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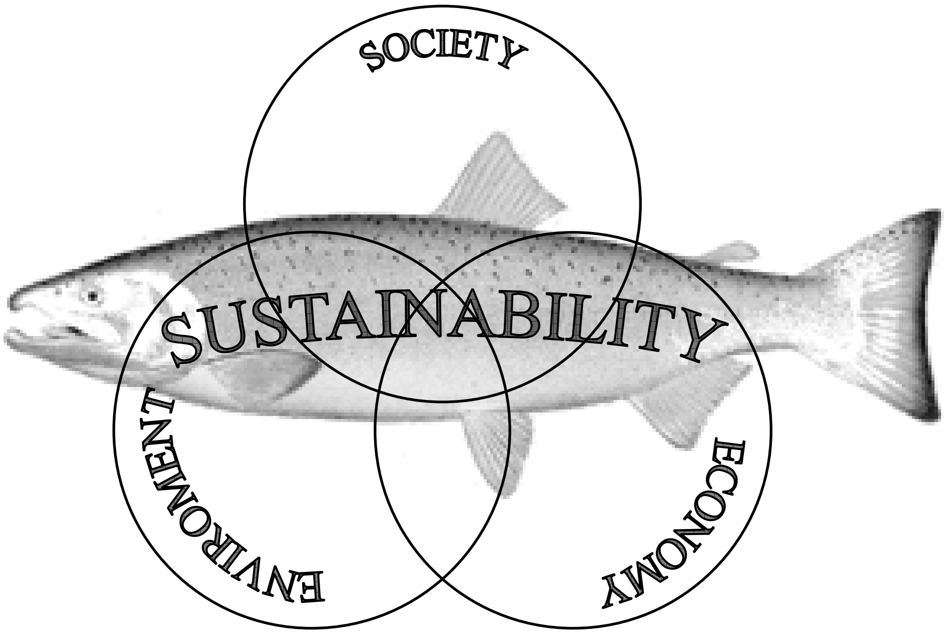
NORWEGIAN COLLEGE OF FISHERIES SCIENCE

Sustainability of Norwegian salmon farming evaluated on the basis of marine feed resources -

An exploratory assessment



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This thesis is representing both an ending and a beginning: The ending of a challenging and fruitful residence in a class full of characters, here at University of Tromsø. We have discussed and argued and learned every day. The thesis also represents a new beginning, I feel equipped to take on new challenges. The path is forged as it is walked.

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Abstract

This study examines the sustainability of Norwegian salmon farming on the basis of its use of marine feed resources, from a *biological* perspective. The salmon farming industry in Norway is deemed *moderately sustainable* according to the assumptions and methodology applied in this thesis. However, it is pointed out that these results would most likely have been different if social and economic aspects had been included. Another aspect is that the food vs. feed issue does not accrue to the current discussion, as this is purely decided by economic considerations. The study also point out that at present, salmon is the best overall existing alternative for food production. Salmon can be produced more efficiently and with higher output than any other livestock, such as pig and poultry. The limited supply of marine resources is not considered to restrict a further expansion of the salmon farming industry in near future, but poses a challenge in the long term.

Keywords: Sustainability, salmon, feed, forage fish, FCR, fisheries management

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Acronyms

ANF	Anti-Nutritional Factor
ASC	Aquaculture Stewardship Council
bFCR	Biological Feed Conversion Ratio
B_{lim}	Lowest Acceptable Spawning Stock Biomass
B_{pa}	Precautionary Spawning Stock Biomass
DHA	Docosahexanoic Acid
EEZ	Exclusive Economic Zone
eFCR	Economic Feed Conversion Ratio
EAF	Ecosystem Approach to Fisheries
ENSO	El Niño Southern Oscilliation
EPA	Eicosapentaenoic Acid
EU	European Union
F	Fishing Mortality
FAO	Food and Agricultural Organization of the United Nations
FCR	Feed Conversion Ratio
FHL	Norwegian Seafood Federation (Fiskeri-og Havbruksnæringens Landsforening)
FIFO	Fish In – Fish Out
GDP	Gross Domestic Product
GMO	Genetically Modified Organisms
HSMI	Heart and Skeletal Muscle Inflammation
ICES	International Council for the Exploration of the Sea
IFFO	International Fishmeal and Fish oil Organization
IMARPE	Instituto del Mar del Perú
IMR	Institute of Marine Research (Havforskningsinstituttet)
IPN	Infectious Pancreatic Necrosis
ISA	Infectious Salmon Anaemia
IUCN	International Union for the Conservation of Nature and Natural Resources
IUU	Illegal, Unregulated and Unreported
LAP	Land based Animal Protein
LRP	Limit Reference Point
MAB	Maximum Allowable Biomass
MIT	Massachusetts Institute of Technology

MSC	Marine Stewardship Council
NEAFC	North East Atlantic Fisheries Commission
NOFIMA	The Norwegian Institute of Food, Fisheries and Aquaculture Research
NSSH	Norwegian Spring Spawning Herring
NOK	Norwegian Krone
RS	Responsible Supply
PCB	Polychlorinated Biphenyl
PD	Pancreas Disease
SCP	Single-Cell Proteins
SSB	Spawning Stock Biomass
TAC	Total Allowable Catch
TRP	Target Reference Point
UN	United Nations
UNEP	United Nations Environmental Program
USD	United States Dollars
WCED	World Commission on Environment and Development
WCS	World Conservation Strategy
WWF	World Wildlife Fund

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Chapter 1: Introduction

This is an exploratory study of the Norwegian salmon farming industry and whether it can be deemed sustainable on the basis of marine feed resources. The study is limited to the management and status of forage fish, which constitute the raw material of fishmeal and fish oil, and the efficiency of aquafeed. A quantitative assessment of the respective stocks is conducted with the use of a sustainability scale, and the management regimes are assessed qualitatively according to an assessment tree.

The study is based on reviewing existing literature, qualitative in-depth interviews and quantitative data portraying the Norwegian aquaculture industry and the forage fisheries.

1.1 Norwegian salmon farming in context

Management of natural resources is congruent with the concept of sustainable development, coined by the United Nations (UN) Brundtland-commission in 1987[1]. Sustainable development is a normative principle with an anthropocentric perspective, which emphasizes the urgent need for sustainable global management and environmental governance. Regarding fisheries, management has been crucial for a number of reasons. For instance the immediate risk of overexploitation and fish stock depletion, balancing conflicting goals and ensuring that resources will continue to be available in the future (Holdgate, 1995; Charles, 2001).

The Food and Agriculture Organization (FAO) of the UN states that 28% of all global stocks are either overexploited, depleted or recovering from depletion, and 52% are exploited to its limits (FAO, 2009). Measures to improve management have been implemented, and the ecosystem approach to fisheries (EAF) is attempting to make management more holistic (Garcia et al., 2003). Forage fish are normally species on a lower trophic level, and they are important as food for other species higher up in the food chain (Fréon et al., 2005). Farming of carnivore fish and shrimp is a practice being accused for draining the ocean of fish (Allsopp et al., 2008; Naylor et al., 2000), with worry amongst the general public as to whether this practice is sustainable in the long run.

Salmon farming has also received a lot of attention and has faced considerable scrutiny in recent years. The media and various interest groups have raised concern regarding the effect of aquaculture on the environment. I was especially taken aback by one particular

[1] WCED (1987) *Our Common Future*.

documentary, the *Pink Gold*[2], where independent journalists portrayed the Norwegian salmon farming industry in a way that caused uproar and turmoil both nationally and internationally. The documentary stated that Norwegian salmon caused food deficits in developing countries, that the companies involved did not have any internal traceability practices and that the raw material, the fish, was harvested in an unsustainable manner. This inspired me to explore the topic further, as I had problems believing that Norway, as a fisheries nation and a management pioneer, is conducting fishing operations in such an unhealthy manner.

To be able to conduct this study I have explored the concept of sustainability and further looked into both the aquaculture industry and the aquafeed industry.

Sustainability

Sustainable development is a concept that became widely recognized through the work of the World Commission on Environment and Development (WCED). The report *Our Common Future* was published in 1987. This concept points out that the human inhabitants on Earth ought to live responsibly with the notion that some resources are limited, they do not last forever. The report concluded that the present generation must not destroy the health of the Earth so that the next generation can inherit the same benefits as we did from the generation before us. Hence, intra- and intergenerational equity are central concepts in the report.

Norwegian aquaculture industry

Capture fisheries and aquaculture make up the seafood sector in Norway. In 2006, the value of the Norwegian aquaculture industry surpassed that of traditional fisheries, with a steady increase since the 1980s (Ministry of Fisheries and Coastal Affairs, 2010b).

The aquaculture industry is of large national importance as it contributes significantly to Norway's GDP, it is a significant employer and it sustains rural areas that would otherwise be abandoned had it not been for the aquaculture operations. There are about 4,500 people employed directly within core activities of the industry (SSB, 2010a). The sector also creates considerable employment in related segments. According to Sandberg et al. (2009) the spill-over-effects in 2007 were large: For every man-year[3] spent in the industry, 1.7 man-years were created in other sectors. In terms of GDP, every NOK created by the aquaculture industry generated 1.4 NOK in other sectors. In the traditional capture fisheries the spill-over-

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[2] The documentary was originally sent at Swedish television, SVT, but broadcasted 17.03.2009 on Norwegian television, NRK.

[3] A man-year is 1800 hours a year. (7.5h/day*5days/week*48working weeks/year).

effects were significantly smaller: Every man-year generated 0.68 in other sectors, and one NOK brought 0.6 outside the core activity (Sandberg et al., 2009).

Salmon farming is by far the most important sector of Norwegian aquaculture and has been a tremendous success. From the start in the 1960s, production has increased steadily to 859,056 tonnes in 2009, with only a few setbacks due to fish diseases, and will most likely pass 933,000 tonnes in 2010 (Directorate of Fisheries, 2010; FiskeribladetFiskaren, 2010). Salmon is mainly destined for foreign markets as more than 80% of national production is exported, which brought earnings of about 24 billion NOK in 2009 (Ministry of Fisheries and Coastal Affairs, 2010b). Even though the aquaculture industry is important on a national basis, Europe including Norway is only responsible for 4.2% of global aquaculture output. Regarding global salmon production, Norway holds a big market share, 58% in 2009 (Kontali Analyse, 2010a).

The aquafeed industry

Raw material mainly from small pelagic species is utilized in the production of making salmon feed. Fishmeal and fish oil included in Norwegian salmon feed originate from the North Atlantic and the South Pacific. Main species are anchoveta, capelin, sprat, herring, blue whiting and sandeel. All are harvested in North Atlantic waters, with the exception of anchoveta, which is harvested in the South Pacific outside Peru (Sheperd et al., 2005). The content of marine resources in salmon feed, and how much feed is needed to produce a kg of salmon is constantly changing and varies a lot between producers.

1.2 Research strategies, aims and research questions

The thesis is conducted using inductive and abductive research strategies, with the aim of examining the sustainability of salmon farming and whether or not a further growth is possible on the basis of limited marine resources. To be able to achieve this aim, the following research questions must be answered:

1) *What is the origin of the marine resources utilized in Norwegian salmon farming?*
2) *To what extent is the above resources based on sustainably managed fisheries?*
3) *What are the current conversion ratios and what is the future outlook?*
4) *Will availability of fishmeal and fish oil be a constraint for further expansion of the Norwegian salmon farming industry*

Both quantitative and qualitative methods are applied in this study. In-depth interviews present a subjective "insider-view" that together with literature reviews forms the qualitative input. Quantitative secondary data used is derived from the International Council for the Exploration of the Seas (ICES), various government sites and the feed companies themselves. A literature review has been necessary to provide a comprehensive understanding of the problem.

1.3 Limitations

Aquaculture has experienced a rapid expansion and environmental concerns have been raised in its wake. Salmon farming is without doubt negatively affecting the environment in many ways. The Ministry of Fisheries and Coastal Affairs has in collaboration with the industry and other stakeholders identified five main areas that pose a threat to the environment. These are presented in the *Strategy for an Environmentally Sustainable Norwegian Aquaculture Industry*[4] and are: genetic interaction and escape, pollution and emission, disease, area utilization and feed and feed resources. I have chosen to concentrate my efforts on the last aspect, the feed resources. In larger studies, evaluating the sustainability of the entire salmon farming industry should certainly include all the factors mentioned above.

The feed constraint is investigated with a *biological perspective* on the management of forage fisheries. Biological parameters are applied to determine whether the stocks are healthy and if current harvest is sustainable. It is important to be aware of the shortcomings such an approach could have. It is evident that with another perspective, including economic or social concerns, the outcome would likely be different from the results of this study. Nonetheless, due to limited time this approach is the most practical.

Calculations of the feed conversion rate (FCR) and the Fish in-Fish out ratio (FIFO) must be thoroughly examined on a case-by-case basis. Among the different producers and farmers there will be variations. Additionally, due to the sensitive nature of the data, information provided by the feed industry is restricted. It is also difficult to determine sustainability of food production in general, due to the fact that the system is depending on a range of input factors. A broader theoretical background could have tackled this limitation, and it would be beneficial to have developed a more comprehensive sustainability scale.

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[4] Ministry of Fisheries and Coastal Affairs (2009) *Strategy for an Environmentally Sustainable Norwegian Aquaculture Industry*.

The most immediate limitation of this study is the lack of continuous data considering the anchoveta. This species is an important component in Norwegian aquafeed, but I have not been able to find complete information about the status of the stock, nor information about management advice. I have mostly relied on secondary sources; a practical difficulty is the fact that catch statistics from the FAO database differ from the statistics used by the Peruvian government. These inadequacies questions the reliability of the data and hence, the assessment of the stock in this study.

Regarding the literature used as a foundation of the study, one can always question its validity and relevance and whether it was a satisfactory selection. The in-depth interviews can also be questioned because the researcher might have had a pre-adopted perception of the interviewees or the company they were representing. It is important to keep in mind that the foundation of the researcher will change during the interviewing process. Empirical research will influence comprehension and opinion that might affect the outcome of the interview. Interviewing other groups of stakeholders would most probably also portray a different reality than my interviewees. This must be considered in discussing the reliability of the interviews. However, given the time limits and the extent of my study, I believe I have covered the most important actors in the aquafeed industry.

1.4 Structure of the study

Chapter 2 provides an overview of the theoretical foundation needed to answer the research questions, while chapter 3 describes the research methods required to apply the theory and conduct the study. In chapter 4, a background of the industries in question is presented. Management of forage fish, the aspects of sustainable management and harvest, and the destination of catches will be dealt with in chapter 5. Chapter 6 provides an overview of the salmon feed and possible substitutes, and examines the third aspect of sustainability, namely efficient use. All the preceding chapters will be linked together and discussed in chapter 7, followed by conclusions and recommendations in chapter 8.

