Fisheries

Environmental Impacts of Wild Caught Cod and Farmed Salmon – A Comparison with Chicken

Harald Ellingsen* **and Svein Aanond Aanondsen**

SINTEF Fisheries and Aquaculture, 7465 Trondheim, Norway

* **Corresponding author** (harald.ellingsen@sintef.no)

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Abstract

Goal, Scope and Background. The objective of this study was to assess environmental impacts of Norwegian cod fishing and salmon farming and compare these with chicken farming in order to find reference levels for environmental performance and identify problem areas and potentials for improvements.

Methods. A Life Cycle Screening following the production of 0.2 kg fillets as a functional unit through the respective food chains is performed for all 3 products. The analysis is partly quantitative and qualitative focusing on energy use, antifouling and land use impacts. Case studies are performed to investigate potentials for improvements within the fisheries and aquaculture industry.

Results and Conclusions. It can be concluded that the fishing phase for the cod and the feeding phase for both salmon and chicken dominate for all environmental impacts considered. Chicken is most energy effective followed by salmon and cod, which are almost on the same level. The area of sea floor affected by bottom trawling is around 100 times larger than the land area needed to produce the chicken feed for production of the 0.2 kg fillet.

The case studies show potentials for improvement of environmental performance, both for salmon farming and cod fishing, especially when it comes to energy use. The environmental impacts on the sea floor imposed by bottom trawling are not fully explored, but based on the precautionary principle a reasonable conclusion is that bottom trawls with less impact on the sea floor should be developed.

Recommendation and Perspective. LCA methods have initially been developed for land based industrial applications. More effort should be given to adapt these to fishing applications in order to obtain more accurate assessment of environmental impacts from seafood products. It is recommended to put more emphasis in finding improved indicators for impacts imposed by over-fishing, fuel emission from combustion at sea, use of antifouling and seafloor ecosystem disturbance.

Keywords: Antifouling; chicken farming; energy use; environmental impacts; land use; life cycle screening (LCS); Norwegian fisheries; salmon farming; seafloor impacts

Introduction

Environmental impacts of food production are increasingly focussed upon, also when it comes to fish (Degnbol et al. 2003). Not only the content and the quality of the fish as food are important to the consumers. The environmental impacts of catching or farming, processing and transport to the market are becoming important issues as well. Increased pressure from strong consumer groups and retailer organisations is thus expected in the direction of a more sustainable food production chain (Mandag Morgen MicroNews 1998). This also includes requirements with respect to documentation. Introduction of various environmental labels combined with requirements versus traceability and safety of foods is expected to take place.

Within the fisheries sector both official and private organisations, such as the Marine Stewardship Council (Marine Stewardship Council, 2005), are developing criteria in order to separate environmentally friendly seafood from what is not. The strategy is to leave it to the market or the consumer to judge in that question. This will challenge the established management regime and put forward new requirements to systemisation of the sea food production chain. Several NGO's, such as the association for Norwegian fishing vessel owners (Fiskebåtredernes Forbund 2005), are now in the process of connecting there fisheries to the MSC label.

It is anticipated that LCA will be important as a basis for the development of product oriented information versus future documentation of environmental performance of food products.

LCA methods are initially developed for land-based industrial applications, and the methodology is so far not brought to the same level when it comes to food products, especially not for fish. Several studies related to fish products, however, are available. Among these are Ziegler (2001), Ziegler et al. (2003), Thrane (2004), Christensen and Ritter (2000), Eyjolfsdóttir et al. (2003), Silvenius and Grönroos (2003) and Mattsson et al. (2003). It is generally agreed that better adapted environmental indicators are needed for both wild caught and farmed fish.

1 Methods, Goal and Scope

The objective of this study was to assess environmental impacts of Norwegian cod fishing and salmon farming and compare with chicken farming in order to find reference levels for environmental performance and identify problem areas and potentials for improvements. The point of departure was fish, while chicken was used for bench-marking. Bench-marking with chicken was assumed to be of interest as chicken is one of the most effective land-based meat producers. Both cod, salmon and chicken products are substitutes in the grocery cabinets, and it should be a reasonable assumption that these food products easily can be selected at the sacrifice of the other if the choice is influenced by information regarding environmental impacts.

