Food and Agriculture Organization of the United Nations

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Background paper for The State of Agricultural Commodity Markets (SOCO) 2018

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Impacts of climate change on the production and trade of fish and fishery products

Background paper for
The State of Agricultural Commodity Markets (SOCO) 2018

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Food and Agriculture Organization of the United Nations
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Contents

Acronyms

EEZ	Exclusive Economic Zone
IUU	Illegal, Unregulated or Unreported
TAC	Total Allowable Catch
UNCLOS	United Nations Convention on the Law of the Sea

Abstract

Global seafood production has been increasing steadily in recent decades, at a rate faster that global population growth. Seafood is the most important source of animal protein in several regions, being of particular importance in several African countries. Fish and fisheries products are provided from two main modes of production – fisheries and aquaculture. While fisheries landings has been stagnant since the late 1980s, aquaculture is the world´s fastest growing food production technology.

The impact of climate change on global seafood production remains uncertain on aggregate. Recent evidence suggests that global capture fisheries production will remain relatively unchanged, but with significant variation across regions as various species change migration patterns due to direct and indirect effects of climate change. In addition to impacting food security and local economies, this may also cause jurisdictional challenges. Aquaculture production will continue to be the main driver of growth in the seafood sector, and climate change is likely to impact areas where production takes place.

If it turns out to be correct that the main impact of climate change on seafood production will be on where production takes place, trade has the potential to serve as an adaptive tool. Places that experience a reduction in production can compensate through imports. Seafood is also better placed than most other foods in terms of capacity to respond to climate change through increased international trade since it is already one of the most traded animal protein products worldwide. Several challenges remain, however, and countries whose fisheries and aquaculture are most vulnerable to climate change are also the poorest with the most limited capacity to adapt.

1. Introduction

Fish and fisheries products are provided from two main modes of production, fisheries and aquaculture.[1] The impact of climate change on both production modes remains uncertain, but shifts in migration patterns and jurisdictional issues will likely be one of the greatest impacts (IPCC, 2014). This will increase abundance for harvest in some areas while reducing it in others, and analogously, it will improve conditions for aquaculture in some areas while reducing it in others. These changes are also likely to create social challenges, which can be partly mitigated by trade.

In the academic literature, there has been more attention given to fisheries than aquaculture in terms of the impact of climate change on production patterns. There are a number of studies indicating changes in fish migration patterns, but the uncertainty with respect to the impact of climate change on production largely reflects the uncertainty with respect to these patterns and the extent to which they will be beneficial for some species and detrimental for others (Cheung *et al.*, 2009; Barange *et al.,* 2014). Changes in fish migration patterns have already started to create international jurisdiction issues and pose challenges to the governance structure of fisheries management - both internationally as well as within nations - as countries or vessel groups gain access to new fish stocks. Spillover effects from changes in management systems also occur. Examples are the migration of cod and mackerel stocks in the north Atlantic (Hannesson, 2006; 2014), or fish stocks shifting to the management zone of new regional fisheries management councils in the United States of America (Cunningham *et al.*, 2016). It is also recognized that the changes in migration can have strong impacts on communities that depend on fisheries (Allison *et al.,* 2009; Melnychuk *et al.*, 2013; Barange *et al.*, 2014; Ding *et al.,* 2017) and also impact biodiversity (Bax *et al.,* 2003; Cheung *et al.,* 2011).

The main mechanisms for the uncertainty with respect to the impact of climate change vis-à-vis aquaculture are largely the same, but with the additional complication that less is known about the biophysical systems in which aquaculture operate and the production process' dependence on them. Certainly, climate change can influence productivity of some species in specific regions (e.g. Hermannsen and Heen, 2012). However, aquaculture has been the world´s fastest growing food production system in recent decades (FAO, 2016; Anderson *et al*., 2017). An important part of this expansion is caused by new technologies and species being introduced to new environments (Kumar and Engel, 2016). For the production of the many aquaculture species taking place in coastal zones that are highly vulnerable to climate change, it is believed that aquaculture can adapt by changing production locations or production practices (Bueno and Soto, 2017). Studies such as

[1] In this paper, fish and fisheries products cover finfish, crustaceans, molluscs, frogs, turtles and other edible aquatic animals (such as sea cucumbers, sea urchins, sea squirts and jellyfish) caught or farmed in inland and marine waters. Aquatic plants and mammals are not included. The terms fish as well as seafood are used in the interest of brevity and include the above mentioned species.

Gentry *et al*. (2017), which show that availability of marine production locations is many times higher than those current as well as projected to be used in aquaculture production, support this perspective. Changing the geographical location of aquaculture to adapt to climate change will affect the livelihoods that depend on them.

Climate change is not the only challenge facing the oceans' health and its ability to provide food. There is a growing consensus that our oceans are in poor and declining health, plagued by a myriad of issues ranging from pollution and coastal development to ocean acidification; all of which interacts with climate change and can impact the future of fisheries and aquaculture. Pollution, in forms of untreated sewage, industrial and agricultural runoff, has contributed to the rapid expansion of hypoxic zones characterized by low productivity and reductions in carrying capacity (Diaz and Rosenberg, 2008). Increased plastic pollution has received equal, if not more, attention and is expected to continue increasing. Currently there is no evidence linking plastics to stock population levels, or of plastics entering the seafood supply (Luster *et al.,* 2017), and more research is needed to understand the indirect threats to human health.

Aquatic food production systems differ from terrestrial production systems in several important ways that will impact adaptation to climate change and trade. Seafood may well be the segment of the food production and market system where the most dramatic changes have taken place in recent decades (Anderson, 2003; Anderson *et al*., 2017). In 1970, global seafood production was primarily based on traditional capture fisheries. Despite increasing evidence of over-exploitation, production was still increasing rapidly due to improved fishing technologies and targeting of new stocks. Traditional fisheries harvest had to take place where the fish were located, generally at substantial distances from most large consumer markets. Therefore, most fish had to be conserved and were mostly marketed in product forms such as canned, frozen, smoked, or dried before it reached the consumer. This contributed to making seafood one of the most traded foods worldwide (Asche *et al*., 2015).

In the 1970s, several events took place that are still having a major impact on the transformation of the seafood market. By then ten percent of marine fish stocks were already overfished. As most fish stocks can be found on or along the continental shelf relatively close to the coastline, extending an Exclusive Economic Zone (EEZ) to 200 nautical miles provided the part of the solution to the overfishing challenges in the ocean. Fish stocks within the 200-mile national jurisdiction could be managed by the associated coastal country. After some tense episodes,[2] the 200-mile zone became global practice in 1976 and was formalized by international law in 1982 with the UN Convention on the Law of the Sea (UNCLOS) (United Nations, 2017). The 200-mile EEZ allowed a country or a group of countries to impose a total quota, mostly known as the Total Allowable Catch

[2] Such as the Fish War between the United Kingdom of Great Britain and the Republic of Iceland, when the latter extended its EEZ unilaterally.

(TAC) to protect a fish stock from overfishing. As the 200-mile EEZs excluded a number of countries' fishing fleets from their traditional fishing grounds, the so-called distant water fleets, it constrained the world´s seafood supply system and created a substantial incentive for increased international trade of seafood. This effect could be similar to that of future climate change, in that a number of fish stocks were made unavailable for fishers who normally targeted them, but which could be accessed by consumers through international trade.

The fish stocks that were overfished saw a reduction in supply while economic and population growth increased demand, correspondingly, prices increased (Delgado *et al*., 2003). This created incentives to find alternative sources and provided an additional motivation to increase international seafood trade, as imported fish could substitute for what could not be locally produced. It also provided strong incentives to develop new technologies for producing seafood. Aquaculture is an old production technology, practiced in ancient China, Egypt and Rome (Lockwood, 2017). A "blue revolution" occurred in the 1970s, as knowledge from the agro-sciences was increasingly transferred to the culture of aquatic animals driving productivity growth, reducing production costs and increasing competitiveness for aquaculture products (Asche, 2008; Kumar and Engle, 2016). This proved immensely successful, aquaculture has been the world´s fastest growing food production system since the 1970s (Smith *et al*., 2010; FAO, 2016), and is expected to continue to grow albeit at a slower pace (Kobayashi *et al*., 2015; OECD-FAO, 2017). The growth in aquaculture production was further helped by the fact that the growth of global capture fisheries leveled off in the mid-1980s and has been around 90 million metric tonnes since then, with few possibilities for further production growth. By 2013, aquaculture provided over one half of the seafood for human consumption. However, capture fisheries are still larger in total as about 20 million metric tonnes are landed for other purposes (with reduction to fishmeal and fish oil as the most important).