Chapter 2: Theoretical framework

This chapter intends to define and elaborate on the concept of sustainable development and sustainability. The concept has a long historical lineage and has been a desirable objective throughout human history. Perspectives and interpretations have differed over time, but at present the need for a greater global responsibility regarding the use of natural resources has become evident. The notion of sustainable development as known today was born in the 1980s with the WCED report, *Our Common Future*.

There has been a dialectic development of normative concepts, where one concept answers and overshadows the previous one. Banik (2010) uses the term *buzzword* for concepts like sustainable development. Sustainable development was the buzzword of the 1990s and became popular mostly because of its fuzziness, being open for subjective interpretations. Particular buzzwords are popular and important in a certain period of time, for then to be replaced by others[5] (Banik, 2010).

A brief overview of the sustainability concept prior to the publication of *Our Common Future* is provided here, while the main emphasis is on the analysis of the report by the WCED. A wrap up of the important elements of the concept, and the construction of a definition and tools practicable for the purpose of this study, is finalizing the chapter.

2.1 Sustainability prior to contemporary time

The normative concept of sustainability has existed for a long time in some cultures and can as a theory be traced back to Greek natural philosophy around 500 BC (Stryken, 2000). Sustainability as a perception has however existed since the mythical times. Natural balance, self-preservation and moderation are central aspects of this perception - exemplified by Hàvamàl, the Norse tales of Odin (Hegge, 1978; Stryken, 2000). In Hàvamàl it is made clear that one should never use more than needed, and greed was considered bad.

The importance of a balance in nature has been emphasized throughout history, and was later adapted as a theory by natural scientists and philosophers like Linnè, Malthus and Rosseau and predecessors of Darwin in the 1700s. They were concerned about humans' role on earth and whether population growth would lead to a collapse of the ecosystems. Induced by this change came a gradual disconnection from the mythical perception where humans and

[5] Banik (2010) states that sustainable development has been overshadowed by poverty and at present, climate change and global warming are the new buzzwords.

nature were interconnected. Conceptualism replaced the mythical sensations of the Greek philosophers (Hegge, 1978; Stryken, 2000).

Sustainability as a concept stems from the Latin word *sus tenere* which signifies to uphold or sustain (Langhelle, 2000; Stryken, 2000). The first description from modern history depicts the concept employed in German forestry practices, where a long-term perspective governed how much forest that was cut down in one period. The yield should be small enough to ensure that the same yield could be provided infinitely (Stryken, 2000). In contemporary times, the concept has evolved, and a description follows in the next subchapter.

2.2 Sustainability in the contemporary era

Societies evolve, and so do norms and guidelines surrounding humans. Sustainability as a concept has become much more refined after the contributions of important institutions like the Massachusetts Institute of Technology (MIT), International Union for the Conservation of Nature and Natural Resources (IUCN), United Nations Environmental Program (UNEP), World Wildlife Fund (WWF) and the UN World Commission of Environment and Development (WCED).

2.2.1 The MIT-reports

The Massachusetts Institute of Technology (MIT) published the reports *The Limits to Growth* and *Mankind at the turning Point*, in 1972 and 1975 (Meadows et al., 1972; Mesarovic and Pestel, 1975). The two MIT-reports were important contributions to the environmental dialogue in the 1970s and heavily influenced the international debate further. Sustainability is not applied as the working concept for these reports, instead they utilize global equilibrium (Stryken, 2000). The reports argue that when the global resources are restricted, there are limits to consumption and utilization of these resources. Simulations predicted that if the exponential population growth were not haltered, then ecological collapse could occur.

In the MIT-reports equilibrium is defined as "a state where population and capital are stable, with the forces tending to increase or decrease them are in a carefully controlled balance" (Meadows et al., 1972:171). These driving forces are identified to be:

1) Forces that cause an increasing population or capital (e.g. big families, inefficient population control and high investment rate).
2) Forces that reduce population or capital (e.g. food deficits, pollution and general depression).

The main point in the reports is that population and capital must be kept in constant equilibrium, while non-consumptive activities like education, art, music, religion and research, can continue to grow. These activities do not require use of non-renewable resources and therefore do not generate pollution. A static view on resource utilization is forwarded in the MIT-reports and are therefore more of a visionary character. Development as a concept is not discussed in the reports, and it is not a goal *per se* as the objective is constant equilibrium. Zero growth, which is associated with these reports, is not possible or beneficial in the global society (Stryken, 2000). Nonetheless, it has been realized that there are limits to growth if the nature of growth does not change to one of a more environmentally friendly character.

2.2.2 World Conservation Strategy

Published in 1980, the World Conservation Strategy (WCS), is the result of a collaboration between the International Union for Conservation of Nature and Natural Resources (IUCN), United Nations Environment Program (UNEP) and World Wildlife Fund (WWF) (IUCN/UNEP/WWF, 1980). WCS calls for a globally coordinated implementation of conservation actions, which are presented in the strategy. It is stressed that a trade off between use and conservation of resources is crucial for the welfare of the earth and survival of humans. The aim of the WCS is to achieve three main objectives:

1) To maintain essential ecological processes and life-support systems.
2) To preserve genetic diversity.
3) To ensure the sustainable utilization of species and ecosystems.

These objectives form the basis of a sustainable development, as sustaining biodiversity at all levels is necessary not only for ecological reasons. Human welfare is dependent on the well-functioning of ecosystems, and societies must therefore manage their resources (IUCN/UNEP/WWF, 1980). Further, the WCS defines development as “the modification of the biosphere and the application of human, financial, living and non-living resources to satisfy human needs and improve the quality of human life” (IUCN/UNEP/WWF, 1980:18). Socio-economic and biological factors of the living and non-living resource base must be considered, in addition to an assessment of long- and short-term advantages and disadvantages, for development to be sustainable. Conservation and development ought to go hand in hand, and conservation is defined as “the management of human use of the biosphere so that it may yield the greatest sustainable benefit to present generations while maintaining its potential to meet the needs and aspirations of future generations” (IUCN/UNEP/WWF, 1980:18). Both definitions are anthropocentric, i.e. development that aims to fulfill human goals through use of resources, and conservation aims to fulfill human goals by ensuring that such use can continue. Both the WCS and the WCED-report share this view.

Criticism has been directed to this startegy because of its deterministic view on utilization of natural resources (Langhelle, 2000; Stryken, 2000). The general perception of the strategy is that nature has its limitations no matter what actions are executed by humans. Because of this perception it is argued that ecological principles should govern human action and establishments. It is stated by Stenseth and Hertzberg (1992) that people discount the future, thereby ignoring to prioritize the next generation. The anthropocentric view further strengthens this; if humans perceive nature as something that should be "exploited" for their benefit, then there is no immediate incentive to change this behavior. The deterministic view presented in the WCED-report is therefore in line with intergenerational equity.

The strategy has also received criticism because of its anti-poverty profile (Stryken, 2000). Developing countries' use of resources is often of a short-term character and the WCS states that this is one of the main causes of environmental problems throughout the world. The skewed relationship between developed and developing countries is neglected in the strategy, and this makes it developmentally static. However, it is specifically mentioned in the strategy that ecological limits can be raised by technological innovations and increasing levels of knowledge (Stryken, 2000).

2.2.3 World Commission on Environment and Development

The World Commission on Environment and Development, also known as the Brundtland-commission, published its report *Our Common Future* in 1987. This report is the result of the UN General Assembly giving the commission the task of devising 'A Global Agenda for Change' (WCED, 1987). This agenda had to include strategies to achieve long-term sustainable development, realize greater cooperation between developed and developing countries, tackle global environmental issues, and improve the global perception regarding conservation of resources (ibid.). The Brundtland-commission defines sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987:43).

Critique has been directed towards the report because the definition is imprecise and unspecific (Stryken, 2000; Banik, 2010). Individual and subjective interpretations of the concept have led to the definition being applied to a wide range of subjects. Some might argue that it is being exploited and as long as something is labeled sustainable it is ethical and correct. The new "good" in our times is being sustainable (Guldseth, 2010).

According to Banik (2010) the above are exactly what accrue to buzzwords and makes them popular. There are four reasons for the fuzziness: first, the supporters of the concept utilize its vagueness as an excuse to embrace the *status quo*, and ignore the radical changes needed in technology and behavior. Second, the focus on intergenerational equity has become one sided, and tend to focus only on possible negative effects. Benefits from for example new technology have been largely overlooked. Third, the focus on renewable energy and policies aiming to invest in such projects is flawed by not being pragmatic. Even though fossil fuel is finite, the use can be part of a sustainable process. Lastly, the Brundtland-report has not been successful in keeping focus on social equity and human rights. Instead, the concept has become a slogan for "greenery"[6] and is often misused. It is also argued that the concept should be abandoned because it leads to faulty thinking about the real causes of economic and environmental troubles, and does not therefore contribute to any solutions (Banik, 2010).

2.3 Sustainability after the Brundtland-report

Sustainability and sustainable development are imprecise and unspecific concepts originating from *Our Common Future*. How it is defined here has made room for individual and subjective interpretations, and this is also the reason for its applicability. Because of the broad definition, many coherent definitions have sprung out in the wake of the Brundtland-report. Ott (2003) explains that "sustainability means that present and future persons have the same right to find, on the average, equal opportunities for realizing their concepts of a good human life" (Ott, 2003:60). Vucetich and Nelson (2010) defines sustainability as "meeting human needs in a socially just manner without depriving ecosystems of their health" (Vucetich and Nelson, 2010:539). Both definitions are anthropocentric, but regard ecosystem health as essential for human well-being.

In the work by Gillund and Myhr (2010), participants generally described sustainability as a practice that secures future use of the resource without irreversible damage to the environment or changes in the ecosystem from where the resource originates. This definition is more precise and is not of an equally anthropocentric character as the WCS and the Brundtland-report. It is more a statement of living in harmony with, and within the boundaries of nature.

[6] A contemporary term concerned about conservationism. The term denotes a form of "window-dressing", that is, gives the impression that important changes in the right direction (conservation) have been made, without any serious challenges to the existing order.

Sustainable development as presented in the Brundtland-report recognizes that there are trade-offs between social, economic and ecological needs, and that these must be related to current and future generations (Banik, 2010). When implementing policies, a balance between economic and social concerns must be in place, which must be seen in relation to ecological concerns and requirements (Banik, 2010).

The complexity of the concept, and the normative intention behind it, is evident. However, a practicable definition for this study does not exist. Several institutions have realized the inadequacy of sustainable development. A normative concept intends to guide and influence actions (Stryken, 2000), however, without indicators informing about performance or direction, it is not possible to put the concept into action. Langhelle (2000) interprets the Brundtland report and argues that the broader conceptual framework has been overlooked. Interpretation is about bringing light to an underlying coherence or sense, and in the case of *Our Common Future,* Langhelle (2000) links sustainable development as a concept to the framework of normative preconditions and empirical assumptions. Further, it is claimed that overemphasis has been placed on the debate on the relationship between sustainable development and limits-to-growth. This is an important part of the report, but not the entire message. It is declared by Langhelle (2000) that *Our Common Future* is more coherent and radical than what is the present perception.

To understand the above, it is necessary with a more comprehensive description of the concept itself: Both Langhelle (2000) and Stryken (2000) describe sustainability as a concept that can be divided into three types of sub-concepts:

1) As a physical concept for a single resource.
2) As a physical concept for a group of resources, or an ecosystem.
3) As a socio-economic concept, used in an ecological, sociological and economic way.

The first sub-concept is similar to the German forestry example; renewable resources where the annual growth is harvested in such a manner that the physical stock is stable at a certain level. Within fisheries, maximum sustainable yield is one example denoting this type of sustainability.

The second significance implies that the whole ecosystem is considered; harvesting one resource within the ecosystem might have negative effects for the system as a whole. It is necessary with ample knowledge of the whole ecosystem and interaction between the components making it up. The ecosystem approach to fisheries is a way of trying to ensure the infinite existence of marine ecosystems.

The third usage does not constitute that much concern for ecological factors; it is of a more anthropocentric character. The goal is an "unspecified sustained increase in the level of societal and individual welfare" or a "sustained level of need satisfaction" (Langhelle, 2000). This third sub-concept is what forms the basis for the Brundtland-report.

Even though there is little tangible about sustainable development as a definition, Langhelle (2000) states that it contains two key notions:

1) The essential needs of the world's poor should be given overriding priority.

2) The idea of limitations that are imposed by the state of technology and social organization on the ability of the environment to meet present and future needs.

The first notion, satisfying the needs of the poor, is the goal of development. However, this development is required to be sustainable, meaning that each generation can satisfy its needs with the limitation that ecosystems and the resource base must be sustained, and not deteriorated. This is called the proviso of sustainability (Langhelle, 2000) and ensures that future generations will have the same ability for need satisfaction as present generation. In this way it is clear that the proviso of sustainability is necessary to reach the goal of development.

The two key notions impose consequences on understanding the definition of sustainable development. It is important to understand that the proviso of sustainability is not only concerned about the environment, but it forms a central part by being the minimum requirement for sustainable development, also referred to as physical sustainability; "at a minimum, sustainable development must not endanger the natural systems that support life on Earth: The atmosphere, the waters, the soils and the living beings" (WCED, 1987:44).

The proviso of sustainability is also concerned about other constraints on future development. *Our Common Future* identifies potential constraints of political, social, economic, technological and cultural character. The follow up to the WCS, *Caring for the Earth*, was published in 1991, and defines sustainable development as "improving the quality of human life while living within the carrying capacity of supporting ecosystems" (IUCN/UNEP/WWF, 1991:10). This definition is considered to be narrower and it excludes obvious threats. Langhelle (2000) argues that it neglects threats that are not of an environmental character, and that this should be considered a limitation. Nonetheless this definition is coherent with the minimum requirement for sustainable development in *Our Common Future* (ibid.).

Another consequence of the above framework is that the aim of sustainable development is not necessarily to sustain a resource or an ecosystem, but rather it aims to conserve the process of development (Langhelle, 2000). This is reasoned by the logic that the goal of development is prior to the proviso of sustainability. This again has certain implications; it is not evident that all environmental concerns are sustainable development issues. However, it is a prerequisite for development that the injunction to sustain biodiversity in *Our Common Future* is understood. It is reasoned by WCED that because the environment is vulnerable to destruction through development itself that the constraint of sustainability is placed on the goal of development (WCED, 1987). However, it is pointed out that all cases must be judged relatively. A pragmatic and holistic assessment on the before and after state of an action undertaken, must be executed.

The second implication pointed out by Langhelle (2000) is that an activity which itself is not regarded as sustainable, can be a part of a sustainable process. This can be exemplified by looking at the three different sub-concepts again. The two first sub-concepts refer to sustaining physical stocks or ecosystems. While the third opens for a physical reduction of the stock or the health of the ecosystem, as long as it serves a greater good. Giving some extra thought to this, it is possible to think of *degrees of sustainability*. This however implies some difficulties, as one has to define a scale of measurement[7].