It is anticipated that the establishment of reference levels may contribute in the process of developing improved environmental labels for seafood.

A Life Cycle Screening (LCS) was performed using the software tool SimaPro and the impact assessment method Eco-indicator 99 (H)/ H/A (Goedkoop and Spriensma 2001). The databases ETH-ESU 96 (Frischknecht and Jungbluth 2004) and BUWAL 250 (Spriensma 2004) are used for background processes.

For all three food chains, a 200 g fillet is used as a functional unit (FU). This corresponds to the meat content in a standard dinner meal served at restaurants.

The cod is caught by factory trawlers using bottom trawls dragged along the sea floor normally within Norwegian waters. The salmon is farmed on the West Coast of Norway and the chicken is raised in the southern part of Norway. The fillets are sold in Mid-Norway. Production of fish meal and oil for the salmon feed is based on pelagic species swimming in shoals higher up in the water column. These are normally caught by combined mid-water trawling/purse seiner vessels operating in the Norwegian zone or in the North-East Atlantic. Mid-water trawls are normally larger than the bottom trawls and are towed in the pelagic. A purse seine is a huge net used to encircle the fish. Grain products used for feed are produced partly in Southern Norway, France and in Brazil. All feed are processed in Western Norway.

The analysis has followed the steps in the respective food chains. The industrial processes involving slaughtering and processing of salmon fillets are to a large degree identical with those used for chicken fillets. A main distinction is that the cod is filleted on board the trawler while the salmon and chicken are processed on land.

System boundaries include catching, breeding, farming, processing and transportation. This includes processing of feed including provision of raw materials as industrial fish and grain products and transportation between various processing facilities. Environmental impacts during wholesaling, retailing and the consumer's final food preparation, however, are left out. Furthermore, packaging materials and waste treatment are excluded from the analysis. Capital goods as buildings, trucks and fishing vessels are excluded as their contribution are assumed to be of minor importance in line with earlier studies (Ellingsen and Pedersen 2004, Thrane 2004).

The catch data for cod also include other ground fish species, mainly saithe. The economic value for cod landed by the trawlers is about 50% higher per kg than the average catch, but all species are fished with the same method, within a quota system limiting the catch volume and for the same purpose of human consumption. Mass allocation is therefore used for calculation of energy use for cod versus other ground fish species In other respects, economic allocation is used.

Environmental impacts from use of biotic resources as fish resources, arable land and the sea floor are relatively new in LCA methodology and cannot be treated in the same way as use of materials and energy and accompanying emissions (Ziegler et al. 2003). Use of energy and antifouling are in line with earlier studies (Thrane 2004) regarded as most important and included in the impact analyses. Use of arable land and sea floor impact are quantified, but not included in the impact analysis. The impact from over-fishing and disturbance of the sea bottom ecosystem is discussed on a qualitative basis.

2 Life Cycle Inventory

Data are generally collected from various sources by both literature surveys, a study of available data sources, telephone conversations and meetings.

2.1 Feeding efficiency

The salmon and chicken feed content is shown in **Table 1**. The economical feed conversion ratio used for both food chains can be found in **Table 2**. This is the actual amount of feed in weight units needed to produce one unit of living weight. Losses due to diseases, escape, inefficient feeding routines, etc. are included in this ratio. Table 2 also includes the factor used for converting round fish and live chicken to fillet weight, i.e. the factor defining the round or living weight needed to produce one weight unit of fillet.

Data are collected from Anon (2002), Waagbo et al. (2001), Berge (1997), Bjørkli (2002), Bagley (2002) and Widheden et al. (2001).

