Project Report
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Rannsóknastofnun fiskiðnaðarins

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LIFE CYCLE ASSESSMENT OF SEAFOOD 2ND WORKSHOP

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Skýrsluágrip Rannsóknastofnunar fiskiðnaðarins

Icelandic Fisheries Laboratories Report Summary

Titill / Title	**Life Cycle Assessment of seafood. 2nd workshop**		
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Ágrip á íslensku:

Þessi skýrsla greinir frá niðurstöðum annars vinnufundar í samnorrænu verkefni um vistferilgreiningu, sem haldinn var í Reykjavík dagana 21.-22. mars 2002.

Um var að ræða tveggja daga vinnufund (workshop). Fundinum var skipt í þrjú "þema" og voru haldnir fyrirlestrar og umræður í hverju þema fyrir sig.
Þessi þrjú þema voru:

- orkunotkun í fiskiðnaði
- Staða norrænna rannsóknaverkefna um LCA fyrir fisk og fiskafurðir
- Ástand sjávar og mælingar á mengandi efnum í sjávarlífverum.

Þátttakendur voru vísindamenn á Norðurlöndum sem nýta vistferilgreiningu á einn eða annan hátt í starfi/ námi sínu .
Í lok vinnufundarins ræddu þátttakendur hvernig þessi ofangreind þema tengjast aðferðafræði vistferilgreiningar og mismunandi túlkun á gögnum.

Lykilorð á íslensku: *LCA, fiskur, umhverfi, viðmiðunareining, ferilgreining*

Summary in English:

This report presents the outcome of the 2nd workshop in a Nordic project on LCA of seafood. The workshop was held in Reykjavik, Iceland, 21.-22. March 2002.

The meeting was divided into three themes, with lectures and discussions.
The three themes were:

- Energy usage in the fishing sector
- The current status of the Nordic LCA research projects for fish and fish products.
- The current status of marine pollution and the monitoring of contaminants in the marin biota.

The participants were scientists from the Nordic countries who use LCA in their work and other interested persons, as well as invited guests.
At the end of the workshop, the participants and invited guests discussed how these themes connect to the methodology of LCA and the different evaluation methods.

English keywords: *LCA, fish,environment, functional unit, allocation*

TABLE OF CONTENT:

1. INTRODUCTION

This workshop is the 2nd of three workshops to be held in the project "Work forum: Life cycle assessment for seafood". The Nordic Council of Ministers finances two different network projects in different programs concerning LCA of seafood. Like the 1st workshop, this was a joint workshop for these network projects (Work forum; Life cycle assessment for seafood and Network for environmental assessment of seafood products through LCA).

Both of these networks concern the application of LCA in the seafood sector and some of the participants are members of both projects. However, the objectives of these two projects are quite different. The objective of the project “Network for environmental assessment of seafood products through LCA” is to strengthen the communication of environmental information between stakeholders in the Nordic fisheries sector and to create a forum for interactive communication. The objective of the other project “Work forum; Life cycle assessment” is primarily to create a forum for researchers in the area LCA of seafood products, and is primarily dedicated to the development of LCA methodology for seafood.

2. WORK PROGRAMME AND PARTICIPANTS

Workshop programme 21. March 2002

8:45	Welcome /practical information
9:00	Development of energy simulator in the fishing industry - ORKUSPAR Sigurjón Arason / Eva Yngvadóttir, IFL
9:30	Estimating fuel inputs to North Atlantic Fisheries Peter Tyedmers, Dalhousie University
10: 00	Coffee
10:15	Energy use in the fishing fleet and strategic program for LCA at SINTEF Harald Ellingsen, SINTEF
10:45	Environmental assessment of seafood with a life cycle perspective Friederike Ziegler, SIK
11:30	Discussion
12:00	Lunch
13:00	LCA of Icelandic cod products, the present status Bryndís Skúladóttir IceTech / Eva Yngvadóttir, IFL
13:30	The status of the Danish LCA project Mikkel Thrane, Aalborg University
14:00	LCA of rainbow trout cultivation Frans Silvenius, FGFRI
14:30	Visit to Marel, producer of processing equipment
16: 00	Visit to a fish farming Íslandslax in Grindavík
18 :00	The Blue lagoon
19 :30	Dinner at the Blue lagoon