Different countries are in different states of development, have different levels of available resources, are different in terms of size and population, have different levels of need satisfaction and different possibilities of substituting natural capital with man-made capital. All these aspects make it evident that sustainable development will have varying implications among different countries (Langhelle, 2000). Banik (2010) argues that sustainable development implies for fortunate rich people that they must adopt restraint, to make do with less. It implies for poor people to adopt appropriate technologies from developed countries.

In the Brundtland-report, limits to global development are determined by two factors; the availability of energy and the ability of the biosphere to absorb pollution or residues from energy use (Langhelle, 2000). Other material resources have higher thresholds than for instance oil. Depletion of oil reserves and release of carbon dioxide have led to low remaining reservoirs. It is also emphasized that there are other limits and constraints to global development, but the problem of climate change will most likely approach us first. In this respect, the report has clearly proven to be ahead of time. Global warming has been

[7] This will be further discussed in section 2.5 Measuring sustainability.

underlined in many of the recommendations by the WCED, and was seen as a real threat to future development. It is stated that a low energy scenario where "a 50% reduction in energy consumption *per capita* in industrial countries, to allow for a 30% increase in developing countries within the next 50 years" (WCED, 1987:173) should be adopted. However, it is also stated that technological change and increasing levels of knowledge can enhance the carrying capacity of resources and lift limits to a certain degree.

WCED's definition of sustainable development is a normative concept. Moral aspects of the report are implicit and clearly communicated in *Our Common Future*. Langhelle (2000) argues that the commission states that they have "tried to show how human survival and well-being could depend on success in elevating sustainable development to a global ethic" (WCED, 1987:308). Langhelle (2000) further states that "this ethic is constructed on the assumption of duties and obligations in a specific historic context of growing ecological awareness, ecological threats and widening North-South disparities and agendas" (Langhelle, 2000:139). In this broad context, the link between the goal of development and the proviso of sustainability must be understood as a widespread ethical position. Social justice or satisfaction of human needs is the primary goal of development in the Brundtland-report (ibid.). The proviso of sustainability is a precondition for social justice between generations. If the proviso of sustainability is violated, the goal of development is placed at risk (Langhelle, 2000).

2.3.1 The precautionary approach

Due to the vague nature of sustainability as a concept, the precautionary approach has been established as a tool for dealing with risk. It entails that ignorance should not be used as an argument for not taking action. Instead, being precautionary deals with the risk that insufficient knowledge constitutes. In relation to ecosystems, it is of extreme importance due to the complexity of the natural systems themselves. Being environmentally responsible includes the creation of buffers against serious or irreversible damage to nature (Ministry of Fisheries and Coastal Affairs, 2009b).

Nature consists of complex systems linked together and we have gathered empirical knowledge about our ecosystem throughout our history. However, when dealing with management, the precautionary approach is of eminent importance because ecological knowledge can never be acquired to the extent that uncertainty does not subsist (Stryken, 2000). It is a principle that provides a buffer to our decisions that are characterized by risk.

There is always a risk that errors in scientific research guiding fisheries management and aquaculture development can occur, or that the system itself is prone to uncertainty. Due to this inherent uncertainty, decision-making must always be about by balancing risk. According to Charles (2001), management of fisheries must operate after this principle because:

> "Management according to the precautionary approach exercises prudent foresight to avoid unacceptable or undesirable situations, taking into account that changes in fisheries systems are only slowly reversible, difficult to control, not well understood, and subject to change in the environment and human values" (Charles, 2001:216).

Risk management through the precautionary approach has been implemented in fisheries management. Total allowable catch (TAC), effort limits and harvest rates have integrated buffers so as to take uncertainty into account.

Stenseth and Hertzberg (1992) argue that the precautionary approach should govern decision making. They also state that a precautionary approach must include an action plan if the buffer is unsatisfactory. At present, in large parts of the world the precautionary approach is congruent with the concept of sustainable development (Costanza et al., 1998). In most cases where sustainability of resources is discussed, one of the criteria is whether or not the stock is managed according to the precautionary approach. In this study, a step-by-step assessment will be undertaken to evaluate the whether management of the forage fish stocks included in salmon feed is sustainable. The precautionary approach will be one of the requirements, as well as ecosystem considerations in the management of specific stocks.

2.3.2 Ecosystem approach to fisheries

When harvesting a certain species, considering its place in the ecosystem is in line with sustainability, and should be an integrated part of the management plan (FAO, 2009). Garcia et al. (2003) defines ecosystem approach to fisheries (EAF) as:

> "An approach to fisheries that strives to balance diverse societal objectives, by taking account of the knowledge and uncertainties about biotic, abiotic and human components of ecosystems and their interactions and applying an integrated approach to fisheries within ecologically meaningful boundaries" (Garcia et al., 2003:6).

This definition stems from the multiplicity of societal needs and desires, combined with the importance of sustainability[8] and the possibility for future generations to benefit from nature's

[8] The authors do not define sustainability, but refer to the Brundtland-report.

goods and services. Planning, development and management of ecosystems must address these aspects in a holistic and precautionary manner (Garcia et al., 2003). Practically, this implies that it is necessary to move from just considering the target species in question, to considering all aspects affecting the respective target species.

In the 2008 edition of FAO's report, the *State of World Fisheries and Aquaculture,* the need towards implementing EAF is highlighted. Progress has been made in incorporating the principles of EAF in management policies at international and national levels. However, a larger effort is needed in order to implement EAF in practical management (FAO, 2009). In this study, ecosystem considerations add to the sustainability of a harvesting regime, and are therefore included in the assessment tree.

2.4 Linking it all together

Sustainable management has become the guiding principle for management authorities across the world. Even though the concept is elusive, management regimes have enhanced in some parts of the world, and the concept continues to improve. Fads or not, according to Garcia et al. (2003) it is clearly positive for the resource base to move from single stock assessments to an ecosystem approach, the latter clearly seems more beneficial for the world's ecosystems.

In this study, the aim is to explore the sustainability of the Norwegian salmon industry on the basis of forage fish used as an input factor. Sustainability includes three aspects:

1) Sustainable management and harvest.
2) Sustainable destination, therein feed or food for humans.
3) Efficient use.

The theoretical framework presented in this chapter forms the foundation of the study. To be able to draw some generalities regarding sustainability of salmon farming in Norway, I have developed a definition based on the present chapter. This definition will be the working concept in this thesis, and has been developed with the theoretical framework in mind.

Langhelle (2000) identified two key concepts in the Brundtland-report; the goal of development is fighting global poverty, and the necessity of physical sustainability to assure that the goal of development is not risked. From this it is possible to deduct two major implications. First, forage fish utilized in salmon feed should not be harvested at the expense of the poor. Second, the resource base should be stable across time, independent of environmental variations. With the last criteria it is evident that the management regimes of the forage fish must be evaluated.

Sustainable marine feed ingredients are harvested from a stock subject to a comprehensive management regime, in accordance to the precautionary approach and with consideration of the resources' interaction with the ecosystem. The resource base in question must be physically sustainable over a longer period[9] *to ensure the continuity of the resource across generations, and its use should be socially just, and not conflicting with the needs of the world's poor.*

2.5 Measuring sustainability

To determine whether salmon farming is sustainable on the basis of its use of feed will require a step-by-step analysis, and the outcome will not be as simple as yes or no. There are degrees of sustainability as mentioned by Langhelle (2000), even though a particular action itself is not sustainable, it can be a part of a sustainable process. I have developed a method of assessing sustainability demonstrated by the two assessment trees (figure 2.1 and 2.3), which are based on the literature relevant for this study, and influenced by actual discussions. I intend to illustrate that there are many aspects that should be considered, and that there is room for improvements along the scale. The first tree considers physical sustainability of the resource base. The second is concerned about the first key notion derived from the Brundtland-report, namely the overriding prioritization of the poor. A third assessment tree evaluating the efficient use would be beneficial, but it is not possible to assess the use of marine resources without indicators.

Determining sustainability of management is a complex matter as illustrated by the assessment tree, figure 2.1. The intention behind this assessment tree is to demonstrate that there are some components that should be included in a basic management regime for it to be sustainable. Due to the extent of this study, I have concentrated on the above three boxes in the figure, but all factors should be assessed in larger studies. In addition to the arguments from *Our Common Future*, Stenseth and Hertzberg (1992) state that the precautionary approach should be incorporated into management. Also, FAO (2009) states that a move towards EAF will improve worldwide management and ill-functioning institutions. Blanco et al. (2007) argue that is it not a sustainable practice to not utilize the whole catch, or apply gear that retains by-catch. This is a practice which also harms the surrounding ecosystem and is therefore not regarded to be sustainable (Gillund and Myhr, 2010). These factors are therefore also included in the assessment tree below, although they are not fully assessed in this study.

[9] For this study, I have chosen to operate with a period of ten years due to practicable reasons.

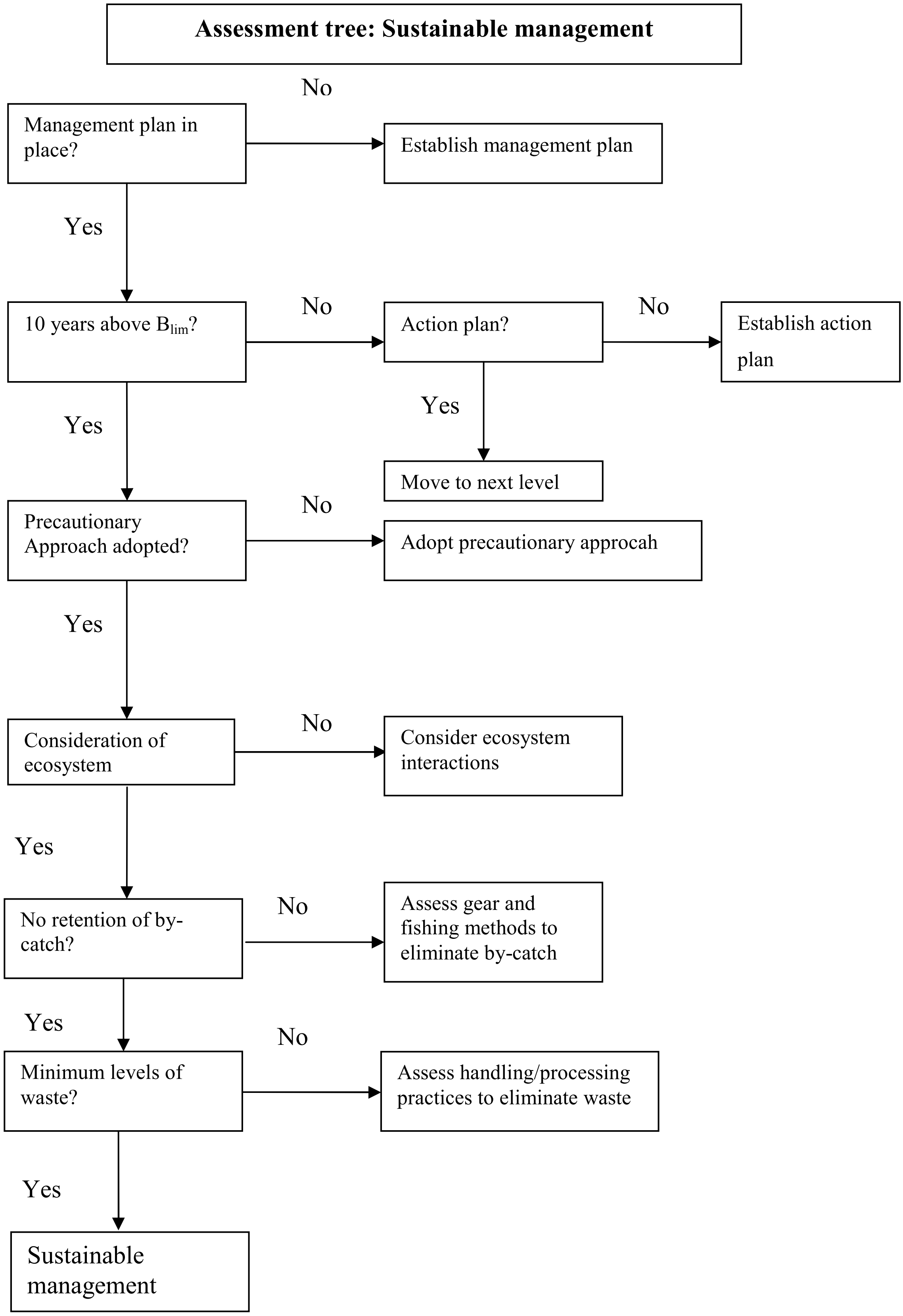

Figure 2.1: Assessment tree of the sustainability of management, developed for the purpose of this study (inspired by Gladwin, 1989; Miles and Huberman, 1994).

For the second criterion (ten years above B_{lim}), I have developed a scale of measurement, figure 2.2. This scale is an attempt to demonstrate that there are indeed degrees of sustainability. It is important to note that improvement can be made along the scale, and the optimum is ten. My purpose with the scale is to demonstrate that it is not constructive to dismiss the fish stock as not sustainable if it falls below B_{lim} equal to ten years. It is more constructive to have a goal (ten) and attempt to achieve this on a long term basis. Another aspect worth remembering is that pelagic species are unpredictable, and even though a stable management regime has been implemented, there might be years with great fluctuations independently of fishing pressure (Fréon et al., 2005).

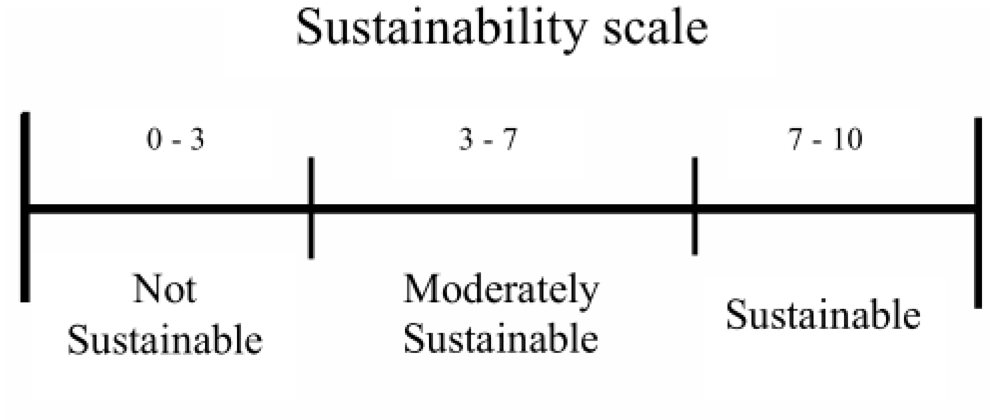

Figure 2.2: A sustainability scale, developed for the purpose of this study.

The needs of the poor are addressed in the second assessment tree, figure 2.3. This figure is concerned with the prioritization of the rural poor as pointed out by WCED. This aspect of sustainability is dynamic, and will be analyzed in qualitative terms.