According to Table 2, it takes 460 g live salmon to produce the FU, which is 200 g times the factor 2.3. Furthermore, it takes 593 g of salmon feed to produce the 460 g live salmon, which is 460 g times 1.29. The average fat and meal content in the pelagic species used for feed is 14.3% and 18.6%, respectively, which means that 143 g fish oil and 186 g meal are

Table 1: Feed content used in the analysis

Feed ingredients	Feed content in weight units	
	Salmon	Chicken
Fish meal	35%	5%
Fish ensilage	5%	
Fish oil	28%	
Fish products in all	**68%**	**5%**
Oat		20%
Maize- and wheat gluten	7%	
Soy products	6%	15%
Soy oil	3%	
Wheat	12%	35%
Maize		20%
Rape		5%
Plant products in all	**28%**	**95%**
Various minerals, vitamins and colour	4%	
In all	**100%**	**100%**

Table 2: Feed and fillet conversion factors used in the analysis

Factors	Units	Chicken	Salmon	Cod fish
Feed factor	kg feed / kg live animal	1,92	1,29	
Fillet factor	kg live animal / kg fillet	2,9	2,3	2,8

extracted per kg of industrial fish (Einen and Mørkøre 1997). By combining these figures with the feed content in Table 1, it can be derived that 1.3 kg of wild fish is needed per FU, or alternatively 2.8 kg of wild fish to produce one kg of salmon.

2.2 Energy use

Energy use during harvesting, transport phases with boats, trucks and other cars are calculated. These include energy needed for cooling, feed production and for slaughtering and processing for the three food chains. Energy consumption during fishing is calculated based on economic data from (Anon. 1980–1999) combined with oil price data from (Ellingsen and Lønseth 2005). Fuel consumption is calculated in kg oil used per kg round fish landed. For cod trawling, an average figure of 0.47 kg oil/kg fish landed is found. The same figure is found to be 0.07 for the catching of pelagic fish used for salmon feed by combined mid-water trawling/purce seining. This fishery is far more energy efficient than bottom trawling. Further data sources are Statistics Norway (Anon. 2002), other studies (Widheden et al. 2001, Thrane 2004) and personal conversations with producers of feed, salmon and chicken.

2.3 Nutrient emissions

Data for nutrient emissions from manure and use of fertilisers within grain production on land are collected from Widheden et al. (2001) and Bagley (2002).

Manure and feed spill from salmon farming is a main contributor of nutrient salts along the Norwegian coast line and accounted for 56% of the total emissions in 1999 (Borgvang and Tjomsland 2001). The environmental impact from this is disputed, however, and work is ongoing aiming at identifying the carrying capacity for nutrient loads imposed by fish farming (Anon. 2003). Norwegian fish farms are today placed at locations with good water quality and production conditions so that the emissions in general are assumed to be within the carrying capacity both on a local and regional level (Dalen and Holm 2004). What will happen in case of a further expansion of the aquaculture industry is an open question. In other areas, as in Scotland (MacGarvin 2000) and in Finland (Silvenius and Grönroos 2003), the problems due to eutrophication impacts are considered to be far more severe.

In the further analysis, nutrient emissions to fresh water imposed by grain production are included, while the nutrient emissions from salmon farming to salt water are neglected.

2.4 Antifouling

Both fishing vessels and sea cages are normally coated with antifouling paint, containing copper, to prevent fouling by shellfish, algae, etc. The great share of the copper in this paint, 80–90%, leaks out into the sea during normal operation. Impacts on biotopes close to cleaning facilities for aquaculture cages are observed, and zero discharge is now required by law at these facilities (Anon. 2000). It is further a management strategy to reduce the emissions imposed by antifouling.

Vannebo et al. (2000) estimates that about 200 tonnes of copper is discharged into Norwegian water from the aquaculture industry each year. That gives 1 gram of copper leakage for every 2 kg of salmon produced or 0.19 g of copper per FU. Copper leakage to the sea from fishing vessels was found by calculating the average wetted hull area for a Norwegian trawler. Data for use of paint was found via personal conversations with antifouling paint producers. Effluent of 0.02 g copper per FU of cod fillet was found. The antifouling paint production process is not included.

