Green Growth in Fisheries and Aquaculture Production and Trade

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1. Introduction

Fisheries and aquaculture are an important sources for food and livelihoods for people along the world's seashores and waterways (Smith *et al.*, 2010a), and influence the livelihoods for more than one billion people. Both industries exploit renewable natural resources with a substantial potential for environmental degradation if the industries' production practices are not sustainable, a feature that are not uncommon (Pauly *et al.*, 2003). The industries are also important users of energy with a significant carbon footprint. Tyedmers, Watson and Pauly (2005) estimate that the world's fishing fleets are using 1.2% of the global oil consumption, primarily as fuel, and by a rough estimate this number will increase to 2% if aquaculture is included.

Green growth policies in relation to fisheries, aquaculture production and trade will, depending on the conditions of production, have to address different challenges and opportunities, although there are also a number of common threads. Hence, when discussing the issues, I will provide different discussions for the two different production processes, but treat them together after the fish has come out of the water through the value chain on its way to the final market and the consumer. This will allow identification of the key challenges in the different sectors, and give the necessary background for the discussion on green growth policies.

The main objective of this paper will focus on the potential for green growth and outline which policies may enhance the greening of fisheries and aquaculture through the supply chain. The starting point will be a discussion of the consequences of not changing the current policies for industries with a major potential for environmental impact. Based on this, I will discuss the potential for green growth policies. It is important to recognise that while some policies can promote win-win potentials, some policies and strategies may be conflicting.

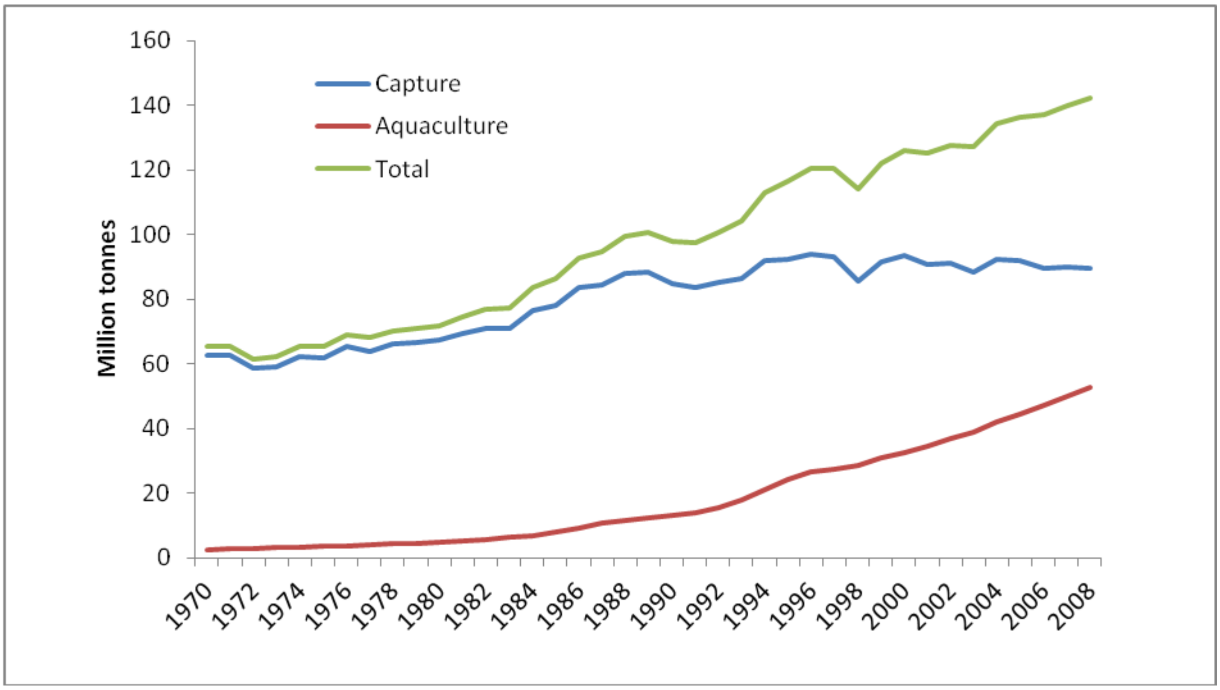
Most importantly, the world's waterways and oceans cover about two thirds of the surface of the planet and they are the earth's most underutilised natural resource when it comes to food production. The fact that aquaculture is the world's fastest growing food production technology indicates not only that one has started to exploit this potential. The rapid growth also indicate how powerful systematic R&D process can be together with knowledge from other sectors, primarily agriculture. If humanity succeeds in using the oceans more efficiently, this can be the largest single contributor to less pressure on marginal land and less deforestation on land. However, as this is largely a new way of using and interacting with the environment, increased aquaculture production and it's interaction with wild fish is in many cases creating controversy and the industry's environmental sustainability is challenged.

I will not in this text discuss green growth policies in general, and different definitions in this respect. OECD (2010a) and Stevens (2011) provides a more complete discussion. However, it is important to note that green growth has three main pillars: Economic contributions, environmental contributions and social contributions. Standard growth policies have a tendency to focus on the economic contribution, and in the short run the different pillars can be conflicting. In the long run there are no such conflicts, as any industry has to be sustainable in all dimensions. Emphasising this long-run complementarily is the main objective of green growth policies.

2. Background

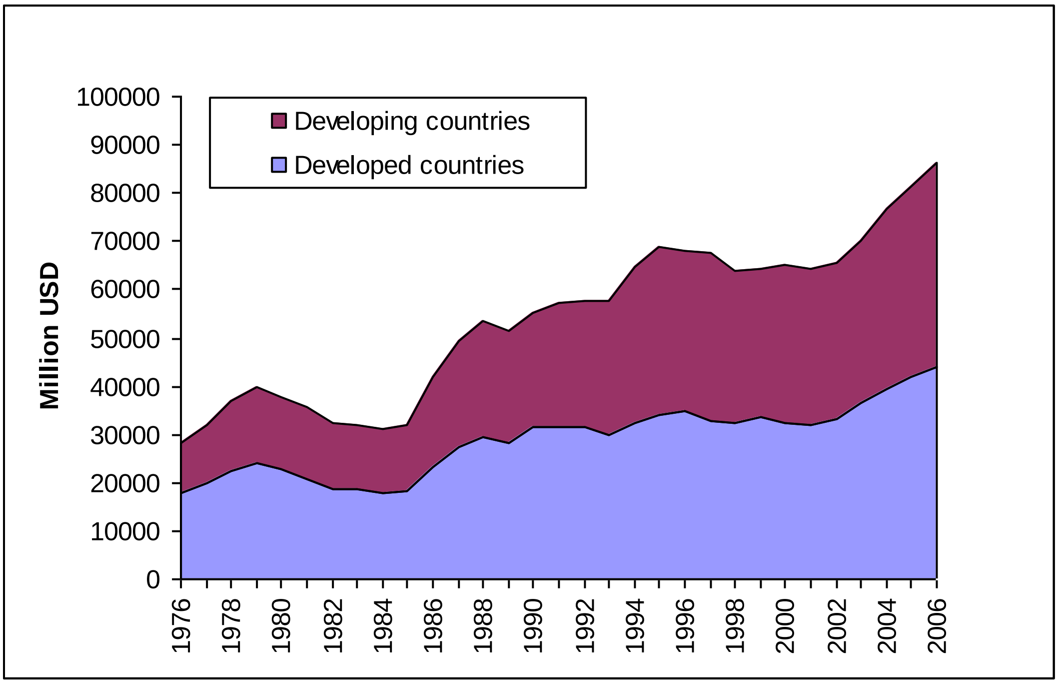
The total supply of seafood increased from 69.0 million tonnes in 1976 to 142 million tonnes in 2008 (FAO, 2011). Hence, the availability of seafood has more than doubled during this period. Seafood appears from two main modes of production – harvest and aquaculture, and the development of production in total and by production technology since 1970 is shown in Figure 1. Capture fisheries production is the largest. From the early 1950s, when data is available, fisheries production increased to the mid-1980s, and has thereafter fluctuated between 80 and 90 million tonnes in annual landings. Until the 1970s, aquaculture was not very important. However, since then a virtual revolution has taken place. In 1970 aquaculture production was still rather miniscule with a produced quantity of about 3.5 million tonnes, representing 5.1% of total seafood supply. In 2006, aquaculture made up 41.8% of total seafood supply with a production of 66.7 million tonnes. The increased production in aquaculture is accordingly the only reason why global seafood supply has continued to increase since 1990. The increased production has been sufficient to not only maintain, but also to slightly increase global per capita consumption of seafood.

Figure 1. Global production of seafood, 1970-2008. Million tonnes



Source: FAO

Figure 2. Real world trade value, exports (2006=1)



Source: FAO (2010)

International trade has increased much faster than total seafood production.[1] From 1976 to 2006 the export volume of seafood increased from 7.9 million tonnes to 31.3 million tonnes, or almost fourfold. Adjusted for inflation, the export value during this period increased threefold from USD 28.3 billion to USD 86.4 billion (Figure 2). One should note that export quantities are not directly comparable to the production quantities, as exports are measured in product weight, which can lead to dramatic differences. According to FAO (2010), 39% of total seafood production was traded in 2008. In addition, seafood trade also influences many domestic markets significantly, as local fishers and fish farmers are exposed to competition from imports.

When export quantity increases fourfold and export value only threefold, the unit value of the seafood decreases. This has increased seafood's competitiveness as a food source, and is an important factor explaining the increased trade. Successful aquaculture species such as salmon and shrimp demonstrate this phenomenon, where real prices now are less than one-third of what they were 25 years ago. The profitable expansion in the production of these species, despite decreasing prices, is largely due to lower production cost, improved production technologies, and lower distribution and logistics costs (Asche, 2008).

The trade patterns are widely different between exports and imports. The export sources were split almost equally between developing and developed countries in 2006, as shown in Figure 2. The share for developing countries has increased from 37% in 1976 to 49% in 2006. For imports, it is a very different story. Imports to developed countries comprised 80% of all imports in 2006. Even

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[1] Anderson (2003) provides a thorough review of international seafood trade, and also discusses trade of the most important species.

though the share declined from 86% in 1976, most of the increased trade in seafood is due to developed countries, and a considerable share is exported from developing countries. This picture is confirmed in Table , which shows the world's 10 largest seafood exporters and importers. The 10 largest importers make up 67.5% of all imports, while the 10 largest exporters make up 51.5% of the exports. Hence, imports are more concentrated. Additionally, four of the exporters are developing countries, but only two of the importers are developing countries.

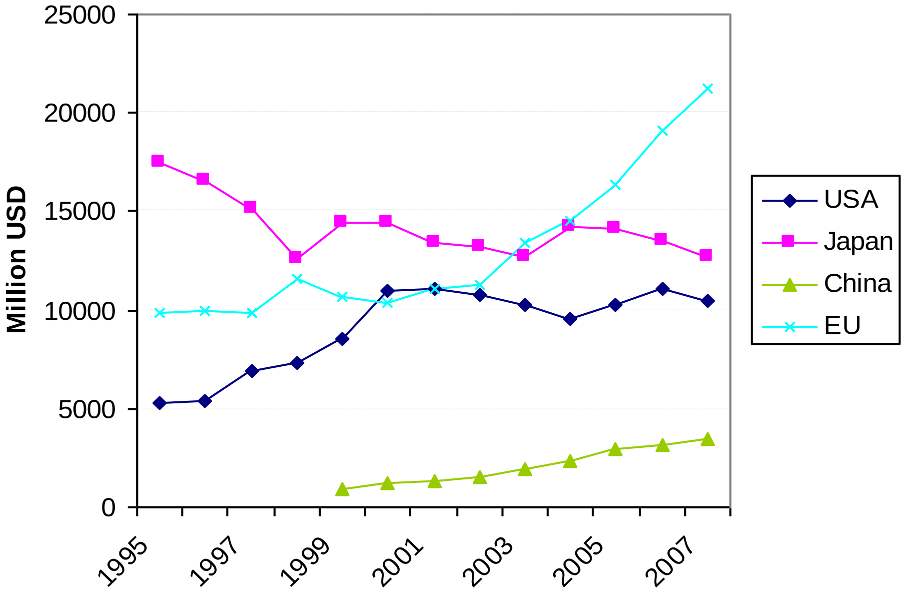
Japan and the USA appear as the two largest importers (Table 1). However, if the EU countries are aggregated, the EU is clearly the largest market. Figure 3 illustrates this strong growth in the EU market. It is also worthwhile to note that while the USA and EU are large exporters, they are even more significant importers. The USA imports 80% of its seafood consumption, while the EU imports more than 60%. Hence, in wealthy countries, the seafood consumed must be of the right quality, and if domestic production and value chains are not up to standard, they are not competitive.