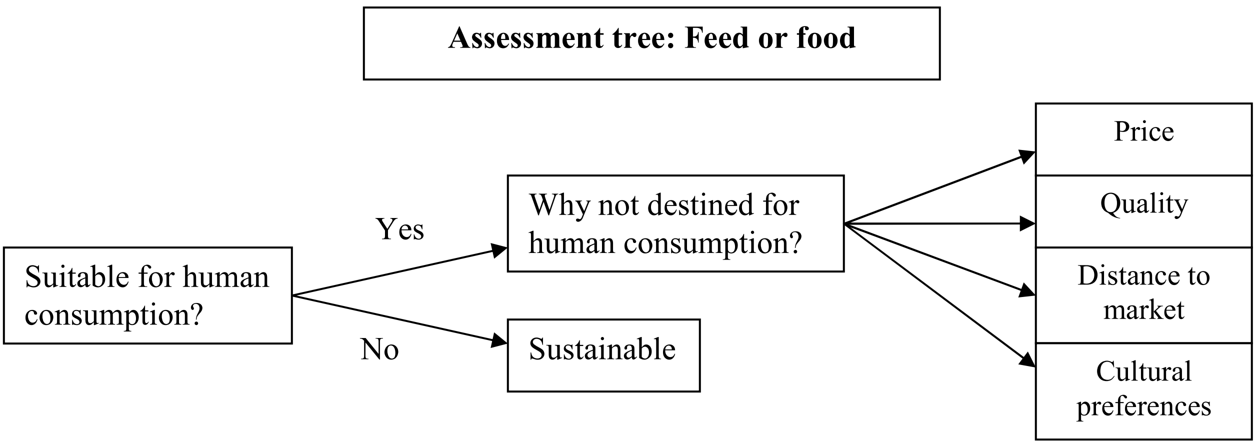

Figure 2.3: Assessment tree determining sustainability based on utilization, developed for the purpose of this study (inspired by Gladwin, 1989; Miles and Huberman, 1994).

It would be fairly straightforward to evaluate the sustainability of Norwegian salmon on the basis of the criteria above. However, the third level affecting sustainability of Norwegian salmon, namely the efficiency of the feed, must be discussed separately. The Fish In-Fish Out (FIFO) ratio denotes the efficiency of salmon production across several steps, from production of fishmeal and fish oil, to the production of aquafeed, to feeding operations and finally the growth of the fish. The FIFO ratio is dependent on the feed conversion ratio (FCR), which denotes how much feed is required to produce one kg of salmon. In aquafeed other ingredients than marine raw materials are included. In a sustainability discussion these ingredients might also have implications for the sustainability of the salmon production. This problem will not be addressed in this study, but should be considered in a larger and more comprehensive research project. The FCR is a useful measure of comparing the efficiency in production of different livestock. Both ratios are dynamic and change over time, due to changes in price, availability of ingredients, and demand and price for the final products.

Some stakeholders state that if the resources are managed sustainably, then the production of salmon is automatically sustainable (EWOS, 2010a). Is it not that simple; in this thesis sustainability depends on sustainable management and harvest, sustainable utilization and efficient use. These three factors should all be incorporated in the same assessment tree or another type of index. Currently, this is not possible as indicators and reference points are still to be developed. Discussing the conversion ratios is a different matter. Salmon is naturally a net consumer of protein, but under controlled circumstances (like farming), the total use of marine protein has decreased. While some may claim that salmon farming is not sustainable until consumption equals production, I find it more suitable to do a comparison between salmon and other forms of meat production.

This chapter has dealt with the theoretical framework surrounding sustainability, and the concept has indeed proved to be imprecise and vague. In the wake of *Our Common Future* several trials of clarification have been done, so far with limited success. Over time the concept seems to become more complex, with a number of added requirements. I have made an attempt to develop a working concept based on the literature review and an analysis of sustainable development. Hence, this definition, the assessment trees and the sustainability scale should be kept in mind when dealing with the remaining chapters.

Chapter 3: Method – how to study sustainability?

Studying sustainability is a complex matter as there is no precise answer and no prescribed path to follow. In my case, I will examine different problems in need of separate methodological approaches. The questions at hand have in common that a combination of qualitative and quantitative methods will be applied in the process of enlightening them. Qualitative methods are commonly applied for studies of a sociological character, like for instance management studies. These methods are suitable for this thesis, as they answer research questions by describing social actors' interpretations of life (Blaikie, 2009). The characteristics and regularities are analyzed and form a conclusion regarding certain aspects of the topic under study. Relevant quantitative data present the Norwegian salmon industry and the forage fisheries, and are necessary for a satisfactory description of the basis of analysis.

My aim through this study is to produce a holistic overview of the context examined, with a systematic, encompassing and integrated account of relevant aspects (Miles and Huberman, 1994). To achieve this objective I have used three types of sources: Primary, secondary and tertiary data.

3.1 The problem at hand

Farming of salmon affects the environment, nearby communities and the country as a whole in different ways. A complete assessment of the sustainability of the Norwegian aquaculture industry would require information of ecological, economic and social character, hence, more funds and time than what have been available for this study. This thesis is concerned with and limited to three aspects of sustainability: sustainable management and harvest, fish destined for feed or food and efficient use of the resources, as demonstrated by figure 3.1.

Quantitative data of management advice and actual harvests are assessed qualitatively with the use of the first assessment tree in chapter 2. Quantitative information concerning the health of the stocks is assessed quantitatively according to the sustainability scale; scores are given according to years of the stock size above the limit reference point, B_{lim} within the timeframe of the study.

The second aspect of sustainability is concerned with the destination of the resource after it has been harvested. I have examined this aspect qualitatively, as this aspect is of a dynamic character and will most likely change over time.

The third aspect of importance for this study is how the resources are utilized as feed. I have looked into how much raw material is needed to make a unit of feed and again how much feed is needed to produce a unit of salmon. Efficiency of feed is compared to food production also applying marine resources (fishmeal) in its production, for instance poultry and pig. This aspect is dynamic, as the demand for marine resources is increasing due to a stagnating supply, substitutes are therefore attractive.

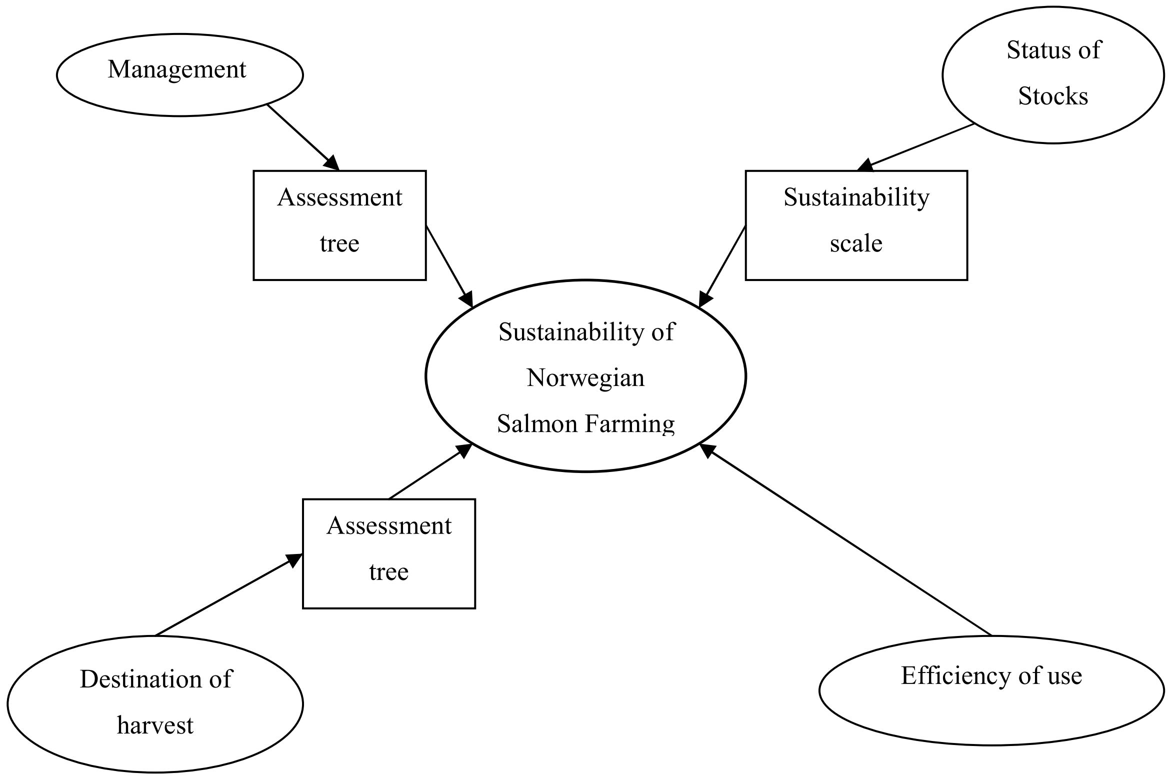

Figure 3.1: The conceptual framework guiding this study (inspired by Miles and Huberman, 1994).

I have through the two assessment trees and the sustainability scale attempted to operationalize the definition of sustainability. The methods are indicated by figure 3.1; the assessment trees are used to assess whether management and health of the stocks are sustainable and if current use (food or feed) is sustainable. Degrees of sustainability of the forage fish are determined according to the sustainability scale. Tools for assessing efficiency of use are yet to be developed; this aspect is therefore discussed qualitatively.

3.2 Research questions

There are three main groupings of research questions according to Blaikie (2009): *what, why* and *how* questions. These three groups are associated with three main categories of research purposes: description, explanation/understanding and change, respectively. In this study the research questions mainly accrue to the what-category and require descriptive answers. According to Blaikie (2009:60) what questions “are directed towards discovering and describing the characteristics of and patterns in some social phenomenon”. Blaikie (2009) also defines to describe as to ”provide a detailed account, or the precise measurement and reporting, of the characteristics of some population, group or phenomenon, including establishing regularities” (ibid.:69). However, the research questions also partly fall into the why and how categories, in the parts concerned with explanation and change. The last two questions require explanations and are of a dynamic nature, they are therefore concerned with change. All the three types of questions are thus present in this study. What questions describe relevant characteristics, the why questions explain why these are of relevance and provide understanding in regard to future change, which is answered by how questions.

3.3 Research strategy

The study has an exploratory and descriptive perspective and Blaikie (2009) argues that a good description is what is needed for a satisfactory understanding of a topic. I expect that my thesis will contribute in that manner. Blaikie (2009) explains that “social research is the use of controlled enquiry to locate, describe, understand, explain, evaluate and change patterns or regularities in social life” (ibid.:36). I have based the sustainability of Norwegian salmon farming on links between management of forage fish, to where the fish is destined and how efficiently the resource is utilized.

The starting point of the thesis has been to address the three aspects separately before they are linked together. In this way, a holistic overview form the basis for a discussion concerned with the sustainability of Norwegian salmon farming that is limited to feed resources. Description and exploration of social phenomenon were needed to conduct this thesis. Coherent with describing and exploring are the inductive and abductive research strategy, which I have chosen. Through the inductive research strategy my aim “is to establish limited generalizations about the distribution of, and patterns of association amongst, observed or measured characteristics of individuals and social phenomena” (ibid.:83). In this study, descriptions of patterns between salmon farming, the feed industry and management of forage fish is highlighted and related to the research questions.

The abductive research strategy is different from the inductive research strategy, because it integrates social actors’ meanings and interpretations of life. Blaikie (2009) describes that an abductive research strategy “involves constructing theories that are derived from social actors' language, meanings and accounts in the context of everyday activities" (ibid.:89). To be able to construct models and theories it is necessary with a thorough description from where it is possible to gain understanding. Social actors are central in research and their perception forms the basis of how the social world is portrayed (ibid.). When conducting abductive research, the task is to discover and describe such an inside view and transform it too more technical descriptions suitable for this study. In other words, it constitutes a more "bottom-up" approach, where descriptions and understanding reflects the social actors' point of view (Blaikie, 2009). For me, the abductive research strategy came to life through interviewing important stakeholders in the feed industry and participating in the Aquavision conference, arranged by the industry itself. Perspectives the industry share and individual perspectives provided me with a much deeper insight and understanding than I would have gained by utilizing the inductive research strategy only.

3.4 Research design

This thesis is conducted on the basis of primary, secondary and tertiary data sources. Primary data is "new" data generated by the researcher who is conducting the research. Secondary data have been collected, analyzed and utilized by other researchers for a different purpose than this particular study. Such data might have been utilized in government statistics or scientific research, and raw data is in most cases still available. Tertiary data is secondary data gathered and analyzed by a researcher, and in most cases only the results of the analysis are available. The raw data utilized in the analysis is normally not available (Blaikie, 2009).

Secondary and tertiary data is mainly used to achieve the aim of this study, while primary data adds to and highlight some of the important aspects. Scientific research constitutes the main source for discussing the development of feed efficiency, while interviews provide the feed industry's perception on the problem.

3.4.1 Primary data – interviews

I conducted interviews[10] with representatives from the Norwegian Seafood Federation (FHL) and the three largest aquafeed producers in Norway: Ewos, Skretting and BioMar. These representatives have in common that they possess a wide knowledge about the farming itself, the feed industry and the management of forage fish. These three representatives also represent about 90% of the national production of compound aquafeed (FHL, 2010b), and

[10] The interview guide is included in the appendix.

thus constitute a major part of the industry. This is also the reason for the low number of interviewees, which I believe is satisfactory for the purpose of this study. Adding more representatives would probably not provide me with significant new data to any extent.

According to Seidman (1991:4) "interviewing provides access to the context of people's behavior and thereby provides a way for researchers to understand the meaning of that behavior". In this study, my intention was to include stakeholders' perception and describe their world, which is in accordance with the abductive research strategy. Interviewing required that I as a researcher took contact with people whom I have never met, and it was at first a very daunting experience. However, it was evident that most of these representatives wished to express their personal views and experiences, and this served as a motivation for me.

According to Kvale (1997) there are seven phases of the qualitative interviewing process; thematising, planning, interviewing, transcribing, analyzing, verifying and reporting. This set-up will eliminate some of the problems usually encountered when performing interviews. It is quite common for novice researchers to set out interviewing people on the basis of a brilliant idea, only to discover problems analyzing the data. They might lack a purpose and sufficient background knowledge to utilize their interviews. I spent quite a lot of time preparing for the interviews; a large amount of literature concerning many aspects of the industry was ploughed through, and I discussed the appropriateness of the interview guide with my supervisor. I intended to get as broad and ample knowledge of the sector as possible before the actual interviews commenced.

Seidman (1991) mentions how the word interviewing can imply practices ranging from very structured and concise questions to meetings where there is no structure whatsoever. My interviews were something between the above extremes, thematically structured, but open-ended. My intention was to get the interviewee to describe and explain as much as possible after an introduction, and I only interfered when there was a need for follow-up questions. Kvale (1997) refers to this type of interviews as *semi-structured.* This approach required that I was well prepared and had a general up to date knowledge of the topics covered in the interview.