2.5 Land use impacts

It is accepted that available arable land for food production is a limited resource, but the sea floor is not unlimited either. Over the last two decades, this concern has increased with interest mainly focussing on the impacts of towed fishing gears such as trawls and dredges on benthic habitats and organisms. Numerous investigations, however, have been conducted on these impacts during the last decade, but still little is known and few clear conclusions can be drawn (FAO 2004).

(Fosså, 2000) estimates that bottom trawling and dredging have damaged up to half of all the coral reefs in the North-East Atlantic. Some researchers even compare bottom trawling with clear cutting of the rain forest (Watling and Norse, 1998). Experiments performed inside the Marine Protected Area around the Bear Island in the Barents Sea in 2000 and 2001 (Huse et al. 2002) indicate, on the other hand, that changes in the biodiversity attributed to fishing gear disturbance are generally low, especially for areas exposed to such natural stress as waves, current, eutrophication and salinity fluctuations.

Ziegler et al. (2003) have estimated the area impacted by Swedish trawlers in the Baltic Sea and discussed the possible environmental impact. They indicate that bottom trawling can contribute to oxygen depletion, but conclude that more studies are needed in order to quantify the biological effects of trawling in a specific area.

The seafloor swept by trawling is calculated based on data for average trawl dimensions, average trawling speed and average catch landed per day. Data is collected from conversations with fishermen and Anon. (1980–1999).

Necessary land area to produce grain for chicken and salmon feed is found in (Widheden et al. 2001). The calculations show that 2.5 m^2 are occupied for production of the chicken feed and 1.2 m^2 for the salmon feed, whereas an area of 215 m^2 is covered by trawling to produce the 200 g fillet.

3 Results

3.1 Characterization

Characterization has been performed for all three food chains, but only the results from the farmed salmon are shown (**Fig. 1**).

The farming phase dominates all investigated impact categories. Only minor contributions are due, for example, to transport. The same can be concluded for the cod and chicken food chains. They are dominated by the fishing phase and farming phase, respectively. For salmon and chicken, this is due to extraction of the feed ingredients and the processing of the feed. For the cod chain, this is due to the energy consumption during fishing. It follows that further investigations should concentrate within the operation of the fishing vessel and the feed production.

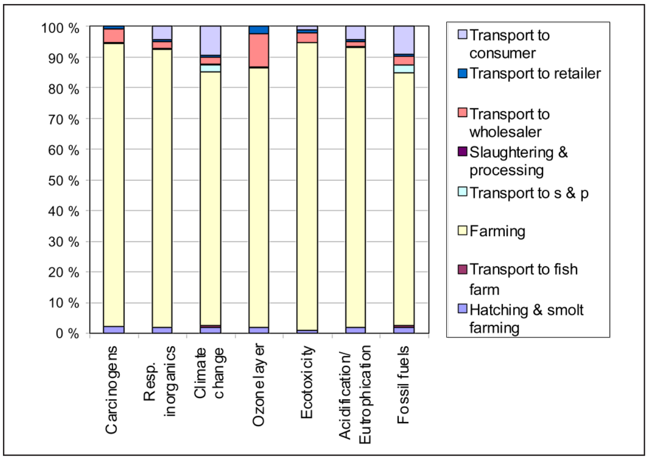

Fig. 1: Characterization results for salmon farming

3.2 Energy use

Fig. 2 shows the result of the energy flow analysis.

Mineral oil is the dominating contributor to the energy flow for all three food chains followed by hydropower as is used in the salmon and chicken chain. Mineral oil is used for fishing operations, transport in general, feed processing and heating. Chicken is most energy effective, followed by salmon and cod which are almost on the same level.