Workshop programme 22. Mars 2002

9:00	Heavy metals in marine biota in Icelandic waters Eva Yngvadóttir, IFL
9:30	Organochlorine pollution in Icelandic waters Kristín Ólafsdóttir, University of Iceland
10:00	The anti-fouling agent TBT (tributyltin) in the Nordic environment: effects and present status Jörundur Svavarsson, University of Iceland.
10:30	Coffee
11:00	Changes in quality (sensory) attributes of fish during storage Emilía Martinsdóttir IFL
11:30	All salmon are not created equal: Measuring the biophysical costs of salmon fishing and farming in British Columbia, Canada Peter Tyedmers, Dalhousie University
12:00	Discussion
12:30	Lunch
13 30	workshop questions- • How is the quality of fish taken into consideration in LCA studies ? • How is ISO 14000 series used in LCA studies? • How are valuation methods chosen/used/changed? • How are levels of contaminants (metals, POP's) in the marine environment (biota, sea, sediment) validated in LCA studies?
15: 30	Coffee
16: 00	Planning of the next workshop and planning of additional project proposals
16:30	Summing up
17:00	Closing

Participants:

Jens Munk	DTI	Denmark
Mikkel Thrane	Aalborg University	Denmark
Harald Ellingsen	SINTEF	Norway
Staffan Larsson	National Board of Fisheries	Sweden
Frans Silvenius	FGFRI	Finland
Friederike Ziegler	SIK	Sweden
Berit Mattsson	SIK	Sweden
Halla Jónsdóttir	IceTec	Iceland
Bryndís Skúladóttir	Ice Tec	Iceland
Eva Yngvadóttir	IFL	Iceland
Helga R. Eyjólfsdóttir	IFL	Iceland

Invited speakers:

Peter Tyedmers	Dalhousie University	Canada
Kristín Ólafsdóttir	University of Iceland	Iceland
Jörundur Svavarsson	University of Iceland	Iceland
Emilía Martinsdóttir	IFL	Iceland
Sigurjón Arason	IFL	Iceland

3. PRESENTATIONS

The workshop was divided into three different themes as can be seen in the programme. Each theme had a number of lecturers and after the presentation there was a forum for discussions. These three themes were:

- Energy use in fishery
- The status of the Nordic LCA research projects for fish and fish products.
- The status of the sea and measurements of contaminants in marin biota.

In appendix 5 there are overheads and brief summaries from the presentations.

4. SUMMARY OF DISCUSSIONS

Before the participants arrived they were given some questions to consider for the workshop. The questions were:

- How is the quality of fish taken into consideration in LCA studies ?
- How is ISO 14000 series used in LCA studies?
- How are evaluation methods in LCA chosen/used/changed?
- How are levels of contaminants (metals, POP's) in the marine environment (biota, sea, sediment) validated in LCA studies?

A brief summary from the discussions follows:

4.1 How can quality of fish be taken into consideration in LCA studies?

Fish is a biological raw material, which contains proteins, water, vitamins, minerals etc. Therefore, the quality regarding e.g. the shelf life is of great importance. The shelf life can differ a lot depending on the storage temperature, the size of the fish, fishing gear etc. Any discussion of of LCA should therefore take these factors into account.

In this group, there were two aspects discussed about how quality affects LCA studies of fish and fish products. The first one concerned the definition of the functional unit and the second one concerns the use of data from different sources (for example, different fishing gear, handling and storing the raw material etc.). What is the function of the functional unit? If the goal of the LCA study is to assess the environmental impact of a certain process, the evaluation of the product quality from that process is not taken into consideration. However, using LCA in comparison, it has to be of great importance to make sure that the functional unit does not differ in quality. So it would be a good thing to know about all the "hot spots" in a process and be able to identify whether quality aspects are of importance. Finally, it can be said that quality is important and is directly related to the objectives of the LCA study and methods to quantify quality (e.g. QIM) could be very useful for seafood LCA practitioners.