Seidman (1991:72) states that: "interviewing is both a research methodology and a social relationship that must be nurtured, sustained and then ended gracefully". Kvale (1997) also emphasizes the importance of being aware of ethical considerations throughout the interviewing process, especially with regard to an informed consent and confidentiality. For me this meant that I had to consider ethical aspects of this relationship, and emphasized beforehand that the interviewees could read through the transcribed material prior to use in the actual study. Taping the interviews was optional (only the representative of FHL agreed) because it was important for me that the representatives felt at ease, and thereby providing me with information they otherwise might not have shared. I have also chosen to refer to the interviewees as representatives of their respective companies, and they are therefore cited as anonymous in terms of specific names.

The strength of utilizing interviews as primary data is argued by Seidman (1991) to be:

> "In-depth interviewing's strength is that through it we can come to understand the details of people's experience from their point of view. We can see how their individual experience interacts with powerful social and organizational forces that pervade the context in which they live and work, and we can discover the interconnections among people who live and work in shared context" (Seidman, 1991:103).

I believe that I have gained information and perceptions through the interviews that otherwise would be overlooked. Interviews are clearly subjective and some might consider this as negative, but I will argue that it was beneficial for this particular study.

3.4.2 Secondary and tertiary data

The salmon industry is currently being portrayed in media on a weekly basis, in some periods even daily. Even though media coverage cannot be defined as scientific, it is catalyzing research by enlightening problematic areas of the Norwegian aquaculture industry. Large amounts of literature concerning the aquaculture industry exist, but I have used only what is relevant for this study. This delimitation might affect the result, as excluded factors influence the sustainability of Norwegian salmon farming. Even though I believe I have covered a lot of relevant literature, there is always the possibility of shortcomings in terms of newly published data and other methods of enlightening the topic.

Important literature for this study has been articles and books about the development of aquaculture in Norway, trends in fishmeal and fish oil use, substitutes for fishmeal and fish oil and research concerned about the development of the Fish In-Fish Out ratio (FIFO) and the feed conversion ratio (FCR). Various reports regarding sustainable development have been significant for the theoretical framework forming the basis for this study. *Our Common Future* is especially important and I have also made use of analyses of this report.

3.4.3 Private and official statistics

Government documents and statistics are significant for describing the aquaculture industry and the fisheries in questions. Statistics from the feed-companies and the Norwegian Seafood Federation (FHL) is also made use of to a large degree. Private statistics is applied in the parts of the thesis where the feed composition and conversion ratios are addressed. Government statistics and documents are important in the background chapter where the Norwegian aquaculture industry is described, but also in chapter 5, which is concerned with the management of forage fish.

3.4.4 Constructing the assessment trees

Assessing the sustainability of a management regime involves several steps, and I have constructed an assessment tree with the aim of illustrating this. I was inspired by the methodology applied in Gladwin (1989) and Miles and Huberman (1994). However, this qualitative method operates with decision trees depicting "insiders' decision processes from the insiders' own terms and phrasing of their own decision criteria" (Gladwin, 1989:9). Decision trees are hence quite different from my assessment trees, but both utilize decision criteria. In my assessment trees I have focused on factors influencing sustainability. The steps in the tree are based on relevant literature, and therein what has been argued to be necessary for a sustainable fishery. For each step, measures for improvement have been suggested if current management is considered inadequate. The assessment tree depicting the food or feed situation is also highlighting what should be considered when assessing this aspect.

3.5 Challenges and problems

Any research design will pose certain challenges and problems, and for the reliability of the study it is important for me to elaborate on possible limitations.

When utilizing interviews as a source of data, it is important to note that the interviewer will have an influence on the actual interview, as well as the process of transcribing and analyzing the material subsequent to the interview. A possible limitation is that the researcher often develops an anticipatory frame of mind before the interview commences (Seidman, 1991). Anticipation is based on readings and other preparations for the interview; however, personal values might also affect the researcher's frame of mind. Another limitation worth mentioning is that it might be a possibility that knowledge gained through interviews might be erroneous. In this study, the media's scrutiny has caused an incentive within the industry to embellish the truth, and it is therefore important to consider this possibility.

For me it was a challenge to interpret the body language of the interviewee. I felt that I should receive certain reactions when I brought up sensitive topics, but after the interview I was left with a feeling that it was I that had felt the apprehension. This was also challenging when I processed and analyzed my data. My strategy was to do this shortly after the interview as to not forget crucial impressions, but this might have been a liability as well, because the anticipation and apprehension was still present. Another problem is the fact that personal chemistry has affected my results; in the case of two of the four interviews, I got along well with the interviewees, and I might have been less critical and have not pursued comments and answers in the same way as with the other two interviewees. In the middle of the series of interviews, I participated in the Aquavision conference in Stavanger, and during this stay I learned more about the industry itself and also gained more knowledge of the topic at hand. This affected my knowledge base and further equipped me for extracting more from the interviews than prior to the conference. This might be a liability for the whole series of interviews.

A more specific problem was experienced during one of the interviews and later in the process of analyzing the information. I was told that I would receive more concrete information regarding the species utilized in their production and the feed efficiency. However, I have still not received this information, in spite of several requests. The same interviewee has not commented on the finished material either, which is a source of concern. On the other hand, I have received no protests on the draft sent to the representative, which I recognize as a sign of tacit acceptance.

Secondary data sources are characterized by numerous limitations that can affect the result of the study, the most elementary shortcoming is that research conducted by others is motivated by different aims and has different research questions. Blaikie (2009) mentions that such studies possibly were based on certain assumptions that might make the results invaluable for other studies. Another disadvantage is that all areas of relevance to the current study might not have been included in the research; which will most likely affect the results. Like in my thesis, delimitation has been necessary due to limited time and financial resources.

An implicit drawback of utilizing secondary sources is the quality of the data in question. I have assumed that the data sources are valid, but it is important to be aware of this drawback when discussing the results. Secondary data might be old and depending on the topic, this might pose a drawback. For instance, basing a conclusion on ten year old data for a management study would not be considered ideal. The fish stock in question can fluctuate greatly in ten years, especially in the case of forage fish. When utilizing secondary and tertiary data, it was important for me to keep in mind that it has been produced for other purposes and that this might be a liability for my study.

Tertiary data constitutes even more considerations or limitations. The researcher will be further away from the original primary data when utilizing tertiary data sources. Government statistics or reports include manipulated raw data often summarized in tables or graphs. In these occasions it is normally not possible to get a hold of the primary data. Blaikie (2009) emphasizes that tertiary data should be treated with caution because one has no control of the transformation process from primary to tertiary data. Analysis of secondary data will also have the possibility of being selective, and tertiary data might therefore constitute the risk of the exclusion of important. Blaikie (2009) states that the risk of unintentional or deliberate distortion increases the further a researcher is removed from the original primary data.

Statistics have been crucial for this study because of the combination of quantitative and qualitative method and set-up. Due to the time and money constraints, it has been necessary for me to rely on statistics provided by others. I consider official statistics to be reliable, but private statistics however seem to be more variable. Companies have their own interests and are protective of information that might be unfavorable for them if made public. For me this implies that I have used their data with caution, and emphasized the possibility of inaccurate data.

3.6 Possibility of generalization

There are undoubtedly numerous factors influencing the result of any study; background knowledge, disciplinary traditions, and time and financial constraints are some worth mentioning here (Blaikie, 2009). It seems to me that making generalizations on the basis of the above mentioned is difficult, but with the right assumptions it is possible.

Regarding the primary data, I have assumed that the representatives' views are in line with the companies they are representing. The three companies producing aquafeed are the main actors supplying about 90% of the compound aquafeed in the Norwegian market, and I have therefore assumed that their views also represent the remaining share of the producers. This is something verified by the contribution from the Norwegian Seafood Federation (FHL), which represents both the aquaculture industry and the aquafeed industry. I have also assumed that the data from the respective feed companies are valid, but they should be treated with caution and if further utilized, the reliability of such data should be brought up for discussion.

The most immediate drawback is the lack of information concerning management and status of the anchoveta. As this species makes up a very important ingredient in Norwegian salmon feed, incomplete information is a major limitation for the study. I have made several attempts to make contact with both IMARPE and FAO Peru, but have received no response. Assessment of the anchoveta is based on some official data found online, and some tertiary data. However, the data is inadequate, as there is no available information about the continuous time series applied in the rest of the study. This problem separates this stock from the rest of the species in terms of methodology and this is most probably a cause for error.

The strength of this approach has been the attempt of constructing a quantitative indicator measuring the sustainability of Norwegian salmon based on the marine feed resources applied by the sector. This indicator covers about 80-90%[11] of the marine resources and the status of the respective stocks is evaluated over a ten-year period.

This chapter has dealt with the methodology applied to conduct this study. In chapter 4 follows a description of the Norwegian aquaculture industry needed as a background for answering the research questions.

[11] This is dynamic depending on state of the stock and harvest. In 2008/2009, the six main species constituted 81% of marine resources applied in salmon feed (FHL, 2009; EWOS, 2010; Helland, 2010; Skretting, 2010).

Chapter 4: The Norwegian aquaculture industry – an overview

This chapter will provide a brief overview of the Norwegian aquaculture industry, including the aquafeed industry.

The practice of aquaculture worldwide has long traditional roots as subsistence and cultural cultivation of aquatic organisms. Industrial aquaculture is a more recent phenomenon, and production is playing an increasing role in satisfying demand for human consumption of fish and fishery products. An increase in food fish production over the last decades has been due to increasing aquaculture practices on a global scale as demonstrated by figure 4.1. Supply from capture fisheries has on the other hand has been stable more recently (Grainger, 1999).

Further growth in the availability of fish for human consumption is expected to come mainly from aquaculture, which is acknowledged as the world's fastest growing food production system in later times. An average annual growth rate of 8.7% worldwide (excluding China with a growth rate of 6.5%) has been maintained since 1970 (FAO, 2009). The continued growth of the aquaculture sector seems to be possible in near future, however at a smaller growth rate.

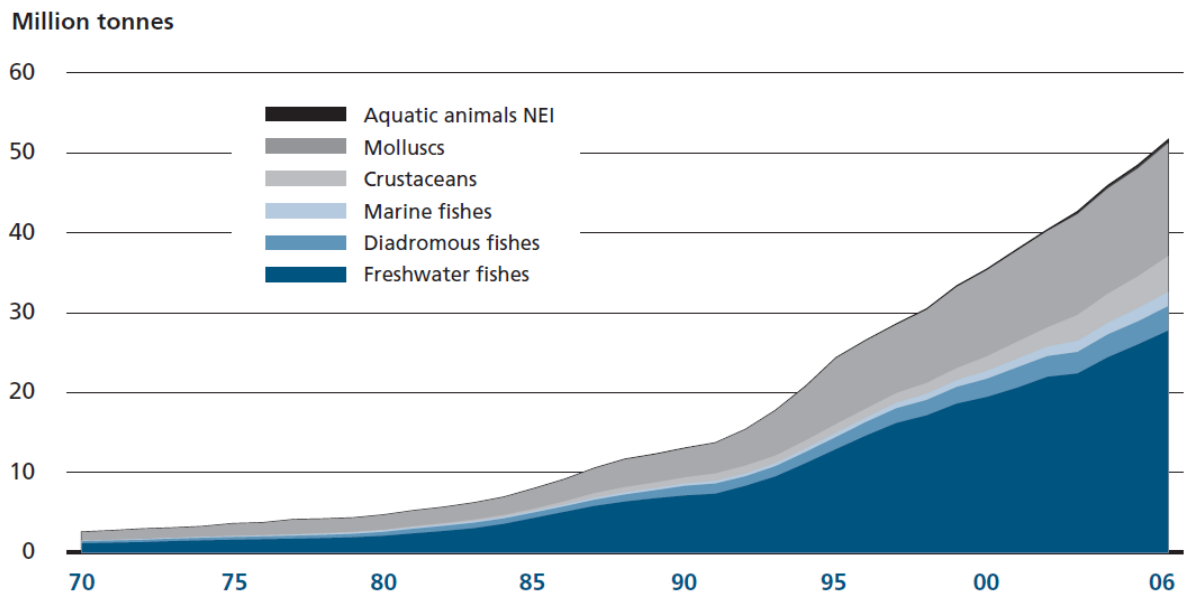

Figure 4.1: Development of global aquaculture production 1970-2006 (FAO, 2009).

Worldwide there is a wide diversity of cultivated species, and different species of carp (*Cyprinidae*) dominate the production (Naylor et al., 2000; Naylor and Burke, 2005).

Wealthy consumers prefer shrimp and carnivorous finfish species like salmon, halibut, cod and tuna (New, 1995). Diadromous fish, mainly salmonids, form nearly half of global finfish aquaculture production outside Asia (New, 1995). Salmon is produced mainly in high latitude areas like Europe, Canada, USA and Russia (see figure 4.2). However, Chile, New Zealand, Australia and Japan have also succeeded in salmon production (Naylor and Burke, 2005). Chile has been one of the top producing countries, until the aquaculture sector experienced severe outbreaks of infectious salmon anemia (ISA) in 2008 (Marine Harvest, 2009). Currently, Norway is the largest producer of salmon on a worldwide basis (FAO, 2009; Gillund and Myhr, 2010).

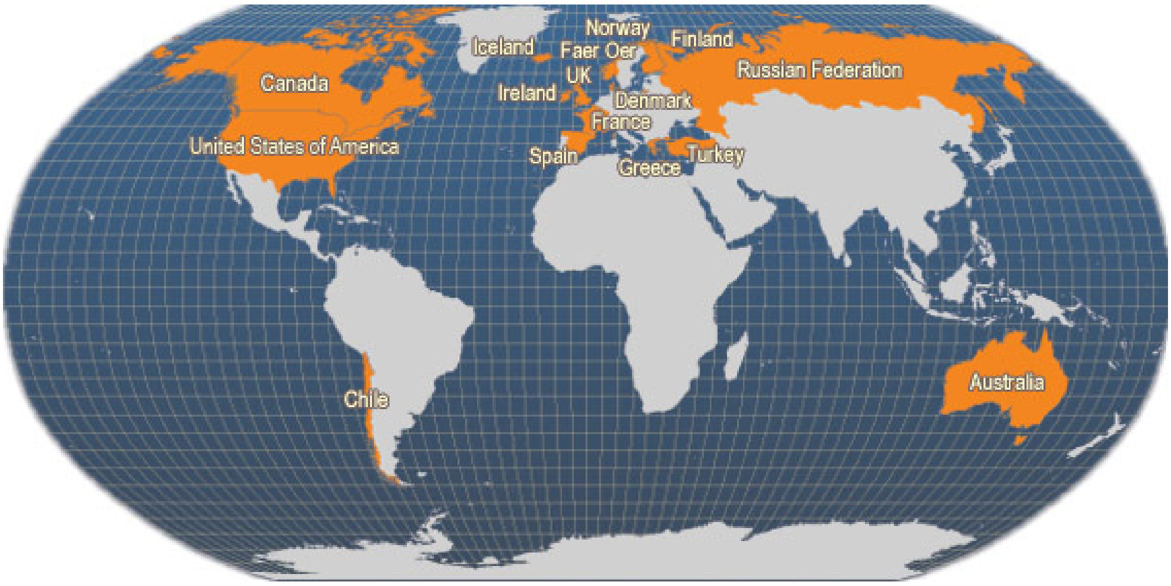

Figure 4.2: Producers of Atlantic salmon (*Salmo salar*) in the world (FAO, 2004-2010).