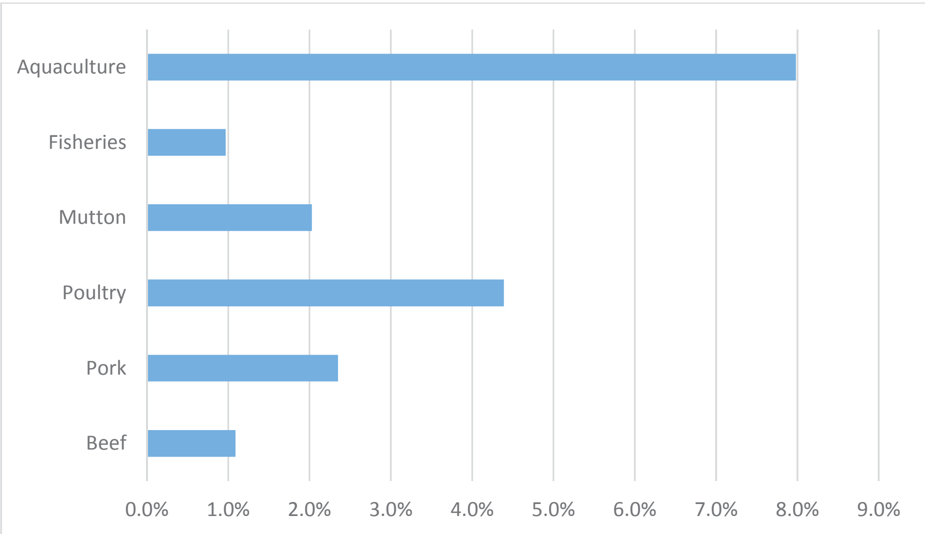
Fish and fishery products are among the most highly traded food products, with 35.2 percent of total production traded in 2015 (FAO, 2018a). As much as 78 percent has been estimated to be exposed to trade competition (Tveteras *et al*., 2012).[3] The high trade share in the seafood market makes it more susceptible to increased trade costs due to climate change than most other foods. On the other hand, existing trade networks also provide an established logistics system to mitigate local production shortages through trade.

[3] Products that face trade competition are products where domestic producers face competition from imports or products where domestic consumers have to pay competitve prices to avoid having the product exported by producers that also have that opportunity.

2. Seafood production

Seafood constitute about 17 percent of the global consumption of animal protein (FAO, 2016), and is the most important source of protein in many poor societies (Allison *et al.*, 2009). Moreover, there have been substantial changes in composition over animal protein availability since 1980. This is illustrated in Figure 1, where the annual growth rates are shown for the period for the main sources. Aquaculture has by far the largest annual growth rate at 8.3 percent – poultry, the fastest growing terrestrial animal protein source, has an annual growth rate of 4.6 percent. As total animal protein production has an annual growth rate of 2.9 percent, all other meat sources are losing production share. This is relatively moderate for pork and mutton as they have annual growth rates over two percent. For beef it is more dramatic as an annual growth rate of 1.1 percent has lead the production share to decline from 25.8 percent in 1980 to 14.5 percent in 2013, and the growth rate is even lower for wild fish at 0.9 percent. It is also worthwhile to note that wild fish has an even lower growth rate when this is computed using only data after 1990.

Figure 1: Annual growth rates in global animal protein production by category, 1980-2015



Source: FAO, 2018a.

As noted above, fish originates from two main production technologies: aquaculture and fisheries.[4] The development in production since 1970 is shown in Figure 2. There was a dramatic shift in the late 1980s. Landings of wild fish stagnated, and stabilized at around

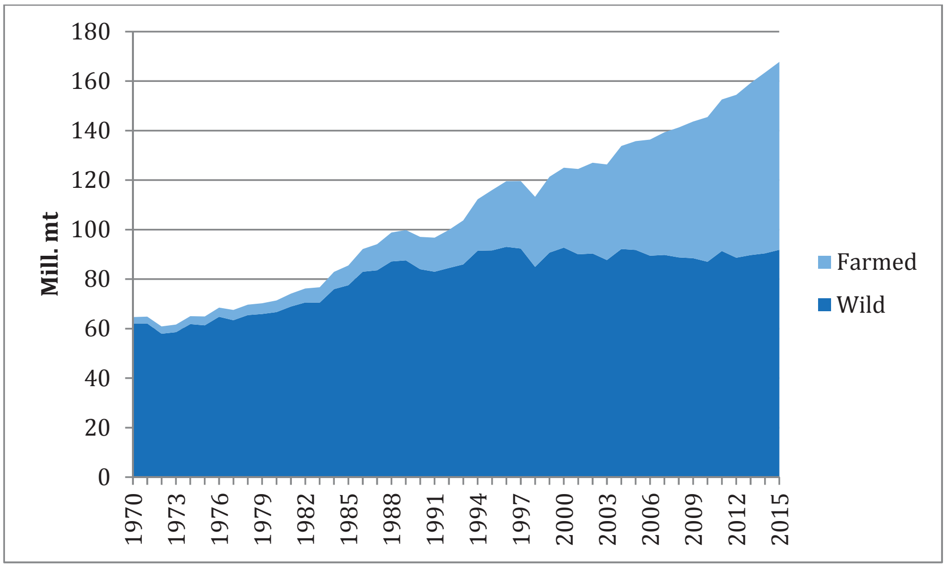
[4] Somewhat surprisingly, it is hard to draw the exact line between aquaculture and fisheries (Klinger et al, 2013). This challenge is due to the fact that human intervention in fisheries production systems is undertaken in a number of production systems to protect stocks or enhance yield. For instance, hatcheries based salmon fisheries have an aquaculture element, and fish bait can often be an important source for feed (for instance in lobster traps).

90 million metric tonnes (the mean landings for the period 1986-2015 is 89.5 million metric tonnes). The landings are not expected to increase much, as only 10.5 percent of the world's fish stocks are under fished. The largest group of species are fully fished at 58.1 percent, while 31.4 percent are regarded as over fished (FAO, 2016).

Fish farming was quite limited in 1970 with a harvest of about 2.6 million metric tonnes. Since then, there has been a rapid expansion in aquaculture production and in 2015 farmed seafood accounted for 45.3 percent of the total seafood supply, with a production of 76.6 million metric tonnes. Aquaculture is the main source of global seafood supply growth since 1990. In 2013 farmed seafood became larger than wild fisheries as a source for food, when taking into account that about 20 million metric tonnes of the landed fish goes to non-food uses, including for reduction to fishmeal and fish oil (FAO, 2017a).

Total global seafood production reached 169.2 million metric tonnes in 2015 (FAO, 2017a). This production growth is strong enough to increase not only the total supply of seafood, but also the global per capita consumption, as per capita consumption of seafood surpassed 20kg in 2015. Global per capita seafood production was 20.2 kg in 2016, the highest on record (FAO, 2017b).

Figure 2: Global fisheries and aquaculture production, 1970-2015

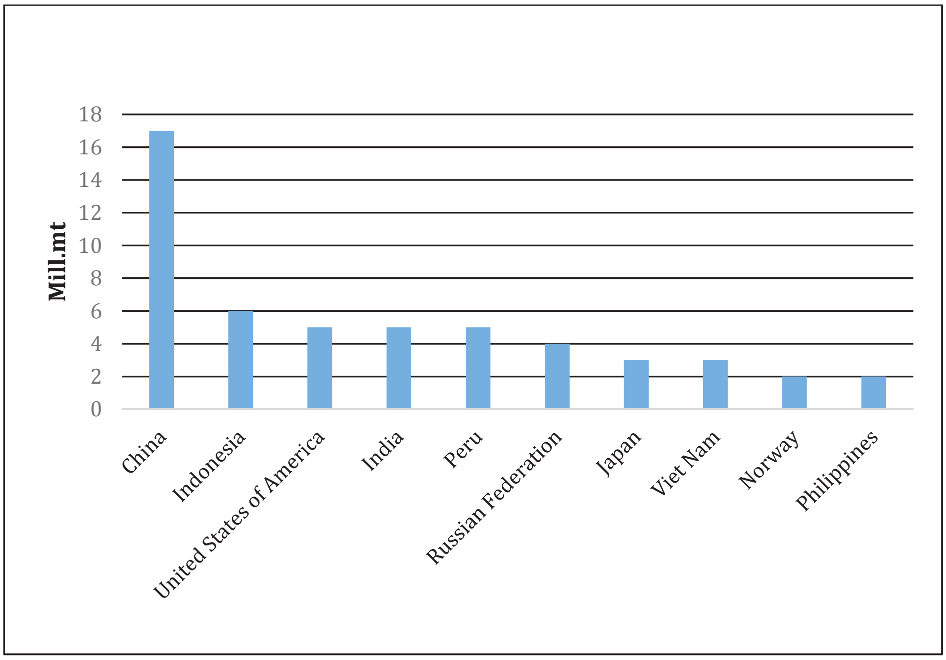


Source: FAO, 2018b.