4.2 How is ISO 14000 series used in LCA studies?

Today there are published several ISO standards within the 14000-series. They are guidelines for the researcher going through the different stages in LCA analysis and evaluation parts. These standards are good to have in mind when structuring an LCA report.

4.3 How are evaluation methods in LCA chosen/used/changed?

There are several valuation methods available to day that emphasise on different environmental objectives. The evaluation methods used today in software tools like Sima Pro and in LCAit focus on process industries like paper, polymer etc. Again, fish is a biological raw material and there is no valuation method available today which fully takes this aspect into account. However, some researchers working on biological material have used different evaluation methods and modified them like EDIP. That raises the question: How far should researchers go in the evaluation process? Sweden has only done the characterisation, but no weighting and normalisation, while both Iceland and Denmark have tried to normalise.

One of the goal of this project is to streamline the concept of LCA by creating guidelines or a valuation method for the fishing industry to make processes more environmentally friendly.

4.4 How are levels of contaminants in the marine environment valuated in LCA studies?

The discussion group agreed that it is difficult to evaluate levels of contaminants in the environment in LCA-studies because there are different levels of contaminants in different species at different locations. Local effects need to be taken into consideration; furthermore, it is difficult to assess global effects.

5. APPENDIX

5.1 Development of energy simulator in the fish industry - ORKUSPAR

ORKUSPAR - The Energy Efficiency Improvement Simulator" is the name of a project, funded by the Commission of the EC´s Directorate-General for energy and transport. The project is co-ordinated by the Icelandic Fisheries Laboratories.
It began in 2001 and will end in 2003.

The objective of this project is to develop an energy efficiency improvement simulator, called **ORKUSPAR**, specifically aimed at ocean freight shipping and the fishing industry, both sea- and land based. The simulator will, hopefully, be an effective tool for the assessment and monitoring of envisaged energy efficiency measures.

The simulator will enable owners, management, designers and operators of the relevant facilities (fish processing- and freezing plants, ocean trawlers, container and other shipping) to quantify attainable energy efficiency improvements for energy use and environmental pathways in shipping and deep-sea fishing vessels (fish processing trawlers).

The software simulates the economic and other benefits affected by diverse measures, intended for instance to:

- Decrease primary fossil fuel consumption
- Improve energy efficiency of processing systems
- Improve automatic control and monitoring of systems
- Decrease deleterious pollutant emissions

The primary goal is to decrease harmful gaseous emission into the atmosphere in a sustainable manner whilst trying to meet the targets set in Agenda 21 and subsequent Kyoto declarations.

The end-users especially targeted for the ORKUSPAR simulator are: Sea Fishing Trade Associations, Shipbuilders, Fish Processing Plant Manufacturers and Designers, individual Fishing and Fish Processing Companies, Fisheries Research Institutions, Shipping Companies, Technical Colleges, Universities.

The participants in the project are:

Iceland: Icelandic Fisheries Laboratories, The Icelandic College of Engineering and Technology, The National Energy Authority in Iceland, Grandi hf, Skipatækni LTd.
Sweden: Energivision Stockholm, Swedish Energy, National Board of Fisheries in Sweden
Norway: Western Norway Research Institute