Salmon and trout are becoming increasingly more important in the world market, and represented 11% of the seafood trade in 2008 (FAO, 2009). This development is driven by a steadily increasing demand and the establishment of new markets. Supply is driven by increasing production in Northern Europe and North and South America, while trade is facilitated by improving retail channels and means of transportation (FAO, 2009).

A brief description of the history and development of the Norwegian aquaculture industry is necessary to understand the setup and interaction between actors of the industry. The current status with challenges and future prospects is also important for recommending steps that should be undertaken in the future.

4.1 The Norwegian aquaculture industry

The aquaculture industry in Norway represents large socio-economic values and 2009 was yet another record year for the seafood sector: 2.58 million tons of seafood was exported, representing a value of 44.6 billion NOK. Aquaculture products made up more than 50% in terms of value in 2009 (25.9 billion NOK) (EFF, 2010). About 4,500 people are employed within core activities of the industry, but extensive spill-over effects are generated outside the sector (Ministry of Fisheries and Coastal Affairs, 2009b; Sandberg et al., 2009).

The aquaculture industry in Norway is mainly based on producing Atlantic salmon (*Salmo salar*). However, there are a number of other species currently farmed, including rainbow trout (*Oncorhynchus mykiss*), cod (*Gadus morhua*), halibut (*Hippoglossus hippoglossus*), wolffish (*Anarhichas spp.*), char (*Salvelinus alpinus*) and turbot (*Psetta maxima*) (Ministry of Fisheries and Coastal Affairs, 2010b).

Salmon farming in Norway is characterized by deep fjords with optimal water flow and favorable hydrological conditions. Farming cites are normally located a long way from large cities, and the industry has been characterized by a tremendous growth (in terms of production and profitability) throughout its existence.

4.1.1 History and development[12]

Aquaculture practices in Norway originate in the mid-19th century with the establishment of salmonid hatcheries; juveniles were kept in dams before release into rivers and lakes. However, cultivation trials of food-fish both in salt and freshwater were unsuccessful. In the beginning of the 20th century, cultivation of rainbow trout in dams was again topical in the southeast part and the west coast of Norway (Jakobsen, 2005). The technology was still not in place and the costs were unacceptably high. In the 1950s the interest for practicing aquaculture increased, especially for cultivating rainbow trout. Numerous dams were established and there were persistent trials also in saltwater with limited success (Jakobsen, 2005). At the same time centralization was causing problems for the small coastal communities, and there were few livelihood opportunities (Johnsen and Lindal, 2006). This added to the determination of succeeding with the rearing of salmonids in saltwater. A small group of people, mostly farmers and fishers, managed to keep salmon in saltwater pens by the end of the 1960s (Jakobsen, 2005; Johnsen and Lindal, 2006). High costs were still an

[12] For a more comprehensive historical overview: Berge (2001), Hersoug (2005), Jakobsen (2005) and Johnsen and Lindal (2006).

issue, and actors were refused by banks for financial support and therefore risked both home and savings to continue with the cultivation trials. However, two organizations[13] realized the growing potential and provided some financial support, but earnings were minimal in the infancy of industrial aquaculture.

According to Johnsen and Lindal (2006) the brothers Grøntvedt from the Hitra-island, were the true pioneers of aquaculture. They had observed how fish could survive in seines over longer periods and when the herring stocks suffered from overfishing, the brothers got the idea of rearing salmon in seines. They started with 20,000 small salmon of 30 grams that grew up to 12 kg (Johnsen and Lindal, 2006). This was the start of the success story as we know it today. The brothers willingly shared their recipe with others who wanted to give it a try, and soon sea cages were scattered along the west coast.

The Grøntvedt brothers had applied floating net pens, but these systems were refined early in the 1970s to sea enclosures and floating sea cages (Knapp et al., 2007). With the improvement of techniques came increasing profits, which inspired others to give aquaculture a try, and led to the gradual interest from banks. By 1972, there were five farms totaling 46 tonnes, and only eight years later the number of farms had increased to 173 with a production of 4,300 tonnes (Knapp et al., 2007).

Aquaculture served as a remedy for small coastal communities with few other options to earn a living. Governmental investments were beneficial for the industry and the communities as well; substantial investment led to the development of a complex infrastructure of roads and rail links along the coast (Knapp et al., 2007). These factors together with increasing knowledge and improving techniques led to a period of impressive growth. Concessions or limited entry to aquaculture, were imposed by the authorities to distribute the farms according to rural policies.

There have been three regimes controlling production. First, the introduction of the Aquaculture Act in 1973, which came to life five years after its implementation, in 1978 (Hersoug, 2005). The act resembled the Participation Act governing the traditional capture fisheries. The main reason for the implementation was primarily to match production to existing markets, but other needs were also prominent; limited production of smolts and fingerlings could possibly create a high demand and soaring prices, the fear of bankruptcies and a strong desire to control the structure (ibid.). The aim of the act was that aquaculture should serve as a rural support system, with more and smaller production sites to employ

[13] A semi-private development organization (Kongelige Selskap for Norges Vel) and the State Development Bank (Distriktenes Utbyggingsfond).

more people (ibid.). In 1981, the first round of concessions was distributed; 54 concessions, each with a sea pen volume of 3,000m^3. Two years later, 100 concessions of 5,000m^3 were allocated, where more than 50% ended up in the north (ibid.). The concessions distributed earlier were then allowed to increase the pen volume to 5,000m^3. The volume was further increased in 1985, to 8,000m^3, when 150 new concessions were available for distribution (ibid.). Lastly, 30 concessions were established in northern Norway, with a production volume of 12,000m^3. The production volume of 12,000m^3 was the maximum pen volume per concession up to 2004 (Hersoug, 2005). The distribution of new concessions in this period led to an explosion in number of sea pens, and between 1971 and 1990 an annual increase of 33% in production was observed (Bailey et al., 1996).

The second production regime occurred in the mid-1990s due to the falling prices and overproduction in 1990 (Hersoug, 2005). The sales organizations tried to tackle this problem by freezing large parts of production, with financial help from banks. This tactic failed and resulted in the bankruptcy of the sales organizations in 1991, causing repercussions among farmers and requiring new trade practices. The ownership regulation was liberalized leading to a concentration of ownership; at that time the largest 10 firms was responsible for 8% of total production, while in 2001 this share rose to 46% (Aarset and Jakobsen, 2009). This reorganization and economic down-fall had consequences for the number of companies as well, with a decrease from approximately 1,100 in 1990 to 270 companies in 1998 (Knapp et al., 2007). This consolidation period marked the beginning of vertically integrated production. Companies were able to invest in hatcheries, smolt production and farms for grow-out and processing facilities. It was thereby possible to gain control over the various production stages of salmon. This has also been a reason for the decreasing number of companies. The consolidation process allowed the Norwegian farming industry to retain its highly competitive profile in today's global market (Knapp et al., 2007).

The above problematic period received attention in the EU, and Norway was accused for dumping and subsidizing the industry. A new structure of the industry and the adoption of a feed quota in 1996 was the result of the commotion in the early 1990s. The feed quota was the outcome of a signed agreement between Norway and EU, stating that Norwegian exports was limited to a growth of 10% annually[14] (Ministry of Fisheries and Coastal Affairs, 1997).

The third production regime is the Maximum Allowable Biomass (MAB) implemented in 2005. For all counties except Troms and Finnmark, the MAB is 760 tonnes.

[14] Commonly known as the Salmon Agreement.

For the two most northern counties MAB is 920 tonnes. MAB is higher in the north due to slower growth (Ministy of Fisheries and Coastal Affairs, 2005). The MAB system is a tool for output control, but the main goal is also to increase fish welfare and reduce pollution (Hersoug, 2005).

It requires great knowledge and experience to produce salmon, and the Norwegian aquaculture industry has had the possibility to improve its techniques and knowledge since the first successful rearing of salmon in 1969 (Johnsen and Lindal, 2006; Knapp et al., 2007). Norway has also been important for the world salmon production, providing knowledge, technology and capital. The industry has experienced a growth of an average of 17% between 1984 and 2004 (Knapp et al., 2007). Currently, as seen from figure 4.3, Norway is the largest producer of salmon on a worldwide basis with a share of 58% (Gillund and Myhr, 2010; Kontali Analyse, 2010a). More than 80% of the Norwegian production is destined for export (Ministry of Fisheries and Coastal Affairs, 2010b).

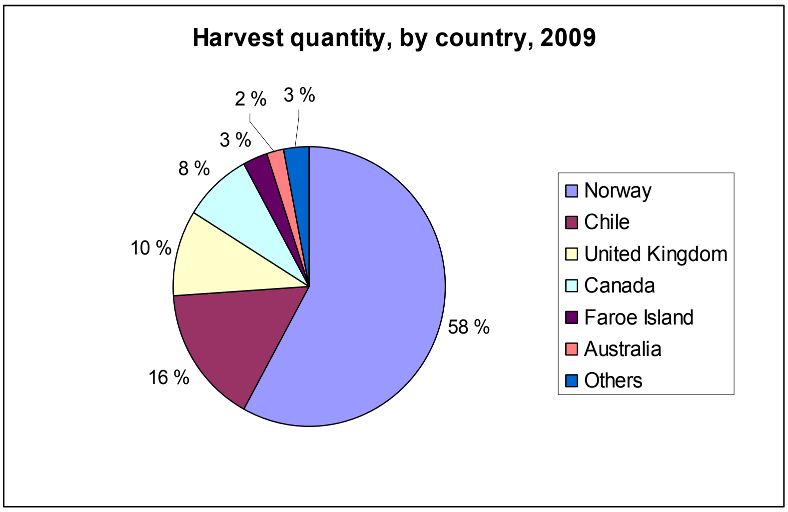

Figure 4.3: Countries' share of global salmon production (Kontali Analyse, 2010).

4.2 Current status

The last ten years has been characterized by continuous growth of production in the salmon sector as illustrated by figure 4.4. Economic difficulties caused by low prices have been tackled by a competent industry. The industry has learned to take advantage of beneficial market conditions and has experienced lower operational costs due to innovation. The majority of costs constitute feed, smolt and wages (Jakobsen, 2005). However, costs are decreasing due to continuous improvement of the feed conversion ratio (FCR), yield of smolt and production efficiency. More recently, research and development by the private sector, especially the feed and pharmaceutical firms, have been essential for continued productivity gains (Knapp et al., 2007).

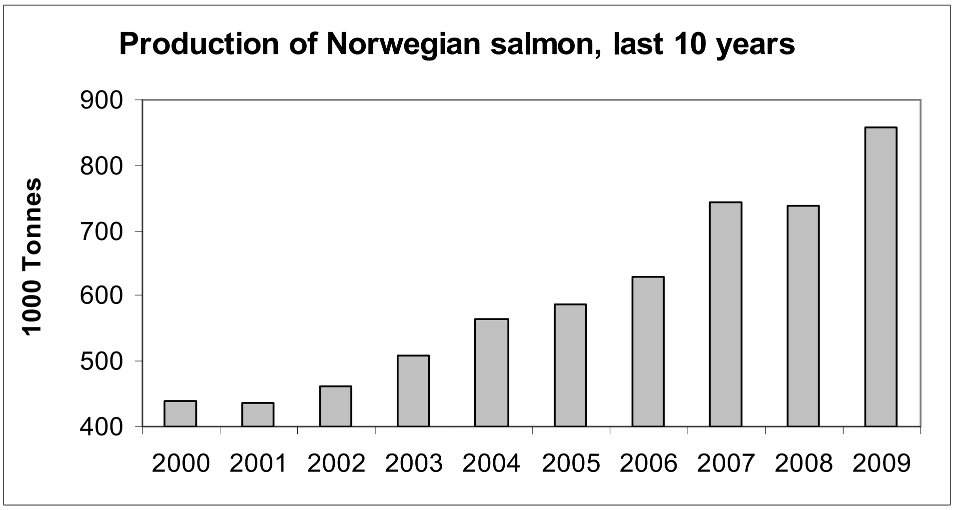

Figure 4.4: Production of Norwegian salmon 2000-2009 (SSB, 2010c).

In 2009, production of salmon was 859,056 tonnes (Directorate of Fisheries, 2010; SSB, 2010c) which is a 14.1% increase from 2008. Production in 2010 is estimated to be around 933,000 tonnes (FiskeribladetFiskaren, 2010).

In Norway, seafood products, both farmed and captured, currently constitute the third most important export earner, after oil/gas and minerals, figure 4.5 (Ministry of Fisheries and Coastal Affairs, 2010b).

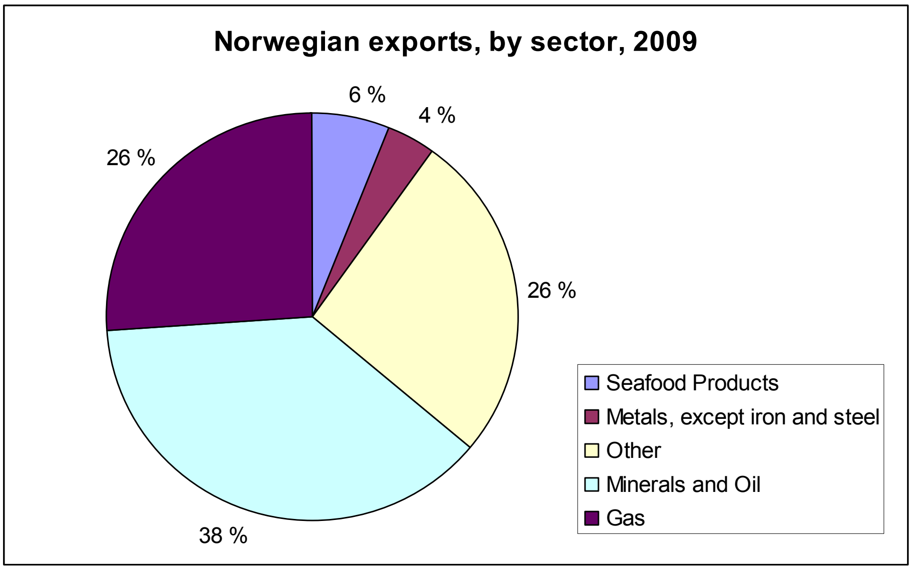

Figure 4.5: Major export-sectors in Norway, 2009 (Ministry of Fisheries and Coastal Affairs, 2010b).