Table 1. Largest seafood importing and exporting countries in 2006 (Values in USD)

Export Value			Import value		
Country	Value	Percent	Country	Value	Percent
China	9150.3	10.6 %	Japan	14258.7	15.7 %
Norway	5543.7	6.4 %	USA	13399.7	14.8 %
Thailand	5244.9	6.1 %	Spain	6377.8	7.0 %
USA	4190.1	4.9 %	France	5108.7	5.6 %
Denmark	3999.1	4.6 %	Italy	4745.6	5.2 %
Canada	3682.8	4.3 %	China	4188.5	4.6 %
Chile	3638.9	4.2 %	Germany	3778.6	4.2 %
Viet Nam	3363.4	3.9 %	United Kingdom	3751.9	4.1 %
Spain	2871.9	3.3 %	Denmark	2939.0	3.2 %
Netherlands	2827.2	3.3 %	Korea, Republic of	2767.9	3.0 %

Source: FAO

Figure 3. Annual import value for seafood in China, EU, Japan and USA (Norwegian Seafood Export Council)



It is certainly not arbitrary that developed countries take most of the imports and that the EU, Japan, and the USA are the largest seafood importers. These are the wealthiest regions in the world, with the best ability to pay. In a similar manner, economic growth has led to an impressive growth in seafood demand and also imports in growing economies like China and Southeast Asia (Delgado *et al.* 2003).[2] Improved (and cheaper) transportation and infrastructure give an increased number of developing country producers access to these markets, and thereby lead to increased seafood exports. Improved transportation has further catalyzed the development of industrialised aquaculture, and, as such, is the main reason why an increasing number of new species is available at fish counters and restaurants in the EU, Japan, and the USA, and now, increasingly in China and South East Asia.

3. Trends in wild capture fisheries

Fishing takes place in virtually all the world's oceans and waterways, with a myriad of vessel types and gears. Gears vary from small scales lines and traps, via nets and longer lines to huge trawls and purse seines. The vessels vary from small rowing boats and canoes to ocean going factory trawlers of several thousand tonnes. This variation in technology is partly due to fisheries specific factors such as species targeted, fishing grounds and climate, but also to cultural, social and economic factors as well as fisheries management systems.

According to the FAO (2010), about half of the fish stocks are fully exploited, a third is overexploited or rebuilding and 15% is not fully exploited. There are different opinions with respect to the implications this has for the status of the world's fish stocks, as it is not clear if it is good or not that a stock is fully exploited. However, there is general agreement that production from wild fisheries cannot increase significantly. The landings seem to have stabilised around 90 million tonnes

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[2] In Figure 2.4, the import figures for China start in 1998.

(Figure 1), and to the extent that wild seafood resources are to contribute to economic growth, it must primarily be due to increased value added.

The stocks that are not regarded as fully exploited, and that has to be utilised if the production of the oceans are to be increased largely involve targeting species in Antarctica, to the extent that there are economically viable resources in these areas, or resources at lower trophic levels, or both (*e.g.* krill). These approaches are regarded with skepticism in the environmental community, as they often target vulnerable species and have potential for substantial ecological impact. The controversies around the Pathagonian toothfish fisheries in Antartica are relevant examples. There are regulated fisheries in the EEZs (exclusive economic zones) of different countries for Pathagonian toothfish, including under the name Chilean sea bass, but there are also unregulated fisheries in international water targeting a slow growing and very vulnerable resource.

How much one can fish is limited because the main production is carried out by nature, and fishers are harvesting nature's bounty. Hence, the fishing industry does not produce fish, it only harvests fish. As such, it can be regarded as the world's last significant hunting or harvesting industry. The world's oceans and waterways have a natural production capacity that cannot be exceeded.[3] If one stock is fished down, it will largely be replaced by other species (Sanchirico and Wilen, 1998; Smith and Wilen, 2003). Hence, there are few cases where biomass production is severely reduced when a fish stock is significantly fished down. Rather, other species will exploit this opportunity to obtain food to thrive. Often the value of the harvest will be reduced as the new species are less desirable, but there are also examples of increased harvest value. One such example is when crustaceans took over for the cod in Atlantic Canada. However, there can often be social disturbances when one (group of) fish stock(s) is being fished down and the stocks of other species increase as different fishing gears, vessels and crews are often required.

The fact that fishing is harvesting creates a strong interaction between fisheries and the environment where the fishing operations take place. Unfortunately, this relationship is often not sufficiently recognised, and many fish stocks has been overfished because of short-term considerations, poor fisheries management and competition between fishermen as well as competition between fishing nations over stocks where there is disagreement on allocation keys and lack of ownership or clearly defined rights in national fisheries regulations (Wilen, 2000). In such situations, fisheries offer perfect examples of Harding's (1968) *Tragedy of the commons*. This typically lead not only to too low stocks of the targeted species, but also to overcapacity and capital stuffing in the fishing fleets, too high levels of effort, and a race to fish that leads to poor resource handling, discarding (throwing less valuable fish over board) and other resource waste.

3.1 Fisheries Management

The *tragedy of the commons* is likely to take place for all unmanaged renewable natural resources, including fisheries. The basic problem is that the agents who are exploiting the resource, in our case the fishers, have no incentives to protect the resource (the fish stock). This leads to over exploitation, and the stock is fished down to low and possibly unsustainable levels. Because it is profitable for any fisher in the short run, this process attracts fishers and capital and normally leads to substantial overcapacity. This is the case for fisheries with large and modern vessels as well as fisheries with a large number of small coastal vessels. In principle, this process can be prevented with a good management system (Gordon, 1954). Unfortunately, there are few examples where a good

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[3] That is, one can in principle expand the production capacity in some areas by fertilizing parts of the oceans. However, while this option is raised at infrequent intervals, it does not seem practical as it is deemed to have a too large potential for a negative environmental impact.

management system was in place before the stocks had largely been fished down, and too often, management does not start before the stocks have collapsed (Hannesson, 1996; Wilen, 2000).

A large part of the world's fisheries is still basically unmanaged, as many developing countries do not have resource to obtain the information necessary for constructing a management plan or to enforce it. In those countries where fisheries are managed, there is a myriad of management systems. These spans from community-based management systems via so-called command and control systems to systems where a fishing right is treated as a property right. As fishers are economic agents trying to make a living, their behavior will respond to the management system. This response, which is privately optimal for each fisher, will often lead to completely irrational behavior with substantial waste for the fishery at large. Classic examples are "Olympic fisheries", "the race to fish" or other terms that describes competitive fishing.

The first management action when one start managing a fishery is in most cases to set a Total Allowable Catch (TAC) to protect the fish stock. The TAC is normally enforced by limiting the harvesting season, that is, the fishery is closed when the total landings reach the TAC. However, this gives each individual fisher incentives to catch the fish more rapidly, first by using the present vessel harder, and then by acquiring faster and larger vessels and fishing gears that catch much fish rather than high quality fish. As this process unfolds, fisheries that normally has seasons that lasted for months where shortened down to a few days and even hours (Homans and Wilen, 1997). Examples include Pacific halibut, Alaska Pollock and Georgia Strait herring.

Because the TAC regulations often succeed in giving the stock some protection, harvesting levels increase relatively to the open access situation associated with the tragedy of the commons. As this increase revenue from the fishery, it will attract more fishing effort and overcapacity. Homans and Wilen (1997) simulates that the fleet can be up to ten times larger than what is necessary to land the fish under an optimal management system. Homans and Wilen (2006) show that the reduction in revenue due to competitive fishing gears can be substantial, as a short harvesting season force the fish to be used as inputs in conservation processes that gives a lower price. The competition for the fish can also lead to the fish being harvested at the wrong time, and is not allowed to obtain optimal quality or size, again leading to a loss of revenue (Larkin and Sylvia, 1999).

To prevent competitive fishing, different fisheries management systems have implemented a number of additional regulations such as limited vessel size, restrictions on which gear can be used, number of fishing days, restrictions on engine power and limited entry to the fishery, giving rise to the notion of command and control management systems (Wilen, 2000). However, in all these systems the incentives of the fishers are to try to adapt to the regulations to fish as much as possible (Munro and Scott, 1985). The value that is wasted is substantial. What is known as Wilen's Rule of Thumb states that half of the landing value is resource rent. While this value certainly varies with fisheries, it still gives a general idea of the magnitude. Moreover, these values are realised as overcapacity or over-capitalisation when they are not explicitly realised monetarily-

The only management systems that correct these incentives are when the TAC is divided into Individual Vessel Quotas (IVQ), because each fisher then can harvest the quota without interference (Arnason, 1990; Costello, Gaines and Lynham, 2008). When these quotas are made transferable, the fishers also have incentives to reduce the overcapacity, and the resource rent will be realised monetarily. The empirical evidence again indicates that the value of the quotas are substantial (Newell, Sanchirico and Kerr, 2005). However, IVQ systems exacerbate other problems such as discarding (Copes, 1986), and targeting of non-quota species (Asche, Gordon and Jensen, 2007). A paradox is also that reduction of capacity in some fisheries, which mostly will be regarded as good, may not be positive on a global scale, as the vessels will often be transferred to fisheries with poorer regulations, often to different countries and international waters, and increase fishing pressure there. Remaining open access fisheries may then see additional fishing pressure. This effect could have significant consequences, as some researchers have argued that globalisation has increased the speed with which fleets can exploit remaining open access resources before management institutions can respond (Berkes *et al.*. 2006).

3.2 Discarding and bycatch

The price varies substantially for different types of fish from a few cents per kilo for trashfish to more than 1 000 USD/kg for fresh bluefin tuna. As a fishing vessel has limited hold capacity, there has always been a trade-off for the fishers with respect to whether one should bring a low-value species to port or discard it in hope to catch something more valuable. This trade-off is also present for the same species, as larger fish tend to be more valuable per kilo than small fish, and can also influence genetic composition of a fish stock (Guttormsen, Kristofersson and Nævdal, 2008). When fisheries management systems impose restrictions on the composition of the harvest, the incentives to discard increase. For instance, with competitive fishing it becomes more important to get a higher trip value as the fishery can be closed before one can make more trips. With limitations on vessel size, the holding capacity becomes a scarcer resource, again increasing incentives to discard. With IVQs, the incentives to discard becomes the largest, because the quantity one can land is limited, and the incentives are then clearly to maximise the value of the quota (Vestergård, 1996).

Bycatch is incidental catch of species that in general are not targeted by the fishing vessel, and much of this is thrown back but does not survive. In some cases, bycatch can be targeted though, when there are valuables species on a fishing ground that a vessel does not have quota to fish. To the extent that non-targeted species are economically valuable and is not handled in a good manner, bycatch is economically wasteful. Bycatch can also be a form of an ecosystem interaction. Even if bycatch species themselves are not economically valuable, they may be ecologically valuable in sustaining marine food webs, and thus catching them constitutes an important opportunity cost. In addition, other management principles can influence discarding. For instance, to avoid targeting of bycatch species by the fishers, the EU does not allow landings of any fish above the quota. As some bycatch is unavoidable, and it is impossible not to get over the quota at times because the last haul is a good one, this basically force fishers to discard fish.

There is little doubt that discarding waste significant resources, even though it is difficult to estimate the degree of discarding with much precision. Pauly *et al.* (2003) estimate that a quantity of fish equivalent to 30% of what is actually landed is discarded.

3.3 Subsidies and buyback programmes

It is natural to think that fishery managers' effort are targeted at reducing overcapacity, discarding and other forms of wasteful behavior, and largely they are. However, it may come as a surprise that a number of countries also subsidise fishers directly and indirectly, exacerbating the environmental problems. The main reason for this is political, as many coastal communities are relatively poor, and a major objective behind the subsidies are to support incomes or to support a transition that helps the fishers and coastal communities to keep up with the wealth development in the rest of society. Subsidies are in general economically wasteful in themselves, but when applied to fisheries that are poorly regulated, they can exacerbate existing problems of biological overexploitation, and they make it privately optimal to fish stocks down to even lower levels than without the subsidy. They will also in most cases fund even larger overcapacity than what one would observe without the subsidy.

Many fisheries around the world receive sizable subsidies. Following a World Bank study (Milazzo, 1998) that estimated that fisheries subsidies made up 30-35% of total cost, there has been significant attention to this issue (OECD, 2005; 2006). Other, researchers have estimated the magnitude of subsidies for particular regions such as the North Atlantic (Munro and Sumaila 2002) and globally (Sumaila *et al.*, 2010). Examples of fishery subsidies include boat construction and/or modernisation, fuel and other transport subsidises, foregone government revenue on income taxes, and foregone government revenue on fuel taxes. The literature also discusses fisheries buybacks, port construction, and fisheries research as subsidies to fisheries, although there is not a general agreement whether these measures indeed are fisheries subsidies.

