreased by 2%, which according to the STECF analysis might indicate a tendency towards higher specialization and less part-time employment in the sector (even if part-time labour is still of high importance to the sector).
- Female employment made up 24% of EU aquaculture employment and 17% of total FTE.
- Average yearly wage was €22 100, an 9% increase compared to 2011.

3.4 Seafood production in 2013

The EU seafood production contributes to 3 % of the world seafood production of 190 million tonnes (EUMOFA 2015). The total production of seafood in the EU is 5.4 million tonnes of which 80% (4.2 million tonnes) come from capture fisheries and 20% (1.2 million tonnes) from aquaculture. The value of the seafood produced in the EU is in total €10.8 billion of which capture fisheries accounts for 65% (€6.9 billion) and aquaculture for 35% (€3.9 billion).

Spain produces the largest volume of both wild-caught and farmed seafood, and is the most important seafood producer in terms of total value (Figure 2). The most important fishing nations after Spain in terms of volume are Denmark, France and the United Kingdom, and in terms of value, France, Italy and the United Kingdom. The relatively low value of the large Danish catches reflects that Denmark's main catches are of small pelagic fish mainly destined to feed with a low price per kilo. The Spanish catches include high value species like tuna and hake.

The most important aquaculture producers in terms of volume are Spain, the United Kingdom (UK) and France, and in terms of value, the UK, France, Greece and Spain. The large production of high-value salmon puts the UK in the top of aquaculture producers in terms of value, whereas Spain's production of mussels generates large volumes but less value.

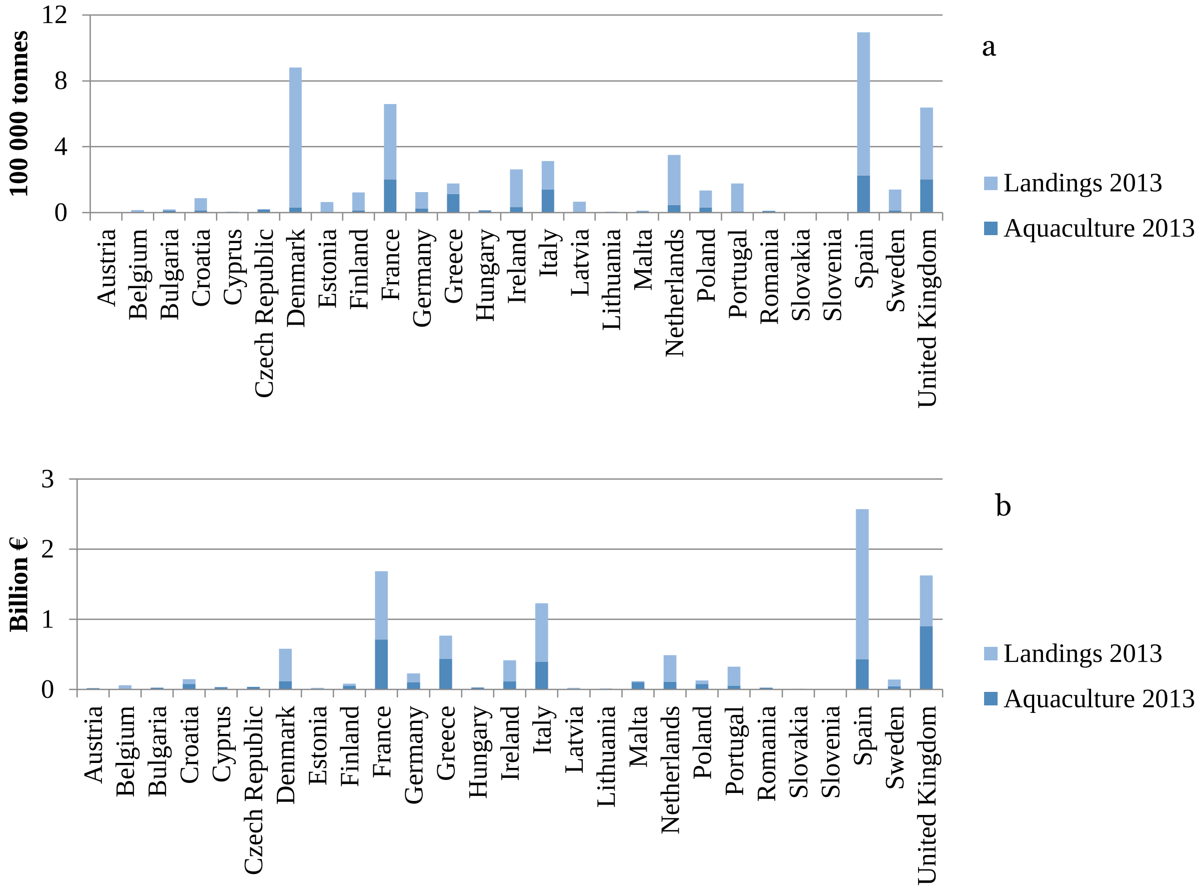


Figure 2 Seafood produced from capture fisheries and aquaculture per EU country in 2013 in a) volume (100 000 tonnes) and b) value (billion €).

The dominating type of seafood (including species mainly used for feed) from capture fisheries is small pelagics, mostly herring, sprat and mackerel (Figure 3a). Groundfish, which is the second largest commodity group (see material and methods section above for definition of commodity groups) in terms of volume, include blue whiting, hake and cod as the three most abundant species.

From the large volume produced, the commodity group small pelagic fish is the most important one also in terms of total value; other species are caught in considerably lower volumes, such as tuna and crustaceans (mainly Norway lobster and shrimps), but are also very important due to much higher prices per kilo (Figure 3b).

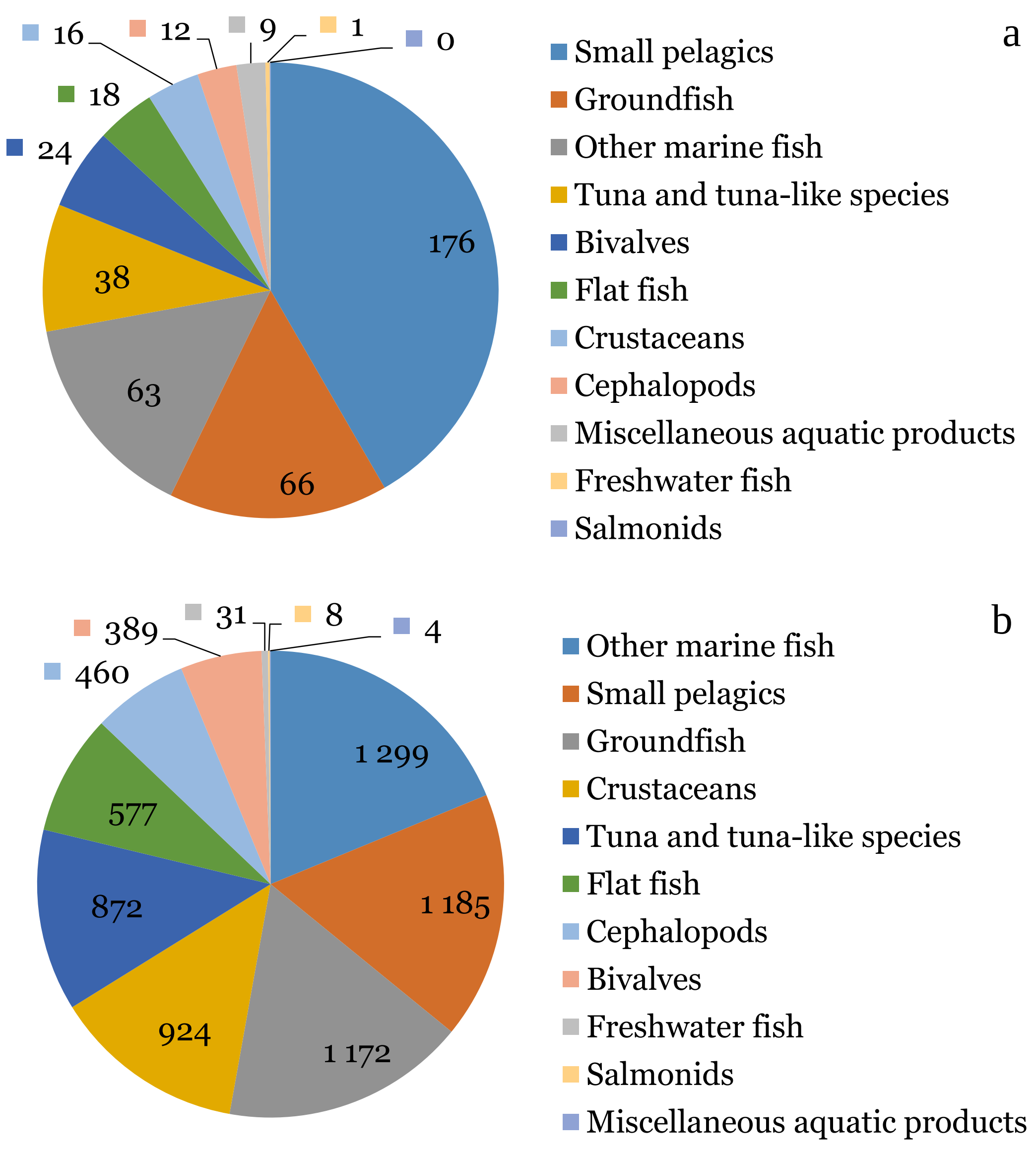
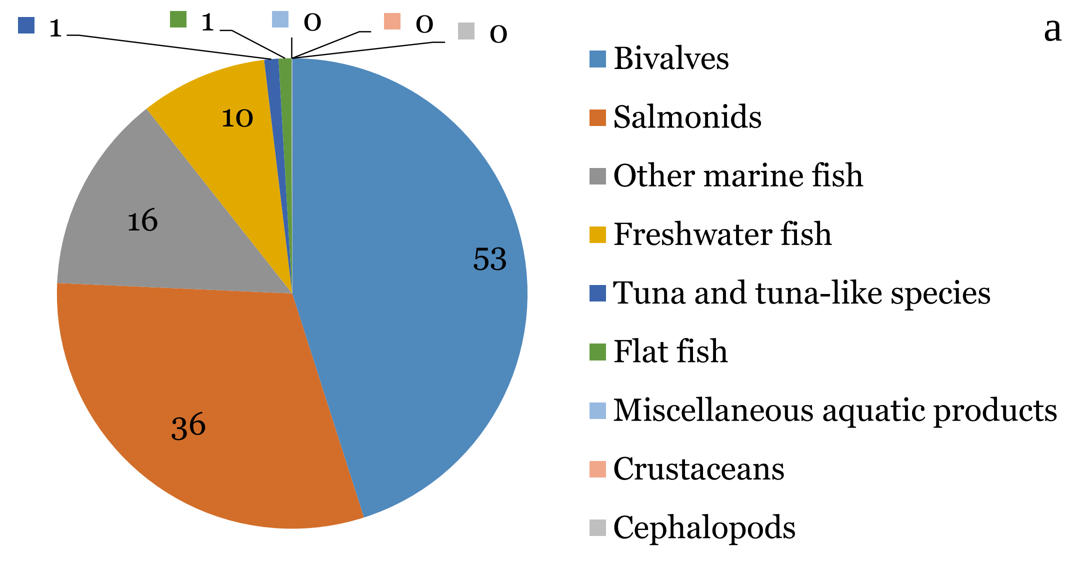


Figure 3 EU capture fisheries catches in 2013 per commodity group in a) volume (10.000 tonnes) and b) value (million €).

Aquaculture of bivalves (e.g. mussels, oysters) generates the largest volumes of farmed seafood in the EU, followed by salmonid farming of mainly salmon and trout (Figure 4a). Production of gilt-head seabream and European seabass (part of the group other marine fish in Figure 5) is also considerable. The aquaculture production of salmonids is the most important in terms of value, exceeding the value of the large production volume of bivalves.



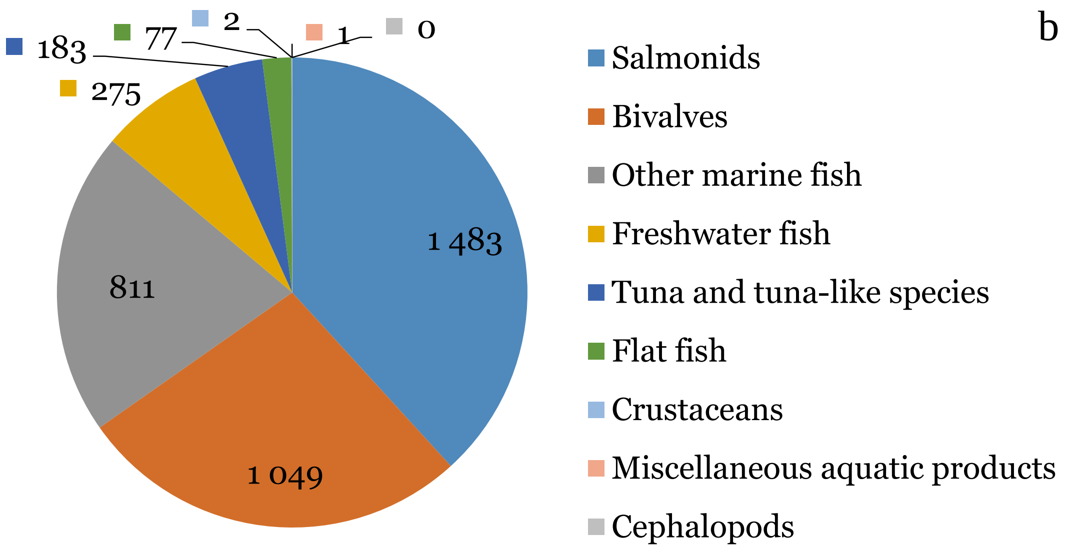


Figure 4 EU aquaculture production in 2013 per commodity group in a) volume (10.000 tonnes) and b) value (million €).

3.5 Trade

Overall, the EU is dependent on seafood imports. The self-sufficiency rate (ratio between own production and consumption) has been stable for seafood around

45% in the latest estimates (2008-2012; EU 2016). The unbalance however varies considerable between commodities; for pelagic fish, EU production covers 74% of its need, whereas for crustaceans, only 21%.

The EU imports 5.7 million tonnes of seafood from non EU countries (extra trade) annually to a value of €20 billion, and export only around a third of the import volume, 1.9 million tonnes to a value of €4.3 billion (Figure 5). The total internal EU trade of seafood products was in 2013 almost as large as the extra EU imports, 5.6 million tonnes with a value of €19 billion.

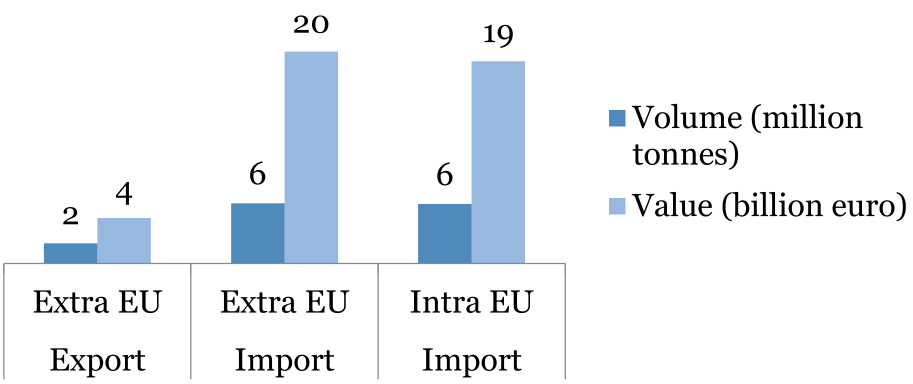
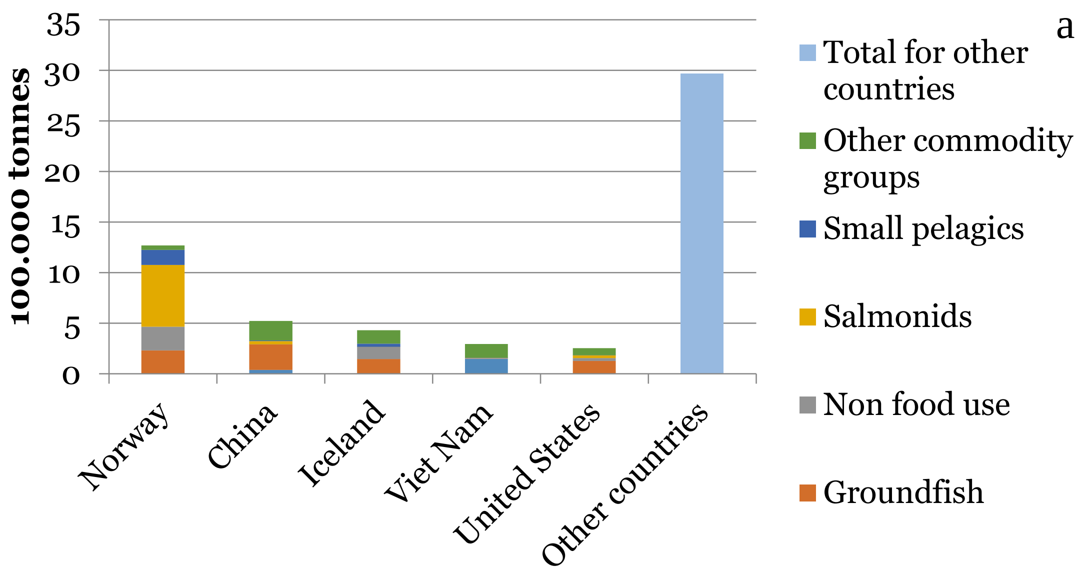


Figure 5 Volume (million tonnes) and value (billion €) of the extra- and intra-EU trade of seafood in 2013.

Norway is the largest external supplier of seafood. Norway alone provides the EU with 22 % of imported seafood (Figure 6a). The seafood imported from Norway is mostly salmon, but also considerable amounts of cod and non-food use products like fish meal and oil. China, the second largest exporter of seafood to the EU, mainly exports Alaska Pollock (commodity group groundfish, probably re-export after processing) in the form of frozen fillets, and Iceland, the third largest exporter to the EU, mainly exports cod and fish meal.

The imports of salmon from Norway and Alaska Pollock from China are also the largest in terms of value, followed by the imports of tuna and tropical shrimps from Ecuador and cod from Iceland (Figure 6b).



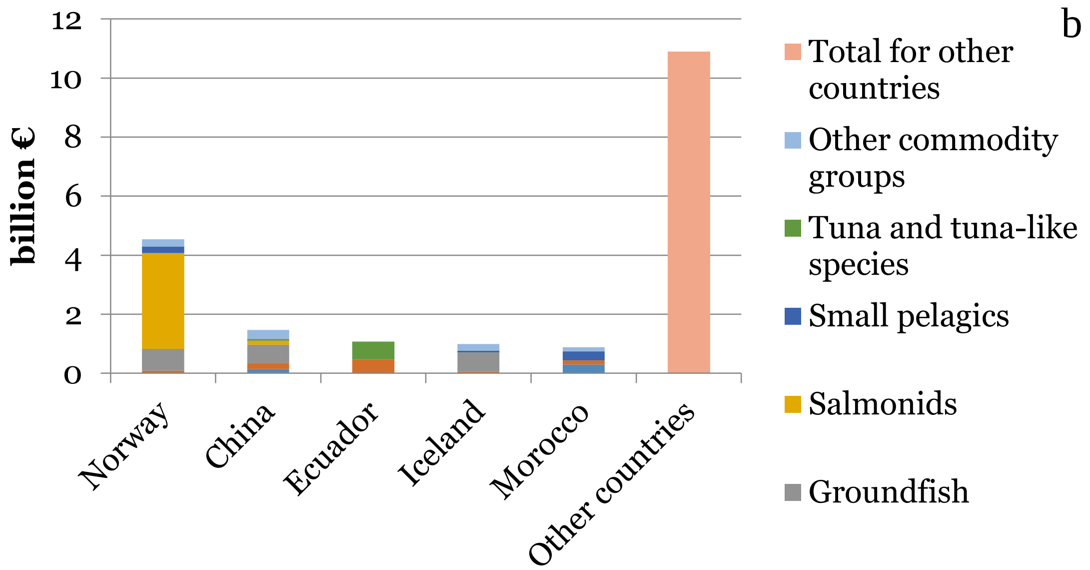


Figure 6 The five largest seafood extra EU import flows in a) volume per partner country and commodity group and b) value per partner country and commodity group.