5.2 Estimating fuel inputs to North Atlantic Fisheries

As part of the *Sea Around Us* project at the University of British Columbia, research was undertaken to quantify the fuel energy consumed by contemporary North Atlantic fisheries. Where possible, this included evaluating changes in direct fuel inputs to fisheries over time. Two distinct methods were employed in estimating both the total fuel consumption and the energy intensity of specific fisheries and fishing fleet sub-sets. The first method involved soliciting relevant data directly from fishing companies. The second technique combined estimates of the generic rates at which fishing vessels consume fuel in relation to their main engine horsepower, as derived from real-world vessel performance data, with detailed catch and fishing effort data. Ultimately, a total of 58 analyses were conducted, representing 54 distinct North Atlantic fisheries or fleet sub-sets. Based in five countries, these 54 fisheries together account for total annual landings, as of the late 1990's, of over 5.2 million live weight tonnes of fish and/or shellfish, and encompass a range of fishing gears, vessel sizes and primary target species. Moreover, for almost half of the fisheries analysed, time series estimates of energy intensity and total fuel consumption were possible for periods ranging up to 21 years. For the most recent years in which data were available, the results indicate that these 54 fisheries together consumed just over 1 billion litres of fuel annually. Amongst the 29 groundfish fisheries analysed, energy intensities ranged from a low of 230 litres/tonne to just over 2,700 litres/tonne. When taken together, however, these 29 fisheries experienced a mean energy intensity of about 510 litres/tonne of groundfish and associated bycatch species landed. In contrast, amongst the twelve fisheries targeting small pelagic species analysed, contemporary energy intensities ranged from 19 to 159 litres/tonne of fish landed and averaged just 62 litres/tonne. The single relatively small fishery for large pelagic species analysed experienced an energy intensity of 1,740 litres/tonne of tuna and swordfish landed. Amongst the invertebrate fisheries evaluated, the average energy intensity of the eight fisheries targeting shrimp was 918 litres/tonne, while the two scallop fisheries had an average energy intensity of just 347 litres/tonne landed, and the single crab fishery evaluated had an energy intensity of about 330 litres/tonne. Finally, the lone fishery for Norway lobster analysed, experienced an energy intensity of 1,025 litres/tonne of total landings.

5.3 Energy use in the fishing fleet and strategic program for LCA at SINTEF

5.4 Environmental assessment of seafood with a life cycle perspective

Fishery, just like other types of food production, causes a number of different types of environmental impact. The types of impact caused by fishery include direct effects on stocks of the fished target and by-catch species, but also indirect effects on the marine ecosystem due to the removal of biomass from certain levels of the foodwebs. A part of the catch is, for different reasons, unwanted and thrown over-board. Marine organisms generally do not survive being fished and later discarded, while discarding must be regarded as a waste of a limited resource, especially when it concerns discarding of under-sized specimens of commercially fished species. Other types of environmental impact caused by fishery are emissions from fuel combustion, emissions of active substances from anti-fouling paints and seafloor impact by towing gear, such as trawls. Knowledge is limited about several of the types of environmental impact connected to fishing activities.

In the presented research project, environmental aspects connected to fishery have been quantified for a specific case, the Swedish cod fishery in the Baltic Sea. The aim was to demonstrate how the different types of environmental impact can be quantified in a case study. It was also a goal to present environmental data for the entire life-cycle of a seafood product. The method used for environmental assessment was Life Cycle Assessment (LCA), which assesses resource use and emissions throughout the life cycle of a product. The Baltic cod was followed from the fishery through a processing industry where it is filleted, frozen and packaged to consumer-packed blocks of 400g. From there, the product was followed to wholesalers, retailers and finally to the household. Resource use and emissions caused throughout the life cycle is included in the assessment.

Results showed that fishery dominates all investigated environmental impact categories (Global Warming Potential, Eutrophication Potential, Acidification Potential, Aquatic Ecotoxicity, Photochemical Ozone Creation Potential). Fishery is responsible for 75% of the total energy consumption in the life cycle of the product, mainly due to onboard diesel consumption. The difference between gillnet and trawl fishery is considerable, because the fuel consumption in trawl fishery is higher than in gillnet fishery. A separate study concerning fuel consumption and emissions in the Swedish cod fishery was presented. Following fishery, the car transport home from the retail store affects the categories global warming, acidification, photochemical ozone formation and eco-toxicity most. The consumer phase was also shown to be important. Preparation at home contributes to impact categories global warming, acidification and photochemical ozone formation, mainly due to the electricity consumption of the oven. The total amount of discarded fish was shown to be around 50g per cod block and discards mainly consisted in under-sized cod and flounder. Cod stocks in the Baltic are, at present, not fished on a sustainable basis. The seafloor area impacted by trawls was determined to be around 700 m^2, corresponding to a square of 27*27 m, per average cod block through analysis of fishing effort data in a GIS (Geographical Information System).