There is also discussion of whether there is a distinction between good and bad subsidies, where good subsidies are used to reduce fishing effort (Hatcher and Robinson, 1999; FAO, 2003; OECD, 2005). An example of a potentially good subsidy is a buyback programme where fishers are compensated to remove their vessel from a fishery and thereby, presumably reduce fishing effort. However, opponents of the notion that there are good subsidies claim that all transfers will eventually be transformed into effort as the fishers do everything they can to disseminate the resource rent. Hence, entry to the fishery or increased capacity in the remaining fleet will make up for the reduction in effort implied by the removal of one vessel.

Buyback programmes are a common tool to reduce capacity in fisheries, particularly in developed countries. As discussed above, overcapacity is often regarded as a main problem threatening the fishers' livelihoods as well as the fish stocks. Moreover, in many cases, the vessels have little alternative value and it is therefore difficult for the fishers to withdraw from the fishery. Buyback programmes can then provide the means to change the dynamics in the fishery. Groves and Squires (2007) give eight categories of reasons why fishery buybacks are used as a management tool: (1) increasing economic efficiency, (2) modernising fleets and adjusting fleet structure, (3) facilitating transition between management regimes, (4) providing alternatives when rights based management forms are not an alternative, (5) providing disaster or crises relief, (6) addressing compensation and distribution issues, (7) helping conserve or rebuild overexploited stocks, and (8) protecting ecological public goods and biodiversity. They recognise that a buyback programme often targets several different and even conflicting objectives and that the programme is the outcome of a policy process that in most cases will target improved, not optimal, management as the objective.

How well a buyback programme works does to a large extent depend on objectives, circumstances, design, and implementation. Groves and Squires (2007) and Hannesson (2007) show that buyback programmes in fisheries without access restrictions cannot achieve any objective (with the possible exception of transferring revenue to a group of fishermen). In fact, if the programme is poorly designed and restriction on access or capacity expansion for the vessels remaining in the fishery, a buyback programme can reduce both stock size and fisher's profitability.

3.4 Illegal, unregulated and unreported (IUU) fishing

IUU fishing has become a major concern during recent decades as researchers have discovered that significant quantities of fish come from IUU fisheries. This discovery has resulted in the creation of international bodies such as the High Seas Task Force, which was created at an OECD round table in 2003 with ministers from the UK, Australia, New Zealand, Namibia, Canada and Chile. Metuzals *et al.*. (2009) reviews a number of studies reporting that actual landings can be 10 to 60% higher than reported landings. The spectrum of IUU fishing spans illegally harvested fish from regulated fisheries, unreported or misreported fishing activities, and unregulated fishing by vessels with no flag or a flag of convenience. The literature discusses whether fishing must be illegal, unreported, and unregulated to constitute a problem, or whether it is sufficient that fishing meets one of these criteria. In any case, the fisheries that are perceived to be the main problem have all three characteristics. Fisheries in developing countries without infrastructure to report catch are in general not perceived as IUU, and the same is true for bycatch.

As it is difficult to directly stop IUU fishing, different initiatives to restrict market access for the fish have been advocated (Roheim, 2004). These include ecolabels, traceability and other measures that disclose information about how the fish has been harvested.

3.5 Policy implications of green growth for fisheries management

There are a number of aspects related to fisheries management that can be significantly improved from a green growth perspective. The most important is to reduce waste in different dimensions. Many fisheries management systems give incentives to overfishing, over-capitalisation, discarding and are also promoting such behaviour by subsidies. Many of these problems are recognised and should be at the core of green growth policies for fisheries. There are also several policy initiatives to tackle some of them, such as OECD’s initiative to decommission vessels to reduced overcapacity and fishing effort.

The most important barriers to implement greener policies in fisheries management seems to be the classical tension of green growth policies in that sound long-run policies requires short term investments and may contradict short-term objectives. In some cases, there are also disagreements with respect to what is the right course. The economic waste in many fisheries is substantial as the resource rent can be more than one half of the landing value, and as much as two thirds of the vessels in the fleet can be redundant (Asche *et al.*, 2008). Removing this capacity can have significant socioeconomic effects (OECD, 2007). However, recent reports with respect to the implementation of ITQ programmes indicates that while the number of people employed may be reduced the number of hours worked are not, and accordingly, the transformation has provided more fulltime jobs. This has been the case in the Alaska Crab Fisheries (Abbott, Garber-Yonts and Wilen, 2010). However, in the more general literature, there is still substantial disagreement with respect to the socio-economic effects of reducing fishing effort.

For the more detailed issues discussed above, there is also substantial disagreement with respect to what is appropriate measures. For instance, EU discard policies give strong incentives not to target fish that cannot be landed, but by not allowing it to be landed also create strong incentives to discard such bycatch when it is caught. Other countries allow the fish to be landed, and as such, reduce incentives to discard non-quota catch, but in this process also gives stronger incentives to target such species. The fact that there is a discussion with respect to whether subsidies can be good or bad is a good indication of the trade-offs faced by policy makers. Moreover, even measures like port control to prevent IUU fishing are not uncontroversial.

4. Trends in aquaculture

While the growth potential for wild fisheries is limited, it is vast for aquaculture. Aquaculture is a production technology with its origins in Egypt and China thousands of years ago. Beginning in the 1970s, a significant change took place as better control over the production process enabled a number of new technologies and production practices to develop. These changes dramatically improved the competitiveness of aquaculture products both as sources of basic food and as cash crops. The competitiveness of aquaculture has further been increased by the product development and marketing that was possible with a more predictable supply. The combined effect of productivity and market growth has made aquaculture the world’s fastest growing animal-based food sector of the last decades (FAO, 2006; OECD, 2010b).

It is interesting to note that the breadth of species being produced in aquaculture is almost as large as in wild fisheries. Aquaculture production include kelp, mussels, crustaceans, low-value fish like carp, medium-value species like tilapia, and high-value species like shrimp and salmon. High-value species tend to play a more significant role in the international trade of aquaculture products.

While aquaculture has been a success in terms of increased production, it also faces strong opposition in many countries because the new technologies that are enabling the increased aquaculture production are a new mode of food production with new channels to interact with the environment. There are numerous examples of unsustainable practices, although the technology is not inherently unsustainable, and there are also numerous examples of sustainable practices. It is accordingly of the highest importance to encourage sustainable practices and discourage "mining" of locations and unnecessary environmental impacts.

4.1 Aquaculture production

Aquaculture is a truly global production technology, with close to 180 countries reporting some level of aquaculture production. However, there are substantial regional differences. Asia makes up about 92% of the production measured by volume and 79.6% by value. All the other regions have a higher value than volume share, because they produce higher value products. This is particularly true for South America. China is by far the largest producer country, with a value share of more than 50% and a volume share of 70%. Measured by value, Chile, India, Vietnam, Japan, Norway, Indonesia, Thailand, Burma, and South Korea are the other top 10 producing countries. Egypt is the largest producer in Africa and is ranked number 13 on the list. Hence, aquaculture is clearly strongest in Southeast Asia and is primarily conducted in developing countries.

Aquaculture is distinguished from other aquatic production such as fishing by the degree of human intervention and control that is possible (Anderson 2002). Aquaculture can be defined as the human cultivation of organisms in water. As such, it is in principle more similar to forestry and animal husbandry than to traditional capture fisheries. In other words, aquaculture is stock raising rather than hunting. The production process in aquaculture is determined by biological, technological, economic, and environmental factors. However, the key factor is that many aspects of the production process can be brought under human control. This control makes innovation possible and is, accordingly, essential for the rapid technological development that has fuelled production growth since the early 1970s.

In the 1970s, what is sometimes labelled as the "blue revolution" began as humanity's accumulated knowledge of aquaculture allowed for the introduction of semi-intensive and intensive farming practices. As a result, producers were able to influence the growing conditions of the fish through feeding, breeding, and so forth, and the production cycle was closed for an increasing number of species. The increasing control of the production process enabled a number of productivity-enhancing innovations to take place. Improved productivity resulted in a reduction in production costs, and with a given price, this led to more profitable production. High profits were the market's signal to increase production, and this led to both existing producers producing more and new producers entering the industry. To sell the increased production, one needed to give the consumers a reason to buy the product, and in general the most important incentive was a reduction of the price. A substantial part of the savings due to productivity increase was accordingly passed on to the consumers (Asche, 2008). This can clearly be seen in the price development for most successful aquaculture species. Hence, one can sum up the most important drivers in the development of modern aquaculture as follows: Control of the production process allowed technological innovations that reduced production costs. This made the product more competitive and the industry more profitable, which led to increased production and lower prices for consumers. A number of species are being farmed in all parts of the world, in freshwater and in saltwater. Moreover, a number of different production techniques are being used, adapted to different species, environments, and economic conditions. These techniques include ponds, pens, raceways, ropes, cages, tanks, and closed circulation systems.

Cultivation of a new species typically starts by catching wild juveniles and feeding them in a controlled environment. As more knowledge is gained, the degree of control with the production process increases and the farmers can increase their influence on growth and reproduction. The degree of control is often categorised by the intensity of the aquaculture operation. Traditional aquaculture varies between *extensive* and *semi-intensive* farming practices. Mussel farming is an example of an *extensive* method used around the globe, whereby the farmer provides a rope or a stake for the mussel fry to fasten to and undertakes some culling so that the density does not get too high, but otherwise leaves the mussels to grow without further interference. The small ponds used in Chinese aquaculture were traditionally operated on an *extensive* basis, because the farmer did little to control growth and biomass. In *intensive* aquaculture, the production system is closed so that one does not depend on wild fish for reproduction.

What matters for the development of aquaculture is the degree of control of the production process. It is this control that enables innovation and systematic gathering of knowledge that creates further growth. As such, it is the transition from extensive to semi-intensive farming in Southeast Asia, and in particular the feeding of the fish, that is the most important factor for the growth in aquaculture production. As species with highly intensive production systems lead the way, the production process is likely to become even more intensive in most places.

The increased production from aquaculture has a significant market impact for successful species. A substantial increase in production usually results in a significant drop in the price of the species. Shrimp and salmon are good examples of species where production increases have been accompanied by significant reductions in price. Shrimp is a good example. Production increased from 72 thousand metric tons to 3.1 million metric tons from 1984 to 2007, while the price fell from USD 16.40 in 1984 to USD 7 in 2006. It is a similar story for salmon, sea bass, sea bream, catfish, and tilapia, although the strength of the price decline varies (Asche, 2008).

4.2 Aquaculture and the Environment

While the development of new technology has significantly increased the production potential of aquaculture, the increased production has also raised questions about the environmental impact and the sustainability of aquaculture. This is certainly an issue because aquaculture, like other biological production processes, interacts with the surrounding environment. Moreover, for some species there is a global supply network because fish meal and fish oil are used in the feed. The environmental challenges appear as two distinct issues: Increased fishing pressure on species harvested for aquafeed, and local environmental carrying capacity.

4.2.1. The Fish Meal Trap

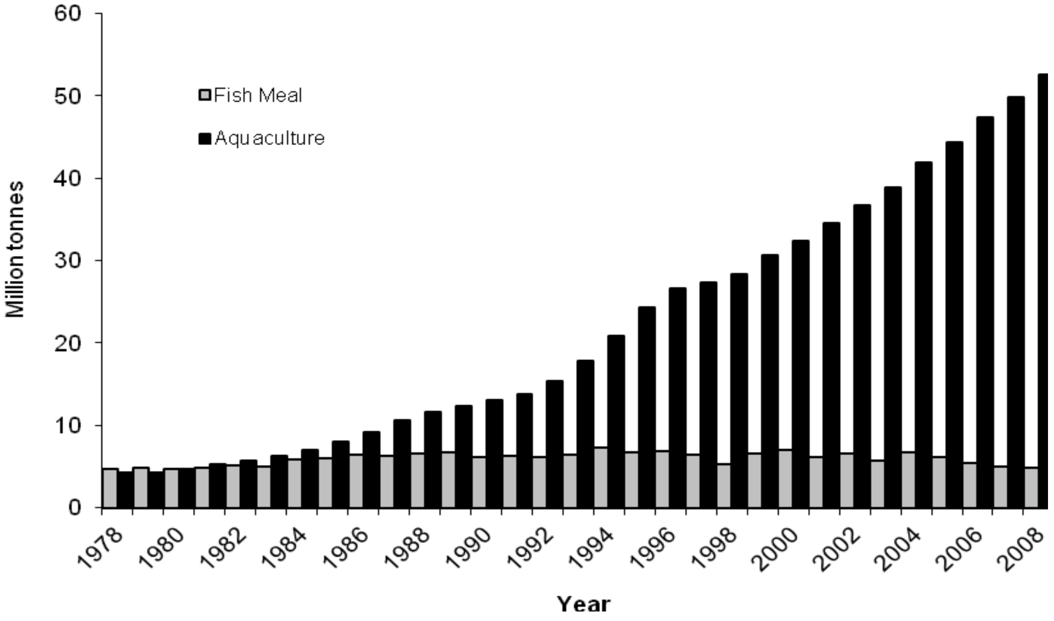
The “fish meal trap” is the hypothesis that aquaculture is environmentally degrading because increased demand for feed leads to increased fishing effort for the wild species used to produce the feed and thereby threatens the viability of wild fish stocks, and that the growth in aquaculture production will be limited by the availability of wild fish to be used as feed in aquaculture production (Naylor *et al.*. 2000).