Norway is not only the largest exporter of seafood to the EU, but also the largest importer of EU produced seafood in terms of volume (Figure 6a, Figure 7a). Norway does not however import seafood for consumption. The largest amount of seafood exported to Norway is fish meal and fish oil for the Norwegian aquaculture industry (EUMOFA 2016). Nigeria, the second largest importer of seafood from the EU, mainly imports herring and mackerel (commodity group small pelagic fish) and blue whiting (commodity group groundfish). Russia, the third largest importer of EU seafood, also mainly imports small pelagics, predominantly sprat.

The economically most important countries for seafood export are the United States, Norway and Switzerland. The value of the EU exports to the United States dominates by the value of salmon exported from the UK. The value of the exports to Norway comes from fish oil and fish meal. Switzerland imports seafood from various commodity groups.

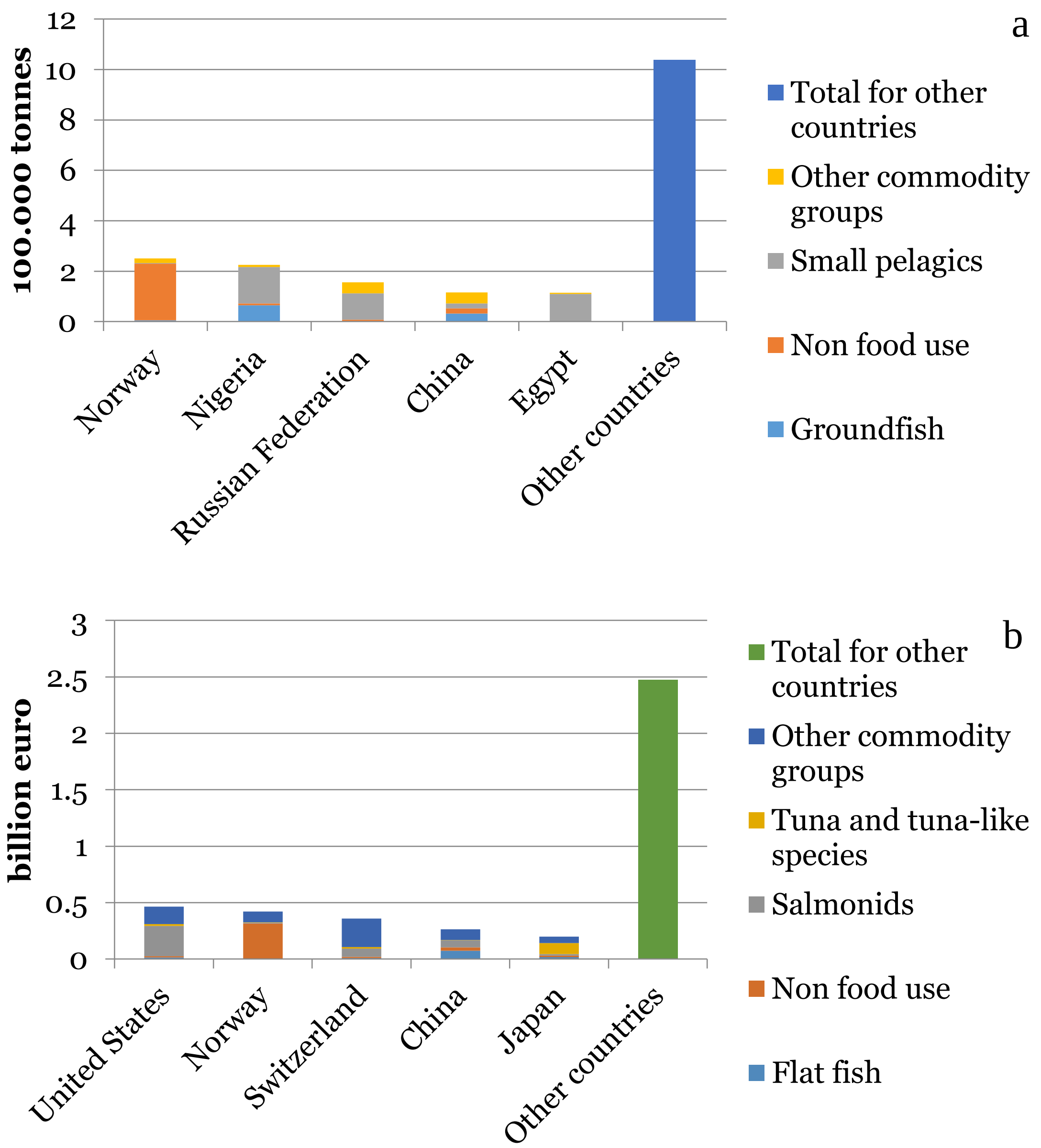


Figure 7 The five largest seafood extra EU export flows in a) volume per partner country and commodity group and b) value per partner country and commodity group.

It should be acknowledged that data on trade flows balances for seafood may be complicated by the fact that fishing grounds are shared between EU countries, and fishing vessels from one country may land the catch in another country's port. EU fishing vessels may also fish in waters outside of the EU through international agreements. Furthermore, as the seafood industry outsources activities, there are also considerable global flows of un-processed fish and seafood products, i.e. value-adding re-exports (Watson et al. 2015a).

3.6 Seafood consumption

The average EU citizen consumes 25 kg live-weight seafood per year. Even if this ranks the EU citizen as having the fifth highest seafood consumption in the world, it should be acknowledged that it varies considerably between member countries– between approximately 5 kg per person in Hungary to 57 kg per person in Portugal (EU 2016). The seafood diet in the EU is mainly wild-caught, only a quarter comes from aquaculture (Figure 8).

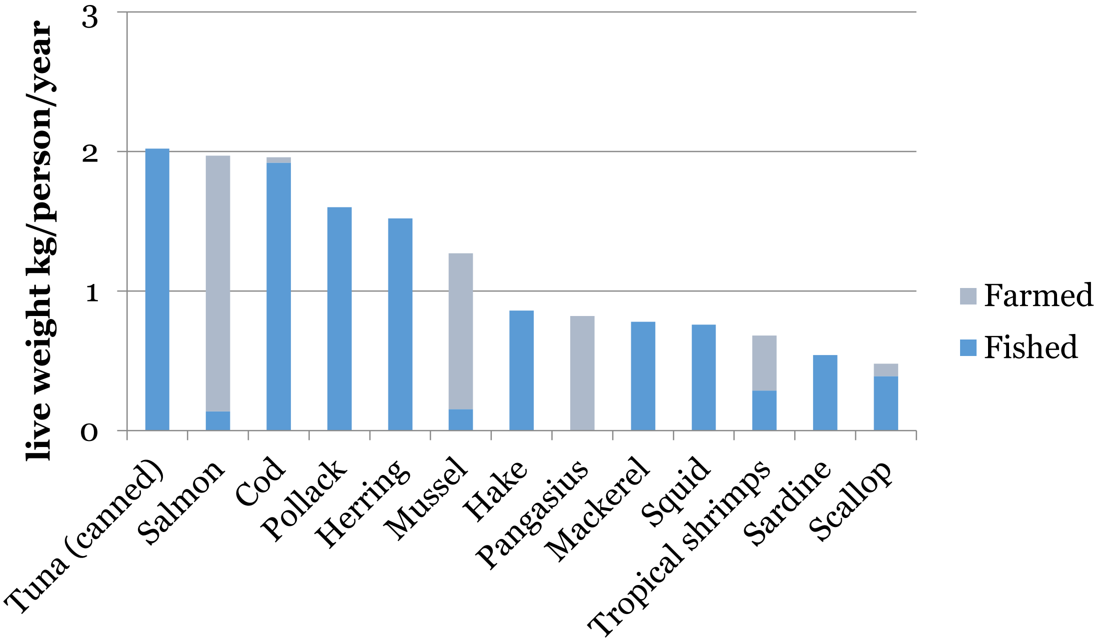


Figure 8 EU citizens' seafood consumption per capita in 2012 (EU 2016).

Seafood contributes to 5% of household expenditure on food for the average EU citizen (EUROSTAT 2016). Furthermore, relative to other food categories (e.g. meat, fruits and vegetables), seafood has low price dispersion between countries for EU citizens.

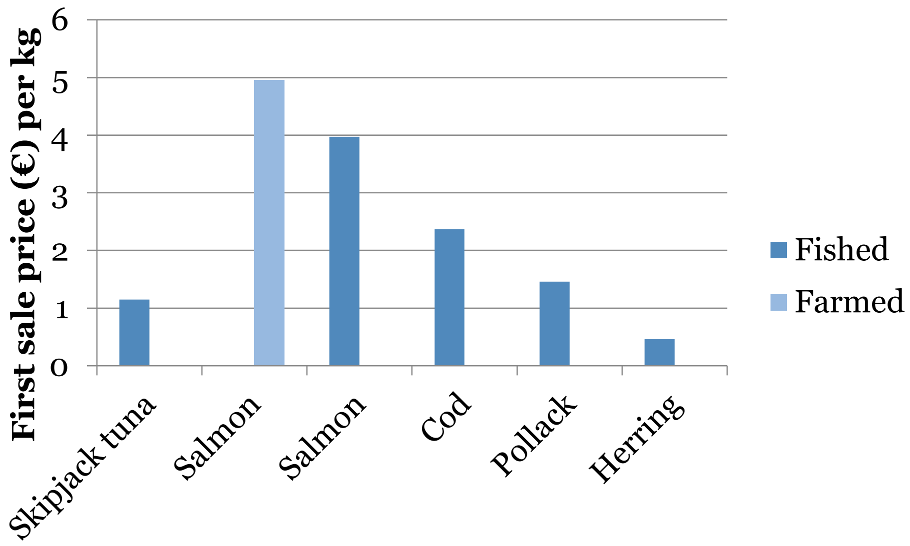


Figure 9 First sale price (€) per kg of the top five consumed seafood products in the EU (EUMOFA 2016). All seafood products are whole and frozen except for farmed salmon and farmed mussels for which the presentation and preservation was unspecified.

The first sale prices i.e. the price for which the European producers sell their products varies among the five species consumed in largest amounts in the EU (Figure 8 and 9). Tuna, the most commonly consumed seafood product in the EU generates a low first sale price as well as a low price for the consumer (EUMOFA 2016). Salmon, which is consumed in almost the same amounts as canned tuna, generates much higher first sale prices regardless if it is farmed or fished. The first sale price of farmed salmon has almost doubled during the ten years from 2003 to 2013 (EUMOFA 2016).

4 Indirect drivers of EU seafood production

Indirect drivers according to the SUSFANS conceptual framework are those that affect the whole food system (Figure 1; Zurek et al. 2016). In this chapter, these will merely be briefly discussed and primarily referring to global issues related to seafood production.

4.1 Global economic development

According to FAO (2016), the main drivers affecting world seafood prices in the next decade will be: income, population growth and meat prices on the demand side; and on the supply side, enabled capture fisheries production volume and costs for feed, energy and crude oil. Furthermore, the average price of traded seafood products will also decline; a 5% decrease in nominal terms and a fall of about 23% in real terms by 2025. The main drivers behind will be the competitive prices of substitutes (in particular chicken), the slowdown in demand from key markets due to slow economic growth, and the reduced production and marketing costs of aquaculture products due to lower transport and feed costs.

Seafood production is a highly fragmented sector, with significant diversity of practice and scale, and frequent conflicts between different producer sectors: large-scale vs small-scale fishing, between gear segments, and between aquaculture and fishing (Einarsson and Emerson 2007). The basic conditions for producers in capture fisheries differ from those of agricultural producers due to their dependency on a variable natural resource. This contributes to volatility in volume and value, where seafood prices are influenced both on the short and longer term by resource availability, fishing quotas, weather conditions and climate events. However, a recent paper by Tveterås et al. (2012) illustrated that compared to other food commodities (such as oils, cereal and dairy), seafood shows less volatility and fewer price spikes.

For seafood, indirect drivers such as energy prices are likely to affect production costs and possibly the role of seafood in affordable diets in developed countries. In e.g. the European Union (EU), there is a preference for more energy-intensive forms of seafood production (such as Norway lobster caught by demersal trawling), and domestic fisheries production has high rates of fleet motorization (Pelletier et al. 2014).

On a macro-economic scale, global fisheries are heavily subsidized (Sumaila et al. 2010). The category capacity-building subsidies is the globally dominating form of subsidies in fisheries (Sumaila et al. 2016), and can be harmful as they contribute to overexploitation. Out of total subsidies, fuel subsidies form the greatest part globally (22%) followed by subsidies for management (20%). Furthermore, at a global scale, it has been estimated that poor governance of fisheries result in $50 billion annual economic loss (Arnason et al. 2008).

From a microeconomic perspective, the value generated from time spent at sea is a central driver of fishing decisions (e.g. Ziegler et al. 2015). This is much influenced by price at first sale, determined by normal market drivers (supply, demand and quality).

4.2 Global population dynamics

The global population is expected to reach nine billions by year 2050 which will increase global demand for food; higher purchasing power from increasing wealth (especially growth in Africa and Asia) will in particular contribute to greater demand for commodities such as seafood (Godfray et al. 2010).

In parallel, increased urbanization is taking place. This stimulate innovation (such as marketing, distribution, infrastructure) to improve availability and accessibility of seafood products (FAO 2016). Furthermore, compared to more rural areas, a greater share of the income is spent on food in cities. Between 1950 and 2014, the proportion of urban population in the world has increased from 30% to 54% and is expected to reach 66% by 2050 (UN 2014). Europe is the third most urbanized region (73%), but is only home to 13% of the world's urban population (FAO 2016).

Analysis shows that global seafood consumption per capita is expected to continue to increase over the next ten years (OECD-FAO 2015), together with population growth. For the EU, projections suggest an increase in average consumption to 24 kg per person and year by 2030, on top of population growth (Failler 2007). Together with increased demand, the limit of natural production of capture fisheries has been an important driver for the rise of aquaculture. As EU aquaculture growth is not at present enough to meet demand, the EU is believed to increase its dependence on import of seafood.

4.3 Agriculture and trade policies affecting the EU

The indirect and direct effects of agricultural and trade policies on the EU food system are discussed in D1.1 (Zurek et al. 2016). In this chapter, global or regional policies and regulations affecting EU seafood production are summarized.

4.3.1 Fishing policies between the EU and third countries

EU has fisheries partnership agreements (FPAs) with third countries, allowing EU vessels to exploit surplus resources in the third country's EEZ. Surplus is defined as resources that the partner country is not willing or capable of fishing; less is said concerning the scientific basis of defining sustainable fishing levels. FPAs comprise of tuna agreements and mixed agreements (covering mainly shrimps, cephalopods and pelagic species). The EU pays partner countries a financial contribution comprising two different elements: firstly, the payment for access rights to the EEZ and, secondly, financial aid called 'sector support', which aims to help develop sustainable fisheries in partner countries (EU 2014).

Regional Fisheries Management Organisations (RFMOs) are international organisations formed by countries with fishing interests in an area. Their role is to safe-guard sustainable exploitation in their fishing area. As some very important commercial stocks are highly migratory, like tuna, there are two types of RFMO; those managing highly migratory fish stocks and those managing other fish stocks. The EU plays an active role in six tuna RFMOs and nine non-tuna RFMOs, most with the power to assert fishing restrictions, and is a member of two Regional Fisheries Organisations (RFOs), which have a purely advisory role (EU 2014).

4.3.2 Food policies and trade barriers

Compared to other animal proteins, the seafood sector is much more complex and diverse (it involves more species and a vast range of technologies), complicating analysis of emerging trends in trade (Einarsson and Emerson 2007). Seafood is also the most traded food commodity, with about 78 % of seafood products exposed to international trade competition (FAO 2016). For many countries, seafood exports are essential to their economies. For developing economies, seafood net export revenues (exports minus imports) reached US$42 billion, which is higher than other major agricultural commodities (such as meat, tobacco, rice and sugar) combined.

The World Trade Organisation (WTO) categorizes seafood as industrial products, but the level of tariff protection is in general relatively low compared to e.g. agricultural products. This has several reasons, discussed in Bellmann et al. (2016): First, the recognition of national EEZs in the 1970s restricted fishing opportunities in foreign EEZs, and left several OECD countries to increasingly rely on trade to meet domestic demand (Swartz et al. 2010a). Several countries maintained higher levels of protection of processed fish, to protect domestic industry and promote value adding, i.e. tariff escalation. Second, tariff protection has been reduced through e.g. regional trade agreements. In addition to these agreements, many countries provide trade preferences to seafood from developing countries as part of their Generalised System of Preferences. It has also been found that import protection in the EU has overall little effect on seafood imports, but protection is more effective for processed products because their trade barriers are higher (Guillotreau and Peridy 2000). Instead, price effects or the distance between countries are more influential than trade barriers on import levels. It has however been suggested that anti-globalization trade barriers are likely to increase (Einarsson and Emerson 2007).

There are different national dietary guidelines for seafood intake per week to benefit health, ranging between 97-550 g per capita (Thurstan and Roberts 2014). Consumers in many developed countries are advised to eat more seafood. However, many European countries do not produce enough seafood on their own to meet their recommended dietary intake of seafood. Therefore, countries with undernourishment end up serving as net exporters to European countries due to the high-value of seafood resources, where weak governance has been identified to threaten the poorer citizens in these countries ability to consume seafood (Smith et al. 2010). On the other hand, fish exports serve as an important source of income to many developing countries and may account for more than 40% of the total value of traded commodities in some island countries (FAO 2016). Another study claims that seafood trade flows are similar in volume, but that it is a quality exchange: developing countries export high-quality seafood in exchange for lower quality seafood (Asche et al. 2015).

The Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) regulates the international trade of few marine fish species (Vincent et al. 2014).

4.3.3 Regulatory environment

During 1750-1850, the industrial revolution brought large problems for traditional freshwater species in the form of drainage and pollution of breeding grounds (Nash 2011). An important driver for e.g. salmonid aquaculture in Europe was the expansion of hydropower in the 1940s-1950s, destroying natural spawning possibilities for Atlantic salmon in Sweden and Finland (Ackefors et al. 1994). Power companies were forced by law to mitigate loss of juvenile salmon by building hatcheries to compensate for population losses. Fertilized eggs began to be shipped around and hatcheries were initiated throughout Europe. Through joint efforts between industries/authorities/scientists, and considerable governmental support, the knowledge gained subsequently resulted in the huge commercial success of Norwegian salmon farming.

Today, there are a number of polices and regulations with global reach that directly or indirectly affect fisheries (Table 5). For seafood, it has been suggested that the introduction of coastal Exclusive Economic Zone (EEZs) in the 1970s was an important driver for many countries to look for other alternatives than fishing for seafood (Ackefors et al. 1994), thus being an indirect driver behind the rise of aquaculture.

Table 5 A non-exhaustive list of global regulations and policies with implications for fisheries.

Name	Year	Organisation	Objective/function
Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES)	1963 (drafted) 1973 (agreed) 1975 (in force)	Secretariat administered by United Nations Environment Programme (UNEP).	International and voluntary agreement between governments. The only legal commitment beyond economic zones Aim is to ensure that international trade in specimens of wild animals and plants does not threaten their survival.

United Nations Convention on the Law of the Sea (UNCLOS)	1982 (signed) 1994 (effective)	United Nations (UN)	Defines the rights and responsibilities of nations in their use of the world's oceans, establish guidelines for the management of marine natural resources.
The Convention on the Conservation of Migratory Species of Wild Animals (CMS or Bonn Convention)	1983	United Nations Environment Programme (UNEP)	Conserve terrestrial, marine and avian migratory species throughout their range
	1993	United Nations General Assembly	Moratorium on the use of large-scale driftnets on the high seas.
UN FAO Compliance Agreement	1993		Treaty.
Convention on Biological Diversity (CBD)	1993	United Nations Environment Programme (UNEP)	International legally binding treaty with obligations on nations to conserve and sustainably use marine biodiversity in areas beyond national jurisdiction.
UN Fish Stocks Agreement (UNFSA)	1995		The only global framework calling for sustainable management of high seas fisheries, based on the precautionary and ecosystem approaches. Applies only to highly migratory and transboundary fish stocks and does not cover sedentary high or deep-sea fish populations.
The Jakarta	1995	Convention on	Decision II/10: gives special

Mandate		Biological Diversity (CBD)	attention to marine resource use, urge for integrated management.
The Kyoto Protocol	2005	United Nations Framework Convention on Climate Change (UNFCCC)	To lower overall emissions from six greenhouse gases - carbon dioxide, methane, nitrous oxide, sulfur hexafluoride, HFCs, and PFCs (baseline 1990). Most European countries have binding targets (Annex I&II).
Nagoya Protocol	2010	Convention on Biological Diversity (CBD)	Pays special attention to genetic resources.