2.1 Fisheries

Global capture of fisheries production in inland and marine waters in 2015 was 92.6 million metric tonnes. In Figure 3, capture fisheries production of the ten largest countries are shown, and in figure 4 the ten largest species. With 17.6 million metric tonnes, the People's Republic of China (hereafter China) is by far the largest fishing nation, followed by the Republic of Indonesia (hereafter Indonesia) with 6.5 million metric tonnes. The tenth largest country, the Republic of the Philippines (hereafter the Philippines), lands 2.2 million metric tonnes. The ten largest nations land 58 percent of global capture fisheries. This is mostly due to the length of the coastline together with local abundance. However, in some cases, and particularly for China, a large distant water fleet that partly operates in international waters and which partly buys fishing rights in other countries´ EEZ is also important (other relevant distant water fishing nations are The French Republic, Japan, the Republic of Korea and the Kingdom of Spain).[5] The figure indicates that there is a relatively high concentration as a large part of the world´s catches are caught by relatively few countries. However, countries in four continents and in the southern as well as the northern hemispheres are represented, indicating a substantial geographical spread.

Figure 3: Capture fisheries production, main countries in 2015



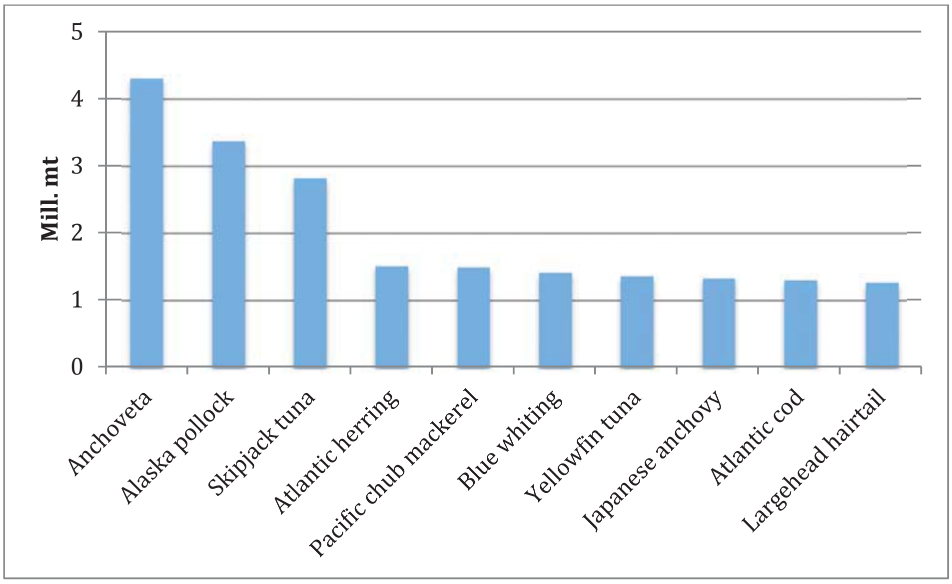
Source: FAO, 2018b.

In Figure 4 the catches are shown for the ten main species. Here, the concentration is much smaller, as the ten most important species make up only 21.8 percent of total

[5] Sales of fishing rights or quotas is an important source of government revenue for several develoing countries, particularly for a number of Pacific Islands and in West Africa.

catches. It is noteworthy that all the top species are finfish, but also that many different types of finfish with a large geographical diversity are represented. Many of the species are small pelagics, like the no.1 species anchoveta, but also groundfish (Alaska Pollock and Atlantic cod) and large pelagics such as tuna are represented in the figure.

Figure 4: Capture fishery production, main species in 2015



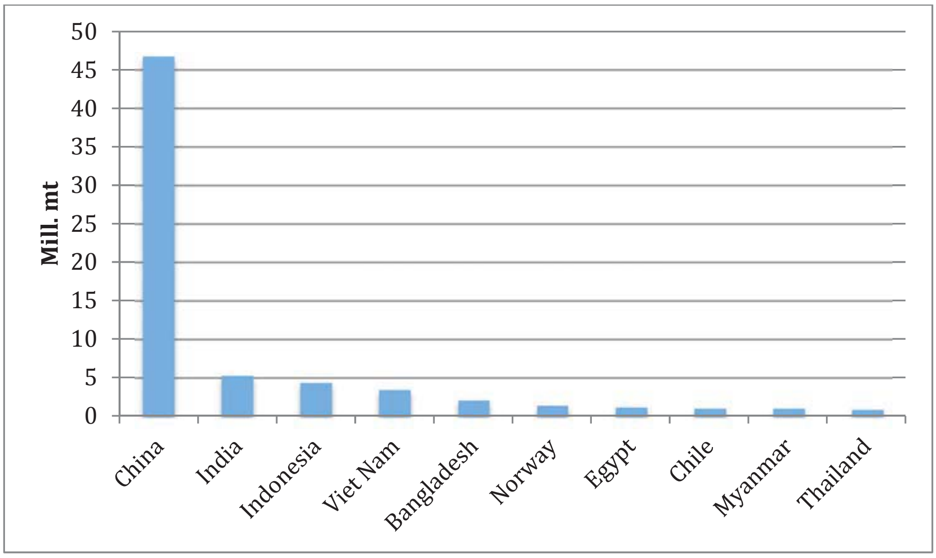
Source: FAO, 2018b.

2.2 Aquaculture

Global aquaculture production in 2015 was 76.6 million metric tonnes. In Figure 5 the production in the ten largest countries is shown, and in Figure 6 the ten most important species (in biomass terms). China is once again the largest producer, its role even more important than in fisheries. With a production of 47.6 million metric tonnes, China accounted for 62.2 percent of total global aquaculture production in 2015 (it is of interest to note, though, that China´s production share by value was substantially lower at 48.6 percent). The Republic of India (hereafter India) was the second largest producer at 5.2 million metric tonnes, and the tenth country on the list. The Kingdom of Thailand produced 0.9 million metric tonnes. In total, the production of the ten largest countries made up 89 percent of global aquaculture production in 2015. Aquaculture production is much more concentrated than fisheries' capture. Also here, four continents are represented in the top list.

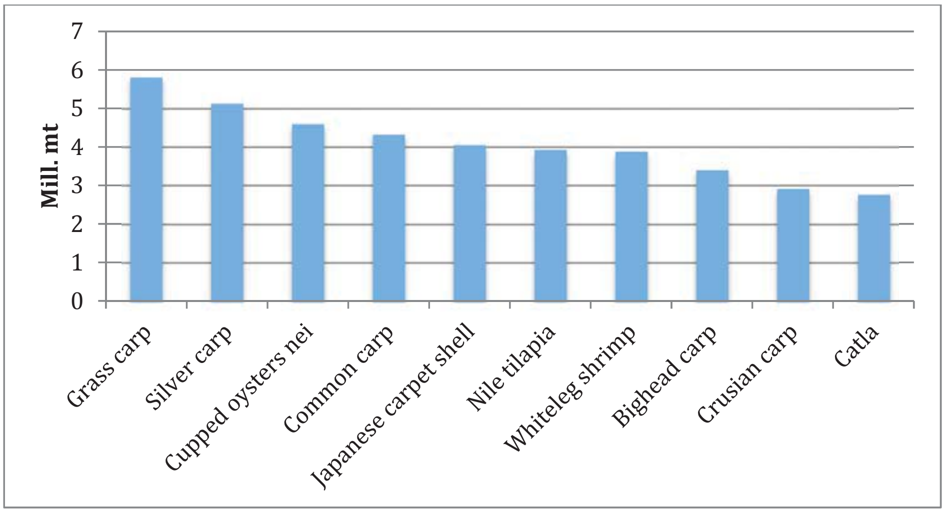
Species' concentration is smaller, as the ten largest species made up 53.3 percent of total production in 2015. As shown in Figure 6, finfish is still most important (seven species), but also two categories of shellfish, oysters and Japanese carpet shell, and whitelegged shrimp are on the list. More importantly, all finfish species are freshwater species in the form of carps and tilapia, and there are no marine species. Shrimps generally also require salt water, but are still usually farmed in land-based ponds. While the concentration in species is higher in aquaculture than in fisheries, this is partly due to a higher degree of geographical concentration in production. Several of the farmed species are, like many terrestrial crops, truly global. For instance, one of the leading aquaculture countries in Central America, the Republic of Honduras, primarily produces shrimp and tilapia, two introduced species (Tveteras, 2015). Tilapia and shrimp, in particular, have become truly global species, and are produced in Asia, Africa, and South America in significant quantities, and in North America and Europe in smaller quantities.

Figure 5: Aquaculture production by main countries in 2015



Source: FAO, 2018b.

Figure 6: Aquaculture production by main species in 2015



Source: FAO, 2018b.

The main reason for the rapidly increasing aquaculture production is a rapid growth in productivity (Asche, 2008; Kumar and Engel, 2016). This has been possible due to a greater degree of control of the production process (Anderson, 2002). In the 1970s control started to be utilized to conduct systematic research and development, and substantial knowledge were transferred from the agro-sciences. This increased productivity in traditional aquaculture systems, and created new technologies that facilitated the domestication of new species and the development of more productive strains. While traditional extensive production methods are still being used, the production cycle is closed for an increasing number of species, and the use of more intensive production technologies continues to increase.