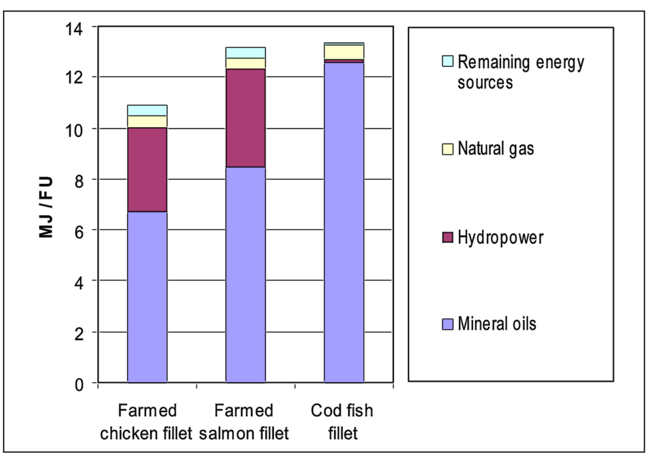

Fig. 2: Energy consumption per FU

3.3 Weighing

The environmental impacts during the various steps in the production chains are further analysed through weighing, see **Fig. 3**.

These results also emphasize the fishing and farming activities as the main contributors to the environmental impacts. The most important environmental categories for all food chains are use of fossil fuel and respiratory impacts from inorganics. The main contributors to the fossil fuel category are the use of marine gas oil and diesel oil. For the category respiratory inorganics, the most important emissions are NO_x, SO_x and ammonia. Ammonia is most important for the chicken chain followed by NO_x. NO_x is most important for the cod and salmon chains.

To illustrate the sensitivity in the conclusions above, an analysis with two alternative impact assessment methods, the Eco-indicator 95 and the EDIP indicator, was performed and compared. The Eco-indicator 95 gave higher scores for the eutrophication impact for the chicken and salmon, while the EDIP indicator gave very high scores for the ecotoxicity for salmon farming due to the copper emissions. The conclusion regarding the fishing and farming phase as the main contributors with respect to environmental impact, however, was supported by both indicators.