While the fish meal trap is mentioned in relation to aquaculture in general, it is clear that it is a serious issue only in some forms of aquaculture, primarily finfish and shrimp farming. It does not apply to farming of seaweeds, mussels, shellfish and other species that are not fed. Furthermore, the fish meal trap will apply only to species that are fed with feed primarily composed of marine inputs. It is difficult to assess which species this is, as feed composition is rapidly evolving in response to the price development of different feed inputs (Tacon and Metianen, 2008). Carnivorous species, such as salmon and sea bass, are most exposed to the fish meal trap as they are using the highest share of marine inputs in their feed. However, also some omni- or herbivorous species, such as tilapia, pangasius and shrimp are exposed because increases the growth rate, and the economic viability of the industries largely depends on this. There are, however, some conditions that must be fulfilled for the fish meal trap to occur (Asche and Tveterås 2004; Kristofersson and Anderson 2006).

The extent to which increasing demand for fish meal leads to greater fishing effort is related to the management regime in operation for the fishery in question. With a properly working management system, increased demand for the species in question cannot threaten the fish stock. Hence, the issue of whether growth in aquaculture production can lead to unsustainable capture fisheries is primarily a fisheries management problem. However, as the track record of many fisheries management systems is questionable, this can be a real problem.

Yet, in order for increased demand from aquaculture to have an impact, aquaculture growth must increase total demand for fish meal. There are two relationships that can prevent this. First, fish meal and fish oil has for a long time been a part of the vegetable oil and meal markets. When this is the case, there are users of fish meal and oil that will substitute away from these products in response to increased demand from aquaculture. As long as this happens, there will be no increase in aggregate demand for fish meal and oil. While this was the state of the world until the late 1990s, there is evidence that the relationship between fish meal and oil and the vegetable meal and oil markets has become weaker and that the prices are increasing relatively to the vegetable meals and oils (Kristofersson and Anderson, 2006). To the extent that there are species that require sufficient quantities of fish meal, producers of these species will find that feed costs will become more volatile, and if the price continues to increase, it may also be a problem for the profitability of the operation. Aquaculture producers accordingly have strong incentives to reduce the share of marine ingredients in the feed, something that has happened (Tacon and Metianen, 2008). Hence, as shown in Figure 4, aquaculture production has been growing without any effect on fish meal (and oil) production. In fact, fish meal and oil production from wild capture fisheries are going down according to the International Fishmeal Producers Organization, but the total production remains relatively stable because an increasing share of cut-offs from fish processing is being used. This share is now approximately 25% of total fish meal production.

Figure 4. Global aquaculture and fish meal production



Source: FAO

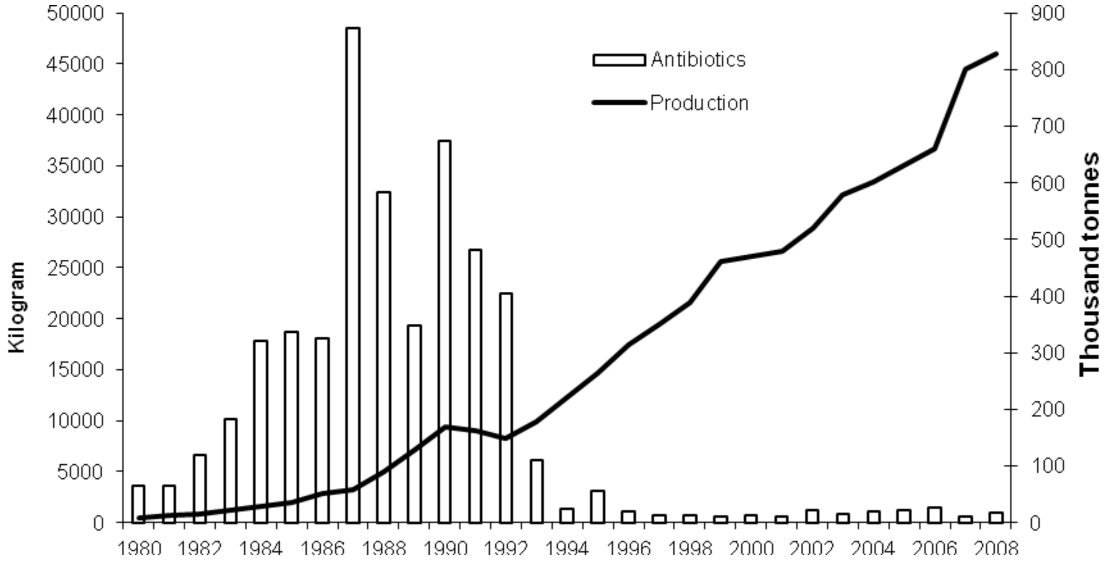
Since productivity growth is the main engine of growth in aquaculture, increased fish meal and oil prices would prevent further growth for species that are highly dependent on marine sources for feed if they could not substitute away from these inputs. Most aquaculture species, however, are herbivores, and even carnivore species like salmon has become semi-vegetarian, so in terms of volume, fish meal required in aquaculture should have at most a limited impact on the fish stocks used.

4.2.2. Local Environmental Issues

Whenever the environment interacts with a production process, the production process has the potential to damage the surrounding environment. The potential damages include destruction of natural habitat and pollution from the production process that influences habitat and wildlife around the site. The two most successful aquaculture species, salmon and shrimp, are also the species that have received most attention with respect to their environmental impact (Naylor *et al.* 2000). The main issues in salmon farming are pollution from organic waste and the interaction between wild and farmed salmon. Farmed salmon may transmit diseases and parasites to wild salmon. An increased number of sea lice parasites on wild salmon have been associated with escaped farmed salmon. Farmed salmon may also attempt to spawn in rivers and may affect the genetic pool. Shrimp farming has received even greater negative publicity than salmon farming regarding its detrimental environmental effects, such as destruction of mangroves, salination of agricultural areas, eutrophication, and disruptive socioeconomic impacts.

The environmental issues in intensive salmon and shrimp farming must be seen in relation to the introduction of a new technology that uses the environment as an input. The greater the production at any site and the more intensive the process, the greater the potential for environmental damage. However, the greater degree of control within the production process in intensive aquaculture also makes it easier to address these issues. Like all new technologies, there will be unexpected side effects, and there will be a time lag from when an issue arises until it can be addressed. First, the impact and the causes must be properly identified. Second, the solution to the problems will require modifications of existing technology or perhaps entirely new technology. In both cases, pollution reduction implies some form of induced innovation. Tveterås (2002) argues that industry growth when the industry reaches s given size has a positive effect on pollution, aspollution tends to increase with industry size up to a certain point, after which growth will reduce pollution because it is necessary and worthwhile to be sustainable. This gives the pollution profile over time the shape of an inverted U. Use of antibiotics in Norwegian aquaculture is a good example, as shown in Figure 5.

Figure 1. Figure 5. Norwegian salmon production and antibiotics use in aquaculture



Source: Norwegian Directorate of Fisheries

The industry addresses environmental effects for four main reasons: (1) the effects reduce productivity and therefore profits, (2) government regulations force the industry to do so (3) consumer perception that influence demand and/or (4) the industry's image influencing future access to resources like locations and recruitment as well as government regulations. Industry size contributes to the ability to handle these challenges in the sense that a large industry allows larger investments and thereby more efficient innovation of abatement technologies. Detrimental environmental effects of aquaculture not accounted for in market prices are negative externalities. Internalisation of the externalities can explain why some of the major environmental issues have been resolved in aquaculture. The arguments are as follows: Production cost and productivity in aquaculture depends on an environment where farmed fish are raised. Fish farms with environmental practices that harm the local environment will experience negative feedback effects such as poorer growing conditions, and this will reduce on-farm productivity. The result is reduced biomass growth due to poor fish health and, in the worst case, disease outbreaks that wipe out entire on-farm fish stocks. Hence, farmers are concerned with cultivating management practices that avoid such negative repercussions on productivity.

If there is no negative feedback on expected profitability, however, it is unlikely that the industry will internalise detrimental environmental effects. In this case, the government has to regulate the industry if the effects are to be avoided. The rapid growth of global aquaculture has represented an environmental challenge for authorities. First, knowledge about the environmental effects of aquaculture has been limited or, at worst, lacking. This has called for extensive research to identify cause and effect. Second, in many places local governments do not have the resources to implement and enforce regulations.

There are a number of examples of poor environmental practices in aquaculture (as in agriculture). However, that does not make the production method inherently unsustainable; there are a number of examples of sustainable aquaculture. Still, intensive and particularly large-scale intensive aquaculture has a larger potential to produce detrimental environmental effects than do other technologies. The higher the degree of control with the production process does, on the other hand, give these farmers a better opportunity to control the negative effects of their production. Thus, there is no doubt that aquaculture can be carried out in a sustainable manner, independent of the level of intensity. Therefore, the real issue with aquaculture and sustainability is whether farmers choose to use sustainable practices. This will be an issue primarily of local regulations and governance, and is one area where green growth policies can have a major impact.

One of the most contentious issues in relation to shrimp farming, the destruction of mangrove forest is a good example. The destruction of mangrove forest to make room for shrimp ponds is well documented (Primavera, 2000). However, the shrimp farmers do not destroy mangrove forest because there is any inherent advantage to use this land. They use this land because it is not useable in agriculture and therefore the cheapest land available. That the bio services of the mangroves are not accounted for is primarily a local governance problem.

4.3 Policy implications of green growth for aquaculture

It is more difficult to derive policy implications for aquaculture than for fisheries as most of the issues are less clear and more contested. It is obvious that one should reduce environmental impact as much as possible. While there are a number of sustainable practices, there are unfortunately also a number of unsustainable practices that can be avoided with good governance. This is particularly true for local issues like land use, pollution and impact on biodiversity. International bodies have a clear role to play here, for instance on the issue of mangrove destruction.

Green policies targeting aquaculture must also be designed with care, as it is an issue that also highlights the general feature that there are risks associated with economic growth. One must ensure that the production practices used are sustainable, if the industry is to be allowed to grow. On the other hand, several of the more contentious issues in relation to aquaculture also seem to come from misconceptions, and measures to tackle such issues can unnecessarily harm industry growth without any positive environmental effects. The fish meal trap is for instance a fisheries management issue, and it does not make much sense to prevent aquaculture producer from using fish meal and fish oil in their feed, while allowing chicken and pork producer to do the same thing.

In contrast to fisheries, aquaculture has a strong growth potential. Green growth policies have a significant role to play, because this growth potential can only be achieved if the industry is sustainable. However, to restrictive policies that does not allow for innovation and economic growth is an equally large threat as to lax policies that allow unsustainable practices to be carried on.

For aquaculture there is also a positive trade-off relative to terrestrial food production and forestry systems. Aquaculture has the potential to relieve pressures on marginal land because it makes this land use unprofitable, but it introduces new types of ecological effects. Although it is clear that feeding humanity with fruits and vegetables is "greener" than aquaculture, comparing aquaculture to animal production is a different matter. The outcome of such comparisons will depend on species and production mode, as shown for energy use and carbon footprint in Section 6. However, we still do not have enough insights to make general conclusions on this issue.

5. Biodiversity and climate change

Fisheries and aquaculture interact with the ecosystem where they take place. Undoubtedly, this influences biodiversity. Moreover, climate change is likely to change the patterns of these impacts.

The impact of fisheries on fish stocks and ecosystems is most clearly presented by Pauly *et al.* (1998) in the fishing down the foodweb hypothesis. This hypothesis states that fishers start by targeting the largest, easiest to catch and most valuable species at high trophic levels such as bluefin tuna, swordfish and cod. When these become less abundant and harder to catch, fishing effort shifts to new species, and also to new fishing grounds and higher water depths (Pauly *e al.*, 2003). More fundamentally, it is clear that as fishers reduce the abundance of one (group of) stock(s), this gives room for other species. This is also described in predator-prey models such as for capelin and cod by Flaaten (1991). It is also clear that fishers played an important part in reducing the stocks of northern cod to very low levels, and allowing for huge increases in the stocks of different types of crustaceans and cephalopods. Hence, there is ample evidence that fishing can and do change the abundance of different species. It has also been demonstrated that fishing can also influence genetic composition of a fish stock, as the species adapt to fishing pressure (Guttormsen, Kristofersson and Nævdal, 2008). A particular challenge is that large individuals are often targeted because they give a higher value per kg.