Because of the importance of fishery for the overall results of the LCA, many improvement options can be found in the fishery phase of the life cycle. Sound management of the fished stocks is a prerequisite for an environmentally sustainable fishery. Education of fishermen in fuel-saving vessel operation and a gradual exchange to modern engine technology as well as development of more flexible gear are some measures that would lead to decreased fuel consumption and emissions. Due to the dominance of fishery in the overall results, one of the most important environmental issues, once the fish has been landed, is that it is used efficiently, minimising product loss and maintaining high quality throughout the production chain. In order to keep high product quality it is important that the fish is handled and cooled properly from the moment of catching it. The environmental burden occurring because of product loss has to be added to the product which is actually used for its purpose, as human food. Therefore, the most important measure to decrease the overall environmental impact of the product can be to decrease product losses.

5.5 LCA of Icelandic cod products, the present status

A Life Cycle assessment of Cod is conducted by the Icelandic Fisheries Laboratories (IFL) and Technological Institute of Iceland (IceTec). The project leader is Helga R. Eyjólfsdóttir, IFL, and other participants are Eva Yngvadóttir, IFL, Halla Jónsdóttir and Bryndís Skúladóttir, IceTec. The collection of information is done in cooperation with the following parties: The fishery Haraldur Böðvarsson Ltd on data for the fishing vessel; the transportation company Samskip on truck transport in Iceland and freighter transport to UK; the seafood distributor SÍF on UK transport chain and; several other parties such as producers of paint, cooling agents and packaging and other companies and specialists for verifying data, comparison and general description of the processes.

The work has so far included decision on the choice of functional unit, the designing of a flow chart, the choice of boundaries and allocation, the collection of information and the building of the process in the LCA software program SimaPro.

A 9 kg frozen cod fillet package was chosen as the functional unit. The fillets are with bones but without skin and are processed on board a freezing trawler. The rationale for this choice is that this is a valuable and important product for the Icelandic economy. Less than 50% of the fish that is caught is used in the fillet production, the rest is usually used in several by-products.

Boundaries were chosen as not to include production of trucks, trawlers, fishing gear, etc. Mass allocation was done towards other species. Some evaluation of the consistency of the data has been made, as well as evaluation of the accuracy and the results of using average data mixed with specific data.

The collection of data has not been completed and preliminary results from inventory analysis and impact assessment are not ready to be published yet. General discussion on whether to include the cod itself as an input from nature has taken place, along with evaluation of different evaluation methods. No Icelandic evaluation method exists so care needs to be taken in this matter.

5.6 The status of the Danish LCA project

5.7 LCA of rainbow trout cultivation

The rainbow trout is the main fish species cultured for consumption in Finland. In 2000, its production volume accounted for 15.251 tons out of the 15.400 tons total aquaculture volume. This work, which is methodologically based on life cycle assessment, is beginning from the extraction of raw materials and ending with the delivery of gutted fish to retailers or to further processing.

The assessment includes the life cycle impacts of technically different production methods as well as methods for emission reduction. The environmental impacts of cultivated rainbow trout are compared with the impacts of Norwegian cultivated salmon, Baltic herring, and pig and cattle meat production in Finland.

Atmospheric emissions have only a minor contribution to the total environmental impacts caused by the production of Finnish rainbow trout. Phosphorus and nitrogen emissions from the cultivation into waters cause the strongest environmental impacts. The main reason is that rainbow trout production cause greater part of nitrogen and phosphorus loads in Finland than of airborne emissions in Finland.

No significant differences were found between the emissions caused by the production of Norwegian cultivated salmon and Finnish rainbow trout, but the Norwegian salmon causes less eutrophication than the Finnish rainbow trout. On the other hand, salmon lice and escaping cultivated salmon, which is giving rise to a genetic threat to the natural salmon populations, are regarded as major problems in Norway – not eutrophication. In the cultivation of Finnish rainbow trout, escapes are not considered a problem.