Furthermore, in 2015, a new sustainable development agenda was adopted, the 17 UN sustainability goals, with the objective to end poverty, protect the planet, and ensure prosperity for all with specific targets to be achieved by 2030 (UN 2016). For seafood, at least six of the goals are of relevance, indirectly or directly (Table 6).

Table 6 Six of the UN sustainability goals (SDG) and examples of targets with bearing on seafood production (UN 2014). Full list available at https://sustainabledevelopment.un.org/sdgs

No	Goal	Seafood production
2	**End hunger, achieve food security and improved nutrition and promote sustainable agriculture**	Social dimension
	2.1 aiming to end hunger and assure access to food, in particular poor and people in vulnerable situations; ***2.2*** aiming to end malnutrition in children under 5 years of age, and fulfil the nutritional needs of adolescent girls, pregnant and lactating women and older persons; ***2.3*** aiming to double the agricultural productivity and incomes of small-scale food producers such as fishers; ***2.4*** aiming to ensure sustainable food production systems that help maintain	More sustainable fisheries and better access to fish resources for local, subsistence/small-scale fishers will support food security and nutrition in the long term. Seafood is of particular importance to poor coastal communities, where industrial scale fishing and intensive tropical shrimp farming compromise food security.

	ecosystems and strengthen capacity for adaptation to extreme weather events	
8	**Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all**	Economic and social dimensions.
	8.4 aiming for improved global resource efficiency in consumption and production and endeavour to decouple economic growth from environmental degradation; ***8.7*** aiming for eradication of forced labour, end modern slavery and human trafficking and secure the prohibition and elimination of child labour; ***8.8*** aiming to protect labour rights and promote safe and secure working environments for all workers	Sustainable development of the seafood sector should minimize the degradation of oceans and marine resources and contribute to long-term socio-economic well-being. Ending harmful subsidies is vital for sustainable fisheries. The seafood value chain has also issues with slavery and poor working conditions (including child labour) in some countries.
10	**Reduce inequality within and among countries**	Economic and social dimensions.
	10.6 aiming to ensure enhanced representation and voice for developing countries in decision-making; ***10.a*** addressing implementation of special and differential treatment for developing countries, in particular least developed countries, in accordance with World Trade Organization agreements; ***10.b*** addressing the need to encourage official development assistance and financial flows, including foreign direct investment, to States where the need is greatest, in particular least developed countries	EU fishing fleets exploit fishing waters around the globe. Reduced inequalities is important to empower developing countries/local fishing communities to assert their rights to domestic fish resources and end unsustainable exploitation by large-scale industrial fishing by foreign fishing fleets.
12	**Ensure sustainable consumption and production patterns**	Economic, social and environmental dimensions.

	12.2 aiming to achieve sustainable management and efficient use of natural resources; ***12.3*** aiming to decrease food waste and losses along production and supply chains; ***12.6*** aiming for encouraging companies, to adopt sustainable practices and to integrate sustainability information into their reporting cycle; ***12.7*** aiming for public procurement practices that are sustainable; ***12.8*** aiming for consumer access to the relevant information and awareness for sustainable; development and lifestyles; ***12.a*** addressing support to developing countries to strengthen their scientific and technological capacity to move towards more sustainable patterns of consumption and production; ***12.c*** addressing rationalization of inefficient fossil-fuel subsidies that encourage wasteful consumption	Eco-certification is on the rise for seafood production, but does not necessarily cover all metrics for sustainability (e.g. energy use and by-product utilization). Capture fisheries involves considerable amounts of waste in the form of discards, and use of by-products from processing could be improved. Poor transparency and frequent fraud in seafood products calls for improved traceability systems. Seafood consumption in the EU is much characterized by resource-intensive products. Fossil-fuel subsidies maintain fishing overcapacity and inefficient fisheries.
14	**Conserve and sustainably use the oceans, seas and marine resources for sustainable development**	Environmental dimension.
	14.1 aiming to prevent and significantly reduce marine pollution of all kinds, in particular from land-based activities, including marine debris and nutrient pollution; ***14.2*** aiming for sustainable management and protection of marine and coastal ecosystems; ***14.3*** aiming to minimize and address the impacts of ocean acidification; ***14.4*** aiming for effective regulation of harvesting from capture fisheries to end unsustainable fishing practices and restore fish stocks; ***14.5*** aiming to conserve at least 10 % of coastal and marine areas;	Overfishing is according to the millennium ecosystem assessment the main driver of biodiversity loss in the sea. Poor management of capture fisheries enable natural resource degradation, and many countries have un-assessed fish stocks with less known exploitation levels. There are also synergies between overfishing and ocean acidification in terms of susceptibility of ecosystem effects; furthermore, ocean

	14.6 aiming to end harmful fisheries subsidies contributing to overcapacity; ***14.7*** aiming to increase the economic benefits to developing countries from the sustainable use of marine resources, including through sustainable management of fisheries and aquaculture; ***14.a*** addressing improved scientific knowledge and transfer of marine technology to improve ocean health and enhance the contribution of marine biodiversity to the development of developing countries; ***14.b*** addressing access for small-scale artisanal fishers to marine resources and markets; ***14.c*** addressing the need to enhance the conservation and sustainable use of oceans and their resources by implementing international law	warming and acidification affect seafood production. Capture fisheries also cause marine debris from lost gears and use of fish aggregation devices. Farmed fish exert pressure on wild fish stocks through feed demand. Furthermore, aquaculture release nutrients and chemicals in coastal areas, and may cause severe coastal de-gradation. Best-available technology is not common practice in most developing countries.
15	**Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss**	Environmental dimension.
	15.1 aiming to ensure the conservation, restoration and sustainable use of terrestrial and inland freshwater ecosystems and their services; ***15.2*** aiming for promoting the implementation of sustainable management of all types of forests, including halting deforestation and restoring degraded forests; ***15.5*** aiming for urgent and significant action to reduce the degradation of natural habitats, halt the loss of biodiversity and protect and prevent the extinction of	Growth of aquaculture exerts increased pressure on land through feed demand. Fish meal has predominantly been replaced by soy, causing tropical de-forestation. Farming of seafood may also spread invasive alien species and diseases. Poorly managed farming in freshwater systems may cause nutrient emissions

threatened species; ***15.8*** aiming for measures to prevent the introduction and significantly reduce the impact of invasive alien species on land and water ecosystems and control or eradicate the priority species;	and spread of chemicals.

There are also regional frameworks to consider for European fisheries (Table 7).

Table 7 Regional conventions and agreements affecting fisheries in the EU.

Name	Year	Organisation	Regional reach	Objective/ function
Convention for The International Council for the Exploration of the Sea	1964	International Council for the Exploration of the Sea (ICES)	The Atlantic Ocean and its adjacent Seas, primarily the North Atlantic.	Duties: Promote and encourage ocean research; draw up programmes required and to organise research; Disseminates results. Provides scientific advice for fisheries in the NE Atlantic.
The Bern Convention on the Conservation of European Wildlife and Natural Habitats	1979 (signed) 1982 (effective)	Council of Europe, an international organisation in Strasbourg (comprises of 47 European countries), set up to promote democracy and protect human rights in Europe.	European	Legally binding policy to ensure conservation and protection of wild plant and animal species and their natural habitats.
Convention on the Future Multilateral	1981	North-East Atlantic Fisheries	NE Atlantic	Shall perform its functions in the interests of the

Cooperation in North-East Atlantic		Commission (NEAFC)		conservation and optimum utilization of the fishery resources.
Agreement on the Conservation of Small Cetaceans of the Baltic, North East Atlantic, Irish and North Seas (ASCOBANS)	1991 concluded 1994 into force 2008 extended	United Nations Environment Programme (UNEP)	Baltic and North Seas and contiguous area of the North East Atlantic.	Promote close cooperation amongst its Parties with a view to achieving and maintaining a favourable conservation status for small cetaceans.
Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR)	1992	Managed by the OSPAR Commission, made up of representatives of the Governments of 15 Contracting Parties and the European Commission.	NE Atlantic	The current legal instrument guiding international cooperation on the protection of the marine environment of the North-East Atlantic. Obligations, no specific requirements.
Convention on the Protection of the Marine Environment of the Baltic Sea Area (Helsinki Convention)	1992	The Helsinki Commission (HELCOM) is the governing body, intergovernmental organisation of the nine Baltic coastal countries and the EU.	Baltic	Protect the marine environment from all sources of pollution. Similar to OSPAR, recommendations, fisheries not included, less biodiversity focus.

		Contracting Parties must act on in their respective national programmes and legislation on recommendat ions from the Commission.	Obligations, no specific requirements The HELCOM Baltic Sea Action Plan (BSAP) has vision of a healthy Baltic Sea by 2021.

Besides binding regulations, there are assessments and guidelines that relates to sustainability of fisheries (Table 8).

Table 8 Examples of documents of bearing to fisheries.

Name	Year	Organisation	Objective/function
IUCN Red List of Threatened Species™	1963	International Union for Conservation of Nature (IUCN	Used by individual countries, no legal status. Provides information and analyses on the status, trends and threats to species in order to inform and catalyse action for biodiversity conservation.
Code of Conduct for Responsible Fisheries	1995	Food and Agriculture Organization of the United Nations (FAO)	Non-binding instrument. Rooted in UNCLOS, provides principles and standards.
UNGA Resolution 61/105; 64/72	2007; 2009	United Nations General Assembly (UNGA)	Global, concern deep sea conservation.
International Guidelines for the Management	2008	Food and Agriculture Organization of the United	Vulnerable Marine Ecosystems (VME), impact assessments

of Deep-Sea Fisheries in the High Seas	Nations (FAO)

4.4 Environmental issues related to seafood production

Seafood from capture fisheries represents the only large-scale food production based on a wild resource. As such, production is limited and both direct and indirect ecosystem effects from over-exploitation include feedback such as decreased seafood production capacity.

During history of exploitation, fishing has severely depleted predatory fish (Christensen et al. 2003), caused collapse of major fish stocks (Pinsky et al. 2011), severely impacted seafloor structure and function (Tillin et al. 2006; Cook et al. 2013) and caused biodiversity loss of target and non-target species (Dulvy et al. 2003; Lewison et al. 2004). As a result, the pressures fisheries exert on ecological system have affected ecosystem structure and function, and changed the landing composition (Howarth et al. 2014). One example seen is a rapid increase in crustacean and bivalve fisheries, often following depletion of traditional fish species, and unfortunately also associated to collapses due to poor understanding of population dynamics of the exploited species (Anderson et al. 2011). From an ecosystem production perspective, it has been estimated that global fisheries exceed levels of sustainable exploitation, and have to decrease considerably to avoid risk of impaired function (Coll et al. 2008; Chassot et al. 2010; Watson et al. 2014).

Fuel use is also highly variable between fisheries, with the global median of 639 L/tonne landed, but may range between 8 L to over 17 000 L/tonne (Parker and Tyedmers 2015). The most energy efficient fisheries are those targeting shoaling small pelagic fish, the most energy-efficient form of animal protein, whereas the energy use of some invertebrate fisheries has been found to exceed that of all other food production systems (Pelletier et al. 2011). In general, fuel use during the fishing phase also dominates the greenhouse gas emissions of seafood from capture fisheries (Ziegler et al. 2016a). For capture fisheries, greenhouse gas emissions (GHG) thus vary in magnitude similar to energy intensity (Table 9).

Table 9 Published examples of greenhouse gas (GHG) emissions per kilo live-weight seafood product produced. Note that these figures are indicative as they are based on different methodological approaches (allocation, system boundaries, etc.) and may change between years from stock status and gears used. Furthermore, edible yield differs (affects relative differences) and electricity source (affecting total values).

Seafood commodity	Production form	CO_2-e (kg/kg live-weight)	Standard deviation	References
Tuna	Average for skipjack fished with purse seine in Atlantic, Indian and Pacific oceans at landing	1.3	0.2	Parker et al. (2015b)
Salmon	Global average, farmed, at farm gate	2.4	0.5	Pelletier et al. (2009)
Cod	Weighted average for Norwegian fisheries, various gear types at landing	2.1	n.a.	Ziegler et al. (2013)
Herring	Average for north-west Atlantic, fished with various gears, at landing	0.3	0.1	Driscoll and Tyedmers (2010)
Tropical shrimp	Farmed in China, at farm gate	5.3	0.4	Cao et al. (2011)

The natural constraints of seafood production from capture fisheries have spurred growth of aquaculture. Environmental pressures from aquaculture include: some species and farming practices require high level of feed input based on capture fisheries and may release invasive species, cause eutrophication, conversion of ecologically sensitive coastal land, and transmit diseases to wild fish (Diana 2009). Environmental risks of e.g. Norwegian salmon are nutrient pollution and genetic interactions and transfer of disease and parasites to wild populations (Taranger et al. 2015). For salmonid production in open net pens, feed accounts for, on average, nearly 90% of total GHG emission and energy use (Tyedmers et al. 2007; Parker 2012). However, energy use and GHG emissions are not as strongly correlated as they are for seafood production from capture fisheries. For farmed seafood, other emissions such as those sprung from energy source for electricity use and biogenic emissions of potent climate forcing cases (e.g. methane and nitrous oxide) contribute to overall emissions of GHG of farmed seafood (Table 9).

Seafood production will most likely be affected by climate change through both ocean warming and acidification. Shelled molluscs are and will be increasingly negatively affected (Branch et al. 2013). Commercial species may already have shifted in their spatial distribution, as reflected in landing compositions around the globe (Cheung et al. 2013). Aquaculture may also be vulnerable to effects from climate change, such as warming of waterbodies, sea-level rise, ocean acidification, weather pattern changes and extreme weather events (FAO 2016). Effects from climate change also include implications for seafood safety; toxic algae and harmful bacteria may increase and accumulate in marine bivalves (Turner et al. 2016). Climate change has furthermore been estimated to risk revenue losses for capture fisheries of approximately $10 billion per year by 2050 (Lam et al. 2016).

Thus, to this end, a changing environment and seafood production influence each other in many ways– from changes in ecosystem structure and function caused by fishing pressure to the not fully understood changes to the marine environment expected in an increasingly high carbon world.

4.5 Technological change

There are several interesting interactions between farming and fishing seafood, accompanied with various types of technical innovations and scientific breakthroughs with different drivers behind.

The early reasons behind farming seafood included to assure the continuous supply of fresh seafood in warmer climates, and owning fish ponds developed into being “prestigious showpieces” for the privileged part of society (Nash 2011). Early seafood farming techniques were simple; different species were caught in the wild and kept for fattening; France has e.g. farmed oysters and mussels during the past 800 years in this manner (Ackefors et al. 1994). Aquaculture also emerged as a response to a decline in abundance of traditionally wild-caught freshwater species, and when human population exceeded what natural populations could sustain. The early rise of aquaculture may thus be seen as an innovation to in part continue to eat seafood when traditional fresh-water species were declining, and in part to increase availability of fresh seafood in areas further inland.

Farming of carps was important in Europe for many centuries; in the eighteenth century, carp farming in ponds was practiced in most European countries (Ackefors et al. 1994). However, a combination of new technologies that emerged in society changed the scene: technological development enabled expansion of fisheries further away from the coast in the 1850s, and improved preservation methods and transportation of fresh fish on railway enabled more efficient transportation of seafood (Nash 2011). As a response, carp farming was dramatically reduced in primarily Western Europe in the nineteenth century.

Capture fisheries production was then for long perceived as inexhaustible. The expansion of capture fisheries production continued up until the late 1980s, enabled through motorization in the 1950s and spatial expansion of the fishing fleet (Swartz et al. 2010b) and from a movement further deep in the ocean targeting new species (Morato et al. 2006). However, with increasing fishing effort, many traditionally important commercial stocks were depleted and new species have continuously reached the market. Depletion of traditional stocks has been echoed in the energy efficiency. Fuel use increased in many countries through the 1990s and early 2000s, despite parallel technological improvement taking place (Tyedmers 2001; Hospido and Tyedmers 2005; Schau et al. 2009). Recent years have shown that the energy efficiency per landing has improved in some fisheries (Cheilari et al. 2013; Parker et al. 2015a; Jafarzadeh et al. 2016). Energy efficiencies may be achieved through technological innovation (Eigaard et al. 2014) and changes in fisher behaviour (Abernethy et al. 2010; Branch et al. 2006), but rebuilding of stocks is vital for fuel efficiency (e.g. Svedäng and Hornborg 2015; Ziegler and Hornborg 2014).

Capture fisheries have also been proven to be challenging to manage. Research on how to define sustainable production levels has been intensive. One concept is the *Maximum Sustainable Yield* (MSY) (Mace 2001), the current management objective for yield in EU fisheries. Furthermore, there are also governance innovations that need to be solved, such as curbing illegal, un-reported and un-regulated (IUU) fisheries (Pauly and Zeller 2016) and minimizing un-wanted catches in all forms (Kelleher 2005). Furthermore, as exploitation levels are defined from theoretical models based on uncertain data, and the scientific community does not agree on the status of marine fisheries (e.g. Pauly et al. 2013). What can be said is that there are better and worse examples (Worm et al. 2009): there are both indications of that current global fisheries are exceeding sustainable exploitation levels relative to what ecosystem productivity can sustain (Coll et al. 2008) and that there is room for expansion if better managed (Costello et al. 2016). To this end, besides technological development in fisheries, there is room for innovation in the science supporting capture fisheries exploitation and management objectives to achieve sustainable exploitation levels.

Today around 2500 species (or groups of species) are fished for, based on FAO landing statistics. Since the late 1980s, global production of capture fisheries has remained relatively constant; the limit has been reached, and there are even indications of declining global catches (Pauly and Zeller 2016). According to the latest estimates (2013), roughly 31% of the stocks were fished at unsustainable exploitation levels; 58% were fully fished whereas 11% under-utilized (FAO 2016). Present global seafood production volume is based on 49% from marine capture fisheries, 7% from inland capture fisheries and 44% from aquaculture (marine and freshwater). Already in 1883, during the International Fishery

Exhibition when sea-fisheries was considered to be “inexhaustible”, there was also much interest in marine fish farming technology and the need to replenish marine fisheries was expressed (Nash 2011). This was the start of many marine farming initiatives in Europe, but by 1914 most had failed and turned into general marine laboratories for fundamental science. Even today, with decades of stagnated production from marine capture fisheries, farmed marine species only account for 16% of total global seafood production (FAO 2014).

Even if there is not much marine aquaculture today, farming of seafood has gone through several “blue revolutions” throughout human history (Costa-Pierce 2010). Global seafood production is at present increasingly dominated by aquaculture: aquaculture, predominantly inland systems, now stands for half of the global seafood production in volume. Almost 600 different species are farmed in a range of different aquaculture production systems (FAO 2014). The steep increase in aquaculture production during the past decades can be seen as a technological response to address demand for seafood and the limits of capture fisheries, such as being a limited natural resource, with very few stocks who could tolerate increased fishing pressure and minute further spatial expansion left.

There are some important technologies behind the rise of aquaculture to address. The advent of plastics technology in the 1960s was very important, as it revolutionized possibilities for affordable design and construction (Nash 2011). The development of pelleted feed in the 1950s has also been important to development of commercial aquaculture production (Torrissen et al. 2011). Farming of, in particular carnivorous species, has received critique concerning its dependency on wild fish for feed (Naylor et al. 2009), the so called fish-in fish-out ratio (FIFO), i.e. how much wild-caught fish that is required to produce a farmed seafood product. Progress in this field is however being made (Welch et al. 2010). Just as for fisheries, the energy use is highly variable between farmed species and farming practices as well (Henriksson et al. 2012). Choice of species farmed and farming system are important determinants for aquaculture sustainability; feed sources and requirements (i.e. the feed conversion ratio, FCR) are key parameters. One important innovation needed for improved resource-efficiency of aquaculture is increased production and demand for farmed species that require less feed in general and in particular feeds rich in protein and lipids of marine origin. Instead, global aquaculture production is instead increasingly producing more carnivorous species (Cambell and Pauly 2013). On the other hand, so far, increased production of carnivorous species in recent years has come with no overall increase in fishmeal and oil use, as vegetable proteins are increasingly used (Welch et al. 2010). In Norwegian salmon farming, as an example, 66% of the feed is based on crops (Cashion et al. 2016). Further important technical innovation is closing the life cycle of a farmed species, i.e. not being dependent on capture and breeding of wild juveniles to stock the farm; this did not commence before the 1960s (Ackefors et al. 1994).