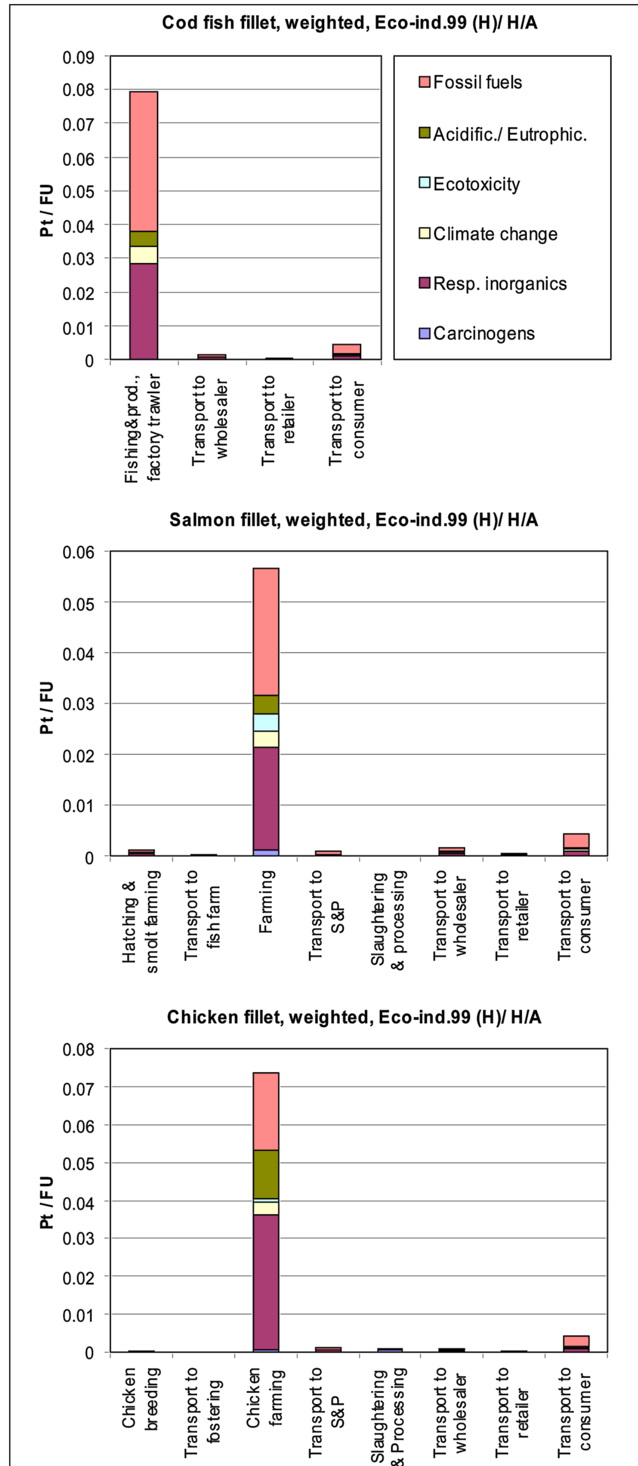

Fig. 3: Life cycle, weighted results

4 Are Improvements Possible?

In order to investigate possible improvements with respect to environmental performance in cod fishing and salmon farming, two scenarios where defined and tested. We called these scenarios *Green fuel* and *The vegetarian salmon*.

4.1 Green fuel

Norway is committed to both the Kyoto agreement versus climate emissions and the Gothenburg protocol versus especially sulphur and NOx emissions. The progress with respect to reaching agreed levels of especially NOx and CO_2 emissions is by far on schedule and focus is now on coastal shipping and fishing to find improvement potentials (Anon. 2005). Use of natural gas, as LNG, is assumed to be a possible environmental friendly alternative as this will reduce the NO_x emissions with 85% and CO_2 emissions with 20%. An analysis was performed to find the potential environmental improvement impact both in cod fishing and salmon farming by substituting diesel oil with LNG. **Fig. 4** shows the result of this analysis. Use of LNG as an energy carrier is so far not implemented in fishing vessels or within feed processing, but this is proven technology and implemented in Norwegian ferries and supply vessels.

The results indicate a considerable potential for improvement due to green oil, both for the cod and the salmon when it comes to all impact categories except fossil fuel use as a non-renewable resource, and except for impacts on the sea bottom ecosystem, which are mostly unchanged.

4.2 The vegetarian salmon

According to FAO (2004), most captured fish stocks are exploited on or even beyond its safe limits, but the world total fish consumption is expected to increase in the years to come. A consequence of this is that the value of wild caught fish is expected to rise. An increasing share of the fish production will go to human consumption and less will be left for such industrial purposes as fish oil and meal. An expected shortage in supply for fish must be filled with increased aquaculture production.

Alternative feed sources should be found and one of these is the extended use of vegetables as an alternative to marine ingredients. We thus wanted to find the environmental qualities of a vegetarian salmon. As we have not included environmental impacts of over fishing, only the energy flow was investigated. The results are shown in **Fig. 5**, where the energy use in chicken production is also included.