A further substantial increase in aquaculture production is expected. The IFPRI, FAO and Wold Bank´s Fish to 2030 project (Kobayashi *et al*., 2015), estimates that aquaculture production in 2030 will increase by 50 percent from 2011. This amounts to an average annual growth rate of 2.5 percent.[6] This estimate is based on a relatively large general equilibrium model with separate demand and supply equations for the most important species in each country. The main drivers of demand growth are population and economic growth, while the main driver for production growth is supply growth. While the model does not explicitly account for climate change, the authors acknowledge the challenge, and implicitly accounted for the effects to influence rates of productivity growth.

The estimated growth rate of 2.5 percent per year is lower than it has been in previous decades, but is likely to maintain aquaculture´s position as the world's fastest growing food production system. However, there is substantial uncertainty in the estimates, and the Fish to 2030 project also provides projections for six different scenarios (based on various assumptions for future productivity growth) to account for some of this uncertainty. The projections' range varies from 90.7 million metric tonnes to 116.2 million metric tonnes of total aquaculture production in 2030. It is worthwhile to note that the distribution of the estimates is skewed, indicating a much larger upside potential than downside potential, that is, the projections indicate that it is more likely that the aquaculture production in 2030 will be in the higher end of this range. This implies that while climate change may influence the growth rate, aquaculture production under any scenario is likely to continue to grow rapidly.

There are of course a number of factors that will influence how large the production growth will become in addition to climate change (Asche, Roheim and Smith, 2016; Knapp and Rubino, 2016). Some are natural endowments, and hence South America has an advantage with respect to access to water. Population growth influences potential demand. Management systems, and particularly the extent to which diseases and other consequences of unsustainable practices can be prevented on a large scale will also be important. In particular, the regulatory systems in many developed countries are so averse to allowing any environmental risks that aquaculture production will not expand

[6] Other projections have a similar range. For instance, OECD-FAO (2017) has a sligtly higher growth rate at 2.6 percent.

in these countries (Chu and Tudur, 2014). Trade barriers can also influence where production takes place, although so far producing countries have proved quite able to circumvent the main intention of the trade barriers through a reallocation of trade patterns or products, as in most cases the trade barriers apply to named producers and/or specific product forms (Asche *et al*., 2016).

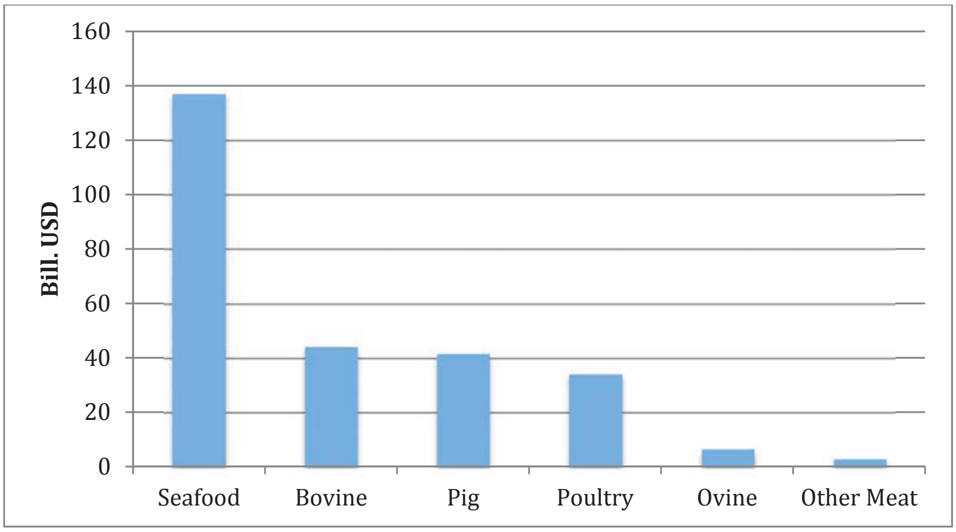
Still, the most important factor influencing aquaculture production seems to be economic growth. A large share of aquaculture production is primarily a cash crop (Smith *et al*., 2010), and income growth is likely the most important driver for production growth (Belton, Bush and Little, 2018). The conflux of these factors indicates that aquaculture production in East Asia will continue to grow and this will remain the most important producing region. There is a huge potential in South America where production is likely to increase substantially and maybe even faster than in East Asia (Kobayashi *et al*., 2015). There is most uncertainty with respect to production growth in Africa, where the growth in aquaculture production is likely to be moderate.

3. International seafood trade

During the last 30 years, the world´s seafood markets have also changed profoundly. Improved logistics and distribution as well as lower transportation costs have created global markets for a number of species, where earlier there were regional or local markets (Tveteras *et al.*, 2012). The international trade of seafood, as measured in total real value exported, has grown substantially over the past four decades.[7] In 1976 the total traded value was USD 30.9 billion. This increased more than fourfold to USD 131.5 billion in 2015. This has made seafood one of the most traded groups of food products. The trade value for seafood is shown in Figure 7 together with the different sources for animal protein. At 48 percent of total trade value in 2013, the international trade in fish and fishery products is almost as large as all the trade with terrestrial meat combined.

[7] Since the data are in USD, they were adjusted for inflation using the US CPI.

Figure 7. International animal protein trade by group in 2013



Source: FAO, 2018a.

Most fish stocks reside along the continental shelf, which means that most fish stocks are easily accessible primarily by the relevant coastal nations. This is an incentive to trade in itself that was substantially strengthened with the introduction of the 200 miles EEZ, as this limited access to many fisheries resources by distance water fishing nations. Seafood is regarded as an industrial product by the World Trade Organization (WTO), and therefore is not included among agricultural products.[8] This has contributed to preventing trade barriers from being a major obstacle to trade, particularly into developed countries where the tariffs tends to be lower. However, many developing countries still limit imports with high trade barriers. In addition, several countries/regions have limited tariffs on product forms with a limited degree of processing to supply domestic industries with input factors.[9]

The increased aquaculture production and trade have not come without controversy, as indicated by the prevalence of aquaculture species in anti-dumping/countervailing duty conflicts, concerns related to seafood quality, fraud and adulteration and issues related to food security in developing countries with a high dependence on fisheries and often ineffective fisheries governance. Not surprisingly, the two most valuable farmed species, salmon and shrimp, show up most often in these cases although a number of other species have also been involved in anti-dumping cases.[10] However, as trade has continued to

[8] Although it is not entirely clear why seafood is treated as an industrial product, the main reason appears to be that one did not want all the exceptions that limits agricutural trade to apply also here.
[9] For instance, the tariff on whole salmon and salmon fillets into the European Union is 3 percent, while it is 13 percent for smoked salmon (Kinnucan and Myrland, 2002).
[10] Kinnucan and Myrland (2002) and Keithly and Poudel (2008) provide two case studies for Atlantic salmon and shrimp respectively. Little *et al.* (2012) provides an example of another species, pangasius.

increase rapidly, these issues do not appear to have had a major negative consequence even though they might have increased trade costs (Asche *et al*., 2016).

Increased seafood trade has been facilitated by technological innovations and globalization in general (Anderson, 2003; Anderson, Asche and Tveteras, 2010). Improved transportation and logistics have facilitated globalization by leading to substantial reductions in transportation costs by surface and air promoting the international trade of fresh seafood. Lower transportation costs have given new producers access to the global market. Delink *et al.* (2017) indicate that climate change is likely to increase trade costs in general. This could affect trade in fish and fishery products, but as trade costs for shipments by sea (the most common transportation form for seafood) generally constitutes a small part of the total cost of a product (Anderson, Asche and Tveteras., 2010), the effect is likely to be limited.

Improved logistics have also created economies of scale and scope at all levels of the supply chain, particularly in the retail sector where supermarkets have replaced fishmongers and markets in a number of places. Progress in storage and preservation has continued, allowing a wider range of seafood products to be traded. Freezing technology has improved to such an extent in recent years that many product forms can be frozen twice, allowing products to be processed in locations with competitive advantages in processing fish rather than in locations close to where the fish is caught. Lastly, the improved control in the harvesting process in fisheries and throughout the production process in aquaculture has enabled producers to better target the needs of the modern consumer and to further innovate in the supply chains.

These various factors tend to reinforce each other, even though the strength of each differs by market and species. Increased trade has profoundly affected seafood markets; an increasing number of markets have gone from regional to global and more species from widely different places have become substitutes (Asche *et al.*, 2001; Tveteras *et al*., 2012). Moreover, a growing share of producers have access to the global market as global transportation systems improve and can take advantage of new market opportunities, increasing trade competition in export as well as import markets. For those consumers who have the ability to pay, these trends increase the available supply of seafood in the short run. Hence, the share of imports of developed countries – the European Union, Japan, and the United States of America in particular – remains high.