Seafood is also a highly perishable food commodity. Developments in freezing technology and long-distance refrigerated transportation have thus enabled the present considerable trade and consumption of a range of seafood commodities, both new species and the same produced farther away (FAO 2016). Furthermore, an important driver for increase in seafood consumption has been growth in retail channels such as supermarkets; in many countries more than 70–80% of retail purchases of seafood take place there. With seafood being such a highly traded commodity, risks associated with increased international trade comprise among other of how the higher sanitary requirements set by the markets will be met– this also offers an opportunity in the form of advancement of these technologies (Einarsson and Emerson 2007).

To this end, with the considerable technological innovations taken place in society and the science supporting seafood production during the recent decades, increase in sustainable aquaculture is now seen as most important for present and future food security (FAO 2011).

4.6 Culture and lifestyles

Seafood has since the earliest prehistory been an important part of the human diet– initially, from fishing but also since, at least, the past 4000 years also from various forms of aquaculture (Nash 1988). Consumer interest is very important for aquaculture production. There has been both great public interest and vice versa during the past 500 years (Nash 2011). Foreign trade of seafood has occurred since at least the Bronze Age, and eating exotic fish was popular already in Roman homes (Nash 2011).

The preparation of seafood is often perceived as difficult by consumers compared to other food commodities, and the industry is challenged with decreasing seafood consumption in e.g. the US (Undercurrent news, 2016). On the other hand, health and well-being also put increasing influence on consumption decisions (FAO 2016). In this respect, seafood is prominent, with growing evidence of the health benefits of eating fish. Still, there are diet restrictions for some seafood products for certain consumer groups; for instance, pregnant women should avoid products with elevated mercury levels and high seafood consumption may also be associated to high levels of dioxin exposure (Booth et al. 2013). This can make consumers avoid certain products to be “better safe than sorry”.

There are also cultural differences in seafood cooking preferences, where e.g. fillets are the preferred production output in Europe and North America whereas heads are exported to Asian and African countries. EU, and other wealthy nations, have in general resource-intensive high-protein diets and dominate appropriation of available resources of seafood from capture fisheries (Swartz et al. 2010a; Henning 2011). The choice of species also differs between regions of the world, based on economy, availability and consumer preferences. Demersal fish are important in Northern Europe whereas cephalopods are mainly preferred in Mediterranean countries (FAO 2016). Even if carp farming was important all over Europe in the 1800s (Nash 2011), carps are mainly produced and consumed in Asia today (FAO 2014). The European (in particular Western Europe) seafood diet is instead dominated by farmed and wild-caught top predators such as salmon, cod and tuna (EU 2016). More than two-thirds of the seafood used for human consumption in the EU is frozen (FAO 2016).

Market forces (such as seafood guides, ecolabels and certification schemes) are important drivers of consumption patterns and thereby for more sustainable seafood production (FAO 2016). The global supply chains of seafood can mask signals of local depletion to the consumer, as depleted fish stocks are simply substituted by other stocks or species (Crona et al. 2015). As a response, there is a plethora of labels and consumer guide initiatives covering seafood (Jacquet et al. 2010). However, given that there is no clear consensus on what characterizes successful marketing of sustainable seafood items (Roheim 2009; Christian et al. 2013; Gutierrez et al. 2014), or what even sustainable seafood is (Hilborn et al. 2015; Tlusty and Thorsen in press), retail and consumers can by choosing certified seafood only make informed choices to a certain extent. Directed sustainable marketing initiatives by retailers (green, yellow, red label) have shown to have little effects on the seafood purchase other than in an overall decline in seafood sale (Hallstein and Villas-Boas 2013); if e.g. beef is chosen instead, the net result of seafood awareness campaigns may be questioned (Henning 2011). In on-line seafood recipes, consumers are not guided towards sustainable choices (Apostolidis and Stergiou 2012). In Portugal, with the third highest per capita seafood consumption in the world, tradition has been found to be an important determinant to choice of species; information sought for during purchase is expiry date and price, much less so sustainability metrics (Almeida et al. 2015).

Seafood consumption requires buying power on a global market with insatiable appetite for limited resources. Falling incomes and financial collapses risk decrease in seafood consumption patterns, such as the drop seen in Japan (FIS 2016a).

5 Direct drivers for EU seafood producers

5.1 Regulatory environment

5.1.1 Regulations and policies concerning seafood production

Europe has a history of productive fisheries, increasingly strict environmental legislations and limited population growth (Frid and Paramor 2012). Since the initial collaboration commenced between European countries, eventually transforming into the European Union, seafood production has gone through considerable changes (Table 10). The increasing micro-management of fisheries is sprung from decades of overcapacity and associated environmental pressures, conflicting sustainable use.

Table 10 Schematic overview of general EU characteristics and the development of capture fisheries, aquaculture and seafood policies.

Time period	Societal characteristics[1]	EU countries	General fishing pattern in European waters[2]	Aquaculture production in Europe[3]	Seafood policies[4]
1945-1959	Peace in Europe and EEC-collaboration commences	Belgium, France, Italy, Luxemburg, the Netherlands and Germany	Number of significantly exploited species: 8 Total landings: 3 000 000 tonnes		-
1960-1969	Economic growth		Increase in number of species exploited and volume landed		-
1970-1979	EEC grows, environmental legislation intensifies	+Denmark, Ireland, Great Britain	Peak of landings (7 200 000 tonnes)	576 000 tonnes (22% of global)	Separate fisheries policy is initiated with the intention to create a free trade area in fish and fish products with common rules, i.e. equal access to all EEC fishing waters. Driver: rich fishing nations applying for membership. Extension of fishing

[1] http://europa.eu/about-eu/eu-history/2000-2009/index_en.htm
[2] Including non-EU countries and excluding the Mediterranean; Gascuel et al. (2014); Piet et al. (2010)
[3] Including non-EU countries; FAO (2012)
[4] http://www.europarl.europa.eu/aboutparliament/en/displayFtu.html?ftuId=FTU_5.3.1.html; Villasante et al. (2011)

					waters from 12 miles to 200 miles.
1980-1989	Fall of the Berlin wall	+Greece, Spain, Portugal	Highest fishing impact, 24 species significantly exploited, decrease in landings	916 000 tonnes (20% of global)	After several years of negotiations, regulations were adopted in 1983 concerning relative stability and total allowable catches (TACs), i.e. the first Common Fisheries Policy (CFP). Political TAC overshooting is around 30%.
1990-1999	EU forms (Maastricht)	+Finland, Austria, Sweden		1 600 000 tonnes (12% of global)	The CFP is reformed in 1992 with the objective to remedy fleet overcapacity, introducing the concept of fishing effort. Reduction of the fleet was called for, and structural measures to lessen the social impact, and licences to get access to resources. Political TAC overshooting is 30-70%.
2000-2009	Expansion continues	+ Czech Republic, Cyprus, Estonia, Latvia, Lithuania, Hungary, Malta, Poland, Slovenia, Slovakia, Bulgaria,	Decrease in fishing mortality and number of species exploited	2 051 000 tonnes (6% of global)	New reform adopted in 2002 to remedy overexploitation, with amongst others, measures scrapping fishing vessels and the introduction of long-term approaches to fisheries management (e.g. multiannual recovery plans). Socio-economic measures were also introduced. The reform also gave fishers more influence through the creation of Regional Advisory Councils (RACs). Political TAC overshooting is around

		Romania			60%.
2010-present	Challenges and possibilities– economic crisis and need for sustainable growth	+Croatia	Decrease in fishing mortality continues Total landings: 4 300 000 tonnes	2 523 000 tonnes (4% of global)	New agreement was reached in 2013 on a new fisheries regime aiming to ensure that the seafood sectors, including aquaculture, are environmentally sustainable in the long term and are managed in a way that is consistent with the objectives of achieving economic, social and environmental benefits. Political TAC overshooting is decreasing. Aquaculture policies have dual objectives: increasing yields to supply the EU fish market and boosting growth in coastal and rural areas through national plans. It is also a goal to strengthen the competitiveness of the EU fishing industry, with producer organisations playing a major role. New marketing standards on labelling, quality and traceability are also enforced that enables more information to consumers about the sustainability of EU fisheries products.

For capture fisheries, the current CFP can roughly be described as adapting the fleet to the resource, i.e. decreasing fishing effort. The EU fishing fleet has had (and still has in some fleet segments) severe overcapacity (i.e. a much higher catch capacity than may be caught sustainable), and wasteful practices in the form of discard. The reforms of the CFP have been characterized by increased micro-management from Brussels, until the latest reform, where regionalization has been encouraged.

At present, fisheries in the EU are regulated through a combination of different management tools: commercial fishing vessels require licences to fish, mainly key stocks (historically important) are scientifically assessed and regulation comprises both of input control, such as restrictions in fishing effort (time spent fishing, engine power) and/or use of gears, and output controls, the amount of fish allowed to bring to dock, i.e. fishing quotas called Total Allowable Catches (TAC) (Marchal et al. 2015). TACs in the NE Atlantic are ideally set by the scientific advice provided by the International Council for Exploration of the Sea (ICES). However, it has been shown that political overfishing, i.e. that quotas negotiated exceed scientific advice, can be substantial. During 2001-2015, seven out of ten TACs exceeded advice, on average by 20% (Carpenter et al. 2016). The risk of deviation increases with stock size, number of countries involved in the fishery (the more countries fish for a stock the greater the deviation), level of fish consumption and the unemployment rate (Hoffman et al. 2015). Still, the EU has agreed on that, at the latest by 2020, all stocks should be fished at a level allowing for them to produce long-term *MSY*. Progress in this objective has been made in the northern fishing areas, while the Mediterranean shows little success (Figure 10).

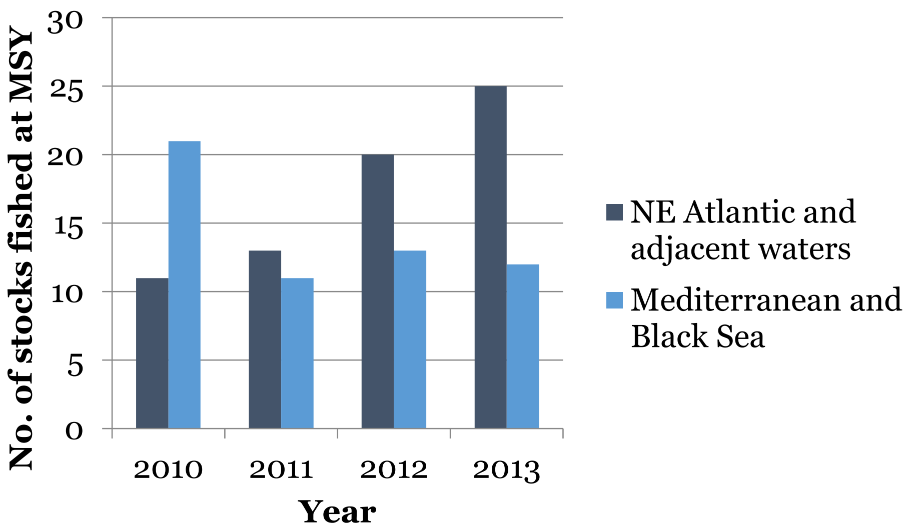


Figure 10 Number of stocks fished at *Maximum Sustainable Yield MSY*. Source: EU (2014).

In contrast to capture fisheries, growth in EU aquaculture production is promoted. As EU aquaculture production has failed to keep up with the global pace of growth, strategic guidelines were presented in 2013 (EC 2013). Member states are encouraged to set up multiannual plans to promote aquaculture, and the European Commission is assisting with the identification of bottlenecks and facilitates cooperation, coordination and exchange of best practices between EU countries.

In consultation with stakeholders, four priority areas were identified comprising of:

- reducing administrative burdens
- improving access to space and water
- increasing competitiveness
- exploiting competitive advantages due to high quality, health and environmental standards

5.1.2 Environmental policies and regulations

Apart from the direct regulatory framework for seafood production in the EU, there are several environmental policies and legal documents in the EU which interfere with seafood production in the EU (Table 11). The requirements of the Water Framework Directive (WFD) and the Marine Strategy Framework Directive (MSFD) in relation to the development of seafood production in the EU have recently been compiled in a guiding document (EC 2016a).

Table 11 Environmental regulations in the EU affecting domestic fishing opportunities and aquaculture production.

Name	Year (in force)	Objective/function
The Birds Directive	1979	The EU's oldest nature legislation. Amended in 2009. Bans activities that directly threaten birds and establish Special Protection Areas (SPAs).
The Habitats Directive	1992	Covers habitats and species and requires establishments of Special Areas of Conservation (target amounts). Includes Natura 2000, the core of EU nature & biodiversity policy, which is an EU-wide network of nature protection areas. For Natura 2000, site selection must be strictly on basis of information on habitat, socio-economic information should not be used for selection. Covers territorial

		waters (not deep sea, nor muddy habitats).
Water Framework Directive (WFD)	2000	An integrated river basin management for Europe, addressing water pollution.
The Marine Strategy Framework Directive (MSFD)	2008	A common framework and objectives for the protection and conservation of the marine environment to achieve Good Environmental Status in European Seas by 2020. Brings everything together: Birds- and Habitats directive, OSPAR, HELCOM. Critical differences with Natura 2000: covers all habitats and species, where suitable; can take account of socio-economics.

5.1.3 Product policies

From a product perspective, several EU polices related to seafood have emerged. The EU is at present by far the largest single market for fish imports (FAO 2016). As amounts of fish caught illegally are substantial globally (Pauly and Zeller 2016), the EU has a specific regulation to hinder these products from entering the market (Council Regulation No. 1005/2008), in force since 2010. This requires that all imported seafood must be accompanied by a catch certificate, otherwise imports can be stopped. Traceability schemes have been found to be most important for the effectiveness of this regulation, but the overall impact is less clear as it is e.g. not clear how consistent this scheme is implemented by different EU member states (Palin et al. 2013).

Furthermore, with the long and complex product chains, seafood fraud has been found be substantial in some markets (e.g. Miller and Mariani 2010). Even if the EU has comparatively superior seafood traceability regulations and requirements, including specific requirements for seafood traceability (e.g. article 58 of EC 1224/2009), there are still problems with implementation (Leal et al. 2015). The European Parliament supports a strong traceability system for seafood products, as this is an important tool to improve consumer confidence and strengthen the EU seafood market (EP 2016). For producers, this requires substantial documentation for access to markets. Traceability is also important to combat illegal fisheries and for food safety reasons (to be able to backtrack contaminated products). The EU has one of the highest food safety standards in the world, much enabled through the tool RASFF - Food and Feed Safety Alerts (EC 2016b). According to the preliminary RASFF report for 2015 available at EC (2016b), roughly 18% of the alerts concerned seafood products.

There are also general product standards with an environmental scope, such as Product Environmental Footprint (PEF). The overarching purpose of PEF is to reduce the environmental impacts of goods and services, and a seafood pilot has been initiated (EC 2015).

From a qualitative search on trade barriers in the sector Agriculture and Fisheries in the EU, barriers for agricultural products are much more frequent than for seafood products (EC 2016c).

5.2 Input and farm gate prices

According to STECF (2015), an improved economic performance of EU fisheries can be observed and may have been the result of: recovery of some stocks; research and innovation; capacity reduction, fuel price reduction, certification schemes and growing demand for certified products and more fuel efficient fishing techniques. When economic performance is poor it is based on lower average first sale prices; market effects of the global economic crisis; export embargos; reduced quotas for several key stocks; market saturation and poor marketing to place products on new markets; low abundance and/or low quality of some species; severe weather conditions; damage caused by marine mammals (e.g. seals); shortage of local crews and closed areas for stock recovery.

The seafood processing industry within the EU has an annual turnover of €28 billion, and, is despite low profit margins, an overall viable industry (EU 2016). However, Europe is the second highest subsidizing region in the world for fisheries (25% of total; Sumaila et al. 2016). At a macroeconomic scale, fisheries in Europe is heavily subsidized, about 56% of Europe's catch value (Sumaila et al. 2010).

According to the summary statistics on EU fisheries (excluding Bulgaria, Cyprus, Greece and Malta) for 2013 provided by STECF (2015):

- Gross Value Added (GVA) and gross profit (all excl. subsidies) generated by the EU fishing fleet was just over €3.4 billion and €1.3 billion, respectively.
- GVA as a proportion of total revenue was estimated at 49% and gross profit margin at 20%.
- The net profit was €506 million for the covered EU fleet (also excluding The Netherlands), 7.4% of the revenue was retained as net profit.
- Sixteen out of the 19 member states covered generated net profits in 2013; the remaining three member states (Belgium, Finland and Portugal) generated net losses.

For developed countries (much based on data from the EU), the weighted average of variable cost per tonne of catch has been estimated to be $1181 in 2005, and the weighted average fixed cost per tonne of catch $198 (Lam et al.

2011). The average output per fisher in Europe is about a tenfold larger than that of African and Asian fishers (Arnason et al. 2008).

Major costs for capture fisheries in the EU are labour and energy, representing 37% and 27% of total operating costs, respectively (STECF 2015). The average annual wage (including crew wages and unpaid labour) per FTE was €23 000, ranging between the lowest for Greece fishers (€8 000) and highest for Belgian fishers (€120,000). Labour costs can be substantial for some fishing segments. Of the total variable cost, it contributes to the largest proportion (59%) for scallop dredging as this fishing method is labour-intensive for at-sea processing of meat (Lam et al. 2001).

Fuel costs can also be substantial, especially for vessels using fuel-intensive gears such as bottom trawls (Parker and Tyedmers 2015). If energy prices increase, fisheries in the EU will see price effects from a highly motorized fleet and preference for energy-intensive seafood products. Pelletier et al. (2014) perceived the fleet as having an in general high adaptive capacity, whereas Abernethy et al. (2010) showed a severe vulnerability for the fisher as they had to absorb increased costs while stable fish prices based on price-setting power of buyers. Removing subsidies on fuel could render fuel-intensive fishing segments such as large demersal trawlers non-profitable (Ziegler and Hornborg 2014). For fisheries in the North Sea, modelling suggests that even if removing subsidies might reduce the total catch and revenue, it increases the overall profitability and the total biomass of commercially important species (Heymans et al. 2011).

The price at first sale (i.e. ex-vessel price) varies with time, fleet, area caught, and the landing port (Davie et al. 2015). This variability influences fishers' decisions (Marchal et al. 2007), both in the long-term such as e.g. level of investment (Pinnegar et al. 2002), the annual planning of how to best make use of the available quota and on a more daily basis, such as whether it is worth going fishing at all and where to go (Bastardie et al. 2013; Ziegler et al. 2015). With the landing obligation enforced in the new CFP (EU 2013), fishers will have to land species/sizes of low commercial value. This may influence profitability, if e.g. smaller fish needs to be counted of a limited quota. Still, while factors that may to a greater extent be affected by daily decision-making by the fisher (such as fishing gear and landing size, Ziegler et al. 2015) are important attributes for determining the price , the origin of the fish (locally produced or imported) may also be an important attribute in determining the price *(*Asche and Guillen 2012).

Basic financial data for the EU aquaculture production (covering 20 member states) for 2012 provided by STECF (2014) states:

- Profitability was positive in 2012 and the Gross Value Added of the sector increased by 4%. However, the Earnings Before Interest and Taxes

(EBIT) decreased by 26% and Return on Investment (ROI) decreased from 9% to 7%.

- Of the three main sectors (Marine, Shellfish and Freshwater production), the most profitable was the Marine sector which generated €179.3 million in EBIT, followed by the shellfish sector with €130.1 million and the freshwater sector with €32.6 million.

The EU has provided considerable amounts of structural funding for capacity support in aquaculture; thirteen countries received sixteen billion European currency units (ECU) during 1989-1999, resulting in an increase in their aquaculture production from 620 thousand tonnes in 1986 to 1.2 million tonnes by 1996 (Nash 2011).

5.3 Contract opportunities

According to the Centre for the Promotion of Imports from developing countries (CBI), the largest growth market is Eastern Europe from increased buying power and acceptance for seafood as substitute for meat products (CBI 2015a). Short-term demand is expected for low value products, such as Pangasius and canned tuna. Furthermore, due to financial situations within Europe, increased intra-EU trade is expected; North-Western companies will increasingly import seafood destined for Southern European markets (CBI 2015a).

The two main market segments in the EU are retail and food service. Supply chains are expected to become shorter in the future, based on e.g. quality requirements and sustainability issues, and large retailers such as the Metro Group are already importing directly from exporters from developing countries (CBI 2015b). This is particularly the case for large volumes with little added value (e.g. Pangasius), whereas lower-volume products (e.g. pricier tuna) are mainly channelled through importers first.