Farmers started exporting salmon in 1976 when production exceeded domestic demand (Jakobsen, 2005). Today 80-90% of total production is exported (Ministry of Fisheries and Coastal Affairs, 2010b). Norwegian salmon is predominantly exported to European markets, France being the top country both in terms of quantity and value, as implied by figure 4.6. USA, Russia and Japan are also important markets. Poland and Denmark's salmon imports are mainly destined for further processing, and re-distributed within the EU countries.

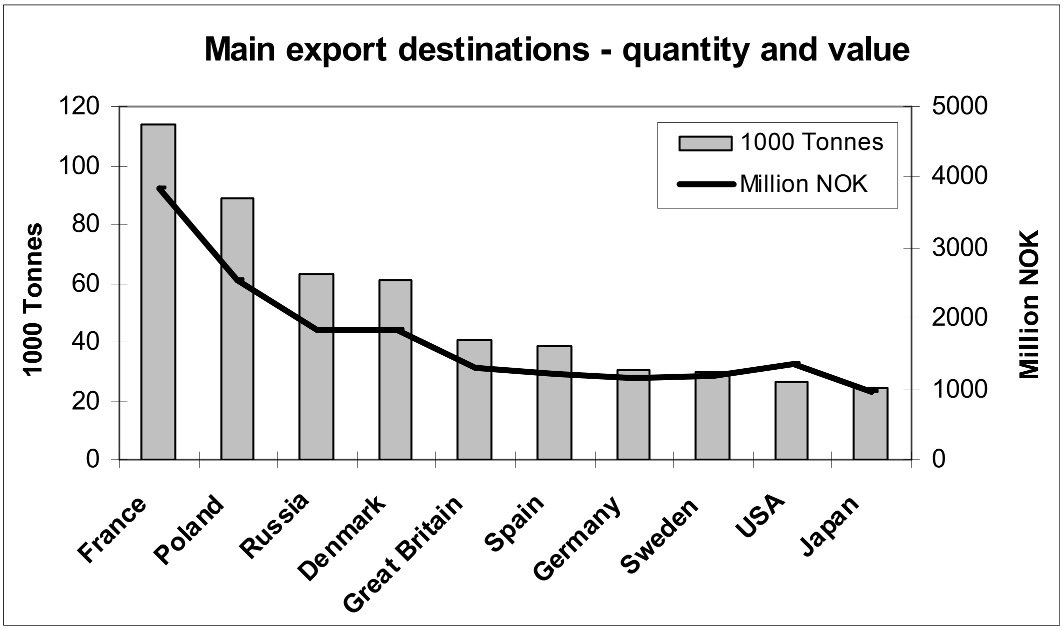

Figure 4.6: Main export markets for salmon produced in Norway, 2009 (adapted from Ministry of Fisheries and Coastal Affairs, 2010b).

In 2009, total Norwegian exports of salmon were 711,053 tonnes with a value of about 24 billion NOK. Exports have increased significantly, demonstrated by the export value in 2008, of 1.7 billion NOK, which signifies an increase of 5.7 million NOK. In terms of quantity, this represented a 13% increase from 2008 when 618,182 tonnes were exported (Ministry of Fisheries and Coastal Affairs, 2010b).

As mentioned previously, the salmon industry is mainly based along the coast (figure 4.7). Norway has a coastline extending 2,532 km from north to south, however, if including all fjords and bays, the distance increases tenfold to 25,148 km (SSB, 2010b). The fjords are exactly what make Norway suitable for salmon farming. Fjords provide a certain sheltering effect from the harsh weather in open ocean, and normally have sufficient water flow to prevent local pollution from aquaculture practices (Ministry of Fisheries and Coastal Affairs, 2009b).

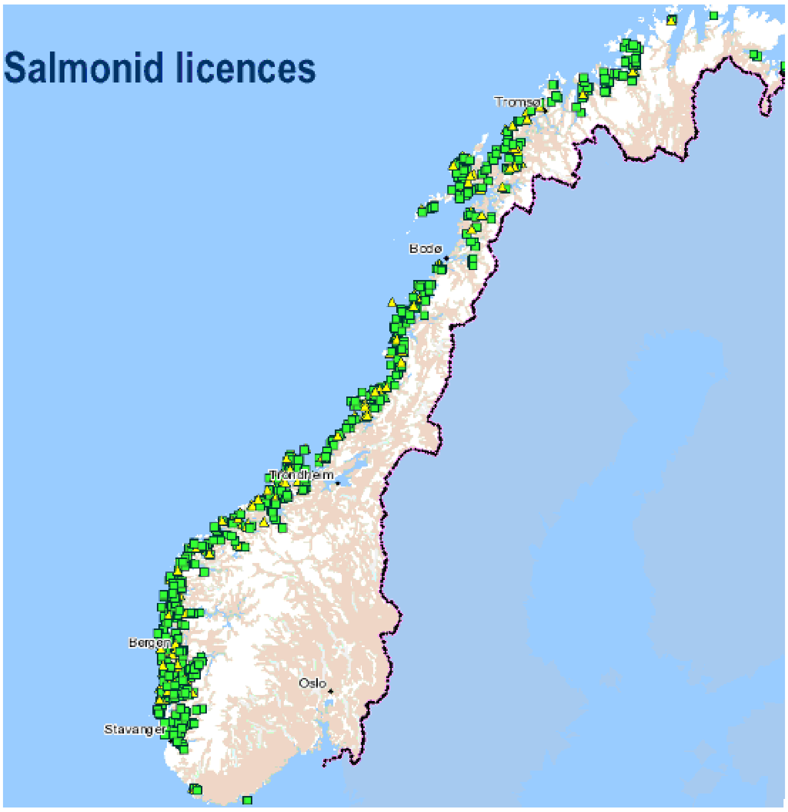

Figure 4.7: Distribution of salmonid licenses in 2009 (Gullestad, 2009).

The coastal counties of Nordland, Hordaland and Møre og Romsdal have most grow-out facilities for salmonids, with 156, 154 and 108 concessions respectively (table 4.1.)

Table 4.1: Geographical distribution of the salmon farming industry (adapted from Directorate of Fisheries, 2010b).

Year 2009	Number of Concessions				Production		
County	Smolt	Grow Out	Broodstock	R&D	Quantity	Value (1000 NOK)	Price/kg NOK
Finnmark	4	90	1	2	29 774	703 193	23.62
Troms	11	93	2	3	100 900	2 547 232	25.25
Nordland	33	156	5	6	152 389	3 510 320	23.03
Nord-Trøndelag	17	71	1	3	75 495	1 550 451	20.54
Sør-Trøndelag	22	94	2	4	112 004	2 229 893	19.91
Møre og Romsdal	34	108	6	5	109 102	2 737 863	25.09
Sogn og Fjordane	23	90	1	0	67 127	1 750 123	26.07
Hordaland	60	154	5	6	145 514	3 291 606	22.62
Rogaland	21	61	2	11	63 859	1 424 512	22.31
Other counties	31	71	5	3	2 883	59 809	20.74
Total	256	988	30	43	859 056	19 805 001	Average 23.05

Table 4.1 shows the most important salmon producing counties, with number of concessions of different production stages, together with production volume and value. The two top counties in respect to number of grow out concessions are also the most productive. In spite of this, the prices *per* kg are lower in Nordland and Hordaland, both below the national average.

Salmon farming contributes significantly to society through spill-over-effects, and if compared to the traditional capture fisheries, aquaculture is more valuable as indicated by figure 4.8. Production has increased while employment has remained stable.

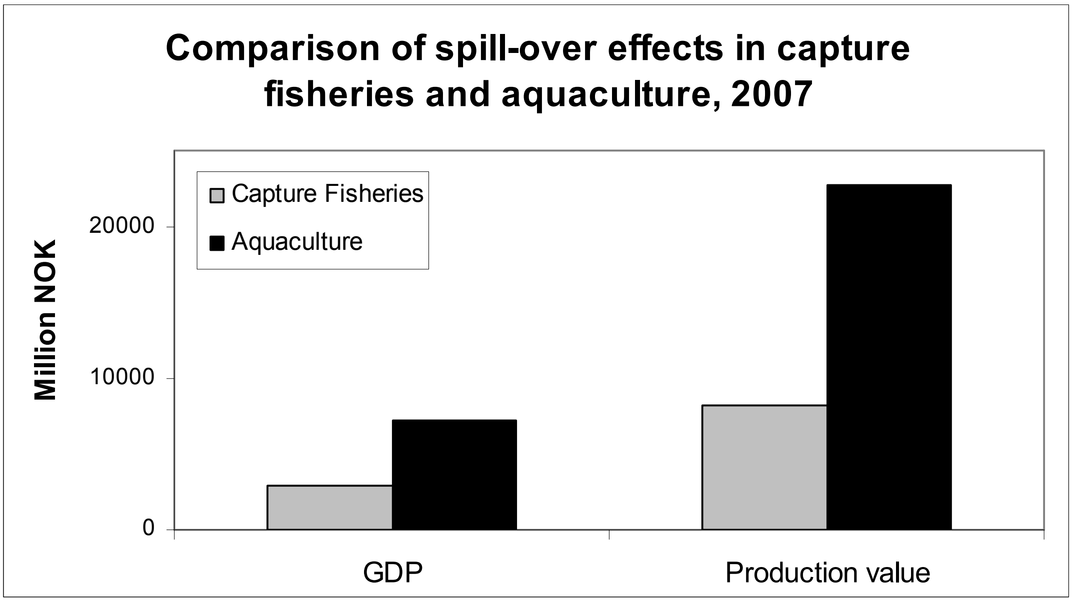

Figure 4.8: Spill-over effects caused by capture fisheries and aquaculture in Norway (adapted from Sandberg et al., 2009).

4.2.1 Challenges[15]

There are a number of challenges affecting the salmon farming industry and its reputation. The most important issues, highlighted in the *Strategy for an environmentally sustainable Norwegian aquaculture industry,* will be briefly addressed here: genetic interaction and escapees, pollution and discharges, disease with the inclusion of parasites, and area zoning. Another challenge is the possible reduction of marine resources, which is partly covered by my research questions. This topic will be more comprehensively addressed in chapter 5.

[15] For a more comprehensive overview: Ministry of Fisheries and Coastal Affairs (2009) *Strategy for an Environmentally Sustainable Norwegian Aquaculture Industry.*

Escapees threaten wild salmon on several levels: ecologically, as a competitor for food and a spreader of disease and lice, and genetically, through genetic drift and an altered selection regime (Holm et al., 2003). Development of escapees is demonstrated by figure 4.9, but unreported escape events also occur, questioning the reliability of this figure (Ministry of Fisheries and Coastal Affairs, 2009b). Most events occur in grow-out facilities because of wrecking and inadequate state of the installations, human errors when handling the fish and damage by predators (Ministry of Fisheries and Coastal Affairs, 2009b; RKA, 2010). Research on developing sterile fish for aquaculture is currently being conducted. Because the genetic variation in farmed salmon is different from wild, this will decrease the genetic influence of escapees. Several other measures to prevent escapees are undertaken, and the goal is zero escapees (Ministry of Fisheries and Coastal Affairs, 2009b).

Figure 4.9: Development of salmon escapees in Norway, 2001-2009. Numbers are based on reports from the industry (adapted from RKA, 2010).

Discharge from fish farming operations is also an important challenge that has to be addressed by the industry. Pharmaceuticals in treatments of lice, antibiotics, copper, nutrient salts and other organic materials from feed surplus and fish excrements are common effluents from farming operations. The various types of organic discharge can potentially have tremendous effects on the nearby ecosystems if the carrying capacity is exceeded. The chemicals released have varying degrees of detrimental effects on the environment and effluents should be minimized (Holm et al., 2003). It is mandatory with environmental investigations prior to the establishment of a farm site, and then regular monitoring during farming operations. The aim is to keep pollution levels within the carrying capacity of the environment (Ministry of Fisheries and Coastal Affairs, 2009b).

Disease and parasites are still representing casualties in Norwegian aquaculture, but the situation has improved significantly over the last decades (Ministry of Fisheries and Coastal Affairs, 2009b). Pancreas disease (PD), heart and skeletal muscle inflammation (HSMI), infectious salmon anaemia (ISA) and infectious pancreatic necrosis (IPN) are common viral diseases. Salmon lice (*Lepeophtheirus salmonis*), however constitute a much greater risk for the wild salmon than the viral diseases (Ministry of Fisheries and Coastal Affairs, 2009b). Salmon lice exist naturally in Norwegian oceans, but its distribution and abundance have increased in line with the growth of salmon farming. Figure 4.10 illustrates the development in lice the last couple of years. Lice are the most common problem in the sector and affect wild populations by spreading to salmon or trout passing by sea pens, or spread by wild fish being in contact with infected escapees. Lice are treated with chemicals or biologically and eco-friendly with wrasse (Lusedata, 2010). The increasing problem of lice spreading to wild fish and the fact that the lice are becoming more resistant to chemical treatments, nurture the opposition against salmon farming. Opponents of aquaculture use transmission of disease and escapees as main arguments. It is stated in the *Strategy for an Environmentally Sustainable Norwegian Aquaculture Industry* that the structure of the industry must be arranged in a way that reduces the risk of disease, and measures to combat disease and developing resistance is also presented (Ministry of Fisheries and Coastal Affairs, 2009b).

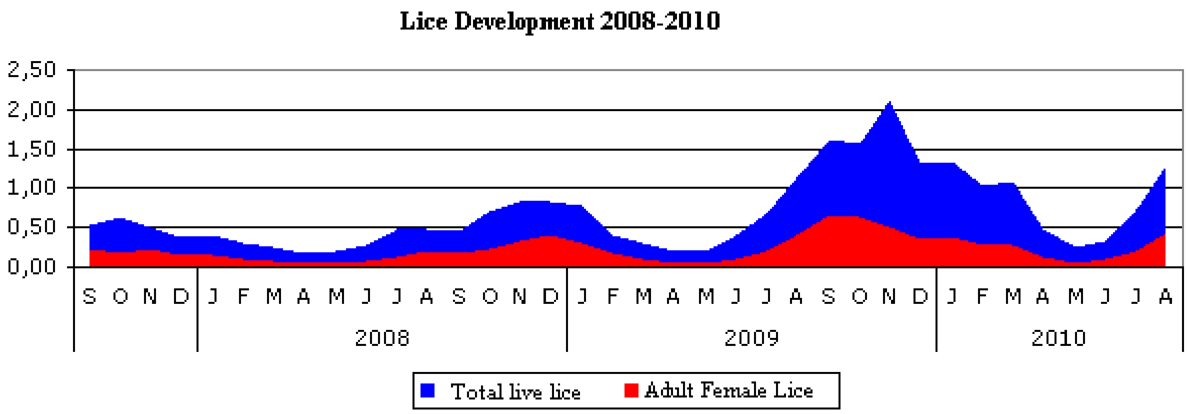

Figure 4.10: Norwegian lice outbreaks in recent years, values designated as number of lice *per* fish (Lusedata, 2010).