Economic growth in many developing countries has increased demand in regions that did not traditionally import much seafood, and particularly in East Asia including China (Delgado *et al.*, 2003; Kobayashi *et al.*, 2015). As a result, there is a declining import share for developed countries despite growth in total values of seafood exports from developing to developed countries. Economic growth in China has caused it to become the first importer by quantity, primarily due to imports for domestic consumption but also due to value-added re-export. China is also the largest exporter.

Trade with seafood in general, and thereby also for aquaculture, create food security concerns, as it is often perceived to move large volumes of fish of high nutritional value from poor (i.e. developing) to rich (i.e. developed) countries. From a food security perspective, this could be interpreted as a substantial problem, as it might mean that poor countries may be deprived of these proteins (Swartz *et al.*, 2010). On the other hand, this could be interpreted as contributing to poverty alleviation due to the increased earnings and purchasing power resulting from export growth (Kurien, 2004; Smith *et al.*, 2010). Béné *et al.* (2009) provide an overview of the literature on these different perspectives on seafood trade. While the increase in trade flows and aggregate economic growth is indisputable, the effect on poverty reduction, via economic growth, of those trade flows is contentious (Roheim, 2004; Asche, Roheim and Smith, 2016; Belton, Bush and Little, 2018).

Asche *et al.* (2015) show how the FAO´s data on global seafood trade can be used to separate exports from imports to both developing and developed countries, using data for the period 1976-2011.[11] The developing countries' share of seafood exports rose steadily from 36.5 percent in 1976 to 53.7 percent in 2015. Hence, exports from developing countries, where most of the aquaculture production takes place, have grown faster than the total increase in global seafood exports.

Global seafood imports for developing and developed countries tell a different story, as developing countries' share of the imports by value is much lower. In 1976, developing countries imported only 12.4 percent of the total value of seafood imports. While that share steadily increased throughout the period 1976-2011, it was no more than 29 percent of the total value of seafood imports in 2015. This asymmetry in exports and import between developing and developed countries can be used to argue that exporting seafood is detrimental for the food security of developing countries.

According to Asche *et al*. (2015) the focus solely on values can be misleading as one must also account for quantities and their impact on unit value. While developing countries make up only 29 percent of the imports in 2015 when measured in value, they made up 45.9 percent of the imports measured in quantity. In other words, the seafood trade deficit for developing countries is much smaller when measured in quantity than in dollar value. Asche *et al.* (2015) shows that the much larger value share of the exports than imports means that developing countries in aggregate are very well compensated for the quantities they give up. This export revenue can be spent on imports of other goods, including other foods, and accordingly contribute to food security as well as other economic activity. However, there are certainly also examples where exports are not necessarily beneficial to a country (Béné *et al.*, 2009).

[11] The product categories "aquatic plants", "inedible", and "sponges, corals, shells" from the FAO seafood trade statistics are excluded to focus on the trade of seafood products.

For trade to potentially alleviate some effects of climate change, the increasing imports by developing countries are important as that implies that the capacity to import seafood is improving. Nigeria provides a good example in that it is now the tenth largest importer by quantity, but as it imports relatively low valued fish, it is lower by value. Nigeria is the world's largest importer of mackerel and several other lower valued pelagic species (Asche, 2017). While such oily fish is of lower economic value they nonetheless represent an important source of proteins and other nutrients, being especially rich in omega 3 fatty acids. Nigeria is also an important market for many fisheries byproducts. For instance, it is the largest importer of dried cod heads from Iceland. The small pelagics also provide a good illustration that most likely there is no relationship between nutritional value and the price of seafood products, although this is a topic that appears to have been poorly studied.[12]

The geographical extent of seafood markets was traditionally limited because of the perishability of the product. Until a hundred years ago, it was only a few heavily processed product forms that were shipped over longer distances. For other product forms the market was, at best, regional, and often very local. As transportation, conservation and logistics improved, and fueled by increased demand that could not be met from regional fisheries, the sources for the fish became increasingly global. The whitefish market is a good example (Asche, Roll and Trollvik, 2009). In 1980 it included primarily North Atlantic species, such as cod, saithe, and haddock. By 1990, Alaska pollock and Pacific cod were established as a major part of the market, linking the North Atlantic and North Pacific fisheries. During the 1990s, species such as Nile perch, Argentinean and Namibian hake, and hoki from New Zealand, and after the turn of the century farmed species such as *pangasius* and tilapia, made the market truly global (Bronnmann *et al*., 2016).

A similar development has taken place for most main species groups, creating global markets with a common price determination process. This is the case for shrimp (Vinuya, 2007; Asche *et al.*, 2012), salmon (Asche, Bremnes and Wessells, 1999) and tuna (Bose and McIlgrom, 1996; Jeon *et al*., 2007). Moreover, when farmed fish becomes a large enough part of supply, production cost in aquaculture determines the price (Asche, Bremnes and Wessells, 1999). This is because farmers adjust production (primarily as a part of businesses fails) when prices are low, while in most fisheries it is only over-capacity that is adjusted.

Most of the main trends in the seafood market lead to more trade and more integrated markets. However, during recent decades there are also an increasing number of factors that contribute to market segmentation, particularly in the European Union and the United States of America. The most important concern is the environmental impact of the fishing or aquaculture activity, although quality or safety signals can also segment the

[12] However, there is no doubt that higher seafood consumption is beneficial for public health (Mozzafarian and Ram, 2006; Larsen, Eilertsen and Elvevoll, 2011).

market by allowing producers to obtain a margin, and in some cases to obtain a completely independent price determination process. There is, for instance, increasing evidence that ecolabeling succeeds in segmenting the market (Fonner and Sylvia, 2015; Stemle *et al.*, 2016).

4. The impact of climate change

Climate change impacts fisheries and aquaculture production in numerous ways, and while the aggregate effects on fisheries have received substantial attention (Barange e*t al.* 2014; Cheung *et al.,* 2009), less focus has been given to aquaculture (Bueno and Soto, 2017). Because the two production systems are fundamentally different, they will be discussed separately, despite the fact that the main physical effects of climate change remain the same. These are changes in water (and air) temperatures, changes in precipitation, river flows and flooding, changes in ocean salinity, circulation and mixing and changes in storm frequency and intensity that affect the physical systems where production takes place (Barange and Perry, 2009; Stenseth *et al.,* 2002; Lehodey *et al.,* 2012; Brander 2007).

4.1 Fisheries

Fishing is our last great hunting industry, and wild aquatic production or fishing therefore depends on nature´s food chains. Humanity provides a number of impacts on these food chains that influence production levels for various species. These are direct impacts such as with fishing, where the impact depends also on the management system (or lack thereof), and indirect effects through habitat change such as pollution. From this perspective, the combined effects of climate change can be regarded as the most significant habitat change that humans have caused in the world´s oceans, even though other measures may have impacted rivers and smaller inland waterways even more.

As fish production ultimately relies on energy being transferred through the marine food web (Hollowed *et al*., 2013), the first impact of climate change on fish stocks would be through changes in primary production, the start of the food chain in the oceans. Recent projections estimate a moderate global decline of three to six percent in primary production. In addition, higher temperatures can result in metabolic inefficiencies in the transfer of energy from primary to top producers. The combined effects have been estimated to affect the global fish catch potential by less than ten percent (Barange *et al.* 2014). However, global averages mask very significant geographical differences, largely driven by opposing trends in the impacts of temperature and primary production change between higher latitudes and tropical seas. While tropical zones are likely to see a reduction in production, extensions in the “summer” or growth period in more temperate waters would lead to increased production (Cheung *et al.* 2011). As temperature change is highly uneven, there are stronger effects in some zones and weaker in others.

As most of the ocean's production is concentrated in areas of upwellings along various continental shelf or on parts of the continental shelfs where rivers provide a significant influx of nutrients, the impacts of climate change in these waters are particularly important. The impact of different factors again has different impacts on phytoplankton production and thereby ecosystem productivity (Blanchard *et al.* 2012; Hollowed *et al*., 2013). For instance, poorer mixing of water can reduce nutrient loads along the continental shelf, however, slower ventilation can also increase periods where phytoplankton resides in high productivity zones, but maybe with less oxygen due to deoxygenation. Also the impact on zooplankton production is uncertain (Blanchard *et al.,* 2012; Hollowed *et al.,* 2013). Most models indicate lower productivity in low latitude waters and higher productivity in high altitude waters, again with regional and local differences.

Climate change will also influence fish and shellfish directly and indirectly. The direct mechanisms are of course the same as for the primary production. Fish will be exposed to a complex mix of changing abiotic conditions, such as changes in temperature, salinity, oxygen and water pH. In addition, there will be changes in biotic conditions such as shifting distribution and migration patterns, species composition in many areas, and abundance of predators and prey (Sumaila *et al*., 2011; Branch *et al*., 2013; Pinsky *et al*., 2013). These changes may affect the physiology, phenology, and behavior of marine fish and shellfish at any life-history stage, and can increase and reduce local abundance (Hollowed *et al*., 2013). Adaptive capacity does vary with species. Kingsolver (2009) identified three main types of potential responses of a species to climate change: distribution changes in space and time, productivity changes, and adaptation.