Aquaculture production in the EU has continuously decreased from 22% of the global production in the 1970s to 4% at present. There are several plausible reasons behind lack of interest in aquaculture production in the EU (STECF 2014). Low profitability, as seen in sea bream and sea bass production, could be one reason. Despite favourable market conditions, such as for salmon, no licenses for new sites have been issued. Analyses of governance, regulatory system and the sector's performance indicate that development is hindered by (summarized in Hoffher et al. 2015):

- competition for space in coastal areas
- lack of clear priorities for the development of the sector
- fragmentation of competences for the authorization of aquaculture sites
- diverging interpretations and applications of environmental legislations which is causing uncertainty for potential investors

It should however be noted that in EU coastal waters, marine aquaculture sites occupy around 230 ha in Greece, and 34 ha in UK, while representing respectively 28% and 44% of EU marine finfish production by volume (Hofherr et al. 2015). Space should thus not be a limiting factor for expansion in absolute terms; there is instead competition for space at local scales with e.g. tourism.

Recent guidelines to boost sustainable growth of EU aquaculture in the context of the CFP (EC 2013) recommended that governance systems needs to be improved, and bureaucracy reduced. The required licences to farm cover aspects such as discharge into water, health and safety, Environmental Impact Assessment (EIA), and more. Producers consider processing time of application and uncertainties as the main problem, and even if fees are low, potential costs for EIA must be considered.

Thirteen corporations control up to 16% of the global marine catch (19-40% of the largest and most valuable stocks), dominating all segments of seafood production in an extensive global network of subsidiaries (Österblom et al. 2015). Their action is very important and influences the performance of the entire sector. Producer organisations are also key actors. In 2015, there were 190 organisations in fisheries and 29 in aquaculture. The industry increasingly outsources activities. Seafood is processed where there is cheap labour or import tariffs can be avoided, i.e. frozen seafood is filleted in Asian countries. It has been argued that further outsourcing may however be constrained by higher sanitary and hygiene requirements by the market that are difficult to meet; together with growing labour- and transport costs, this might lead to changing practises and increase in fish prices (FAO 2016). Trade has also been important for industry to keep up with consumer demand when traditional stocks have been depleted (Crona et al. 2015), and the mean distance travelled by seafood from source to market has continuously increased since the 1950s (Watson et al. 2015a).

Asche and Smith (2010) summarized challenging aspects of seafood trade. Seafood trade is characterized by both high degrees of segmentation and market integration. There are many product types, resulting in market segmentation for products with low interchangeability. On the contrary, globalization has led to product types such as the whitefish market, species caught in multiple regions around the globe, i.e. market integration. Furthermore, Asche and Smith (2010) identified that seafood production and standard trade theory in terms of trade restrictions or liberalization is complicated. First, it has an unusually close connection to the environment, especially for capture fisheries, where there is direct feed-back on continued production; and second, many fisheries are open access, the root cause of overexploitation in fisheries, causing a backward-bending supply curve for fish where the seafood supply decreases when price increases. This latter aspect can theoretically lead to un-favourable effects from trade liberalization, e.g. increase in trade may not be beneficial in the long run. However, when a fishery is well managed, standard trade theory applies.

5.4 Natural resource availability

Global seafood supply comprise of roughly 93 million tonnes from capture fisheries and 74 million tonnes from aquaculture (FAO 2016). These figures are somewhat uncertain; for cod fisheries in the Baltic Sea during the 2000s, estimates show that catches were 35% higher than reported (Zeller et al. 2011). For Spain, it has been estimated that 43% of total removals from 1950s to 2010 comprised of unreported catch and discards (Coll et al. 2014). Of the in total 167 million tonnes of seafood, over 87% where destined to human consumption. Half of the aquaculture production volume (including seaweed and microalgae, 27% of production volume) was farmed without input of feed. However, growth in production volume has been faster for fed species than for non-fed species.

For capture fisheries, natural production is limiting seafood production. This is determined by location. Some regions such as upwellings, have higher ecosystem productivity (Hunt and McKinnell 2006). Species are also more or less abundant in an ecosystem; species abundance distribution generally follows a pattern of ecosystems consisting of only a few common species and many rare. Life histories of different species are important to productivity. Elasmobranchs, sharks and rays, have lower and slower production rates than lower-trophic level, shoaling fish such as anchoveta. But as fishing intensity is adjusted for differences in productivity, fast-growing, highly productive species are at greater risk to collapse (Pinsky et al. 2011). However, depletion through overexploitation impair productivity at different time scales. If overexploited, slower growing and less productive species have longer recovery times; in fact, recovery rates for marine fish species can be slower than for terrestrial mammals (Hutchings et al. 2012). On the other hand, low-trophic level species, contributing to 30% of global catches, are also to a great extent consumed by other species in the ecosystem; catch levels on these species need to be lowered to reduce impacts on marine ecosystems (Smith et al. 2011).

As illustrated earlier in this report, EU seafood production is mainly based on capture fisheries and at present marginal compared to imports. Even if the EU's combined EEZ is the largest in the world, EU seafood consumption is increasingly dependent on imports. EU dependence on imports for seafood consumption is growing both as a result of increasing consumption as well as constraints on further expansion of supply within the EU (FAO 2014). It has been argued that managing fisheries from a food security perspective will be increasingly necessary (McClanahan et al. 2011; Golden et al. 2016), and Rice and Garcia (2011) even argue that this focus may be incompatible with actions required to address protection of biodiversity. Models indicate that seafood can meet the demand through 2015, but this requires that fish resources are managed sustainably and the feed industry reduces its reliance on wild fish (Merino et al. 2012).

Land use is not as much of a concern for seafood as in livestock production, but for aquaculture there may be competition. Fed species in aquaculture require an increasing share of crops from the global food system, especially as the proportion of marine inputs is reduced (Troell et al. 2014). Furthermore, the natural marine supply of essential omega-3-fatty acids may in this case be insufficient to meet the nutritional demand of the world population as it increases (Budge et al. 2014). However, as the feed conversion efficiency (FCR) of aquatic animals is better than that of terrestrial animals (Welch et al. 2010), redirecting feed from livestock to aquaculture would require lower land use per unit of protein produced than current practice. Many farmed seafood commodities preferred in the EU consumer diet are still highly dependent on feed sources of marine origin (e.g. Cashion et al. 2016). The aqua-feed industry is increasingly utilizing by-products generated from processing, already 25-35% of fish meal and oil production (FAO 2016).

5.5 Available technology

5.5.1 Capture fisheries

The management objectives and scientific basis for providing advice to EU fisheries are continuously evolving (Lassen et al. 2014), and must be considered as an important driver of development of capture fisheries. Scientific advice on catch levels, the basis for quota setting in the EU, may be biased due to poor data (e.g. from misreporting by industry), poor models, changes in biological processes (affecting e.g. natural mortality) or model assumptions (Schwach et al. 2007). This is also the result of fisheries scientists being pushed by management to "inflate the natural science boundary" and simplify a complex reality to provide certainty from uncertain conditions/data, and poor co-operation with fishing industry in terms of data quality exchange due to mistrust.

There is also a need to apply lessons learned elsewhere for more innovative management objectives; e.g. Australia make use of risk-based approaches to fisheries and has a lower yield objective, *Maximum Economic Yield (MEY)* instead of *Maximum Sustainable Yield (MSY)*. This may result in more profitable fisheries with a "biological buffer", allowing for more proactively managed fisheries (Marchal et al. 2015).

There are many different ways to catch fish: small coastal vessels, large offshore industrial vessels, passive gears such as nets, actively-towed gears such as trawls, and more. These factors influence resources use. The overall fuel use of EU fishing fleets decreased between 2009 and 2013 with 16%, reflecting a decrease in fishing capacity (total engine power and tonnage, EU 2016). Besides characteristics of the targeted species (shoaling behaviour or not, abundance, etc.), gear type is the most important determinant to fuel efficiency of capture fisheries (Ziegler et al. 2016a). For EU fleets, Cheilari et al. (2013) estimated that, an average of 670 L/tonnes were used, reflecting the high proportion of fisheries targeting shoaling fish for feed. Parker and Tyedmers (2015) published fuel intensities for different targeted species groups and gear types. In table 12, values for European fisheries are seen. From these figures, it becomes clear that the capture fisheries sector is highly diverse, and resource use is highly variable.

Table 12 Fuel efficiencies (L/tonne) for different gear types and targeted species for European fisheries. From Parker and Tyedmers (2015).

Species group	Gear type	Mean	Min	Max
Crustaceans	Bottom trawls	3 083	377	17 300
Flatfish	Bottom trawls	2 851	631	4 062
Molluscs	Bottom trawls	2 618	1 205	4 103
Molluscs	Gillnets	2 162	2 162	2 162
Large pelagics	Hooks and lines	1 745	570	3 478
Finfish	Pelagic trawls	1 444	413	2 475
Crustaceans	Hooks and lines	1 031	47	2 015
Finfish	Hooks and lines	927	125	4 238
Crustaceans	Pots and traps	834	334	2 156
Finfish	Bottom trawls	756	236	2 724
Crustaceans	Pelagic trawls	634	232	1 035
Small pelagics	Gillnets	602	602	602
Flatfish	Gillnets	598	598	598
Molluscs	Dredges	525	15	1 822
Molluscs	Pots and traps	513	392	641
Finfish	Surrounding nets	466	104	659
Large pelagics	Surrounding nets	447	373	527
Small pelagics	Hooks and lines	323	60	585
Small pelagics	Pelagic trawls	168	45	565
Small pelagics	Surrounding nets	84	8	506
Small pelagics	Bottom trawls	83	65	94

The fishing skill differs between fishers, called “skipper effect”; in the e.g. US menhaden (*Bevoortia* ssp.) fishery, some fishers have been found to have consistently higher catches (on a weekly basis or landings per unit fuel used) than others, even if the differences in catches between fishing occasions were larger for the same fisher due to e.g. environmental factors (Ruttan and Tyedmers 2007).

5.5.2 Aquaculture

Feed innovation is imperative for aquaculture growth to lessen competition for resources (Merino et al. 2012; Troell et al. 2014; Jones et al. 2014). Increasingly exploiting Antarctic krill resources for feed is worrisome. It has recently been estimated that the krill population has fallen between 80 and 90% since 1970 (Piñones and Fedorov 2016). Warming of Antarctic waters may further reduce habitats for krill by 80% by year 2100. Interesting non-traditional feed concepts are being developed, such as microbes grown on residual streams from e.g.

forestry (Alriksson et al. 2014). Over time, feeding efficiencies and mortality rates in fish farming has been improved, and the economic feed conversion ratio (FCR, the amount of feed consumed per production volume of a farmed species) of many farmed species is relatively low (Table 13).

Table 13 Average feed conversion ratios (FCR; mass unit of feed required to produce the same live-weight of a farmed species) for example farmed species. Feed composition however differs in terms of e.g. protein content.

Species	FCR	Reference
Atlantic salmon	1.2	Cashion et al. 2016
Tropical shrimp	1.6	Cao et al. 2011
Seabass	1.8	Aubin et al. 2009
Tilapia	1.7	Pelletier and Tyedmers 2010
Pangasius	1.9	Bosma et al. 2011

Mussel production (i.e. aquaculture without feed requirement) has stable production costs compared to finfish aquaculture and RAS (variation in feed and energy prices are not an issue). But these systems may have problems with stability of supply. The production depends on the environment; toxic algae blooms can be problematic, and in some areas there is shortage of supply of mussel seed (STECF 2014).

To manage other environmental issues of aquaculture, such as spread of disease and eutrophication (Diana 2009), there are also ongoing innovations in farming systems, such as use of re-circulating aquaculture systems (RAS). These emerging technologies may red, but at the cost of e.g. energy-efficiency (Aubin et al. 2009). Farming in RAS may also offer technological solutions to production of e.g. shelled molluscs, which are negatively affected by ocean acidification. In Europe, RAS culture systems were introduced in the late 1980s, and today, more than ten species are farmed in these systems and new facilities are being built (Martins et al. 2010). In the EU, RAS is mainly used in northern countries. The development of the RAS technology must continue to ensure future growth, and the prices of building the new RAS systems must be lowered to become an economically attractive investment (STECF 2014). Furthermore, to allow for *"sustainable intensification"* (*sensu* Godfray et al. 2010), more research is needed for aquaculture technologies such as RAS on waste management of solids, nitrogen and phosphate (Martins et al. 2010). Another and parallel development is offshore farming, with a high potential to reduce environmental impacts and coastal zone conflicts, even if their contribution to improvement has been contested (Holmer 2010).

Intensive aquaculture is a relatively new form of animal production and has a low level of domestication of species compared to livestock (Teletchea and Fontaine 2014). Aquaculture production requires e.g. varied amount of chemical inputs. There are e.g. at least 67 marine infectious diseases can severely affect economy of aquaculture through reduction of growth and survival (Lafferty et al. 2015). Use of fish vaccine to prevent disease has become routine and is under further development (Gudding and Van Muiswinkel 2013). Use of antibiotics can be substantial in some aquaculture production systems and sites, and varies between countries and farmed species. Examples include Vietnamese Pangasius production, which uses a wider range of antibiotics than e.g. salmon production, but in terms of amount, it is at the same level or lower than for salmon production in Chile and Canada (Rico et al. 2013). Compared with poultry and live-stock (varying between 18 to 188 g active ingredient/tonne based on figures in Grave et al. 2010), aquaculture production use in general less antibiotics. Still, this use contributes to the global problem of developing antimicrobial resistance, and through interconnectivity of oceans, risk fast spreading of genes. There are commitments to reduce use of antibiotics in EU aquaculture (FIS 2016b).

Furthermore, other chemical used may also substantial in some aquaculture sites, such as salmon in Chile and shrimp farms in Bangladesh (Rico et al. 2013). In e.g. salmon production, chemicals are needed to avoid anti-fouling of cages, combating parasites, anaesthetics for fish and disinfectants (Burridge et al. 2010).

5.5.3 By-product utilization

The share of world fish production utilized for direct human consumption has increased from 67% in the 1960s to 87% in 2014. About 70% of the seafood production is processed (e.g. de-headed, gutted or filleted) before final sale, and considerable by-product streams (20-80% depending on the level of processing and type of fish) are generated (Ghaly et al. 2013). These streams are usually not put on the market due to low consumer acceptance or quality, but represent an important contribution to e.g. the feed industry (FAO 2016). Interest in these by-product streams is now increasing as they have a valuable nutritional profile. To speed up this development, identification of bioactive compounds or complexes and subsequent development of food, feed and other products, as well as improved processing technologies have been important for more efficient utilization.

5.6 Producer and farm characteristics

Seafood production can strongly contribute to the economy in remote coastal areas in the EU. In Ireland, as an example, fisheries sectors have strong links with the rest of the economy (Vega et al. 2014). Aquaculture production in the EU was commenced by small and medium sized enterprises in remote areas where production conditions were good and alternative employment scarce, such as salmon production in Scotland (Hoffher et al. 2015). Today the sector, especially for salmon, is highly consolidated.

In terms of capture fisheries, three events have had a major impact on the size and structure of the EU fleet and on its catch potential since the start in 1983:

the withdrawal of Greenland in 1985, the accession of Spain and Portugal in 1986, and the reunification of Germany in 1990 (EU 2016b). In the recent decade, one of the world´s largest proportional decrease in number of active fishers has taken place in the EU- at different pace in different countries– from roughly 779 thousands in 2000 to 413 thousands in 2014 (FAO 2016). Fishing vessels operating with a single fishing gear are more likely to exit a fishery than are those that operate using different main fishing gears, and vessels with lower incomes are more likely to change to alternative fisheries or industries (Lagares et al. 2016). Furthermore, important drivers to leave the fishery can be technical characteristics of the vessel: Smaller vessels are more likely to exit the fleet than larger ones (Lagares et al. 2016). This is most likely more an effect from the economic efficiency of the different vessels which varies between fisheries (Ziegler and Hornborg 2014) and management systems (Ziegler et al. 2016b); the most efficient vessels stay in the fishery.

Aquaculture success was early on driven by pioneers with little outside help. Already in the 1850s, successful rearing of Atlantic salmon was achieved, but it was not until the early 1960s the entire life-cycle of a salmon for the first time was completed in captivity (Nash 2011). When products began to reach the market in the 1970s, the rapid increase in production was enabled through government back-up and major investments. With time, production costs for Norwegian salmon have decreased remarkably– over 60% during the past decades (Einarsson and Emerson 2007). However, farms in the EU increasingly use high-tech systems such as RAS to produce freshwater species (eel and catfish) and marine species (turbot, seabass and sole) (Martins et al. 2010). These systems require considerable financial investments.

Aquaculture production within the EU has not increased since 1999, which is remarkable considering the global growth rate of the sector and strategies to increase. In aquaculture, long production cycles of many species (typically 6 to 24 months) implies high financial risks (Godfray et al. 2011). No, or possibly one or two, new farming licences were issued in the past 10-15 years for marine finfish in cages (Hoffher et al. 2015). In the recent European Maritime and Fisheries Fund (EMFF), 21% is allocated to aquaculture support (€1.2 billion). Some EU countries have targets set to increase aquaculture production. Portugal, as an example, aims for doubling the production volume by year 2020 and treble it by 2023 (FIS 2016c). To accomplish this, financial investments will increase considerably, allowing for 60% co-financing of aquaculture projects.

The shellfish aquaculture sector employs more labour compared to the marine and freshwater production; it is often small and family owned businesses with large social importance for some regions in EU (STECF 2014).

6 Discussion

Issues related to seafood in sustainable food and nutrition security (FNS) comprise of improved governance of common natural resources of seafood from capture fisheries, affordability of seafood products, promoting best available technology to minimize environmental impacts and resource demand and identify how demand could be channelled towards more sustainable options.

With over 2 500 species being fished and over 600 species being farmed, the seafood sector is truly diverse. The types of seafood preferred by EU consumers are canned tuna (mainly purse seined), salmon (farmed), cod (mainly trawled) and herring (mainly purse seined). As illustrated in this report, these products are compared to land-based animal products in the lower range in terms of energy use and GHG emissions (Tilman and Clark 2014). Other top consumed seafood products, contribute much more to GHG emissions, such as tropical shrimps (fished and farmed).

As argued by Hilborn (2012), seafood from capture fisheries may be a good alternative to produce food with less impacts and resource use than many land-based protein production systems as fisheries do not require inputs of feeds, fertilizers, pesticides, irrigation and land. However, for seafood from capture fisheries to play an increasing role in global food security, this argument still need some more nuances:

- There are limits to natural production. If all fisheries would be exploited optimally in terms of yield, only 10% of the additional global food demand in 2050 (compared to today) could be met by capture fisheries (Costello et al. 2016). These estimates are also influenced by a changing environment. Climate change has e.g. been predicted to reduce global catches by more than 6% and by as much as 30% in some regions (such as the tropics) by 2050 relative to recent decades (Cheung et al. 2016).
- Countries with undernourished citizens often serve as net exporters of seafood today (Smith et al. 2010). Future EU seafood consumption from capture fisheries has to either be based on increased utilization of available resources (by-products, fish used for feed today) or might have to decrease to achieve global food security (Frid and Paramor 2012); otherwise populations of developing countries may be severely affected (Golden et al. 2016).
- Consumers in the EU and other more wealthy regions prefer to eat seafood species at the top of the food web, at trophic levels unrepresented in terrestrial systems (Duarte et al. 2009). The role of top predators for the planet's ecosystem functioning has repeatedly been pointed out (e.g. Estes et al. 2011), and seafood preferences by EU consumers might have to change.

- The full effects of fisheries on marine ecosystems are still largely unknown. What is known is that marine ecosystem functioning is highly important, e.g. plankton produces half of the planet's oxygen and may be highly affected by factors such as ocean warming and further exacerbated by overfishing (Hoegh-Guldberg and Bruno 2010). With multiple stressors on the oceans, marine ecosystems are changing (Jackson 2010). Future challenges comprise of addressing short-term versus long-term priorities, and trade-offs between different uses.

Seafood production from aquaculture is on the other hand playing an increasingly important role in the food system (Godfray et al. 2010). Aquaculture took off in the 1980s, outpacing population growth in a way not seen earlier leading to increasing seafood supply per capita– the global average has gone from 10 kg per person in 1960s to 19 kg per person in 2012, although there is a major difference both in per capita production and consumption between countries. For aquaculture to increasingly contribute to meet the projected demand, this requires technological innovations and changing consumer demand related to:

- Reduced dependence on feed inputs based on meal and oil from capture fisheries. The diversity of aquaculture in terms of species farmed, feed ingredients and practises offers many opportunities, but the right policy actions are needed to solve emerging competition between different uses of crops (Troell et al. 2014).
- For aquaculture growth in the EU, conflicts in multiple uses of the coastal zone must be solved.
- Increased faming of non-fed species and species with low feed demand (in particular comprising of marine protein and oil) calls for change in EU consumer preferences.