When comparing the emissions originating from pig and cattle meat production, eutrophying discharges, mainly from feed production, appear to be the most significant emissions environmentally. Atmospheric methane and ammonium emissions have also significant environmental impacts. However, it was not possible to make comparisons between the total impacts of the fish and meat products in this work because of lack of adequate assessment methods for some impacts. Comparison is difficult, because fish farming affects aquatic ecosystems, whereas pig and cattle meat production have impacts particularly on terrestrial ecosystems. The fishing of Baltic herring turned out to be most environmentally friendly of the investigated products and even beneficial to the environment, because the nutrients in Baltic Sea decrease due to the fishing of Baltic herring.

The reduction of nutrient emissions from fish cultivation is the key factor in developing the ecological and social sustainability of rainbow trout production. By using new, environmentally friendly feeds it is possible to reduce the environmental impact of fish farming. The increased feed efficiency reduces both nutrient and organic loads. By using a feed containing soya protein, or other similar alternative protein sources, it is possible to decrease the current level of nitrogen and phosphorus load by half. . The use of the soya-feed means about 8 cents (0.084 €) additional cost per kg fish produced. This is reasonable compared to the fish farmers' price (3.2 € in 1999), whereas the technical measures to reduce emissions from fish farms cause higher costs – up to 1-3 € per kg fish produced. In addition, technical measures significantly reduce the phosphorus load but have only minor effects on nitrogen. For this reason, the measures are more suitable for inland water areas. Phosphorus is the main limiting nutrient in inland waters of Finland.

Various needs for further research were identified during this work. The data should also include other important environmental issues such as effects of the fishing of feed fishes on the sea bottom fauna. The impact assessment method should be developed for assessing new impact categories. Furthermore, the method should be capable of assessing regional effects due to domestic emissions.

Socio-economic values were studied also in the study in addition to environmental issues. The parametres were the financial value of fish products, income effects and employment. We had, however, difficulties producing comparable socio-economic values for the production of pig and cattle meat due to the subsidisation of agriculture. Thus, it is not possible to prioritise the use of rainbow trout, pig and cattle from the eco-efficiency point of view .

5.8. Heavy metals in marine biota in Icelandic waters

A monitoring program, AMSUM, has been running annually at IFL since 1989. This project is a part of Iceland´s commitment to OSPAR (the Convention for the protection of the Marine Environment of the North-east Atlantic) and AMAP (Artic monitoring and Assessment Programme).

The goal of this monitoring programme is:

1. To gather information on the current status of the ocean around Iceland
2. To determine if if human health is in danger by consuming fish products
3. To assess potential danger to marine life caused by contaminants.

The main role of the IFL in the program has been gathering data from Icelandic fisheries.

Each year, samples of cod *(Gadus Morhua),* dab (*Limanda Limanda*) and blue mussel *(Mytilus edulis)* are taken at different locations with standardised methods. These species are considered to be representative of different habitats. The heavy metals lead, cadmium, copper, zinc, arsenic and selenium are measured in cod and dab liver and in mussel tissue. Mercury is measured in the muscle of cod, dab and mussel tissue.

The main conclusion for cod from Icelandic fishing grounds is that concentration of heavy metals is low compared to other northern locations. The only exception is cadmium, which is probably of volcanic origin, reflecting natural background values. Research of moss around the active volcanic zone show high levels of cadmium and supports this suggestion. Also, there are no anthropogenic sources at hand where the levels of cadmium are high. No trend can be observed in the concentration of heavy metals, but annual and seasonal variation is significant.

Mussels can give indication of local sources of contamination, but the concentration of heavy metals are in most cases far below the ICES standard. The only exceptions, as for cod, is the concentration of cadmium, which is considered to be of natural origin. The same applies to Dab.

Since heavy metals occur naturally in the environment it is necessary to establish the natural background values to make it possible to identify if these values are from natural sources or not.

The unique characteristics of the Icelandic environment in terms of oceanography, meteorology, geology and biology make determinations of natural background values critical. A simple comparison with values from neighbouring countries can therefore be misleading.