There are a handful of global models trying to predict the impacts on marine production in the oceans. Generally, these models indicate that production will increase at high northern latitudes, less so at high southern latitudes as temperatures increase less in the south and shrinking of ice-cover does not increase "new" habitats to the same extent. The models also predict reduction in production in mid and low altitudes, but with substantial variation between regions, including some areas where temperature actually has a decreasing trend.

Most large scale models reach similar and somewhat imprecise conclusions in that the net impact of climate change on global fisheries production is uncertain, and project important regional differences (Stock *et al*., 2010; Hollowed *et al*., 2013). The only strong regional conclusion that seems to always hold true is that production is expected to increase significantly in the north Atlantic and Pacific, and be reduced in many tropical zones. These results indicate that our best estimate of future fisheries landings confirm that these will still vary around 90 million metric tonnes, but are unable to provide more detail on where or how the distribution of production will change.

There is also a large literature focusing on specific cases, i.e. the observed effects of climate change on the distribution and production of individual fisheries or limited areas. Cases include several studies documenting temperate species moving to higher latitudes, presumably in response to warming (e.g. Beare *et al.*, 2004). However, there is less evidence of contractions in the ranges of boral species (Rijnsdorp *et al.*, 2009). An example of distributional effects in tropical waters is how the near-surface densities of many high-oxygen demand species of pelagic fish increase more in the eastern tropical Atlantic and reduced in the western tropical Atlantic (Prince *et al.*, 2010). Petitgas *et al.* (2012) note that the distributional changes may be the result of either active migration to higher latitudes or from differential productivity of local populations in lower and higher latitudes. More important from a policy perspective is that the causal factors are poorly documented, limiting our predictive ability.

At an even finer scale, the impact of climate change is investigated for specific regions. An example, that also shows that aquatic systems have importance inland, is the Chad basin which converges around a shrinking lake as regional warming drives decreased rainfall and increased evapotranspiration (Coe and Foley, 2001).[13] Another regional example is coastal fishers coping with bleached coral reefs as atmospheric warming leads to warmer seas and higher bleaching susceptibility (Hoegh-Guldberg *et al.* 2007). However, while providing important information and a more nuanced picture of the impact of climate change and possible adaptions, this literature does not help provide a clearer picture of the main challenges than the aggregate models.

As the regional studies tend to have a broader focus then the more global models, they show that the impact of climate change on fish stocks does not occur in isolation, but in interaction with other factors, where fishing may be the most important. The depletion of the northern cod on the east coast of Canada provides an interesting example, in that severe overfishing made the stocks much more vulnerable when climate change occurred, and facilitated stock collapse when climate change occurred (Hilborn, Punt and Orensanz, 2004). A similar collapse did not occur for the Icelandic or the northeast Atlantic cod stocks, although it is not known if this was due to less serious impact of climate change or better management. Hilborn, Punt and Orensanz (2004) also note that the management system influences adaptive capacity in that fishing value actually increased after the collapse of cod as new species thrived, but the changes benefitted fishers with licenses for those species, while the licensing system prevented cod fishers from transferring to those fisheries.

In general, our knowledge of impacts on fishers and societies is more limited. Allison *et al.* (2009) assess the vulnerability of 132 national economies to the impact of climate change on fisheries. Vulnerability to climate change is assumed to have three components:

[13] Fisheries in inland waters represent only 12 percent of capture fisheries production and 7 percent of total capture and aquaculture production but can be important locally, especially from a food security and nutrition perspective, in particular in land-locked and low income countries. They may also face larger challenges in adapting to climate change due their confined regional ecosystems.

exposure to physical effects of climate change, the dependence of the national economy on the returns from the sector and the adaptive capacity. The results indicate that the most vulnerable countries tend to be located in tropical Africa and northwest South America and some countries in Asia. These countries are generally not the countries with the highest seafood consumption, but are countries where seafood makes up a very high share of the proteins and nutrients and are also poor. Ding *et al.*, (2017) reports similar results. They are also countries that have additional substantive challenges due to overfishing and stagnating or declining fisheries landings (Golden *et al.*, 2016). This underlines that impacts of climate change on societies and food security is not necessarily strongly correlated with the physical impacts of climate change. As highlighted by the Canadian cod example, management system may be more important, since well managed fisheries tend to have more resilient stocks. Poor countries also tend to have poorer prospects with respect to replacing lost domestic production by imports. According to Allison *et al.* (2009) and Ding *et al.* (2017), poorer countries are also less able to exploit potential benefits associated with climate change such as increased abundance of some species. The last point is particularly important if the species that increase in abundance is a new migrant and requires adaptive capacity to be utilized, such as adoption of new harvesting technologies, in order to be exploited.

Lam *et al.* (2016) also indicate that the impact of climate change on landed value may be reduced due to climate change because of changes in the composition of landings. Hence, even with no changes in landing levels, the economic value of fisheries may be reduced. However, here also the impact will vary, as shown in the Canadian northern cod example (Hilborn *et al.*, 2004), where the collapse of the cod stocks led to an increase in landed values. Different harvest compositions can also affect the nutritional value of the seafood landed.

4.2 Aquaculture

Even with aquaculture production rapidly increasing and overtaking wild fisheries as a source of food for human consumption, the impact of climate change on aquaculture production has received substantially less attention. The rapid increases in production do, however, indicate that even if there are reductions in fisheries production, they may be made up by aquaculture production in aggregate. As shown in section 2.2, aquaculture production is substantially more concentrated then fisheries in terms of both production and species, and trade is likely to be essential if the increased aquaculture production is to reach those areas where fisheries are in decline. It is worth noting, though, that particularly in Southeast Asia there are examples of declining fisheries production (primarily due to over-fishing) being compensated by increased aquaculture production (Toufique and Belton, 2014). This is particularly important, as productivity improvements in aquaculture production make production profitable at prices that are lower than those of available wild fish, thereby increasing seafood availability and economic access.

The location of aquaculture production units by itself ensures that impacts will differ from fisheries. Production tends to be confined to coastline as in pen (cage)-based marine aquaculture, but more often it occurs in ponds or in various types of cages in rivers and lakes. Freshwater species are also much more important, making climate changes in terrestrial ecosystems more important.

Bueno and Soto (2017) provide the most comprehensive review of the potential impacts of climate change on aquaculture. Increased water temperatures may increase the rate of growth of cultured stock, which may enhance aquaculture production. However, when temperatures rise above the optimal range they may lead to reduced feed intake and feed utilization efficiency (De Silva and Soto, 2009; Bueno and Soto, 2017). Thus, seasonal production, harvest and price patterns are expected to change in response to changing temperature profiles, along with the regional spatial efficiency distribution. For coastal species, extreme weather events and sea level rises may be the most important challenges, and raising temperature may also increase the rate of eutrophication and harmful algal blooms (Peperzak, 2003; Edwards *et al.*, 2006) and the spread of bacterial diseases, which have negative effects on fish health and production. For pond-raised species, salinity of soil may create an additional challenge. In freshwater systems, changed flooding patterns and water availability are potentially important concerns.[14]

Generally, the adaptive capacity of aquaculture is perceived to be larger than for fisheries, as the control of production processes (Anderson, 2002) facilitates movement of the production from less suitable to more suitable locations, and also changing of species. From this perspective it may be important that several species are now truly global, even though they may be exotic species in most production locations.

Gentry *et al.* (2017) map the biological production potential for marine aquaculture across the globe finding vast areas in nearly every coastal country that are suitable for aquaculture. They highlight Indonesia, Australia and the Argentine Republic among countries with particularly high potential for marine aquaculture. They conclude:

> "Given the relatively small amount of space needed for aquaculture to meet global and national seafood demands (especially if optimally sited), the breadth of physiological tolerances found across cultured species and the ability of selective breeding to adapt organisms to future agro-ecosystems, the overarching conclusions of this paper [that there is ample space available for increased aquaculture production] are likely robust." (Gentry *et al.,* 2017)

[14] De Silva and Soto (2009) notes that climate change may also affect the availability and prices of fishmeal and fish oil, important ingredients in aquafeed, increasing production cost and thereby limiting production. However, Tacon and Metian (2016) show how aquacultures dependence rates on fishmeal and fish oil is steadily declining. This is due to improved nutritional knowledge and the fact that many species does not need formula based feed. As a consequence, the fact that global fishmeal production has been declining since the turn of the century has not impacted aquaculture growth.

While this analysis refers specifically to marine aquaculture, the sentiment generally holds for aggregate analysis for all aquaculture, as production is predicted to continue to increase rapidly, independently of assumptions made with respect to climate change (Kobayashi *et al.*, 2015). However, the geographic concentration is likely to be largely maintained as growth is predicted to be strong in Southeast Asia, China and India, although the strongest growth is expected in Latin America. In some of the most vulnerable regions, and particularly in Africa, there is expected to be growth, albeit not strong and from a limited base level.