For seafood products, increased attention needs to be put on social aspects. Thilsted et al. (2016) argue that in the context of growing demand, and if the vision of the SDGs is to be attained, the fisheries sector will require policy frameworks that are nutrition-sensitive. Seafood is an important source of micronutrients both for developing and developed countries. In developing countries, where seafood is caught with simple methods (and resources are declining from export to developed countries) and aquaculture practices often are lacking (Hall et al. 2013), this may cause malnutrition for people in vulnerable situations (Golden et al. 2016). Thilsted et al. (2016) suggest that multi-sectoral policy solutions lie in: (a) diversification of production systems; (b) efficient management and protection of all systems; (c) improved value chain and markets; and (d) consideration of context-specific consumer preferences and nutritional needs. Furthermore, global seafood supply chains does not only mask depletion of stocks (*sensu* Crona et al. 2015), but also involves slavery, child labour and other unacceptable working conditions (Chantavanich et al. 2016).

From a nutritional point of view, there are both health risks and health benefits with seafood consumption (Gerber et al. 2012). Some aspects are dependent on what seafood substitute in the diet (seafood is generally a better option than red meat), other aspects are more related to seafood type and environment (e.g. different seafood uptake of heavy metals and dioxins) or cooking preferences of consumers (e.g. fresh or deep fried). Effects from e.g. climate change may also cause some seafood products to pose increased health risks, such as contamination of bivalves (Turner et al. 2016). Increasingly turning to farmed seafood may also cause risk to human health in terms of spread of antimicrobial resistance (Heuer et al. 2009), or consumption of persistent organic pollutants from feeding farmed fish with contaminated fish oil or meal (Sprague et al 2010). Furthermore, farmed fish may have a lower nutritional value than wild caught fish (Thilsted et al 2016). To this end, health benefits and risks from seafood consumption need to be better monitored and understood in relation to production forms.

According to the FAO, the main driving force behind recent expansion of seafood demand has been a combination of population growth, rising incomes, and urbanization and enabled through the rapid growth of aquaculture production and international distribution channels (FAO 2014). These drivers are all categorized as indirect drivers for producers in SUSFANS conceptual framework.

If to attempt to make a non-scientific hierarchy of the different drivers analyzed in this report, indirect drivers such as rising incomes and improved distribution channels are likely to be important for increased demand and availability of seafood. This will be further augmented by urbanization and lifestyles; the advent of fast-food services offering sushi in e.g. Sweden had most likely an effect on seafood consumption both in volume and species consumed. But satisfying demand requires continuous supply, and production of capture fisheries is limited and seasonal. Thus, sustainable growth of aquaculture (based on less competition of feed resources) is vital to stability of supply and accessibility. Farmed seafood that does not require feed input (mussels, oysters) are important from the producer’s perspective in the EU, but is today not as important to consumers as farmed salmon. If technological innovation of the currently preferred farmed seafood commodities in the EU (salmon, tropical shrimps) can make them less dependent on feed based on capture fisheries, increased utilization of farmed seafood as a protein source would, compared to meat alternatives, offer more sustainable diets (requires less feed, chemicals, water, land use and contributes to lower greenhouse gas emissions). Central aspects for seafood sustainability are thus natural resource availability for capture fisheries, and feed innovation to limit competition of resources for aquaculture. Potential push factors for healthier diets would be increased awareness of the health benefits with seafood consumption and improved affordability; for more sustainable production systems, increased consumer demand for non-traditional and sustainable seafood products, such as directing seafood resources towards increased human consumption (increased utilization of by-products and underutilized species) and aquaculture production of species with less impacts or resource use (such as algae, bivalves, carps).

Overall, seafood both from fisheries and aquaculture has a major potential to contribute to sustainable FNS in the EU as well as globally. This depends on the path chosen ahead by policy-makers, producers and consumers. In fact, it has been argued that, in a global perspective, feeding 9 billion is likely to require a decrease in seafood consumption per capita and year (Frid and Paramor 2012). To achieve continued stability of supply and sustainable demand for seafood, there are thus several options ahead that will be discussed in the next chapter.

6.1 Proposal of solutions: case studies needed

Based on current and future challenges for seafood production, several different case studies would be interesting to investigate related to seafood systems and their role in more sustainable FNS of the EU:

6.1.1 Sustainable production systems

- Minimize competition of feed resources (Troell et al. 2014). Evaluate potentials of utilizing food waste, insects, algae, wood-based fungi, etc. to maximize food supply and nutritious value.
- Identify and make use of best available farming technology for popular consumption species such as salmon and cod.
- Increase production of the most efficient feed-converters and those not requiring feed at all or with low marine protein/oil content.
- Make increased use of underutilized species from capture (Zhou et al. 2013) and increase direct human consumption of traditional species caught for feed purposes.
- Limit size of fish fillets produced from aquaculture. Feed conversion efficiency decrease with fish growth, and aquaculture sustainability would be improved as less feed is required (Tlusty et al. 2011).
- Engage “keystone actors” of seafood production to take the lead in terms of responsible sourcing (Österblom et al. 2015)
- Waste less (Love et al. 2015) and make more use of by-products (Ghaly et al. 2013).

6.1.2 Sustainable consumption

- Accept smaller sizes of fish fillets produced from aquaculture.

- Increase awareness to consumers on what characterizes more sustainable seafood demand through educating few, but important stakeholders such as chefs (Apostolidis and Stergiou 2012), including health benefits of seafood consumption.
- Waste less (Love et al. 2015).
- Change protein source in diet based on improved sustainability.
- Broaden diversity of seafood choice and increase acceptance for sustainable options.

6.1.3 Sustainable policies

- Identify and spread “brave” food dietary advice assisting consumers to make better choices both in terms of health and sustainability (Merrigan et al. 2015)
- Review policies on consumer recommendations concerning seafood consumption. Until demand is balanced with sustainable methods of production governments should consider carefully the social and environmental implications of recommending increasing seafood consumption (Thurstan and Roberts 2014).
- Develop “nutrition-sensitive policies” in a global perspective (Golden et al. 2016). Review policies concerning fishing in distant waters with regard to food security of less economically developed countries populations (Brunner et al. 2010).
- Put more attention to seafood in food and fisheries policies, as seafood has an important role to play in feeding 9 billion (Béné et al. 2015).
- Optimize fishing policies to minimize overall impacts of seafood products. This could be done by e.g. promoting best available fishing technology (Hornborg et al. 2016) or management system (Ziegler et al. 2016b) to achieve e.g. environmental objectives.

6.2 Seafood variables and metrics for assessing EU FNS in relation to EU environmental policies

For environmental assessment of seafood relative to EU policy goals on reduced environmental impacts, several aspects need to be considered (Table 12). Some could be gauged today through e.g. Life Cycle Assessment, others are more complex and need further elaboration on.

Table 12 Seafood production and EU policy goal related to reduction of environmental impacts. The terminology is according to the SUSFANS hierarchical approach to metrics on sustainable food and nutrition security: a performance metric combines aggregate indicators and assess achievements against targets; an aggregate indicator combines derived variables and assesses outcome against threshold; a derived variable combines a number of individual variables; an individual variable can be counted/quantified against a universally agreed upon standard (Zurek et al. 2016).

Performance metrics	Aggregate indicator	Derived variable	Individual variables	Production system	Reference
Climate stabilization	Reduction of radiative forcing caused by the agri-food chain	CO_2-equivalents	CO_2; CFCs; N_2O; CH_4	Capture fisheries, Aquaculture	Parker and Tyedmers (2015); Ziegler et al. (2013); Henriksson et al. (2012); Hu et al. (2013)
Clean air and water	Reduction of acidifying emissions to the air	SO_2-equivalents	NH_3; NO_2; NO_x; SO_2	Capture fisheries, Aquaculture	MSFD descriptor 7: Hydrographical conditions (EC 2008) e.g. Ziegler et al. (2016); Papatryphon et al. (2004)
	Reduction of nutrient emissions to the water	PO_4-equivalents	NH_3; NO_3; NO_2; NO_x; PO_4; N; P; COD	Capture fisheries, Aquaculture	MSFD descriptor 7: Hydrographical conditions (EC 2008) e.g. Diana et al. (2009); Papatryphon et al. (2004)
	Reduction of release of toxic substances		Chemicals in feed production, fish treatment and antifouling	Capture fisheries; Aquaculture	MSFD descriptor 8: Contaminants and descriptor 9: contaminants in seafood (EC 2008) e.g. Diana et al. (2009)

Biodiversity conservation	Decrease competition for land		Land use (m^2) for feed and farms	Aquaculture	Diana et al. (2009); Nijdam et al. (2012); Troell et al. (2014)
	Maintenance of marine biological diversity (ecosystems)		Sea use (m^2) for farms (benthos affected by nutrients) and seafloor area swept	Capture fisheries, Aquaculture	MSFD descriptor 6: sea-floor integrity and descriptor 7: hydrographical conditions (EC 2008)
	Maintenance of marine biological diversity (species)		Threat status according to the IUCN Red List Categories and Criteria	Capture fisheries, Aquaculture	MSFD descriptor 1: biodiversity (EC 2008), CBD targets http://www.bipindicators.net/rli/2010 Hornborg et al. (2013a)
	Maintenance of marine biological diversity (genetic)	% reduction in wild species survival	Number of escapees; disease outbreaks; parasite abundance	Aquaculture	MSFD descriptor 2: non-indigenous species (EC 2008) e.g. Ford et al. (2012)
Preservation of natural resources	Sustainable water use		Freshwater use (m^3)	Aquaculture	Rockström et al. (2009)
	Improved re-cycling of P	Release of P in water	Industrial-based P in feed, P recovered	Aquaculture	MSFD descriptor 7: Hydrographical conditions (EC 2008) e.g. Rockström et al. (2009)
	Improved nitrogen cycle		Industrial-based N in feed	Aquaculture	Rockström et al. (2009)

	Sustainable use of wild-caught seafood resources	Proportion of underexploited or moderately exploited stocks (% stocks fished at *MSY*)	Fishing mortality *F*; F_{MSY}	Capture fisheries, Aquaculture	Common fisheries policy (CFP), MSFD descriptor 3: commercial fish and shellfish and 4: food webs (EC 2008) Coll et al. (2010)
	Sustainable use of marine ecosystems resources	%*PPR* relative to total available ecosystem production	Primary Production Required *PPR* ; primary production *PP* of ecosystem	Capture fisheries, Aquaculture	Watson et al. (2014; 2015b); Cashion et al. (2016); Hornborg et al. (2013b)

6 Appendix

6.1 Drivers of primary production

Hazell and Wood (2008) define a driver as ‘any natural- or human-induced factor that directly or indirectly brings about change in an agricultural production system’. They distinguish global-scale drivers, country-scale drivers and local-scale drivers. According to their nomenclature, global-scale drivers affect all agriculture around the world and include trade expansion, value chain integration, climate change, agricultural support in the Organisation for Economic Cooperation and Development (OECD) and the Word Trade Organisation (WTO), globalization of science and knowledge, technology and products relevant to agricultural development. As such, they are almost identical with our indirect drivers of the agro-food system. Country-scale drivers affect agriculture within a country (e.g. infrastructure, market access) and local-scale drivers are specific to each local geographical area and different types of agricultural production systems. However, the drivers they subsume under country- and local-scale drivers largely differ from our category of direct drivers. In our framework, direct drivers are defined as drivers that directly affect the decision-making on site.

The ultimate decision-making of agricultural production takes place on the farms. The farmers/fishers or producers make their decisions based on a variety of drivers. Examples of decision-making processes in fisheries and their influence on the efficiency of the fishery and its products are given in Ruttan and Tyedmers (2007) and Ziegler et al. (2015). Drivers that affect the producers directly are reviewed in the following.

Öhlmér et al. (1998) identify eight elements of decision-making at the farm level: (1) values and goals, (2) problem detection, (3) problem definition, (4) observation, (5) analysis, (6) development of intention, (7) implementation, and (8) responsibility bearing. Values and goals are internal direct drivers and briefly reviewed below. External direct drivers mainly affect the problem detection. Once a problem due to a change in external drivers is detected, more information is gathered in the elements problem definition and observation, which finally lead to a decision process and a potential change in production activities (Öhlmér et al. 1998).

Within the EU food system, several drivers that influence actions and decision-making processes of primary agricultural and fishery producers can be distinguished. Although a strict assignment of these factors to different categories is barely possible due to their interdependencies, the drivers that are mentioned in the literature are broadly classified into a number of categories” (Zurek et al. 2016).

6.1 Drivers in the context of production economics

Primary agricultural and aquaculture production means transforming inputs into outputs (please note that this does not necessarily apply to capture fishery). In its simplest form, a farm produces a single output for which it uses N inputs (e.g. labour, machinery, feed, fertilizer, etc.). This relationship can be summarized in a production function

$$q = f(\mathrm{x})$$

where q is a function f of $\mathrm{x} = (x_1, x_2, \dots, x_N)$ inputs. Assuming these inputs x are under the control of the decision maker, other inputs like climate might be outside the control of the decision maker and could be added as inputs z leading to production function

$q = f(\mathrm{x,z})$.

There is plenty of literature on properties of production functions and their various transformations (e.g. Coelli et al. 2005). Clearly, decision making will be affected by both controllable and uncontrollable inputs. In the framework of the drivers considered here, all biophysical drivers are inputs that are outside the control of the farmer. Controllable inputs usually have prices attached to them (e.g. machinery, feed, fertilizer). Depending on these input prices, farmers may decide based on a cost function approach where costs are minimized:

$$c(w, q) = \min_{x} \mathrm{w'x}$$

where $\mathrm{w} = (w_1, w_2, \dots, w_N)$ is a vector of input prices. In addition to input prices, farms might also consider output prices in their decision making. Assuming profit maximizing behaviour, this can be represented by a profit function:

$$\pi(\mathrm{p,w}) = \max_{\mathrm{q,x}} \mathrm{p'q - w'x}$$

where profit π varies the M with output prices $\mathrm{p} = (p_1, p_2, \dots, p_M)$ (Coelli et al. 2005). This highlights the importance of both input and output prices in the decision-making process.

Inputs as well as output prices are, in turn, affected by various other drivers. “In economic theory, the price for any specific good is determined by the interplay between supply and demand. As market conditions change (supply and/or demand shocks), price adjustments take place. This way, prices transfer information about markets” (Zurek et al. 2016). Mainly, prices are affected by the indirect drivers considered here: broader economic development, population dynamics, technological change, agriculture and trade policies, environmental issues and culture and lifestyles.

Besides the price information, other factors affect decision-making on farm directly. Thus, the regulatory environment has to be taken into account, contract opportunities might provide options for cost-reduction through collaboration with others and exploiting scale effects, as mentioned above, natural resource availability has a direct impact as well as the available technology and producer and farm characteristics.

6.2 Technological change vs. available technology

One of the main differences of the WP4 deliverables among each other and compared to the SUSFANS Conceptual Framework (CF) is related to the indirect driver 'technological change' and the direct driver 'available technology'. Since the distinction between those two is not necessarily clear, how they are treated in the CF and in the WP4 driver deliverables is shown in Table **A1**A1. The interpretation and usage of these terms in the WP4 driver deliverables highly depends on the production system and the different foci required for their analysis. Generally, one might argue that even the indirect driver 'technological change' very directly affects primary producers.

Table A1. Technological change vs. available technology

Document	Indirect driver 'technological change'	Direct driver 'available technology'	Comment
CF (D1.1)	Innovation Technology development	Technology adoption and diffusion Technology usage	The distinction here is that an innovation is not necessarily used on farm. This depends on technology adoption and diffusion. Usually, there is a considerable time gap between the actual innovation and the use on farm.
Livestock (D4.1)	Progress in feeding technology Progress in breeding	-Feeding and breeding technologies are adapted in e.g. diet formulations	Feeding and breeding strategies aiming to increase productivity will eventually become available on farm. The time gap in which the farmers adopt the breeding and feeding strategies will depend on things as profitability, feasibility and on the corporation the farmer is joining.
Seafood (D4.2)	Historical development and	Science and management	The distinction here is that the indirect

	the interplay between farmed and fished seafood Technical innovations in society enabling growth	behind current production Difference in technology between individual enterprises, e.g. farmers' knowledge, skipper effect Status of production systems and technical progress needed Production efficiency incl. by-product utilization	drivers are those related to the history behind the status and drivers for current production systems, including other technological development in society enabling growth, whereas the direct drivers are those related to the available and needed technology of current production systems
Crop (D4.4)	Public and private research (breeding, fertilizer and plant protection, machinery)	Management	This translates into the concept of technical progress in terms of (1) increasing crop potential through public and private research and (2) decreasing the yield gap (i.e. the gap between potential and actually achieved yields) on farm

7 References

Abernethy, K. E., Trebilcock, P., Kebede, B., Allison, E. H., & Dulvy, N. K. (2010). Fuelling the decline in UK fishing communities?. ICES Journal of Marine Science: Journal du Conseil, 67(5), 1076-1085.

Ackefors, H., Huner, J., & Konikoff, M. (1994). Introduction to the general principles of aquaculture. CRC Press.

Almeida, C., Altintzoglou, T., Cabral, H., & Vaz, S. (2015). Does seafood knowledge relate to more sustainable consumption?. British Food Journal, 117(2), 894-914.

Alriksson, B., Hörnberg, A., Gudnason, A. E., Knobloch, S., Arnason, J., & Johannsson, R. (2014). Fish feed from wood. Cellulose Chemistry and Technology, 48 (9-10), 843-848

Anderson, S. C., Flemming, J. M., Watson, R., & Lotze, H. K. (2011). Rapid global expansion of invertebrate fisheries: trends, drivers, and ecosystem effects. PLOS one, 6(3), e14735.

Anticamara, J. A., Watson, R., Gelchu, A., & Pauly, D. (2011). Global fishing effort (1950–2010): trends, gaps, and implications. Fisheries Research, 107(1), 131-136.

Apostolidis, C., & Stergiou, K. I. (2012). Fish ingredients in online recipes do not promote the sustainable use of vulnerable taxa. Marine Ecology Progress Series, 465, 299-304.

Arnason, R., Kelleher, K., & Willmann, R. (2008). The Sunken Billions: the economic justification for fisheries reform. Joint publication of the World Bank and the FAO. ISBN 978-0-8213-7790-1.

Asche, F. & Smith, M.D. (2010). Trade and Fisheries: Key Issues for the World Trade Organization. Staff Working Paper ERSD-2010-03 for the World Trade Report 2010 on "Trade in Natural Resources: Challenges in Global Governance" https://www.wto.org/english/res_e/reser_e/ersd201003_e.pdf

Asche, F., & Guillen, J. (2012). The importance of fishing method, gear and origin: The Spanish hake market. Marine Policy, 36(2), 365-369.

Asche, F., Bellemare, M. F., Roheim, C., Smith, M. D., & Tveteras, S. (2015). Fair Enough? Food Security and the International Trade of Seafood. World Development, 67, 151-160.

Aubin, J., Papatryphon, E., Van der Werf, H. M. G., & Chatzifotis, S. (2009). Assessment of the environmental impact of carnivorous finfish production systems using life cycle assessment. Journal of Cleaner Production, 17(3), 354-361.

Bastardie, F., Nielsen, J. R., Andersen, B. S., & Eigaard, O. R. (2013). Integrating individual trip planning in energy efficiency–Building decision tree models for Danish fisheries. Fisheries Research, 143, 119-130.

Bellmann, C., Tipping, A., & Sumaila, U. R. (2016). Global trade in fish and fishery products: An overview. Marine Policy, 69, 181-188.

Béné, C., Barange, M., Subasinghe, R., Pinstrup-Andersen, P., Merino, G., Hemre, G. I., & Williams, M. (2015). Feeding 9 billion by 2050–Putting fish back on the menu. Food Security, 7(2), 261-274.

Beverton, R. J. H. & Holt, H. J. (1957) On the Dynamics of Exploited Fish Populations. Fishery Investigations, Series II, 19, Her Majesty's Stationery Office, London.

Black, R. E., Victora, C. G., Walker, S. P., Bhutta, Z. A., Christian, P., De Onis, M., et al. (2013). Maternal and child undernutrition and overweight in low-income and middle-income countries. The lancet, 382(9890), 427-451.

Booth S, Hui J, Alojado Z, Lam V, Cheung W, Zeller D, Steyn D & Pauly D (2013) Global deposition of airborne dioxin. Marine Pollution Bulletin 75(1-2): 182-186.