Bycatch is also a significant factor in fisheries impact on biodiversity, as many types of fishing gear select poorly between different species. The largest impact is due to nets or trawls with too fine mesh size, as not much can get through. Although barriers can be put in to keep large individuals out of a trawl, this is measures that are often unpopular with fishers because they are cumbersome and increase harvesting cost. Bycatch can lead to significant quantities of untargeted species to be caught, killed, and dumped, and as such constitute a pure waste. This can be true also for relatively selective gears. For instance, in the Atlantic there are typically being caught 3 tonnes of shark, which is dumped, for each tonnes of swordfish.

Bycatch also brings us into one of the biodiversity impacts of aquaculture. For many species, and particularly for extensive technologies where the production cycle has not been closed, fingerlings, larva or juveniles are being caught form wild stocks. As the nets employed have a very limited mesh size, however, virtually anything that is swimming in such an area will be caught. When aquaculture production in an area becomes large enough, this can have effects on biodiversity in a larger system. Aquaculture is also using areas, and by claiming these areas, one is excluding other species. This has received most attention with respect to shrimp, as mangrove forests are cleared and destroyed to create room for shrimp farms (Primavera, 2000). In areas with substantial aquaculture activities, a landscape with a large number of ponds gives the same impression of monoculture as a series of wheat farms. Also other types of aquaculture influence and in many cases reduce biodiversity in an area as the ecological system is altered, and a large number of individuals of a single species dominate.

Climate change has the potential to significantly affect many fisheries, as it will influence the workings of ecosystems and the abundance of different species. However, the impact is still far from clear. For instance, the Intergovernmental Panel of Climate Change (IPCC, 2003) states that "Although progress has occurred, it is still not possible to assess regional responses to shifts in climate trends, as it is unknown if general warming will increase or decrease frequency and intensity of decadal-changes in regions where national fisheries occur. Recent studies have not produced evidence to change the conclusion (Everett *et al*., 1995) that future saltwater fisheries production is likely to be about the same as present, though changes in distribution could affect who catches a particular stock". The effect on stock abundance in specific regions can indeed be demonstrated to be substantial, and is demonstrated by *e.g.* McGowan, Cayan and Dorman (1998) for the North Pacific and Stensvik and Sundby (2007) for the North Atlantic. Moreover, even if the total fisheries production is not likely to change, the risk and uncertainty facing fishers and fishery managers are likely to increase, creating additional challenges. Different societies and types of fisheries are likely to have different degrees of resilience with respect to these challenges (McGoodwin, 2007). Moreover, as fish stocks move, existing international agreements to manage these stocks may be destabilised (Hannesson, 2007b). Hence, even if climate change is not likely to influence total fisheries production significantly, it has a substantial potential to influence economic activity and economic growth.

Similar considerations are largely relevant for aquaculture. Changes in climate will alter the geographical regions where growth conditions are suitable for different species, and accordingly where the farming takes place. If the weather patterns become more volatile, this will also make some types of aquaculture more difficult, and it can limit or prevent the development of offshore aquaculture. Volatile weather patterns may also increase insurance premiums for aquaculture.

It is still worthwhile to note that the control of the production process that has driven the development in aquaculture also makes aquaculture more adaptable to climate change than fisheries. While climate change can force aquaculture producers from some regions, they can move to new regions which in many cases will become more suitable for aquaculture. Technology development in itself can also make aquaculture more adaptable to climate changes. That aquaculture is a food production technology with different requirements from terrestrial food production and fisheries can also make aquaculture a valuable tool in adapting to climate change, as it will make the world's food production systems more diversified and thereby more resilient.

6. Energy use

As noted in the introduction, Tyedmers, Watson and Pauly (2005) estimate that the world's fishing fleets are using 1.2% of the global oil consumption, primarily as fuel. For aquaculture, the main energy use is through the feed production. This varies substantially between species, from nothing for mussels to very high levels for eel. As the distribution seems to be similar as for wild fish it does not seem unreasonable to estimate the total oil use for aquaculture to be 0.8%, and as such a rough estimate this for oil consumption in seafood production is 2% of global oil consumption.

The structure of the energy use for fisheries and aquaculture are very different though. As one can see from Table 2, harvesting of cod and salmon from aquaculture has a similar sized carbon footprint. However, for cod, most of the carbon footprint and energy use is due to fuel use in the harvesting phase, while for salmon, most of the carbon footprint and energy use is due to fuel use in the production of feed. Investigation of energy use and carbon footprint in fisheries is a recent field, as most work has been produced after the turn of the millennium. Life Cycle Assessment (LCA) is becoming the predominant methodology (Pelletier *et al.*, 2007), but the results are still somewhat scattered. More complexity in comparing measures is added by the fact that they are carried out at different levels in the supply chain and one make different assumptions with respect to by-products. A comforting feature, though, is that the relative ranking of different product seems to be relatively stable even though the estimates of oil consumption, carbon footprint or energy use varies considerably. Table 2 is based on two recent studies, Cederberg *et al.* (2009) and Winther *et al.* (2009).

Table 1. Table 2. Norwegian salmon production and antibiotics use in aquaculture

Species	Carbon footprint (kg CO2e/kg edible part at slaughter)	Energy use (MJe/kg edible part at slaughter)	Reference
Beef, Sweden	30	79	Cederberg et al (2009)
Pork, Sweden	5.9	41	Cederberg et al (2009)
Chicken, Sweden	2.7	29	Cederberg et al (2009)
Salmon, Norway	2.9	40	Winther et al (2009)
Cod, Norway	2.9	27	Winther et al (2009)
Haddock, Norway	3.3	34	Winther et al (2009)
Mackerel, Norway	0.5	7.12	Winther et al (2009)
Herring, Norway	0.5	6.8	Winther et al (2009)

For fisheries, the main source for energy use and carbon footprint is the harvesting process, and accordingly it depends to a very large extent on which gear and vessel type is being used. The numbers in Table 2 largely reflects this. Cod in Norway is being caught by trawlers and coastal vessels, where the trawlers have much higher energy consumption than then coastal vessels that are using passive gears such as nets and Danish seine. The higher carbon footprint for haddock is largely due to a higher share being caught by trawlers. The energy use for mackerel and herring is much lower, as these are being caught with purse seines, pelagic trawls and coastal vessels. Two fishing practices are significantly worse than the others when it comes to energy use; beam and bottom trawling. These are in most studies reported to use more than three times as much oil as other gear types.

In addition, regulatory systems leading to competition for fish further amplifies incentives to overuse energy. This is partly due to the competition itself, but it is also due to the use of more energy intensive gears than necessary to succeed in the competition. For instance, the introduction of IVQs in several New Zealand fisheries led to the abandonment of trawls and the introduction of more selective gears such as long lines (Wilen, 2000). This was possible because the competitive fishing ceased with the new regulatory system, and although the main motivation for the gear change was the increased prices for better quality fish, the shift was also positive from an energy use perspective.

In aquaculture, the most important energy source is the feed. This is partly due to the effort involved in fishing the marine ingredients or producing the ingredients in agriculture, and partly due to the highly energy intensive drying process when drying fish meal and pellets. While there are few studies, one can use our knowledge of feed composition to infer that, as for fisheries, there is very substantial variation between highly extensive species that are not provided with any feed, to intensive species with formula based feed with a high share of marine ingredients.

While the main share of the carbon footprint occurs before the fish is harvested, there are certainly also significant energy use associated with processing and transports. However, with the exception of air freighted fish, there does not seem to be any specific form of supply chain that is preferable. The lowest energy use in transports seem to be associated with transports of frozen fish by ship, and as such, transporting fish from Europe or the USA to China for processing before it is shipped back/on to consumers in Europe and the USA, is not necessarily a poor alternative from a carbon footprint perspective. Transports of fresh fish by road or rail do not need to be a bad alternative when the distances are not too large, as for instance from Norway to France. However, the energy efficiency for any species is in general improved by transporting as little besides the fillet as possible (it does not make much sense to transport fish heads that will go straight to the garbage, although it is done in several markets since looking at the eyes of the fish is an important indicator for freshness, an important quality attribute). The freight of parts of the fish that will end up as cut-offs is unfortunately to often also institutionalised. In the three main import markets for fish, the EU, Japan and the USA, there is a significant tariff escalation, favouring the imports of unprocessed product forms to promote domestic industries. This tariff escalation is in many cases anti-green, and also prevent economic growth in exporting countries that often are developing countries. Reduced tariff escalation for seafood is accordingly clearly a green growth policy.

The main conclusions from the available information with respect to carbon footprint and energy use largely reflect what is the case for agriculture (Blandford, 2010). Short-travelled food does not necessarily have any advantage when it comes to carbon footprint, and it is hard to come up with a good comprehensive indicator. There are just too many different production practices, processing methods and supply chains. Moreover, if the focus is to be too strongly on carbon footprint or energy use, one also must consider whether there are species that one should not harvest, because they can only be harvested with high energy technologies. While that can make sense from an energy use perspective, it can be poor practices form a resource exploitation perspective. Still, there also seems to be some low hanging fruits with respect to specific technologies in specific supply chains, and as such, relatively easy gains that can be achieved with green growth policies.

It is also important to view fisheries and aquaculture in a broader perspective. As noted by Tyedmers, Watson and Pauly (2006) with respect to oil consumption and reinforced by the numbers in Table 2, fisheries and aquaculture seems to be doing relatively well compared to pork and chicken production, and very well compared to beef.

7. New uses of the sea

In addition to fisheries and aquaculture, there are also a number of potential uses of the oceans that are still only on a trial stage or even less advanced. As the oceans cover more than two thirds of the planet’s surface, this area has a large potential for food and also energy production. However, all the uses also have ecological implications.

Biomass production in the sea is many times larger for lower-level organisms such as krill and algae (Duarte *et al.*, 2009). While there is some commercial harvesting, this is still underutilised resources, largely because their exploitation is uneconomical and controversial. It is quite possible that technology development can help making the exploitation of such resources economical, in particular if scarcity takes food prices to higher levels. However, this is a highly controversial way to exploit the oceans, and environmental NGOs are strongly opposed to it. Offshore aquaculture is another way to utilise the open oceans that are uneconomical today, but that may have potential with further technology development and higher food prices, but again, environmental NGOs are strongly against such practices. In a larger perspective, both production modes have the potential to relieve pressures on marginal lands in land-based production, and this is a factor that should be taken into account when assessing their merit with respect to environmental impacts.

Lately, the coastal waters have also become used for energy production. This is primarily due to wind mills, but there also exist prototypes for wave mills. In addition, there also exist prototypes for facilities where one uses algae to produce gas.

All these new modes of using the oceans for food production pose environmental challenges, and the environmental NGOs seems, with the exception of coastal wind mill parks, to be generally against them. In many ways, this resembles the opposition to aquaculture as a new way of using the environment. Prohibiting any development is surely a way of preventing new environmental interactions in the oceans. Whether it is a beneficial policy with respect to the ecological impact of humanity is less clear. Green growth policies for the oceans need to carefully weigh the benefits and costs, taking into account the alternative ways of providing food and energy.

8. Trade, markets and socioeconomic impacts

Seafood is among the most traded food commodities as 39% of production is traded (FAO, 2010). This is important because it is a source for economic growth and livelihoods in many areas (Smith *et al.*, 2010a). However, it can be a challenge from a green perspective that wealthy regions export what is perceived as undesirable fish, while at the same time importing large quantities of more desirable fish, as discussed in Section 2. This seems to be wasteful from an environmental perspective, although this can be discussed as in the previous section, but can be good from a public health perspective if it leads more people to eat fish.

Not only has trade with seafood increased since the 1970s, but the trade patterns have also changed dramatically. There are a number of reasons for this spanning from cheaper transports and logistics via new and potentially harmful methods for resource exploitation to better preservation technologies and increased demand. An interesting factor is the impact of retail chains that are increasingly dominating sales in developing as well as developed countries, where the potential to enter efficient logistics and distribution chains is a main competitive advantage, possibly with high energy cost.

It must also be noted that there are several commentators arguing that the trade with seafood and the globalisation of the seafood market is not a good thing. In particular, it is often noted that exports from poor communities can reduce food security, and increase hunger and socioeconomic problems. However, when balanced against the benefits of economic growth and the opportunity to use the proceeds from seafood sales to purchase more food, trade with seafood seem to be beneficial (Kurien, 2007; Smith *et al*., 2010a).