Also for aquaculture there exist numerous analyses at the regional or country level, although the geographical extent is mostly more limited than for fisheries. For instance, Gasalla, Abdallah and Lemos (2017) provide an analysis of potential climate change impacts on shrimp farms in the Northeast of the Federative Republic of Brazil that include extreme high salinities in drier zones and loss of farming sites (intertidal farms) due to sea level rises; effects upon high stocking density, dissolved oxygen, metabolism and excretion, increased virulence and new diseases due to temperature shifts; losses of stock, structures and farming sites due to floods in intensely occupied estuaries; osmotic stress and water management difficulty with droughts; losses of stock and mortality due algal blooms; lower hatchery development and decreased pH in high stocking densities due to ocean acidification. Bell *et al.* (2013) look at the tropical Pacific, and find that climate change is expected to enhance tilapia production, since an increase in temperature would allow fish to grow faster and farming would be possible at higher elevations. In addition, greater rainfall provides additional locations for ponds, including perhaps some equatorial islands where conditions for freshwater aquaculture are now marginal. Herrmannsen and Heen (2012) show how Norwegian salmon production is moving north as water temperatures increase. These few examples are largely representative for this literature, which seem to come in three categories: 1) documented or expected negative impacts on existing industries that will lead to reduction in production due to limited ability to adapt, 2) opportunities as climate change improves local conditions and production will increase, and 3) adaptation by moving production geographically or changing which species are being farmed, with indeterminate impact on production (Harvey *et al.*, 2017).

5. Some additional issues

As indicated by the discussion above, assessing the impact of climate change on fisheries and aquaculture production is complicated in itself. This also makes any recommendations to address these issues challenging. Making recommendations are further complicated by the fact that different countries and regions capacity to address issues are confounded with a number of additional challenges. This session discuss some important additional issues to be considered on the potential role of international trade in mitigating climate change.

A review of the literature on the state of the world´s fisheries indicates a sector facing many challenges. A number of fisheries are not managed at all, and the tragedy of the commons is allowed to play out. More than 30 percent of global fish stocks are being overexploited (FAO, 2016), and as illustrated with the northern cod example of Hilborn *et al.* (2004), stocks in poor condition are more exposed whenever any exogenous shock such as climate change occur. An additional complication is that when a natural resource is poorly managed, which basically means at a stock level that is lower than that associated with maximum sustainable yield, increased trade is welfare reducing (Brander and Taylor, 1998). This is caused by the fact that the increased price that is associated with incentives to start exporting or to export more, leads an over-fished stock to become more over-fished using even more excessive effort.

However, there are also good reasons for hope. Fisheries management in the oceans is generally a relatively recent occurrence, as for a long time it was believed that the ocean´s fish stocks were inexhaustible. Huxley (1883) provides one of the most well-known opinions to this effect.[15] While there are early examples of attempts at fisheries management for particularly vulnerable stocks, as for instance the Pacific Halibut Commission and the International Whaling Commission, it was not until the mid-20th century that it became obvious that humanity´s fishing power had, with the advent of engines, sonars, power-block and much larger and more durable gears, became large enough to fish down virtually any stock (Squires and Vestergaard, 2013). Gordon and Hannesson (2015) provide a good example of this process in terms of the Atlantic herring, where the larger vessels not only allowed the traditional fishing ground to be fished down, but also allowed the fishers to move further and further out into the high seas targeting previously un-fished areas.

The first step in any fisheries management system is the protection of the fish stocks. The two most common approaches to achieve this are to restrict effort, for instance in terms of number of fishers, what gear they can use etc., or in terms of a restriction on how much fish can be caught with a quota (often known as a Total Allowable Catch –TAC) (Wilen, 2000). In countries/fisheries where fisheries management systems have been instigated, fish stocks tends to do much better, and there are a number of examples of severely reduced fish stocks that have been rebuilt, particularly in the developed world (Ye and Gutierrez, 2017). Unfortunately, these management systems do not account for economic incentives, and often lead to a race-to-fish as well as over-capacity. These challenges can be exacerbated with subsidies implemented to alleviate income short-falls due to lower quotas and higher costs associated with the race-to-fish. With stronger harvest rights for the fisheries such as catch-shares, the over-capacity challenges are reduced and the fish stocks generally do even better (Costello, Gaines and Lyham, 2008).

[15] In a strong contrast, there have been management systems regulating access and/or take in many inland and fisheries for centuries, as the impact of human activity on the stocks under these conditions were much more apparent (Bolster, 2012).

A perceived challenge with all fisheries management is that it limits access, and thereby has negative social consequences. It is often argued that the stronger the harvest rights the greater the social challenges are, and in the literature the most efficient management system, catch-shares, are perceived to lead to the strongest social challenges (e.g. Olson 2011; Soliman 2014; Pinkerton and Davis 2015). However, social trade-offs are far from straightforward. For instance, Abbott *et al.* (2010) showed that a decline in the number of fishing jobs after the implementation of catch shares in the Bering Sea crab fisheries led to a net shift from more insecure short-term jobs to more secure long term jobs with no overall decline in fishing crew days. Notwithstanding concerns over well-being and job satisfaction, a decline in the number of fishers can also lead to increased employment in the post-harvest sector (Manning, Taylor and Wilen, 2014; Eggert, Greaker and Kidane, 2015), which can at least partially offset the social impacts of fisher exclusion. How serious these challenges are, of course, depend on the societies where the fishing sector operates the capacity for change and the fishers' alternative job opportunities (Bené *et al.*, 2016).

Even though it is increasingly recognized that better management is important for sustainable fisheries and livelihoods based on fisheries, lack of management remains a major issue (Ye and Gutierrez 2017). It is not arbitrary where resources and capacity are available for fisheries management, and even though there are exceptions, most well managed fisheries are in developed countries, or in more advanced developing countries (for instance, both the Republic of Chile and the Republic of Peru operate catch-share systems on their main fish stocks). In addition, even though the 200 miles EEZ led to a large part of the ocean´s fish stock coming under the control of nation states with ability and incentives to manage, there are still a number of poorly or unregulated fish stocks in international waters. Many management bodies in international waters, such as Regional Fisheries Management Organizations (RFMOs), have no direct enforcement tools. These fisheries are grouped together as Illegal, Unregulated or Unreported (IUU) fisheries. While this is a useful label to promote good management, it is problematic for many developing countries with limited capacity to manage their fisheries, and whose fisheries would be labeled as IUU not because they are illegal, but because the fishery is unregulated and catches are often unreported.

Also, with respect to aquaculture, governance capacity is an important issue. Most aquaculture operations use a number of natural inputs such as water and land, and there are often questions with respect to the environmental sustainability of specific operations due to their environmental externalities (Naylor *et al*., 2000; Abate *et al*., 2016). Many of these externalities can be exacerbated by the effects of climate change. Gordon and Bjørndal (2009) show that many externalities can be reduced as the scale of aquaculture operations increase, as larger investments gives stronger incentives and capacity to invest in better environmental practice. However, the capacity for governance from authorities as well as industry and society at large tend to be more limited the poorer and more vulnerable farmers are. This implies that increased aquaculture production can, when governance is poor, create significant environmental externalities.

In addition, increased aquaculture production has often been associated with over-fishing, as many (although far from all) aquaculture operations use feed that contain fishmeal (and sometimes fish oil) from wild fisheries. The increased aquaculture production will then increase demand for fishmeal and thereby forage fish (Naylor *et al*., 2000).[16] However, this issue has become less important over time, as aquaculture production continue to grow rapidly, while fishmeal production is actually declining. The most important reason for this is that improved knowledge has reduced the content of marine ingredients in the feed (Tacon and Metian, 2008; Ye and Guitieretz, 2017; Beveridge *et al*., 2013), and even a highly intensive species like salmon is now a net provider of marine protein (Ytrestøl, Aas and Åsgård, 2015). Still, one can find numerous examples of local sectors where the aquaculture industry depends on locally supplied small fish, which is often over-fished and purchased in competition with the local poor.

An important feature of aquaculture is that many of the most important species, like in agriculture, are exotic. Tilapia and several carps are grown on all continents but Antarctica, shrimp and other species have reached a number of countries, Atlantic salmon is grown in the northern as well as southern hemisphere and almost a third is grown in the Pacific. As with agriculture there are a number of good reasons for this. In particular, it allows knowledge including research associated with the individual species to also travel the world, and farmers in countries that cannot fund much research get it embedded in the input factors they buy. This is true both in developed countries like for salmon (Asche, 2008) and for developing countries like Bangladesh (Belton, Bush and Little, 2018). As the world has got more concerned over introduced species, this can hinder the development of the sector. However, while the spread of knowledge may foster adaptive capacity and resilience, dependence of few species can also increase risk when climate change influence the production environment.