References:

Davíð Egilsson et al., 1999. Mælingar á mengandi efnum á og við Ísland. Niðurstöður vöktunarmælinga. Starfshópur um mengunarmælingar, mars 1999, Reykjavík. 138 pages.

5.9 Organochlorine pollution in Icelandic waters

The levels of persistent organochlorine pollutants (POPs) have been monitored in the marine environment around Iceland for several years. These manmade chemicals can undergo long-range transport either via the atmosphere or ocean currents and are ubiquitous even in the most remote areas of the globe. There has been very little local use of organochlorine pesticides in Iceland, but PCBs and HCB, which are industrial chemicals, can originate at least partly from local sources. The organochlorines are believed to disrupt endocrine functions in animals and humans and can thus affect their development, fertility and immune system. POPs are very stable, lipophilic chemicals that can often bioaccumulate to a great extent, reaching possible toxic levels at the end of the food chain. We have analyzed samples from Blue mussels (*Mytilus edulis*) collected along the coast of Iceland; from Dab (*Limanda limanda*) liver and cod (*Gadus morhua*) liver, collected in the deep ocean around Iceland.

The results indicate very little organochlorine pollution in the Blue mussel; most chemicals analyzed are at or below detection limits. The levels in Dab and Cod are also quite low and comparable to levels found around the Faroe Islands and the NW-coast of Norway. PCBs are the most abundant chemical group in these species with the sum of 7PCBs in the range of 20-100 μg/kg liver. Very little can be said about time trends, since the data is very variable. However, the levels indicate lower pollution in the NW area and higher pollution in the SW area around Iceland.

5.10 The anti fouling agent TBT (tributyltin) in the Nordic environment: effects and present status

5.11 Changes in quality (sensory) attributes of fish during storage

5.12 All salmon are not created equal: Measuring the biophysical costs of salmon fishing and farming in British Columbia, Canada

Technologies play a critical role in mediating the impact of the human enterprise on the ecosphere. Consequently, the adoption of more biophysically efficient technologies is essential if the sustainability of the human enterprise is to improve as populations and per capita consumption demands increase. Within this context, the biophysical efficiency of two salmon production technology systems were analysed and compared using ecological footprint and energy analysis. The two systems evaluated are the vessel-based commercial salmon fishery and the salmon farming industry, as both exist in British Columbia, Canada. In addition, the relative efficiency of the three harvesting technologies employed within the commercial fishery were also evaluated. The ecological footprint analyses entailed quantifying the marine and terrestrial ecosystem support areas needed to grow salmon, sustain labour inputs, and assimilate CO_2 equivalent to the greenhouse gases that result from industrial energy and material inputs. The energy analyses focussed exclusively on the direct and indirect industrial energy inputs to both systems. The results of both the ecological footprint and energy analyses indicate that salmon farming is the least biophysically efficient, and hence least sustainable system for producing salmon currently operating in British Columbia. On a species-specific basis, farmed chinook salmon (*Oncorhynchus tshawytscha)* appropriated the largest total area of ecosystem support at 16 ha/tonne. This was followed by farmed Atlantic salmon (*Salmo salar*) at 12.7 ha/tonne, and commercially caught chinook and coho salmon (*Oncorhynchus kisutch*) at 11 ha/tonne and 10.2 ha/tonne, respectively. Commercially caught sockeye (*Oncorhynchus nerka*), chum (*Oncorhynchus keta*), and pink salmon (*Oncorhynchus gorbuscha*) had the smallest total ecological footprints at 5.7, 5.2 and 5 ha/tonne, respectively. Results of the energy analyses followed a similar pattern. Farmed chinook salmon required a total fossil fuel equivalent industrial energy input of about 117 GJ/tonne while at the other extreme, total energy inputs to commercially harvested pink salmon amounted to only 22 GJ/tonne. Within both systems, however, opportunities exist to improve the biophysical efficiency of salmon production. Finally, amongst the three commercial fishing technologies evaluated, purse seining was approximately twice as efficient at harvesting an average tonne of salmon as were either gillnetting or trolling.

5.13 Contact information of participants

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