8.1 From regional to global markets

The geographical extent of fish markets was traditionally limited by the perishability of the product. Until one hundred years ago, dried, dried salted, and heavily salted fish were the main product forms that were shipped over long distances. For other product forms, the market was at best regional and often very local.[4] From about the turn of the 20th century, the seafood trade has increased steadily due to improved storage and preservation and cheaper transportation. For instance, railways allowed larger but still limited quantities of high-end products, like oysters and lobster, to be shipped by rail. In addition, canning provided preservation that allowed seafood to be stored for a long time. However, canned product is very different from fresh product, and storage and preservation technology led to market segmentation. For canned product, the geographical extent of the market was vastly expanded, and for some species the market became global, *e.g.* tuna and salmon.

While fish was caught throughout the world in the first half of the 20th century, most of what was traded was consumed in the EU, Japan and the USA.[5] When freezing technology became popular in the 1950s, it largely replaced canning (and drying and salting) as the main storage and preservation method for a number of species and markets. Freezing is now the preferred storage and preservation

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[4] It is interesting to note that an important reason for the longstanding, long-distance fish trade in Europe was that Catholics generally did not eat meat on Fridays and during Lent prior to the changes in recommendations by the Vatican.

[5] We use the term EU to describe the countries of Western Europe even before the formation of the European Community and the European Union (EU).

method for most high value species. Because freezing requires capital equipment, both in the freezing process and in storage throughout the value chain, it is still most prevalent in wealthier countries, although its use is steadily expanding. The concentration of freezing in wealthy countries also made most markets appear regional. For instance, the whitefish market was a North Atlantic market involving countries in Western Europe, Canada, and the USA; Pacific halibut was a Pacific Northwest market. However, as transportation and logistics continued to improve, freezing technology spread to other regions, and demand for fish could not be met from regional fisheries due to overfishing, the sources for fish became increasingly global. The whitefish market is a good example. In 1980 it included primarily North Atlantic species like cod, saithe, and haddock. But by 1990, Alaska pollock and Pacific cod were established as major parts of the market, linking the North Atlantic and North Pacific fisheries. During the 1990s, species such as Nile perch, Argentinean and Namibian hake, hoki from New Zealand, as well as farmed species like pangasius and tilapia, made the market truly global (Asche, Trollvik and Roll, 2009).

Until the late 1980s, most seafood trade was in preserved products, although limited quantities of some high-end products were also shipped fresh on ice or live. Fresh seafood was primarily supplied by fishers within the same region, even though improved infrastructure had expanded the market so that it could be accessed by virtually any producer. Innovation in relation to salmon aquaculture changed this picture dramatically. The use of long-distance truck hauling in Europe and North America as well as air freight was important, as it largely removed the barrier that distance previously presented to the global market for fresh salmon. In 2006, Norway and Chile exported fresh salmon to more than 150 countries. Air freight also allowed producers in any location to access the market, and this can be seen as the main factor behind the success of Chile, now the second largest salmon producer.[6] The same pattern can also be found for a number of other species. For instance, virtually all fresh tilapia consumed in the USA is flown in from Central and South America (Norman-Lopez, 2009). Where the regulatory system allows a sufficient degree of control in the harvesting operation, similar systems have also been created for wild fish, with air freight of cod from Iceland being the most prominent example. Therefore, during the last two decades, a global market has been formed for fresh seafood.

8.2 Species and product forms

Despite the fact that the seafood market has largely become global, it is highly segmented. The market is segmented in at least two dimensions, by species and by product forms. The seafood market is highly segmented because for most species prices are determined independently of each other, and this is also the case for many product forms.[7] However, markets for different product forms using the same species as raw material tend to be more integrated than markets for different species. The main reason for this is that a producer does not care much about who the fish is sold to, and the fish will be sold to the buyer willing to pay the highest price. If two processors both want fish from the same fishery, they will have to pay similar prices. As such, the globalisation of the fish market can be seen as a process through which a barrier to trade, namely transportation costs, has been reduced and the

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[6] As the scale of production increases in industrialised aquaculture, the production risks also increase. An example is the recent disease outbreaks in Chilean salmon aquaculture, which may lead to Scottish and Canadian production of Atlantic salmon being higher than the Chilean production in 2010.

[7] This argument indicates that there is a limited degree of substitution between different types of protein. The empirical literature generally supports this view; there seems to be no or very little substitution between seafood and other types of meat in Europe and North America, though there is some evidence of such substitution in Japan (Asche, Bjørndal and Gordon, 2007). However, it should also be noted that this evidence is from developing countries, and circumstances can well be different in developing countries.

market has become more integrated as producers from more places ship their seafood to the highest-paying market.

That the markets for different species are segmented, or unintegrated, can be interpreted as evidence that consumers have different preferences for different types of seafood. Different species have different characteristics, and no chef would consider using the same recipe for cod as for herring or squid. However, globalisation also makes new species compete with each other. This change is most apparent in the whitefish market. Thirty years ago cod was the preferred species in this market. However, there were also several cheaper alternatives such as saithe and redfish. The price movements of these species were influenced by cod; few consumers would buy saithe or redfish if their prices increased too much towards the price of cod, while demand for the alternative species increased when their prices decreased relative to cod.

In the 1980s Alaska pollock and Pacific cod entered the whitefish market, making the price of Alaska pollock related to the price of other types of whitefish. A number of other new species entered this market during the 1990s and later. These include farmed catfish, hoki, farmed pangasius, Nile perch, and farmed tilapia. Hence, the whitefish market not only became global during the last decades, but it grew as new species entered and influenced the price determination process. The market also has more interconnections, since many species have alternative markets in addition to the markets where they were traditionally sold. For instance, surimi has been one of the most important product forms for Alaska pollock. When processors choose whether to produce a frozen fillet or surimi,[8] they make decisions based on the prices in these markets, linking the whitefish and surimi markets. The whitefish market has changed, and there are now indications that cod, which used to be the leading species in the market segment, is no longer a competitor but forms a separate market segment.

The introduction of new product forms is one reason why species with attributes that appear quite different from the traditional whitefish species has enter the market. In particular, with breaded and battered products, as well as ready-made meals, it is often very hard to distinguish between different species. This is exploited by many producers, who rename species to make them more attractive (Pauly *et al*., 2003). As prices of cod and other whitefish species increased and landings decreased during the last decades, cheaper substitutes became more attractive. As a result, cod is no longer used in low-valued product forms like fish fingers. It is also noteworthy that the aquaculture industry has started to target new market segments, and increasingly high volume rather than high price segments. Further, several firms are experimenting with frozen tilapia blocks, targeting the lower-priced end of the whitefish market.

While the seafood market is still diverse, a significant part of product development makes it less diverse. For instance, as more species become “whitefish” and lose their separate identity, the seafood market becomes less segmented, as these species face a similar price determination processes. This development is likely to continue in order for them to meet the requirements of the largest outlets for seafood in many parts of the world, the retail chains.

8.3 Intermediate trade

Traditionally, processing of fish has taken place close to where the fish landed to preserve it, before the fish were transported to the final market. However, with improved freezing technology and aquaculture, low transportation costs for many products, this pattern has changed in many supply chains, and processing is increasingly taking place where it is most competitive and exploits economies of scale.

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[8] Surimi is a processed fish paste that is a common ingredient in Japanese and other East Asian foods.

For most preserved products, transportation costs are not a big issue because they make up only a small percentage of the final price. For instance, the current cost of transporting frozen fish by ship between virtually any two markets in the world is less than US 50 cents per kilo. Hence, for producers with access to the international trade routes, distance is generally no longer a significant barrier.

If distance does not matter much, a supply chain can be optimised to exploit economies of scale, and from several sources. This was first utilised for block frozen whitefish fillets of Alaska Pollock that was imported to Europe, primarily Germany, and when still block frozen, cut to portion sizes and packaged. For an increasing number of products, one can observe supply chains where the final processing is taking place close to the final consumer. Some examples are Vietnamese pangasius in Germany and South East Asian shrimp in the US.

When it became possible to freeze fish twice, large processing plants were set up in China sourcing unprocessed frozen fish from virtually all over the world, thawing and processing the fish in China, before sending it to its final destination. This may even be back to the country where the fish originated, as with US Alaska Pollock.

Also for fresh trucked salmon a similar process has taken place. From the early 1990s, Denmark developed into one of the largest importers of fresh farmed salmon in Europe, but also the leading exporter after Norway, partly due to a processing industry developed to handle primarily Norwegian salmon. After Poland became an EU-member, Danish firms has been partly outcompeted by Polish firms (often at least partly owned by Danish or German investors), and Poland has now taken over from Denmark as the second largest salmon exporter in Europe, without any domestic production.

8.4 Resource utilisation

In Section 3, we saw that discards of bycatch was a major source for resource waste. An equally important source for biomass waste for seafood is most likely due to limited or no handling of the cut-offs. The fillet yield for different fish species vary between 30% and 65%, and also for other seafood products there are significant cut-offs. The small scale nature of fish handling and processing often makes investments in equipment that process the cut-offs impracticable or economically infeasible. This is certainly true for the individual consumer who buys a whole fish, but put the head, the skin, the bones and the leftovers in the garbage, possibly after using it to cook fish stock. The same largely holds true for small and mid-sized processing plants, restaurant etc. This is a state of the world that is largely unheard of in the meat processing business.

There is also substantial anecdotic evidence of waste in the value chain due to poor handling, and seafood products are in many states exposed to this problem since they are highly perishable. However, it need not only be fresh or thawed product that are not sold at the end of a short shelf-life that are wasted, it also happen to frozen or other types of conserved products that for different reasons are kept in storage for too long, or that are kept in storage under unsatisfactory conditions.

There have certainly been some improvements. Large factory trawlers will often also contain a fish meal and oil plant, so that the only leftovers of the fish are sellable products, water and tiny quantities of litter. The same is true for large scale processing plants that are mostly associated with aquaculture (salmon, pangasius), but also wild fish in China and other places where plant with large enough production are established. Hence, an increasing part of these cutoffs are being used to produce byproducts, and these are currently making up about 25% of the raw materials for fish meal and fish oil. However, the volumes are still much smaller then what they can be.

It is virtually impossible to provide a precise estimate of what share of the biomass is actually wasted by not taking care of cut-offs or by improper handling. However, 25% of the total production is most likely a conservative estimate, and it will then make up about 40 million tonnes. It is certainly impossible to create value chains where all this waste is avoided. It is encouraging that fishmeal plants and other types of cut-off processing is increasingly taking place in modern processing plants not only in countries with strict regulations and costly handling of waste, and as such , turning the cut-offs into a useful resource rather than waste. A green growth policy emphasise supply chains with good handling and resource utilisation, but also recognise that there are limits to how far one can go. This is a difficult area since there are economies of scale associated with making the waste an economically viable resource, and to tight regulations can discriminate smaller firms and countries with poor infrastructure.

9. International and national policies

With the numerous interactions between fisheries and aquaculture production, there is a substantial potential for green growth policies, and also a tremendous potential for humanity to conduct environmental damage if new technologies continue to be implemented without better management and concern for environmental impacts. However, to provide a perspective, a good starting point will be a likely scenario if greener policies are not implemented in fisheries and aquaculture.

9.1 What are the implications of continuing current trends in global fisheries and aquaculture production?

If fisheries and aquaculture policies do not change to a greener mode, what will then be the consequences for the global seafood production? The current resource waste will certainly continue, and it is significant. Pauly et al (2003) estimate the global discards to be about 30% in addition to the fish that is landed. This amounts to 27 million tonnes. Metuzals *et al.* (2009) reports that different studies indicate that between 10 and 60% more than the current landings are IUU fish. If we somewhat conservatively set this percentage to 15%, this amounts to another 13.5 million tonnes of fish. In addition, we have estimated that unutilised cut-offs and other waste in the handling of fish will amount to another 40 million tonnes of biomass being wasted. In total, this amounts to about 80 million tonnes of biomass that is taken out of the sea and produced in aquaculture that is wasted every year, given that the production levels are kept relatively stable. This is equivalent to 50% of the total quantity that is being reported as production from fisheries and aquaculture every year.

Opinions with respect to whether the current production level can be kept stable, or whether it will increase or be reduced differs dramatically depending on source. One can certainly get very gloomy future perspectives. Worms *et al*. (2006) estimate that by 2048 all seafood producing stocks will collapse, and if one takes the view of Naylor *et al*. (2000), this will also reduce most aquaculture production to zero as there is not fish meal and oil available for feed. Exceptions will mostly be mussels and oysters, and maybe some carp.