Bosma, R., Anh, P. T., & Potting, J. (2011). Life cycle assessment of intensive striped catfish farming in the Mekong Delta for screening hotspots as input to environmental policy and research agenda. The International Journal of Life Cycle Assessment, 16(9), 903-915.

Bouwman, Emily, Muriel Verain, and Harriëtte Snoek (2016). Analysis of the web-survey on consumers' knowledge about nutrition, environment and the importance of relevant determinants. SUSFANS Deliverable D2.1. The Hague: Wageningen Economic Research

Branch, T. A., Hilborn, R., Haynie, A. C., Fay, G., Flynn, L., Griffiths, J., et al. (2006). Fleet dynamics and fishermen behavior: lessons for fisheries managers. Canadian Journal of Fisheries and Aquatic Sciences, 63(7), 1647-1668.

Branch, T. A., DeJoseph, B. M., Ray, L. J., & Wagner, C. A. (2013). Impacts of ocean acidification on marine seafood. Trends in ecology & evolution, 28(3), 178-186.

Brunner, E. J., Jones, P. J., Friel, S., & Bartley, M. (2009). Fish, human health and marine ecosystem health: policies in collision. International journal of epidemiology, 38(1), 93-100.

Budge, S. M., Devred, E., Forget, M.-H., Stuart, V., Trzcinski, M. K., Sathyendranath, S., and Platt, T. (2014) Estimating concentrations of essential omega-3 fatty acids in the ocean: supply and demand. ICES Journal of Marine Science, 71: 1885–1893.

Burridge, L., Weis, J. S., Cabello, F., Pizarro, J., & Bostick, K. (2010). Chemical use in salmon aquaculture: a review of current practices and possible environmental effects. Aquaculture, 306(1), 7-23.

Campbell, B., & Pauly, D. (2013). Mariculture: a global analysis of production trends since 1950. Marine Policy, 39, 94-100.

Cao, L., Diana, J. S., Keoleian, G. A., & Lai, Q. (2011). Life cycle assessment of Chinese shrimp farming systems targeted for export and domestic sales. Environmental science & technology, 45(15), 6531-6538.

Carpenter, G., Kleinjans, R., Villasante, S., & O'Leary, B. C. (2016). Landing the blame: The influence of EU Member States on quota setting. Marine Policy, 64, 9-15.

Cashion, T., Hornborg, S., Ziegler, F., Hognes, E. S., & Tyedmers, P. (2016). Review and advancement of the marine biotic resource use metric in seafood LCAs: a case study of Norwegian salmon feed. The International Journal of Life Cycle Assessment, 1-15.

CBI (2015a). CBI EU Buyer Requirements: Fishery products. CBI- Ministry of Foreign Affairs. https://www.cbi.eu/sites/default/files/market_information/researches/buyer-requirements-fishery-products.pdf

CBI (2015b) CBI Channels and Segments: Frozen Seafood Products. CBI-Ministry of Foreign Affairs. https://www.cbi.eu/sites/default/files/market_information/researches/channels-and-segments-frozen-seafood.pdf

Chantavanich, S., Laodumrongchai, S., & Stringer, C. (2016). Under the shadow: Forced labour among sea fishers in Thailand. Marine Policy, 68, 1-7.

Chassot, E., Bonhommeau, S., Dulvy, N. K., Mélin, F., Watson, R., Gascuel, D., and Le Pape, O. (2010) Global marine primary production constrains fisheries catches. Ecology letters, 13(4): 495-505.

Cheilari, A., Guillen, J., Damalas, D., & Barbas, T. (2013). Effects of the fuel price crisis on the energy efficiency and the economic performance of the European Union fishing fleets. Marine Policy, 40, 18-24.

Cheung, W.W.L., R. Watson and D. Pauly. (2013). Signature of ocean warming in global fisheries catch. Nature 497: 365-368.

Cheung, W. W., Jones, M. C., Reygondeau, G., Stock, C. A., Lam, V. W., & Frölicher, T. L. (2016). Structural uncertainty in projecting global fisheries catches under climate change. Ecological Modelling, 325, 57-66.

Christensen, V., Guenette, S., Heymans, J. J., Walters, C. J., Watson, R., Zeller, D., & Pauly, D. (2003). Hundred-year decline of North Atlantic predatory fishes. Fish and fisheries, 4(1), 1-24.

Christian, C., Ainley, D., Bailey, M., Dayton, P., Hocevar, J., LeVine, M., ... & Jacquet, J. (2013). A review of formal objections to Marine Stewardship Council fisheries certifications. Biological Conservation, 161, 10-17.

Coelli, T.J., Rao, D.S.P., O'Donnell, C.J., Battese, G.E., (2005). An Introduction to Efficiency and Productivity Analysis, 2nd edition. ed. Springer, New York.

Coll, M., Libralato, S., Tudela, S., Palomera, I., & Pranovi, F. (2008). Ecosystem overfishing in the ocean. PLoS one, 3(12), e3881.

Coll, M., Shannon, L. J., Yemane, D., Link, J. S., Ojaveer, H., Neira, S., ... & Shin, Y. J. (2009). Ranking the ecological relative status of exploited marine ecosystems. ICES Journal of Marine Science: Journal du Conseil, fsp261.

Coll M, Carreras M, Cornax MJ, Massutí E, Morote E, Pastor X, Quetglas A, Sáez R, Silva L, Sobrino I, Torres MA, Tudela S, Harper S, Zeller D and Pauly D (2014) Closer to reality: reconstructing total removals in mixed fisheries from Southern Europe. Fisheries Research 154: 179-194.

Costa-Pierce, B. A. (2010). Sustainable ecological aquaculture systems: the need for a new social contract for aquaculture development. Marine Technology Society Journal, 44(3), 88-112.

Costello, C., Ovando, D., Clavelle, T., Strauss, C. K., Hilborn, R., Melnychuk, M. C., et al. (2016). Global fishery prospects under contrasting management regimes. Proceedings of the National Academy of Sciences, 201520420.

Cook, R., Fariñas-Franco, J. M., Gell, F. R., Holt, R. H., Holt, T., et al. (2013) The substantial first impact of bottom fishing on rare biodiversity hotspots: a dilemma for evidence-based conservation. PloS one, 8(8), e69904.

Crona, B. I., Daw, T. M., Swartz, W., Norström, A. V., Nyström, M., Thyresson, M., et al. (2015). Masked, diluted and drowned out: How global seafood trade weakens signals from marine ecosystems. Fish and Fisheries.

Driscoll, J., & Tyedmers, P. (2010). Fuel use and greenhouse gas emission implications of fisheries management: the case of the New England Atlantic herring fishery. Marine Policy, 34(3), 353-359.

Davie, S., Minto, C., Officer, R., & Lordan, C. (2015). Defining value per unit effort in mixed métier fisheries. Fisheries Research, 165, 1-10.

Diana, J. S. (2009). Aquaculture production and biodiversity conservation. Bioscience, 59(1), 27-38.

Duarte, C. M., Holmer, M., Olsen, Y., Soto, D., Marbà, N., Guiu, J., et al. (2009). Will the oceans help feed humanity?. BioScience, 59(11), 967-976.

Dulvy, N. K., Sadovy, Y., & Reynolds, J. D. (2003) Extinction vulnerability in marine populations. Fish and fisheries, 4(1), 25-64.

Einarsson, H.; Emerson, W. (eds). International seafood trade: challenges and opportunities. FAO/University of Akureyri Symposium. 1–2 February 2007, Akureyri, Iceland. FAO Fisheries and Aquaculture Proceedings. No. 13. Rome, FAO. 2009. 121p.

Estes, J. A., Terborgh, J., Brashares, J. S., Power, M. E., Berger, J., Bond, W. J., et al. (2011). Trophic downgrading of planet Earth. Science, 333(6040), 301-306.

EC (2008). 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).

EC (2013). Strategic Guidelines for the Sustainable Development of EU Aquaculture. European Commission. COM, 229 final. *http://ec.europa.eu/fisheries/cfp/aquaculture/index_en.htm*

EC (2015) European Commission Description of Seafood PEF Pilot. Available at: http://ec.europa.eu/environment/eussd/smgp/pdf/Fiche_fish.pdf Accessed 18th of August 2016.

EC (2016a) On the application of the Water Framework Directive (WFD) and the Marine Strategy Framework Directive (MSFD) in relation to aquaculture. Brussels. http://ec.europa.eu/environment/marine/pdf/SWD_2016_178.pdf

EC (2016b) http://ec.europa.eu/food/safety/rasff/index_en.htm Accessed 18th of August 2016

EC (2016c) http://madb.europa.eu/madb/barriers_crossTables.htm?table=sectormeasure Accessed 18th of August 2016

EP (2016) European Parliament resolution on traceability of fishery and aquaculture products in restaurants and retail. http://www.europarl.europa.eu/sides/getDoc.do?pubRef=-//EP//TEXT+MOTION+B8-2016-0581+0+DOC+XML+V0//EN Accessed 18th of August 2016.

EU (2013) Regulation No 1380/2013 of the European Parliament and the Council of 11 December 2013 on the Common Fisheries Policy, amending Council Regulations (EC) No 1954/2003 and (EC) No 1224/2009 and repealing Council Regulations (EC) No 2371/2002 and (EC) No 639/2004 and Council Decision 2004/585/EC.

EU (2014) Facts and figures on the Common Fisheries Policy. Basic statistical data. 2014 Edition. ISSN 1830-9119.

EU (2016a) Facts and figures on the Common Fisheries Policy. Basic statistical data. 2016 Edition. ISSN 1977-3609

EU (2016b) The Common Fisheries Policy: origins and development. http://www.europarl.europa.eu/aboutparliament/en/displayFtu.html?ftuId=FTU_5.3.1.html Accessed 2016-05-11

EUMOFA (2015) THE EU FISH MARKET. 2015 Edition. European Market Observatory for Fisheries and Aquaculture Products. www.eumofa.eu

EUMOFA (2016) ANNEX 1 List of Commodity groups and Main commercial species. Document available at: http://www.eumofa.eu/documents/20178/0/DM_Annex+1_+List+of+MCS+and+CG.pdf/529e649c-0ad8-4b5d-b290-96b3334eccd8

EUROSTAT (2016) Website accessed 160916. http://ec.europa.eu/eurostat/statistics-explained/index.php/Comparative_price_levels_for_food,_beverages_and_tobacco#Bread_and_cereals.2C_meat.2C_fish_and_dairy_products

FAO (2011) The State of Food Insecurity in the World 2011. Rome, 62 pp.

FAO (2014) The State of World Fisheries and Aquaculture 2014. Rome. 223 pp.

FAO (2016) The State of World Fisheries and Aquaculture 2016. Rome. 200 pp. ISBN 978-92-5-109185-2

FIS (2016a) http://fis.com/fis/worldnews/worldnews.asp?l=e&ndb=1&id=86629

FIS (2016b) http://fis.com/fis/worldnews/worldnews.asp?l=e&ndb=1&id=87169

FIS (2016c) http://fis.com/fis/worldnews/worldnews.asp?l=e&ndb=1&id=86672

Foley, J. A., Ramankutty, N., Brauman, K. A., Cassidy, E. S., Gerber, J. S., Johnston, M., et al. (2011). Solutions for a cultivated planet. Nature, 478(7369), 337-342.

Ford, J. S., Pelletier, N. L., Ziegler, F., Scholz, A. J., Tyedmers, P. H., Sonesson, U., et al. (2012) Proposed local ecological impact categories and indicators for life cycle assessment of aquaculture. Journal of Industrial Ecology, 16(2), 254-265.

Failler, P. (2007) Future prospects for fish and fishery products. 4. Fish consumption in the European Union in 2015 and 2030. Part 1. European overview. FAO Fisheries Circular. No. 972/4, Part 1. Rome, FAO. 2007. 204p.

Frid, C. L., & Paramor, O. A. (2012). Feeding the world: what role for fisheries?. ICES Journal of Marine Science: Journal du Conseil, 69(2), 145-150.

Gascuel, D., Coll, M., Fox, C., Guénette, S., Guitton, J., Kenny, A., et al. (2014). Fishing impact and environmental status in European seas: a diagnosis from stock assessments and ecosystem indicators. Fish and Fisheries 17: 31-55

Gerber, L. R., Karimi, R., & Fitzgerald, T. P. (2012). Sustaining seafood for public health. Frontiers in Ecology and the Environment, 10(9), 487-493.

Ghaly, A. E., Ramakrishnan, V. V., Brooks, M. S., Budge, S. M., & Dave, D. (2013). Fish processing wastes as a potential source of proteins, amino acids and oils: A critical review. Journal of Microbial and Biochemical Technology, 5, 107-129.

Godfray, H. C. J., Beddington, J. R., Crute, I. R., Haddad, L., Lawrence, D., Muir, J. F., et al. (2010) Food security: the challenge of feeding 9 billion people. science, 327(5967), 812-818.

Golden, C., Allison, E. H., Cheung, W. W., Dey, M. M., Halpern, B. S., McCauley, D. J., et al. (2016). Fall in fish catch threatens human health. Nature 534: 317-320

Grave, K., Torren-Edo, J., & Mackay, D. (2010). Comparison of the sales of veterinary antibacterial agents between 10 European countries. Journal of antimicrobial chemotherapy, dkq247.

Gudding, R., & Van Muiswinkel, W. B. (2013). A history of fish vaccination: science-based disease prevention in aquaculture. Fish & shellfish immunology, 35(6), 1683-1688.

Guillotreau, P., & Peridy, N. (2000). Trade barriers and European imports of seafood products: a quantitative assessment. Marine Policy, 24(5), 431-437.

Gutiérrez, N. L., Valencia, S. R., Branch, T. A., Agnew, D. J., Baum, J. K., Bianchi, P. L., et al. (2012). Eco-label conveys reliable information on fish stock health to seafood consumers. PLoS One, 7(8), e43765.

Hall, S. J., Hilborn, R., Andrew, N. L., & Allison, E. H. (2013). Innovations in capture fisheries are an imperative for nutrition security in the developing world. Proceedings of the National Academy of Sciences, 110(21), 8393-8398.

Hallstein, E., & Villas-Boas, S. B. (2013). Can household consumers save the wild fish? Lessons from a sustainable seafood advisory. Journal of Environmental Economics and Management, 66(1), 52-71.

Hazell, P., & Wood, S., (2008). Drivers of change in global agriculture. Philos. Trans. R. Soc. B Biol. Sci. 363, 495–515. doi:10.1098/rstb.2007.2166

Henning, B. G. (2011). Standing in Livestock's' Long Shadow': The Ethics of Eating Meat on a Small Planet. Ethics & the Environment, 16(2), 63-93.

Henriksson, P. J., Guinée, J. B., Kleijn, R., & de Snoo, G. R. (2012). Life cycle assessment of aquaculture systems—a review of methodologies. The International Journal of Life Cycle Assessment, 17(3), 304-313.

Heuer, O. E., Kruse, H., Grave, K., Collignon, P., Karunasagar, I., & Angulo, F. J. (2009). Human health consequences of use of antimicrobial agents in aquaculture. Clinical Infectious Diseases, 49(8), 1248-1253.

Heymans, J. J., Mackinson, S., Sumaila, U. R., Dyck, A., & Little, A. (2011). The impact of subsidies on the ecological sustainability and future profits from North Sea fisheries. PLoS One, 6(5), e20239.

Hilborn, R. (2012). Overfishing: What Everyone Needs to Know. Oxford University Press.

Hilborn, R., Fulton, E. A., Green, B. S., Hartmann, K., Tracey, S. R., & Watson, R. A. (2015). When is a fishery sustainable?. Canadian Journal of Fisheries and Aquatic Sciences, 72(9), 1433-1441.

Hoegh-Guldberg, O., & Bruno, J. F. (2010). The impact of climate change on the world's marine ecosystems. Science, 328(5985), 1523-1528.

Hornborg, S., Svensson, M., Nilsson, P., & Ziegler, F. (2013a). By-catch impacts in fisheries: utilizing the IUCN Red List Categories for enhanced product level assessment in seafood LCAs. Environmental management, 52(5), 1239-1248.

Hornborg, S., Belgrano, A., Bartolino, V., Valentinsson, D., & Ziegler, F. (2013b). Trophic indicators in fisheries: a call for re-evaluation. Biology letters, 9(1), 20121050.

Hornborg, S., Jonsson, P., Sköld, M., Ulmestrand, M., Valentinsson, D., Ritzau Eigaard, O., Feekings, J., Nielsen, J. R., Bastardie, F., Lövgren, J. (2016) New policies may call for new approaches: the case of the Swedish Norway lobster (*Nephrops norvegicus*) fisheries in the Kattegat and Skagerrak. ICES J. Mar. Sci. doi: 10.1093/icesjms/fsw153

Irz X, Leroy P, Réquillart V, & Soler L-G (2016) Beyond Wishful Thinking: Integrating Consumer Preferences in the Assessment of Dietary Recommendations. PLoS ONE 11(6): e0158453. doi:10.1371/journal.pone.0158453

Hoffman, J., Voss, R., Llope, M., Schmidt, J. O.; Möllmann, C, Fricke, L., Quaas, M. F. (2015) Social-economic drivers in (political) TAC setting decisions. ICES CM 2015/B:25 Poster

Hofherr, J., Natale, F., & Trujillo, P. (2015). Is lack of space a limiting factor for the development of aquaculture in EU coastal areas?. Ocean & Coastal Management, 116, 27-36.

Holmer, M. (2010). Environmental issues of fish farming in offshore waters: perspectives, concerns and research needs. Aquacult Environ Interact, 1, 57-70.

Hospido, A., & Tyedmers, P. (2005). Life cycle environmental impacts of Spanish tuna fisheries. Fisheries Research, 76(2), 174-186.

Howarth, L. M., Roberts, C. M., Thurstan, R. H., & Stewart, B. D. (2014). The unintended consequences of simplifying the sea: making the case for complexity. Fish and Fisheries, 15(4), 690-711.

Hu, Z., Lee, J. W., Chandran, K., Kim, S., Sharma, K., Brotto, A. C., & Khanal, S. K. (2013). Nitrogen transformations in intensive aquaculture system and its implication to climate change through nitrous oxide emission. Bioresource technology, 130, 314-320.

Hunt, G. L., & McKinnell, S. (2006). Interplay between top-down, bottom-up, and wasp-waist control in marine ecosystems. Progress in Oceanography, 68(2), 115-124.

Huntington, T. C. (2009). Use of wild fish and other aquatic organisms as feed in aquaculture–a review of practices and implications in Europe. Fish as feed inputs for aquaculture: practices, sustainability and implications, 209-268.

Hutchings, J. A., Myers, R. A., García, V. B., Lucifora, L. O., & Kuparinen, A. (2012). Life-history correlates of extinction risk and recovery potential. Ecological Applications, 22(4), 1061-1067.

Jackson, J. B. (2010). The future of the oceans past. Philosophical Transactions of the Royal Society B: Biological Sciences, 365(1558), 3765-3778.

Jacquet, J., Hocevar, J., Lai, S., Majluf, P., Pelletier, N., Pitcher, T., et al. (2010). Conserving wild fish in a sea of market-based efforts. Oryx, 44(01), 45-56.

Jafarzadeh, S., Ellingsen, H., Aanondsen, S.A. (2016) Energy efficiency of Norwegian fisheries from 2003 to 2012. Journal of Cleaner Production 112:3616-3630

Jennings, S. (2005) Indicators to support an ecosystem approach to fisheries. Fish and Fisheries, 6(3), 212-232.

Jones, A. C., Mead, A., Kaiser, M. J., Austen, M. C., Adrian, A. W., Auchterlonie, N. A., ... & Dicks, L. V. (2014). Prioritization of knowledge needs for sustainable aquaculture: a national and global perspective. Fish and Fisheries 16(4), 668-683

Kelleher, K. (2005) Discards in the world's marine fisheries: an update. Rome: Food and Agriculture Organisation of the United Nations, FAO; 2005. 131pp.

Lagares, E. C., Ordaz, F. G., & del Hoyo, J. J. G. (2016). The determinants that cause small-scale vessels to exit fishing: The case of the Spanish small-scale purse seine fishery. Fisheries Research, 181, 155-162.

Lafferty, K. D., Harvell, C. D., Conrad, J. M., Friedman, C. S., Kent, M. L., Kuris, A. M., et al. (2015). Infectious diseases affect marine fisheries and aquaculture economics. Annual review of marine science, 7, 471-496.