There is also a large literature that documents that most change, even if overall positive, has losers and these are often among the poorest. This discussion will impact any measures that are implemented to address climate change as well. For some, food security is only about being locally self-sufficient, while for others food security is as much about economic development that provides an income to purchase the necessary food (Smith *et al.,* 2010). One part of the literature primarily documents that any social change, both when focusing on management systems and international trade, leads to displacement from traditional fisheries related roles, particularly of the poor (Bené *et al.*, 2009; Olson, 2011; Soliman, 2014; Pinkerton and Davis 2015; and Golden, 2016). Other papers document that while this may be true, communities can be at least partly compensated

[16] In its strongest form, this dependency is known as the fishmeal trap, and asserts that the limited availability of forage fish to produce feed will limit aquaculture production (Naylor *et al*., 2000).

and sometimes be better off as other opportunities are created by the changes directly related to the fisheries sector, and also in other sectors as more economic activity also tend to increase opportunities outside of the fisheries sector (Abbott *et al.*, 2010; Manning *et al.*, 2014; Eggert *et al.*, 2015). Asche *et al.* (2015) and Bené *et al.* (2016) provide reviews that show that total trade is beneficial for developing countries, but that the effects vary substantially at the local level.

During the last two decades, the world has also seen a sustainable seafood movement develop that provides private incentives to foster sustainability in seafood production and supply chains. This includes eco-labels, with the one of the Marine Stewardship Council (MSC) as the most well-known, and guides such as that of the Monterey Bay Aquarium (Roheim, 2009). These initiatives are based on the notion that consumers care more about sustainability than fishers and companies in the supply chain, and that by informing consumers that some products are sustainably produced will increase demand for these and reduce demand for unsustainable/unlabeled products, giving fishers/farmers economic incentives to demand better management and thereby improve the sustainability of their industry. There is increasing evidence that at least consumers in developed countries are willing to pay extra for sustainably labeled seafood (Fonner and Sylvia, 2015), although the evidence is more mixed with respect to whether this creates real change on the water (Stemle *et al.*, 2016; Roheim et al, 2018) or whether the premium actually materializes in the market (Asche *et al.*, 2015). However, such initiatives are also often regarded as a trade barrier, as it is particularly hard for developing countries to meet the standards, and as such, in practice the standards may exclude them from some markets (Sampson *et al.,* 2015). A partial response has been Fisheries Improvement Projects (FIPs) and Aquaculture Improvement Projects (AIPs), where market access is provided to fisheries and aquaculture producers that enter a process of improvement. However, Sampson *et al*., (2015) show that a number of fisheries never get further than market access, hence it is questionable to what extent FIPs and AIPs generate sustainability. Without doubt, they increase the quantity of "sustainable" fish on the market though, reducing potential premiums associated with other schemes. ICTSD (2009) also not that the focus on food miles can be detrimental to trade, and particularly on developed countries' imports from developing countries. This can be a real and unnecessary trade barrier, as emissions from transportation usually make up a small part of any product's carbon footprint.

6. Conclusions and recommendations

The impact of climate change on global seafood production remains uncertain in aggregate, but recent evidence suggests that one can expect that capture fisheries production will remain relatively unchanged, and that aquaculture production will be the main driver of growth in the sector. The growth is still exponential although as production increased, growth rate declined. This relative stability in the aggregate masks potentially significant variation across regions where production will take place. This is most obvious for wild fish as various species change migration patterns due to direct and indirect effects of climate change.

With the exception of a few regions, such as increasing abundance in the north Atlantic and reduced abundance around the equator in the Atlantic, there is vast uncertainly around the exact effects of climate change as global patterns interact with local conditions (e.g. coastal upwelling, river outflows, water mixing, etc.) to exacerbate or dampen the impacts. In addition, changed temperatures will have different impacts on local ecosystems depending on the starting point, where higher temperatures are generally positive for total production in colder ecosystems, and negative in warmer ones. We know even less about the effects on aquaculture production. The fact that the most important species are now largely global indicates an important resilience, as these species are adaptable to a number of local settings. As increased competitiveness due to productivity growth is the main engine of increased aquaculture production (Kumar and Engel, 2016), the main impact of climate change is likely to be on where production takes place. Given that some, although far from all of the most important aquaculture species are highly traded, this production increase is likely to increase trade independently of how strong the impact of climate change turns out to be.

If it turns out to be correct that the main impact of climate change on seafood production will be on where production takes place, trade has the potential to be a very good adaptive tool as the places that experience a reduction in production can compensate through imports, and at the same time provide an export market for producers that allows them to increase production. Seafood is also better placed than most other foods in terms of capacity to respond to climate change with increased international trade. It is a product where the response of other large shocks such as the introduction of the 200 miles EEZ has been increased trade. There also exists a significant logistic and transport capacity given that seafood is one of the most traded animal protein products, that a large part of the global seafood production is traded internationally, and an even larger share is exposed to trade competition. However, there are also several challenges. The most important, as noted by Allison *et al.* (2009) is that "the countries that are most vulnerable to climate change on their fisheries are also the poorest". This is because they face the largest challenges to respond to climate change in virtually any dimension. That includes that these countries to a large extent cannot make up for short-comings in local production with increased imports. In addition, there are a number of more or less well intended initiatives that have increased trade barriers as a consequence ranging from food security definition that depend on local production to imposition of sustainability definitions in the west that restrict market access in practice if not in principle, and thereby the opportunity to obtain income to build capacity. A number of factors limit trade between developing countries (Bené, 2009), and tariffs tend to be higher in developing countries. Hence, several of the poorer countries also contribute to the barriers that make it harder for international trade to be used as a tool to mitigate local shortages.

There exist a number of publications providing policy recommendations with respect to climate change. A recent one is FAO (2017c), which also has a particular emphasis on trade. Compared to most other similar documents that tend to have more focus on production, the below recommendations have more emphasis on trade, and they are one of the few sets of recommendations that do not emphasize improved fisheries management as an important tool to foster resilience.

Somewhat abbreviated, the main recommendations to the member countries are to:

1. Improve understanding of the fisheries and aquaculture sector at a global, regional and national level. Strong producer organizations can help uptake of adaption measures.

2. Determine likely impacts of extreme events.

3. Involve all stakeholders, not only fishers and farmers.

4. Build adaptive capacity.

5. Appropriately design multilateral and bilateral trade rules that discourage economically unviable and environmentally damaging fishing practices. The international community could also use market access and trade policies to foster resilience to climate change in the fish industry including for the most vulnerable communities.

6. Eliminate tariff escalation in processed fishery products that discourage value-added production in developing countries; remove non-tariff barriers that are not aligned to science-based technical standards; eliminate capacity-distorting fisheries subsidies; encourage product and export diversification through appropriate economic development and trade policies; market goods produced following sustainable and legal practices to better inform consumers about their choices and the impact of their consumption on the environment. The recent gains made in improving regional and domestic food security and reduced dependence on international food aid through trade of high value fish products and consumption and/or importation of low value fish, could be exacerbated by climate impacts on global supplies.

7. Increase intra-regional trade, which could reduce the carbon footprint of fish trade. Income support programmes would need to be investigated in situations where it is anticipated that shifts in production systems or trade patterns may put vulnerable populations at risk of food insecurity.

8. Consider trade policy responses to climate change as one of the many adaptation tools that can address three interconnected elements: institutional and governance adaptations; livelihood adaptations; and resilience and risk management.

9. Provide safe havens/harbours for fishing vessels and equipment and the building of 'climate proofed' infrastructures for fisheries and aquaculture. This is increasingly important to maintain fish production and trade competitiveness in those areas vulnerable to climate change and extreme events, including rising sea levels and changes in lake levels. Aquaculture development can also contribute to resilience and risk management through investment in technologies that reduce loss of stocks during floods. These technological innovations can be supported in policy through grant and finance schemes for climate proofing and by provision of technical advice through extension services. Income diversification, storage and selection of stress resistant varieties can also be effective ways to cope with disasters while ensuring continuity in food supply.

10. Pursue structural solutions to reduce future vulnerability to natural disasters. Improved weather information, disaster forecasting and safety at sea all help avoid loss of lives and assets at sea and on shore.

It is important to emphasize that recommendations can be internally inconsistent. There is often a competition between protecting local communities with emphasis on livelihoods directly related to fisheries and aquaculture, and environmental protection that require management systems that limit entry and therefore exclude participants. Similarly, there is a competition between food security based on local production and trade, between sustainably produced, often labeled, seafood and trade distortions and a recommendation to implement new subsidies to foster climate adoption and abolish old ones which presumably lead to overfishing.[17] If international trade is to be used as an effective tool to mitigate the effects of climate change, it would be beneficial if as many of these inconsistencies were removed, especially in a way that facilitate trade.

[17] There is a discussion with respect to whether there are ”good” subsidies (Sumaila *et al*., 2016), which subsidies targeting climate change resilience typically will be regarded as. The discussion exist because all subsidies still have a tendency to increase harvest/production capacity.

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