These very pessimistic perspectives seem highly unlikely though.[9] The FAO and most fisheries experts indicates that current production levels from wild fisheries are likely to be maintained, even in the presence of climate change, and that aquaculture production is likely to continue to increase. However, as fishing technologies continues to improve, and increasing number of highly desirable species will be brought to the brink of extinction, and some can even be driven to extinction. Bluefin tuna is an example of a species that may be very close. However, collapsing stocks like the northern

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[9] It should be noted that the Worms *et al.* (2006) has been heavily criticised.

cod has shown that it is very hard to actually bring a stock to extinction even though it can be driven down to commercially uninteresting levels.

If management systems do not improve, the overcapacity is likely to continue together with the subsidies. This is likely to continue to keep a number of stocks at low levels, and to contribute to high stock variability as stocks at times will be rebuilding before they again are fished down. There will continue to be competitive fisheries, IUU fishing and significant discarding.

As new technologies in aquaculture are introduced, primarily taken from agriculture, production is likely to continue to increase, although like for meat production, only a handful of species are likely to be produced in large volumes. The most likely candidates today are tilapia, pangasius, shrimp, and some species of oysters and mussels. However, it is still too early in the development of aquaculture to make a good prediction of which species it will be. Strict environmental regulations will prevent aquaculture from becoming very large in most developed countries, and because of limited production, these countries will also lose the knowledge edge they enjoy today. The industry will still thrive in many developing countries based on the knowledge that has already been obtained, despite a number of highly questionable environmental practices. Like one has seen with the shrimp industry, many unsustainable operations will give the industry a bad reputation among environmental NGOs, but eventually some firms will develop sustainable practices, as this is the only way to be sustainable in the long run. Independently of how the US FDA rules with respect to the introduction of genetically modified (GM) salmon (Smith *et al*., 2010b), GM-strains of a number of species will be introduced in several countries with little or no control.

9.2 The case for green growth policy action

While wild fisheries represent the last large hunting sector in the world, it is often poorly managed. Better management can protect stocks, reduce ecosystem vulnerability to external shocks like climate effects, be a more reliable food source, and with more reliability, provide more stable landings, thus promoting economic growth in coastal communities.

Aquaculture has a tremendous growth potential as productivity continue to improve, new species are domesticated and more technologies and production practices are transferred between species and from land based animal production. However, to exploit this potential, policies must be implemented in some developing countries that allow some environmental risk, while in other parts of the world and in most developing countries better management and governance systems are necessary to ensure that the industry is sustainable. The merits of aquaculture also needs to be evaluated relatively to other types of food, that it competes with in the marketplace, based on sound science and facts..

9.3 Fisheries and aquaculture in a green growth strategy

With increasing pressure on marginal lands in terrestrial food production, the main benefit of fisheries and aquaculture is to provide an alternative with a potential to alleviate some of this pressure. As more than two-thirds of the planet’s surface is covered with water, the oceans, rivers and lakes are the world’s most underutilised resource when it comes to food production. The fact that aquaculture has been the world’s fastest growing food production technology during the last decades give a fair indication of the potential of what can be achieved with systematic R&D work. Given that the industry still is in its infancy when it comes to knowledge and technology compared to agriculture, there is still much that can be achieved with slight adaption of existing knowledge.

The fact that fisheries and aquaculture use different input and takes place in different ecosystems from terrestrial food production means that it is also food production technologies that are spreading the risk in the global food production system from external shocks such as climate effects, and as such, fisheries and aquaculture have an important role to play in making the global food production system more resilient.

9.4 Green growth policy actions

There are a number of readily accessible policies that can be implemented to promote greener growth, particularly in fisheries, and to let aquaculture take out its growth potential in a sustainable way. There is ample scientific evidence that the major causes of unsustainable fishing practices in global fisheries, *i.e.* overcapacity, IUU fishing and environmentally detrimental subsidies must be addressed by governments, and there are also a number of international efforts. For example, there is now a UNFAO International Plan of Action on managing fleet capacity (Roheim 2007). However, it appears that governments face a number of political and socio-economic challenges when attempting to deal with these issues.

1. Improved Fisheries Management

Too many fisheries are still poorly managed, resulting in too high fishing pressure, overcapitalisation, too high fishing effort and overfished fish stocks. This is partly due to inadequate resources provided for fisheries management, but as the track records of many countries with advanced fisheries management systems are not particularly good, it is clear that lack of formulation of proper objectives for fisheries management is part of the problem. The objective should be to achieve biological, economic and social sustainability at a level that does not impair the services of the larger ecosystem. However, one must recognise that this is not a status quo, as changing culture and real wages in a society will lead to changes in the socioeconomic structure, and technical progress should be utilised for positive purpose while at the same time excesses that leads to increased vulnerability of fish stocks should be controlled.

As resource rent that is not realised in monetary terms tend to result in overcapacity, a larger share of the resource rent should be realised. Whether this is done with taxes, fees or other measures that provides the public sector with revenue or whether it is realised as quota value for those individuals that are given the quota in a system that allow the resource rent to be realised is primarily a political question.

Several organisations which are of the opinion that government based fisheries management is insufficient are now providing private alternatives in the form of ecolabels.

For fisheries, this is clearly the most important area, and points 2, 3 and partly 4 below are in many ways just special cases which in essence are bona fide management issues. Special attention to developing countries and their ability to reform management and development assistance would be helpful to achieve green growth objectives. For the OECD countries this would imply technical assistance to countries heavily dependent on developing their fisheries resources and exports, not least as overfished stocks is a global problem. These are also issues that have been recognised in several OECD works (OECD, 2006; 2008; 2010c).

2. Curb IUU fishing

It is hard to understand how Illegal Unregulated and Unreported fishing can continue with all the focus the issue has received during the last decade. However, management systems that gives fishers poor incentives and limited control and enforcement illustrate that IUU- fishing is difficult to curb effectively even in the Exclusive Economic Zones (EEZ) of coastal states. Moreover, the rights on the high seas and the number of nation allowing vessels to fly a flag of convenience seem to make it surprisingly hard to deal with this issue. However, it should also be noted that distant water fishing nations seem to resist efforts that in practice will give coastal nations in an area even larger control.

Green growth policies must emphasise better incentive structures through fisheries management reform coupled with heightened control and surveillance. Globally, international agreements (like port state measures) are yet another part of the process to curb IUU fishing.

3. Reduce overcapacity and abolish subsidies

Reducing overcapacity is highly linked to improved fisheries management, as it is a symptom of poor management. Many countries are taking steps to reduce capacity directly or indirectly by rationalizing fisheries, but only those that adjust the management systems so that incentives are crafted in such a way that capacity is not increased.

In an industry where resource rent should be harvested it is a paradox that many countries provide subsidies. Even when there are good socioeconomic reasons for providing subsidies, the long-run results are virtually always negative. The only way to ensure viable coastal communities with fishing and aquaculture as important activities is by sound sustainable management. Too often, subsidies are used to mitigate the effect of poor management and to delay necessary actions.

The somewhat limited evidence so far is positive from a socio-economic perspective, as it seems that most overcapacity is capital, and the number of working hours is not reduced at all or only to a limited extent even when a large number of vessels are removed.

4. Reduce waste, better handling and increase value added

Given that the productive capacity of the oceans is limited, economic growth in the fisheries sector can primarily come from reduced waste and more value added. There are several million tonnes of fish being discarded every year, and there is an even larger biomass being wasted because of poor handling of cut-offs. A challenge here is that better handling that reduces waste often has significant economies of scale. This goes all the way from putting inspectors on board large fishing large vessels (*i.e.* to enforce a prohibition against discards), to fish meal plants that utilise the remaining cut-offs. Still, better management can reduce discarding, restrictions on transports of cut-offs together with other policies can result in better handling and product development.

There are also substantial inefficiencies all along the way in most supply chains. While there are encouraging signs that cut-offs and trimming are being used in specialised products, there is still a long way to go. Guidelines can help, although small scale will often be a challenge. What is being transported is also an issue together with handling. Total energy use in different supply chains are, however, often what one would expect at first sight, and care should be taken with respect to how and for what recommendations should be created.

An obvious green growth policy is to reduce or remove tariff escalation. Tariff escalation is a common measure in many large markets importing fish to protect domestic processing industries. However, it promotes the transport of significant volumes of fish that eventually will become unutilised cut-offs. These policies are also hindering economic growth in fish exporting developing countries.

5. Sustainable aquaculture

There are already a wide variety of practices in aquaculture production, and this is likely to increase as new species are being domesticated and new technologies employed. Many aquaculture practices can be sustainable, but they need not be, and many practices are also unsustainable. Local regulations and governance play a similar role as that of fisheries management in fisheries, and good practices are very important. With the rapid pace of the technology development and production increase in aquaculture, it is important that resources are also invested into developing this knowledge. Governments are already lagging, and best practice recommendation has been provided by the Global Aquaculture Alliance and several organisations look at ecolabelling. In many developed countries concerns relating to negative externalities from aquaculture are so strong that regulations prevent the industry from developing. For instance, farmed salmon production in the UK peaked in 2003, and further expansion seems to be unlikely, primarily due to red tape. While this can delay the development in aquaculture somewhat, it is in the longer run more likely to give more opportunities for producers with poor production practices in countries with weak institutions and local governance. This applies to most technology issues in relation to aquaculture, including GM-organisms.

Green growth policies for aquaculture recognise and address the challenges which some production practises may pose with respect to sustainability. It does so without limiting the growth potential of the industry and preventing aquaculture from taking its place as one of the world's most important food production technologies that alleviates pressures on marginal lands by exploiting the most abundant surface on the planet.

Development of guidelines would be extremely useful. Special attention to developing countries and their ability to reform management and development assistance may be helpful. OECD (2010b) also provides several important insights. Lastly, the FAO has recently adopted guidelines for aquaculture ecolabelling. However, the crucial question of sustainability remains undefined.

6. Energy use and climate change

Both fisheries and aquaculture need substantial amounts of energy in their production, and in both cases there are specific sources of energy use.

In fisheries, the main energy use is fuel. Fuel is used to propel the vessel, and for most gears, fuel use increase as the gear is being put into the water. With enough focus on this issue, more efficient engines may also be developed. There are some simple measures that can have significant effects. Few fishers seem to be aware of the how their fuel use is related to the gear use and speed, and installation of fuel meters can change behavior significantly. Fuel subsidies should also be abolished. This seems to be a major measure in terms of perceived effects, as it also has the benefit of reducing capacity.

However, as these subsidies often are short term measures to support employment, their abolishment will in many cases be resisted. Improved fisheries management also plays a role here, as poor incentives promote energy inefficient practices, with “Olympic fisheries” as the worst example.

Several studies have shown that fuel use also differs significantly between different gear types. In some cases this should result in promotion of shifts towards more efficient gear types. This can still not be regarded as a solution in all cases, as there are fisheries that can be conducted only with relatively fuel intensive gear (*e.g.* shrimp trawling), and such fisheries are relatively energy efficient compared to many terrestrial food production systems.

For aquaculture the main energy use is related to feed, and as such, efficient feed use should be promoted. Extensive technologies are more energy efficient than intensive technologies, but has less growth potential and use more of other resources such as land and water per produced unit. The trade-off in this respect is accordingly not clear-cut, and is likely to vary depending on species. Many aquaculture species also compares favorably with terrestrial food production, and will in many cases be preferable.

While of secondary importance, transport and processing should also be given consideration, as energy use can be significant. It seems clear that air-transport of fresh fish is very energy intensive, but then air-transport of goods or people always seems to be on the worst end when it comes to energy efficiency in transportation. As this is a very recent field of research, our knowledge is still quite limited.

REFERENCES

Abbott, J., B. Garber-Yonts and J. E. Wilen. 2010. Employment and Remuneration Effects of IFQs in the Bering Sea/Aleutian Islands Crab Fisheries. *Marine Resource Economics* 25(4): 333-354.

Anderson, J. L. 2002. Aquaculture and the Future. *Marine Resource Economics* 17(2): 133-152.

Anderson, J. L. 2003. The International Seafood Trade. Cambridge: Woodhead Publishing.

Arnarson, R. 1990. Minimum Information Management in Fisheries. *Canadian Journal of Economics* 23: 630-653.

Asche, F. 2008. Farming the Sea. *Marine Resource Economics* 23(4): 507-527.

Asche, F., T. Bjørndal and D. V. Gordon (2007). Studies in the Demand Structure for Fish and Seafood Products. Handbook of Operations Research in Natural Resources. A. Weintraub, C. Romero, T. Bjørndal and R. Epstein. Berlin: Springer**:** 295-314.