Lam, V. W. Y., Sumaila, U. R., Dyck, A., Pauly, D., & Watson, R. 2011. Construction and first applications of a global cost of fishing database. ICES Journal of Marine Science, 68: 1996–2004.

Lam, V. W.Y, Cheung, W. W., Reygondeau, G., & Sumaila, U. R. (2016). Projected change in global fisheries revenues under climate change. Scientific Reports, 6, Article number 32607 doi:10.1038/srep32607

Lassen, H., Kelly, C., & Sissenwine, M. (2013). ICES advisory framework 1977–2012: from Fmax to precautionary approach and beyond. ICES Journal of Marine Science: Journal du Conseil, 146.

Leal, M. C., Pimentel, T., Ricardo, F., Rosa, R., & Calado, R. (2015). Seafood traceability: current needs, available tools, and biotechnological challenges for origin certification. Trends in biotechnology, 33(6), 331-336.

Lewison, R. L., Crowder, L. B., Read, A. J., & Freeman, S. A. (2004). Understanding impacts of fisheries bycatch on marine megafauna. Trends in Ecology & Evolution, 19(11), 598-604.

Love, D. C., Fry, J. P., Milli, M. C., & Neff, R. A. (2015). Wasted seafood in the United States: Quantifying loss from production to consumption and moving toward solutions. Global Environmental Change, 35, 116-124.

Mace, P. M. (2001). A new role for MSY in single-species and ecosystem approaches to fisheries stock assessment and management. Fish and fisheries, 2(1), 2-32.

Marchal, P., Andersen, J. L., Aranda, M., Fitzpatrick, M., Goti, L., Guyader, O., et al. (2016). A comparative review of fisheries management experiences in the European Union and in other countries worldwide: Iceland, Australia, and New Zealand. Fish and Fisheries.

Marchal, P., Poos, J.J., & Quirijns, F. (2007) Linkage between fishers' foraging, market and fish stocks density: examples from some North Sea fisheries. Fish. Res. 83,33–43

Martins, C. I. M., Eding, E. H., Verdegem, M. C., Heinsbroek, L. T., Schneider, O., Blancheton, J. P., et al. (2010). New developments in recirculating aquaculture systems in Europe: A perspective on environmental sustainability. Aquacultural Engineering, 43(3), 83-93.

Marette, S. & Millet, G. (2016) Can Information about Health and Environment Beef Up the Demand for Meat Alternatives? SUSFANS Deliverable 2.4. Preliminary report on Task 2.4: Lab experiment on consumer choice. Paris: INRA

McClanahan, T., Allison, E. H., & Cinner, J. E. (2015). Managing fisheries for human and food security. Fish and Fisheries, 16(1), 78-103.

Merino, G., Barange, M., Blanchard, J. L., Harle, J., Holmes, R., Allen, I., et al. (2012). Can marine fisheries and aquaculture meet fish demand from a growing human population in a changing climate?. Global Environmental Change, 22(4), 795-806.

Merrigan, K. Griffin, T., Wilde P. et al. (2015) Designing a sustainable diet. Sustainability as dietary guidance created political debate Science 350(6257):165-166

Miller DD & Mariani S. 2010. Smoke, mirrors, and mislabelled cod: poor transparency in the European seafood industry. Front Ecol Environ 8: 517–21.

Morato, T., Watson, R., Pitcher, T.J., & Pauly, D. (2006) Fishing down the deep. Fish Fish. 7, 24–34.

Munro, A. L. S., & Wallace, I. S. (2015). Scottish Fish Farm Production Survey 2014.

Nash, C. E. (1988). A global overview of aquaculture production. Journal of the World Aquaculture Society, 19(2), 51-58.

Nash, C. E. (2011). The History of Aquaculture. Blackwell Publishing Ltd. ISBN 978-0-8138-2163-4

Naylor, R. L., Hardy, R. W., Bureau, D. P., Chiu, A., Elliott, M., Farrell, A. P., et al. (2009). Feeding aquaculture in an era of finite resources. Proceedings of the National Academy of Sciences, 106(36), 15103-15110.

Nijdam, D., Rood, T., & Westhoek, H. (2012). The price of protein: Review of land use and carbon footprints from life cycle assessments of animal food products and their substitutes. Food Policy, 37(6), 760-770.

OECD-FAO (2015).OECD-FAO Agricultural Outlook. OECD Publishing, Organisation for Economic Co-operation and Development. Paris, 2015.

Palin, C., Gaudin, C., Espejo-Hermes, J., & Nicolaides, J. (2013). Compliance of Imports of Fishery and Aquaculture Products with EU Legislation. European Parliament, Brussels.

Papatryphon, E., Petit, J., Kaushik, S. J., & van der Werf, H. M. (2004). Environmental impact assessment of salmonid feeds using life cycle assessment (LCA). AMBIO: A Journal of the Human Environment, 33(6), 316-323.

Parker, R. (2012). Review of life cycle assessment research on products derived from fisheries and aquaculture: A report for Seafish as part of the collective action to address greenhouse gas emissions in seafood. Final Report Prepared for: Sea Fish Industry Authority Pr, 67. Available at http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.462.6185&rep=rep1&type=pdf

Parker, R. W., & Tyedmers, P. H. (2015). Fuel consumption of global fishing fleets: current understanding and knowledge gaps. Fish and Fisheries.

Parker, R. W., Hartmann, K., Green, B. S., Gardner, C., & Watson, R. A. (2015a). Environmental and economic dimensions of fuel use in Australian fisheries. Journal of Cleaner Production, 87, 78-86.

Parker, R. W., Vázquez-Rowe, I., & Tyedmers, P. H. (2015b). Fuel performance and carbon footprint of the global purse seine tuna fleet. Journal of Cleaner Production, 103, 517-524.

Pauly, D., Hilborn, R., & Branch, T. A. (2013). Fisheries: does catch reflect abundance?. Nature, 494(7437), 303-306.

Pauly, D., & Zeller, D. (2016). Catch reconstructions reveal that global marine fisheries catches are higher than reported and declining. Nature communications, 7.

Pelletier, N., & Tyedmers, P. (2010). Life Cycle Assessment of Frozen Tilapia Fillets From Indonesian Lake-Based and Pond-Based Intensive Aquaculture Systems. Journal of Industrial Ecology, 14(3), 467-481.

Pelletier, N., Audsley, E., Brodt, S., Garnett, T., Henriksson, P., Kendall, A., et al. (2011). Energy intensity of agriculture and food systems.

Pelletier, N., André, J., Charef, A., Damalas, D., Green, B., Parker, R., ... & Watson, R. (2014) Energy prices and seafood security. Global Environmental Change, 24, 30-41.

Piet, G. J., Van Overzee, H. M. J., & Pastoors, M. A. (2010). The necessity for response indicators in fisheries management. ICES Journal of Marine Science: Journal du Conseil, 67(3), 559-566.

Pinnegar, J.K., Jennings, S., O'Brien, C.M., & Polunin, V.C., (2002) Long-term changes in the trophic level of the Celtic Sea fish community and fish market price distribution. J. Appl. Ecol. 39, 377–390.

Piñones, A., & Fedorov, A. V. (2016). Projected changes of Antarctic krill habitat by the end of the 21st century. Geophysical Research Letters.

Pinsky, M. L., Jensen, O. P., Ricard, D., & Palumbi, S. R. (2011) Unexpected patterns of fisheries collapse in the world's oceans. Proceedings of the National Academy of Sciences, 108(20), 8317-8322.

Rice, J. C., & Garcia, S. M. (2011). Fisheries, food security, climate change, and biodiversity: characteristics of the sector and perspectives on emerging issues. ICES Journal of Marine Science: Journal du Conseil, 68(6), 1343-1353.

Rico, A., Phu, T. M., Satapornvanit, K., Min, J., Shahabuddin, A. M., Henriksson, P. J., et al. (2013). Use of veterinary medicines, feed additives and probiotics in four major internationally traded aquaculture species farmed in Asia. Aquaculture, 412, 231-243.

Rockström, J., Steffen, W., Noone, K., Persson, Å., Chapin, F. S., Lambin, E. F., ... & Nykvist, B. (2009). A safe operating space for humanity. Nature, 461(7263), 472-475.

Roheim, C. A. (2009). An evaluation of sustainable seafood guides: implications for environmental groups and the seafood industry. Marine Resource Economics, 24(3), 301-310.

Martine, M., Achterbosch T., de Boer, I., Crespo Cuaresma, J., Geleijnse, M., Havlík, P., Heckelei, T., Ingram, J., Marette, S., van Meijl, H., Soler, L.-G., Swinnen, J., van 't Veer, P., Vervoort, J., Zimmermann, A., Zimmermann, K., Zurek, M. Metrics, models and foresight for European sustainable food and nutrition security: the vision of the SUSFANS project. Forthcoming in *Agricultural Systems*

Ruttan, L. M., & Tyedmers, P. H. (2007). Skippers, spotters and seiners: analysis of the “skipper effect” in US menhaden (Brevoortia spp.) purse-seine fisheries. Fisheries research, 83(1), 73-80.

Schau, E. M., Ellingsen, H., Endal, A., & Aanondsen, S. A. (2009). Energy consumption in the Norwegian fisheries. Journal of Cleaner Production, 17(3), 325-334.

Schwach, V., Bailly, D., Christensen, A-S., Delaney, A. E., Degnbol, P., van Densen, W. L. T., Holm, P., McLay, H. A., Nielsen, K. N., Pastoors, M. A., Reeves, S. A., and Wilson, D. C. (2007). Policy and knowledge in fisheries management: a policy brief. – ICES Journal of Marine Science: Journal du Conseil, 64, 798-803.

Smith, A. D., Brown, C. J., Bulman, C. M., Fulton, E. A., Johnson, P., Kaplan, I. C., ... & Shin, Y. J. (2011). Impacts of fishing low–trophic level species on marine ecosystems. Science, 333(6046), 1147-1150.

Smith, M. D., Roheim, C. A., Crowder, L. B., Halpern, B. S., Turnipseed, M., Anderson, J. L., et al. (2010). Sustainability and global seafood. Science, 327(5967), 784-786.

STECF (2014). The Economic Performance of the EU Aquaculture Sector (STECF 14-18) (JRC Scientific and Technical Reports No. JRC 93169,). Scientific, Technical and Economic Committee for Fisheries (STECF). Publications Office of the European Union, Luxembourg.

STECF (2015). Scientific, Technical and Economic Committee for Fisheries (STECF) – The 2015 Annual Economic Report on the EU Fishing Fleet (STECF-15-07). 2015. Publications Office of the European Union, Luxembourg, EUR 27428 EN, JRC 97371, 434 pp.

Sprague, M., Bendiksen, E. Å., Dick, J. R., Strachan, F., Pratoomyot, J., Berntssen, M. H., et al. (2010). Effects of decontaminated fish oil or a fish and vegetable oil blend on persistent organic pollutant and fatty acid compositions in diet and flesh of Atlantic salmon (*Salmo salar*). British Journal of Nutrition, 103(10), 1442-1451.

Sumaila UR, Khan AJ, Dyck A, Watson R, Munro G, et al. (2010) A bottom-up re-estimation of global fisheries subsidies. Journal of Bioeconomics 12: 201–225.

Sumaila, U. R., Lam, V., Le Manach, F., Swartz, W., & Pauly, D. (2016). Global fisheries subsidies: An updated estimate. Marine Policy, 69, 189-193.

Svedäng, H., & Hornborg, S. (2015). Waiting for a flourishing Baltic cod (Gadus morhua) fishery that never comes: old truths and new perspectives. ICES Journal of Marine Science: Journal du Conseil, fsv112.

Swartz, W., Sumaila, U. R., Watson, R., & Pauly, D. (2010a). Sourcing seafood for the three major markets: The EU, Japan and the USA. Marine Policy, 34(6), 1366-1373.

Swartz, W., Sala, E., Tracey, S., Watson, R., Pauly, D. (2010b). The spatial expansion and ecological footprint of fisheries (1950 to present). PLoS One 5, e15143.

Taranger, G. L., Karlsen, Ø., Bannister, R. J., Glover, K. A., Husa,V., Karlsbakk, E., Kvamme, B. O., et al. (2015) Risk assessment of the environmental impact of Norwegian Atlantic salmon farming. ICES Journal of Marine Science, 72: 997–1021.

Teletchea, F., & Fontaine, P. (2014). Levels of domestication in fish: implications for the sustainable future of aquaculture. Fish and fisheries, 15(2), 181-195.

Thilsted, S. H., Thorne-Lyman, A., Webb, P., Bogard, J. R., Subasinghe, R., Phillips, M. J., & Allison, E. H. (2016). Sustaining healthy diets: The role of capture fisheries and aquaculture for improving nutrition in the post-2015 era. Food Policy, 61, 126-131.

Thurstan, R. H., & Roberts, C. M. (2014). The past and future of fish consumption: Can supplies meet healthy eating recommendations?. Marine pollution bulletin, 89(1), 5-11.

Tlusty, M. F., Hardy, R., & Cross, S. F. (2011). Limiting size of fish fillets at the center of the plate improves the sustainability of aquaculture production. Sustainability, 3(7), 957-964.

Tlusty, M, Thorsen, Ø. (in press) Claiming seafood is 'sustainable' risks limiting improvement. Fish and Fisheries (Published online)

Tillin, H. M., Hiddink, J. G., Jennings, S., and Kaiser, M. J. (2006) Chronic bottom trawling alters the functional composition of benthic invertebrate communities on a sea-basin scale. Marine Ecology Progress Series, 318, 31-45.

Tilman, D., & Clark, M. (2014). Global diets link environmental sustainability and human health. Nature, 515(7528), 518-522.

Torrissen, O., Olsen, R. E., Toresen, R., Hemre, G. I., Tacon, A. G., Asche, F., et al. (2011) Atlantic salmon (*Salmo salar*): the "super-chicken" of the sea?. Reviews in Fisheries Science, 19(3), 257-278.

Troell, M., Naylor, R. L., Metian, M., Beveridge, M., Tyedmers, P. H., Folke, C., et al. (2014). Does aquaculture add resilience to the global food system?. Proceedings of the National Academy of Sciences, 111(37), 13257-13263.

Turner, L. M., Alsterberg, C., Turner, A. D., Girisha, S. K., Rai, A., Havenhand, J. N., et al. (2016). Pathogenic marine microbes influence the effects of climate change on a commercially important tropical bivalve. Scientific Reports, 6 Article number: 32413 doi:10.1038/srep32413

Tveterås S, Asche F, Bellemare MF, Smith MD, Guttormsen AG, et al. (2012) Fish Is Food - The FAO's Fish Price Index. PLoS ONE 7(5): e36731. doi:10.1371/journal.pone.0036731

Tyedmers, P., Pelletier, N., & Ayer, N. (2007). Biophysical sustainability and approaches to marine aquaculture development policy in the United States. A report to the Marine Aquaculture Task Force, Takoma, Park, MD.

UN (2014) World Urbanization Prospects: The 2014 Revision, Highlights. United Nations, Department of Economic and Social Affairs, Population Division. 2014. ST/ESA/SER.A/352. New York, USA. 27 pp. http://esa.un.org/unpd/wup/Highlights/WUP2014-Highlights.pdf

UN (2016) https://sustainabledevelopment.un.org/focussdgs.html Assessed June 7th 2016

Undercurrent News (2016) http://www.undercurrentnews.com/2015/10/01/snps-new-approach-to-reverse-falling-us-seafood-consumption-is-challenging-industry/ Accessed June 8th 2016

Vandevelde, S., Kuijpers R., Swinnen J. (Forthcoming) Food Standards and Sustainability: A Review and Conceptual Framework. SUSFANS deliverable D3.1/3.2. Brussels/Leuven: CEPS & KU Leuven.

van Zanten, H. & de Boer, I. (2016) The role of livestock in a healthy and sustainable diets: drivers seen from a European perspective with emphasis on the production side. SUSFANS deliverable D4.2 Drivers of livestock production in the EU. Public report.

Vega, A., Miller, A. C., & O'Donoghue, C. (2014). The Seafood Sector in Ireland: Economic Impacts of Seafood Production Growth Targets (No. 163051). IIIS Discussion Paper No. 447. https://www.researchgate.net/profile/Amaya_Vega/publication/260317555_Economic_impacts_of_seafood_production_growth_targets_in_Ireland/links/552e5b3d0cf2d4950717e2cb.pdf

Villasante, S., do Carme García-Negro, M., González-Laxe, F., & Rodríguez, G. R. (2011). Overfishing and the Common Fisheries Policy:(un) successful results from TAC regulation?. Fish and Fisheries, 12(1), 34-50.

Vincent, A. C., Sadovy de Mitcheson, Y. J., Fowler, S. L., & Lieberman, S. (2014). The role of CITES in the conservation of marine fishes subject to international trade. Fish and Fisheries, 15(4), 563-592.

Watson, R., Zeller, D., and Pauly, D. (2014) Primary productivity demands of global fishing fleets. Fish and Fisheries, 15(2), 231-241.

Watson, R. A., Green, B. S., Tracey, S. R., Farmery, A., & Pitcher, T. J. (2015a). Provenance of global seafood. Fish and Fisheries.

Watson, R. A., et al. (2015b). Marine foods sourced from farther as their use of global ocean primary production increases. Nature communications, 6.

Welch, A., Hoenig, R., Stieglitz, J., Benetti, D., Tacon, A., Sims, N., & O'Hanlon, B. (2010). From fishing to the sustainable farming of carnivorous marine finfish. Reviews in Fisheries Science, 18(3), 235-247.

Worm, B., Hilborn, R., Baum, J. K., Branch, T. A., Collie, J. S., Costello, C., et al. (2009). Rebuilding global fisheries. science, 325(5940), 578-585.

Zeller, D., Rossing, P., Harper, S., Persson, L., Booth, S., & Pauly, D. (2011). The Baltic Sea: estimates of total fisheries removals 1950–2007. Fisheries Research, 108(2), 356-363.

Zhou, S., Smith, A. D., & Knudsen, E. E. (2014). Ending overfishing while catching more fish. Fish and Fisheries.

Ziegler, F., Winther, U., Hognes, E. S., Emanuelsson, A., Sund, V., & Ellingsen, H. (2013). The carbon footprint of Norwegian seafood products on the global seafood market. Journal of Industrial Ecology, 17(1), 103-116.

Ziegler, F., & Hornborg, S. (2014). Stock size matters more than vessel size: the fuel efficiency of Swedish demersal trawl fisheries 2002–2010. Marine Policy, 44, 72-81.

Ziegler, F., Groen, E. A., Hornborg, S., Bokkers, E. A., Karlsen, K. M., & de Boer, I. J. (2015). Assessing broad life cycle impacts of daily onboard decision-making, annual strategic planning, and fisheries management in a northeast Atlantic trawl fishery. The International Journal of Life Cycle Assessment, 1-11.

Ziegler, F., Hornborg, S., Green, B. S., Eigaard, O. R., Farmery, A. K., Hammar, L., et al. (2016a). Expanding the concept of sustainable seafood using Life Cycle Assessment. Fish and Fisheries.

Ziegler, F., Hornborg, S., Valentinsson, D., Hognes, E. S., Søvik, G., & Eigaard, O. R. (2016b). Same stock, different management: quantifying the sustainability of three shrimp fisheries in the Skagerrak from a product perspective. ICES Journal of Marine Science: Journal du Conseil, fsw035.

Zimmermann, A. & Latka, C. (2016) SUSFANS Deliverable D4.4 report on T4.4: drivers of crop production. Contact: andrea.zimmermann@ilr.uni-bonn.de

Zurek, M., Ingram, J., Zimmermann , A., Garrone , M., Rutten , M., Tetens , I., Leip, A., van't Veer , P., Verain, M, Bouwman, E., Marette, S., Chang, C., Latka, C., Hornborg, S., Seville Ziegler, F., Vervoort, J., Achterbosch, T., Terluin, I., Havlik, P., Deppermann, A. (2016). A Framework for Assessing and Devising Policy for Sustainable Food and Nutrition Security in EU: The SUSFANS conceptual framework. Public report. Deliverable D1.1 for WP 1. H2020 / SFS-19-2014: Sustainable food and nutrition security through evidence based EU agro-food policy GA no. 633692

Öhlmér, B., Olson, K., & Brehmer, B. (1998) Understanding farmers' decision making processes and improving managerial assistance. Agric. Econ. 18, 273–290. doi:10.1016/S0169-5150(97)00052-2

Österblom, H., Jouffray, J. B., Folke, C., Crona, B., Troell, M., Merrie, A., & Rockström, J. (2015). Transnational corporations as 'keystone actors' in marine ecosystems. PloS one, 10(5), e0127533.