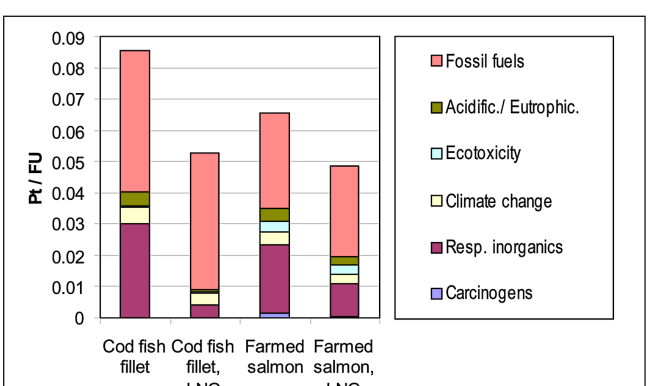

Fig. 4: Green fuel – cod fish and salmon, Eco-indicator 99

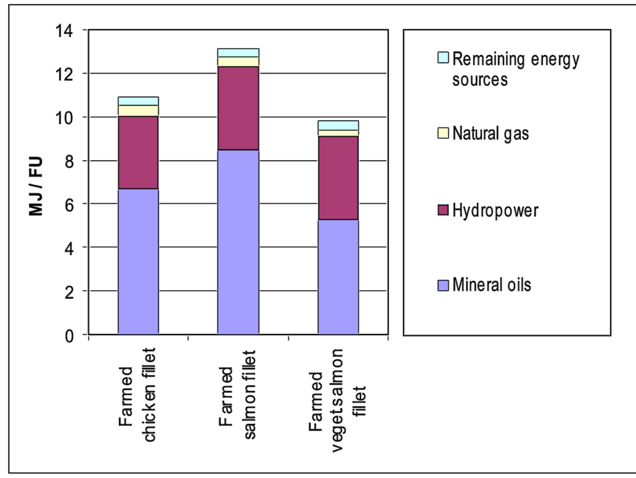

Fig. 5: The vegetarian salmon, energy score

By replacing marine feed with vegetarian feed, the energy use can be reduced to a level somewhat lower than for chicken farming. Salmon convert feed to meat more efficiently than chicken, but some of the impacts are counteracted by more energy use in the farming infrastructure.

5 Discussion and Conclusions

Comparing environmental impacts of different products is a questionable business, but such kind of investigations may turn out to be requested as a basis for future environmental labelling. The analysis presented in this article is by far not complete and covers only a few environmental impact categories. Several potential environmental effects such as use and disposal of pesticides and chemicals, escape of farmed salmon, etc. are excluded, but should be taken into consideration in later work.

It may be argued that such a comparison will have limited value when it comes to the wild fish, since the production is limited by biological capacity and quotas independent of marked mechanisms. This is partly the truth, but several aspects may be influenced such as the fish price, the treatment and the quality of the fish and, perhaps even more important, the share of the fish that is sent to the consumer market instead of to the fish meal and oil processing plants.

The results show that comparison based on energy use seems to be most reliable while other impacts should be compared with care.

One example is that the impact imposed by the use of arable land for the production of feed products cannot be directly compared with the sea bottom area covered by trawling. The area covered by trawling, however, is nearly 100 times the area needed to produce land-based feed when comparing on functional units. Un-published calculations done by SINTEF indicate that the possible disturbance of the sea floor should be included as a major environmental impact if more than 1% of the area covered by trawling is affected over time. In line with the principle of precaution, it follows that this impact should be reduced by introducing more environmentally friendly trawl designs which are less harmful to the sea floor.

Chicken farming is less energy demanding than salmon farming according to this analysis. This is mainly because a substantial part of the salmon feed is wild caught fish. Also cod fishing is more energy demanding than chicken farming, which in many ways confirm a general picture of the fishing industry as energy intensive. Several studies further indicate that fishing does not show a trend towards an improvement with respect to energy intensity (Tyedmers 2001, Huse et al. 2003 and Thrane 2004, Ellingsen and Lønseth 2005). Improved energy efficiency, however, should be expected within fishing taking all technological development into consideration such as better fish finding equipment, more efficient gear, improved control systems, etc.

FAO (2004) states that 75% of all fish stocks are either fully or overexploited. Among these are species commonly used for production of oil and meal as anchoveta and blue witting. The size of the North-East Arctic cod stock has recently increased (Michalsen 2004), but it is not clearly stated that it is within safe biologic limits. There may be a connection between overexploited fisheries and increasing energy use, and it may further be assumed that trend lines versus energy use may serve as indicators also with respect to other environmental impacts such as over-fishing.

Use of natural gas may reduce the environmental impacts, but not the energy use in itself. Measures should be taken within both fishing and aquaculture to reduce both the energy use and the corresponding emissions.

By substituting the marine-based salmon feed content with grain products, the energy intensity in salmon farming is reduced, but it remains to see if this is a sound environmental strategy if other impacts like land use are introduced. This is a rather hypothetical scenario as at least some of the salmon feed must be marine based in any case. An alternative strategy is to exploit marine feed sources lower down the food web.

As LCA methods are mainly developed for land-based activities, more effort should be given to adapt these to fishing applications in order to obtain more accurate assessment of environmental impacts for seafood products. It is recommended to put more emphasis in finding improved indicators, especially for fuel emission at sea, seafloor impacts, overfishing, escapements and use of antifouling.

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