Asche, F., H. Eggert, E. G. Gudmundsson, A. Hoff and S. Pascoe. 2008. Fisher's Behaviour with Individual Vessel Quotas – Over-capacity and Potential Rent: Five case studies. , 32, 920-927. *Marine Policy* 32: 920-927.

Asche, F., D. V. Gordon and C. L. Jensen. 2007. Individual vessel quotas and increased fishing pressure on unregulated species. *Land Economics* 83: 41-49.

Asche, F., K. H. Roll and T. Trollvik. 2009. New Aquaculture Species – The Whitefish Market. *Aquaculture Economics and Management* 13(2): 76-93.

Asche, F. and S. Tveterås. 2004. On the Relationship between Aquaculture and Reduction Fisheries. *Journal of Agricultural Economics* 55(2): 245-265.

Berkes, F. and 14 co-authors. 2006. Globalization, Roving Bandits, and Marine Resources. *Science* 311:1557-1558.

Blandford, D. (2011) The Contribution of Agriculture to Green Growth. Report to the OECD.

Cederberg, C., U. Sonesson, M. Henriksson, V. Sund and J. Davis (2009) Greenhouse Gas Emissions from Swedish Production of Meat, Milk and Eggs 1990 and 2005. SIK Report 793.

Delgado, C. L., N. Wada, M. W. Rosengrant, S. Meijer and M. Ahmed. 2003. Fish to 2020: Supply and Demand in Changing Global Markets. Washington: IFPRI.

Duarte, C. M., M. Holmer, Y. Olsen, D. Soto, N. Marba, J. Guiu, K. Black and I. Karakassis. 2009. Will the Oceans Help Feed Humanity? *BioSience* 59(11): 967-974.

Everett, J.T., A. Krovin, D. Lluch-Belda, E. Okemwa, HA Reiger, J-P Troadec (1996) Fisheries. In R. T. Watson, M. C. Zinyowera, and R. H. Moss (ed): Climate Change 1995: Impacts, Adaption, and Mitigation of Climate Change: Scientific-Technical Analysis.

Copes, P. 1986. A Critical Review of Individual Quota as a Device in Fisheries Management. *Land Economics* 63(2): 278-291.

Contribution of Working Group II to the Second Assessment Report of the Intergovernmental Panel on Climate Change, New York, USA: Cambridge University Press, p. 511-537.

FAO. Report of the Expert Consultation on Identifying, Assessing and Reporting on Subsidies in the Fishing Industry. Rome, 3-6 December 2002. FAO Fisheries Report. No. 698. Rome, FAO. 2003.

FAO (2006) The State of World Fisheries and Aquaculture. FAO Fisheries and Aquaculture Department. Food and Agricultural Organization of the United nations: Rome.

FAO (2010) The State of World Fisheries and Aquaculture. FAO Fisheries and Aquaculture Department. Food and Agricultural Organization of the United Nations: Rome.

FAO (2011) Fishstat Plus – Universal software for fishery statistical time series. Food and Agricultural Organization of the United nations: Rome.

Flaaten, Ola, 1991. Bioeconomics of sustainable harvest of competing species, *Journal of Environmental Economics and Management*, 20(2), 163-180.

Gordon, H. S. 1954. The Economic Theory of a Common Property Resource. *Journal of Political Economy* 62: 124-142.

Groves, T. and D. Squires (2007) Lessons from Fisheries Buybacks, in R. Curtis and D. Squires (ed.). Fisheries buybacks. Blackwell: Ames, Iowa.

Guttormsen, A. G., D. Kristofersson and E. Nævdal. 2008. Optimal Management of Renewable Resources with Darwinian Selection Induced by Harvesting. *Jorunal of Environmental Economics and Management* 56: 167-179.

Hardin, G. 1968. The Tragedy of the Commons. *Science* 162: 1243-1248.

Hannesson, R. 1996. Fisheries Mismanagement: The Case of the North Atlantic Cod. Oxford: Blackwell.

Hannesson, R. (2007) Do Buyback Programes Make Sense? in R. Curtis and D. Squires (ed.). Fisheries buybacks. Blackwell: Ames, Iowa

Hannesson, R. 2007b. Global Warming and Fish Migrations. *Natural Resource Modeling*, 20, 2007, 301-319.

Hatcher, A. and Robinson, K. (Eds.). Overcapacity, overcapitalisation and subsidies in European fisheries, Portsmouth, Proceedings of the first Concerted Action workshop on Economics and the Common Fisheries Policy: UK, 28-30 October, 1998. CEMARE Miscellaneous Publication no. 44 1999.

Homans, F. R. and J. E. Wilen. 1997. A Model of Regulated Open Access Resource Use. *Journal of Environmental Economics and Management* 32(Jan.): 1-21.

Homans, F. R. and J. E. Wilen. 2005. Markets and Rent Dissipation in Regulated Open Access Fisheries. *Journal of Environmental Economics and Management* 49: 381-404.

IPCC (2001) Climate Change 2001: Impacts, Adaption, and Vulnerability. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change, New York, USA: Cambridge University Press.

Kristofersson, D. and J. L. Anderson. 2006. Is there a relationship between fisheries and farming? Interdependence of fisheries, animal production and aquaculture. *Marine Policy* 30(6): 721-725.

Kurien, J. 2005. Responsible Fish trade and Food Security. Rome: FAO.

Larkin, S. L. and G. Sylvia. 1999. Intrinsic Fish Characteristics and Intraseason Production Efficiency: A Management-Level Bioeconomic Analysis of a Commercial Fishery. *American Journal of Agricultural Economics* 81(Feb.): 29-43.

McGoodwin, J. R. (2007) Effects of Climatic Variability on Three Fishing Economies in High-Latitude Regions: Implications for Fisheries Policies, Marine Policy, 31, 40-55.

McGowan, J. A., D. R. Cayan and L. M. Dorman (1998) Climate-ocean Variability and Correspondence in the North Pacific. Science, 281: 201-217.

Metuzals, K., R. Baird, T. Pitcher, U. R. Sumaila and P. Ganapathiraju (2009) In *Handbook of Marine Fisheries Conservation and Management* (Eds, Grafton, R. Q., Hilborn, R., Squires, D., Tait, M. and Williams, M.) Oxford University Press, Oxford.

Milazzo, M. (1998). Subsidies in World Fisheries. World Bank Technical Paper no. 406. Washington.

Munro, G. R. and A. D. Scott (1985). The Economics of Fisheries Management. Handbook of Natural Resource and Energy Economics. A. V. Kneese and J. L. Sweeny. Amsterdam: North Holland.

Munro, G.R. and U.R. Sumaila. 2002. Subsidies and their potential impact on the management of the ecosystems of the North Atlantic, *Fish and Fisheries* 3:233–250.

Myers, R. and B. Worm (2004) Rapid Worldwide Depletion of Predatory Fishing Communities, Nature, 423, 280-283.

Naylor, R. L., R. J. Goldburg, J. Primavera, N. Kautsky, M. Beveridge, J. Clay, C. Folke and J. Lubchenco. 2000. Effects of Aquaculture on World Fish Supplies. *Nature* 405(29): 1017-1024.

Newell, R. G., J. N. Sanchirico and S. Kerr. 2005. Fishing Quota Markets. *Journal of Environmental Economics and Management* 49: 437-462.

Norman-López, A. 2009. Competition between different Wild and Farmed Species: The US Tilapia Market. *Marine Resource Economics* 24: 237-252.

Pelletier, N. L., Ayer, N. W., Tyedmers, P. H., Kruse, S. A., Flysjo, A, *et al.* 2007. Impact Categories for Life Cycle Assessment Research of Seafood Production Systems: Review and Prospectus." *International Journal of Life Cycle Assesment* **12**, 414-422.

OECD. 2005. Subsidies: a way towards a sustainable fisheries? Policy Brief. Organization for Economic Cooperation and Development, Paris.

OECD (2006). Financial Support to Fisheries. Implications for Sustainable Development. Aug 2006, 378 pages OECD, Paris

OECD (2007). *Structural Change in Fisheries. Dealing with the Human Dimension*. OECD, Paris.

OECD (2008). Review of Fisheries in OECD Countries: Policies and Summary Statistics 2008. OECD, Paris.

OECD (2009). Economics of Market Information related to Certification and Standards in Fisheries. Round Table on Eco-Labelling and Certification in the Fisheries Sector. The Hague, Netherlands 22-23 April 2009

OECD (2010a). Monitoring Progress towards Green Growth: Indicators for the OECD Green Growth Strategy. Fifth Meeting of the UN Committee of Experts on Environmental-Economic Accounting. New York, 23-25 June 2010. ESA/STAT/AC.217. UNCEEA/5/16.

OECD (2010b). Advancing the Aquaculture Agenda. Workshop Proceedings. Paris, 15-16 April 2020.

OECD (2010c). The Economics of Rebuilding Fisheries. Workshop Proceedings. April 2010.

Pauly, D., V. Chrisensen, J. Dalsgaard, R. Froese and F. Torres Jr. 1998. Fishing Down Marine Food Webs. *Science* 279(6 February): 860-863.

Pauly, D., J. Alders, E. Bennett, V. Chrisensen, P. Tyedemers and R. Watson. 2003. The Future of Fisheries. *Science* 302(21 November): 1359-1361.

Primavera, J.H. (2000) Development and conservation of Philippine mangroves: Institutional issues. Ecological Economics, **35**, 91-106.

Roheim, C.A. 2004. Trade liberalization in fish products: Impacts on sustainability of international markets and fish resources. in *Global Agricultural Trade and Developing Countries*. A. Aksoy and J. Beghin, eds. Washington D.C.: The World Bank.

Roheim, C.A. 2007. Does Capacity Analysis Help us Meet Fishery Policy and Management Objectives? *Marine Resource Economics* 22:77.

Sanchirico, J. and J. E. Wilen. 1999. Bioeconomics of Spatial Exploitation in. a Patchy Environment. *Journal of Environmental Economics and Management* 37(2): 129-150.

Smith, M. and J. E. Wilen. 2003. Impacts of Marine Reserves: The Importance of Spatial Behaviour. *Journal of Environmental Economics and Management* 46: 183-206.

Smith, M. D., C. A. Roheim, L. B. Crowder, B. S. Halpern, M. Turnipseed, J. L. Anderson, F. Asche, L. Bourillón, A. G. Guttormsen, A. Kahn, L. A Liguori, A. McNevin, M. O'Connor, D. Squires, P. Tyedemers, C. Brownstein, K. Carden, D. H. Klinger, R. Sagarin, K. A. Selkoe (2010a) Sustainability and Global Seafood, *Science*, 327, 784-786.

Smith, M. D., F. Asche, F., A. G. Guttormsen, A. G. and J.B. Wiener, J. B. (2010b) Genetically Modified Salmon and Full Impact Assessment. *Science* 330, 1052-1053.

Stenevik, E. and S. Sundby (2007) Impacts of Climate Change on Commercial Fish Stocks in Norwegian Waters, Marine Policy, 31, 19-31.

Stevens, C. (2011) Agriculture and Green growth. Report to the OECD.

Sumaila, U.R., A. Khan, Andrew J. Dyck, A., Watson, R., Munro, G., Peter Tyedmers, and Pauly, D. (2010). A bottom up re-estimation of global fisheries subsidies. Journal of Bioeconomics, 12:201-225Tyedmers, P. H., R. Watson and D. Pauly. 2005. Fueling Global Fisheries Fleets. *Ambio* 34(8): 635-638.

Tacon, A. G. J. and M. Metian. 2008. Global overview on the use of fish meal and fish oil in industrially compounded aquafeeds: Trends and future prospects. *Aquaculture* 285: 146-158.

Tveterås, S. 2002. Norwegian Salmon Aquaculture and Sustainability: The Relationship between Environmental Quality and Industry Growth. *Marine Resource Economics* 17(1): 121-132.

Vestergaard, N. 1996. Discard Behaviior, Highgrading and Regulation. *Marine Resource Economics* 11(4): 247-266.

Wilen, J. E. 2000. Renewable Resource Economists and Policy: What Differences Have We Made? *Journal of Environmental Economics and Management* 39(3): 306-327.

Winther, U., F. Ziegler, E. S. Hognes, A. Emanuelsson, V. Sund and H. Ellingsen (2009) Carbon Footprint and Energy Use of Norwegian Seafood Products. SINTEF report A096068, Trondheim.

Worm, B, E. B. Barbier, N. Beaumont, J. E. Duffy, C. Folke, B. S. Halpern, J. B. C. Jackson, H. K. Lotze, F. Micheli, S. R. Palumbi, E. Sala, K. A. Selkoe, J. J. Stachowicz and R. Watsonhttp://www.sciencemag.org/content/314/5800/787.abstract - aff-12 (2006) Impacts of Biodiversity Loss on Ocean Ecosystem Services, Science, 314, 787-790.