The physical area needed to perform farming practices is insignificant compared to the agriculture sector, which is producing about 300,000 tonnes of meat a year. Salmon farming is far more efficient with almost 900,000 tonnes in 2009 produced on a much smaller area (Andreassen et al., 2010). Despite of this there is a shortage of suitable locations, and in some areas the density of farms is too high. In western Norway, high density is contributing to fish health problems (Ministry of Fisheries and Coastal Affairs, 2009b). Further growth of the industry might require a restructuring and should include areas between farms to limit spreading of disease and parasites. The trend is that aquaculture sites are growing in size requiring heavier infrastructure conflicting with other uses, for instance fishing and recreational uses. Super localities able to sustain a MAB of more than 5,400 tonnes will be highly attractive in the future, and is believed to be a source of conflict (Andreassen et al., 2010). These super localities might be especially valuable for wild fish as a spawning area or nursery ground, or they might constitute other important functions (Ministry of Fisheries and Coastal Affairs, 2009b).

4.2.2 Further potential

Globally, annual growth rates for aquaculture are slowing partly owing to public concerns about aquaculture practices and fish quality (FAO, 2009). Integrated multi-trophic systems and organic aquaculture seem to be the new trend in some areas, but there are no indications of an immediate halt in growth of salmon farming in Norway (FHL, 2010a). On the long-term there are different views on which factors will limit or constrain further growth. Most stakeholders believe that shortage of marine resources will not be the limiting factor of farming salmon in Norway. Main constraints are perceived to be the supply of good localities near shore, and whether or not it will be possible to conduct farming offshore in an economic sustainable way (BioMar, 2010a). The whole governmental framework can also limit growth. There are many concerns like disease and lice and the environment’s carrying capacity that influences the authorities perspective on aquaculture (Skretting, 2010a).

4.3 The aquafeed industry

Exploitation of marine resources has been practiced since the beginning of human’s existence. Fishing has evolved from satisfying basic needs for food (subsistence fishing) to an immense worldwide fleet of technological fishing vessels. In the course of time, trawls, purse-seiners and acoustic appliances (echo sounders) have been developed in order to locate fish. In 2006, landings from capture fisheries were 92 million tonnes (fish and shellfish) with a value of more than 91 billion USD (Tacon and Metian, 2009a). All marine organisms are however not perceived suitable for human consumption, and other uses of these respective resources have evolved as demonstrated by figure 4.11. Small pelagic species have been processed into fishmeal and fish oil since the beginning of the 20th century (Tacon and Metian, 2009a). About 90% of world fishmeal production is from oily fish species like mackerel, pilchard, menhaden and capelin (New, 1995). Total fishmeal production ranges between 5-7 million tonnes a year, while fish oil is stable around 1 million tonnes (FAO, 2009; Tacon and Metian, 2009a; EWOS, 2010b).

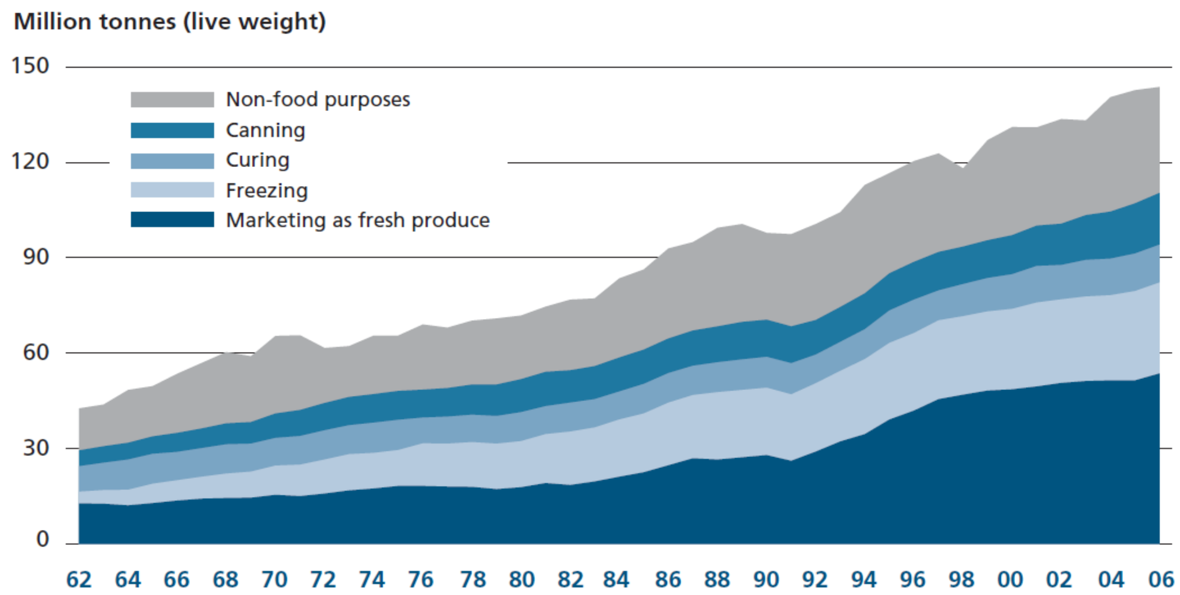

Figure 4.11: Different utilizations of world capture fisheries and aquaculture production (FAO, 2009).

4.3.1 Brief history

The fishmeal and fish oil industry in northern Europe and North America was originally based on oil production from surplus catches of herring from seasonal coastal fisheries (New, 1995). The waste product was used as fertilizer and later dried to fish meal and used as animal feed for poultry, pigs and fish (New, 1995). Fish oil was originally used as an ingredient in paints, lubricants, soaps, printing inks and the tanning of animal hides (Tacon and Metian, 2009a). Currently about 80% of globally produced fish oil is utilized in aqua-feed, while in the 1970s, 80% was used in hardeners (Jackson, 2010a). Total fish oil production in 2006 was 943,167 tonnes, and has recently been fluctuating between 0.85-1.67 million tonnes (Tacon and Metian, 2009a).

Production of fishmeal expanded from 2 million tonnes in 1960 to 5.46 million tonnes in 2006, as indicated by figure 4.12. Recent production have been varying between 4.5-7.5

million tonnes (Tacon and Metian, 2009a). Distribution of fishmeal has completely changed over time; in 1980, about 100% was used in agriculture, while this share decreased to 40% in 2008 (Jackson, 2010a). The main market for fishmeal today is the aquaculture industry.

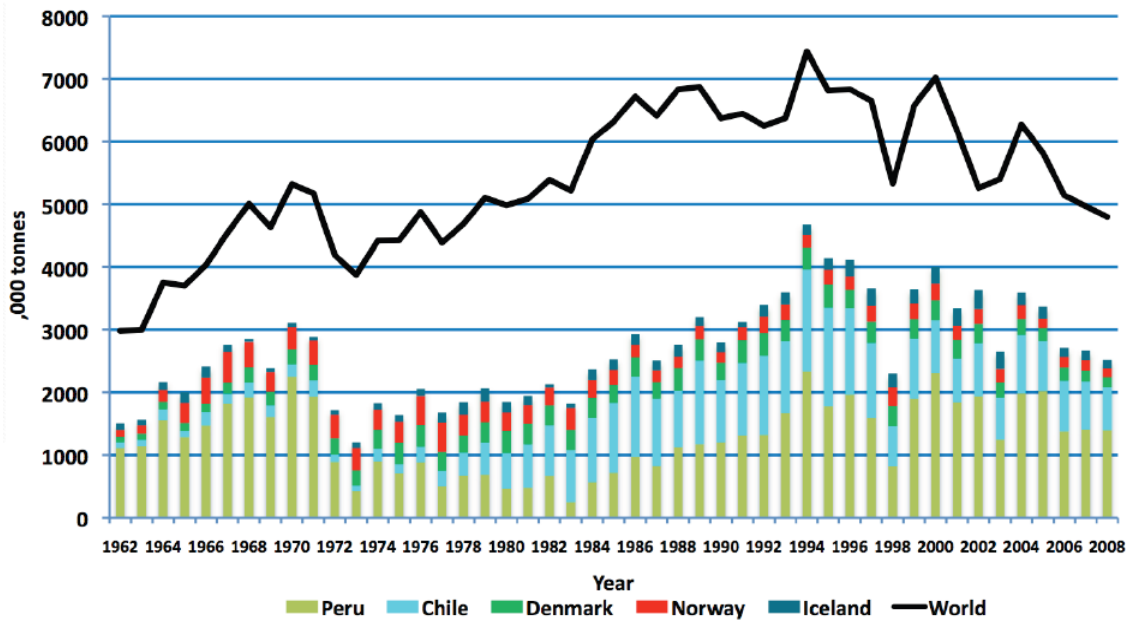

Figure 4.12: World fishmeal production 1962-2008 (Jackson, 2010b).

Feeding techniques and feed formulas have been evolving in parallel with the development of farming techniques in Norwegian aquaculture. The Grøntvedt brothers in 1969 fed their larger salmon capelin, trimmings and offal from shrimp (Johnsen and Lindal, 2006). Since then, the feed industry has developed from semi-moist and dry pelleted feed in the 1980s, to the production of high-energy extruded pelleted feeds in the 1990s and 2000s (Tacon and Metian, 2009a). The technology of making fishmeal and fish oil has however been fairly static since the 1960s (Pèron et al., 2010).

Salmon farming depends on a large range of input factors, and feed normally makes up the largest expense for a firm. Aquafeed is dependent on wild fisheries and the marine protein and fat generated from fish. Traditionally, salmon has been fed a diet dominated by marine raw materials. Fishmeal has made up 40-60% of the feed, while fish oil has had an inclusion level of about 20-30% (Gillund and Myhr, 2010). These resources have satisfied the nutritional requirements of salmon, while at the same time have provided high levels of omega-3.

Concerns have been raised about the stagnating global capture fisheries. A ceiling of about 90 million tonnes per year (Blanco et al., 2007) does not match the needs neither of the increasing human population nor of the growing aquaculture. Fishmeal has traditionally been the principal source of protein in the diet of farmed carnivorous fish and it represents the largest operating costs. This together with the industry's need for flexibility regarding feedstuff, has initiated the work of lowering the marine protein level in feed (Kousoulaki et al., 2008). Aquaculture is growing, while reduction fisheries are stagnating. This fact has made it even more evident that one has to find other, more sustainable protein sources, like soy, wheat and corn gluten. This problem will be further explored in chapter 6.

4.3.2 Compound aquafeed production in Norway

65% of total fishmeal production and 83% of total fish oil production is destined for global aquaculture, where Norwegian aquaculture industry employed 6.8% and 22% from the above in 2007 (FHL, 2009a). Production of fishmeal and fish oil in Norway makes up about 200,000 and 55,000 tonnes respectively. To satisfy demand from the aquaculture industry, about 200,000 tonnes of fishmeal are imported from Peru, Iceland and Denmark and about 17,000 tonnes of fish oil are imported from Denmark, Peru and Iceland (FHL, 2009a). Total aquafeed production in Norway was 1.18 million tonnes in 2008, while the share of imported aquafeed were 18,273 tonnes, as seen from figure 4.13 (FHL, 2010b). Norway is almost able to produce sufficient amounts of aquafeed to satisfy the national demand.

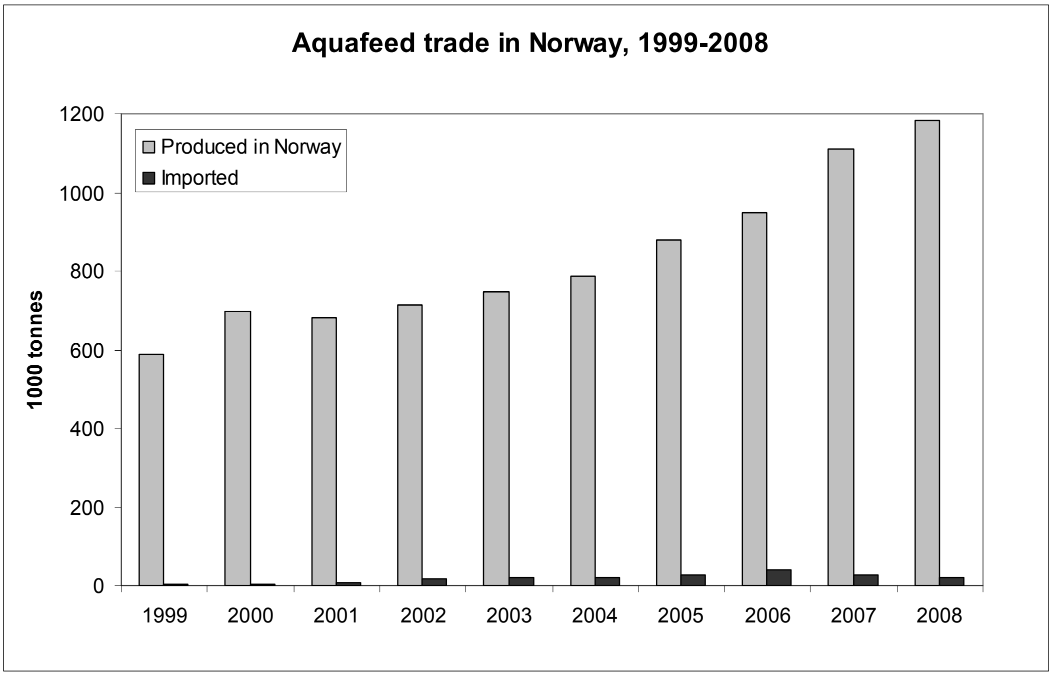

Figure 4.13: Aquafeed trade in the Norwegian market (FHL, 2010b).

There are three large producers of compound aquafeed in Norway: EWOS, Skretting and BioMar. EWOS was the largest company in 2009 with a production of 787,600 tonnes (Cermaq, 2010). Skretting came in second with a production of 539,535 tonnes (Skretting, 2010b), while BioMar produced about 300,000 tonnes (BioMar, 2010b). In addition, Polarfeed AS contributes with a smaller production of about 30,000 tonnes (Polarfeed, undated). All companies have in common that they specialize mainly in salmon feed, but a small extent of feed for other species is also produced.

The Norwegian Seafood Federation has identified the most common species utilized in fishmeal and fish oil production to be anchoveta, blue whiting, capelin, herring, sandeel and sprat (table 4.2). Nonetheless there are a number of other species that are sporadically included in the process, depending on market situations and availability (Skretting, 2010a).

Table 4.2: Composition of marine resources applied in aquafeed in recent years (adapted from FHL, 2009a; EWOS, 2010b; Helland, 2010; Skretting, 2010b).

Main species utilized by the Norwegian aquafeed industry, in percent			
Species	2007	2008	2009
Anchovy	22	23	43
Blue Whiting	27	21	7
Capelin	4	2	1
Herring	20	19	20
Sandeel	4	11	5
Sprat	9	6	5
Trimmings and other species*	14	18	19

*Trimmings are mostly from processing of herring. Other species refers to a wide variety of species included at a low level.

The above table is based on statistics from the three major aquafeed producers, and can be regarded as an overview. There are however individual differences[16] between the companies depending on purchase policies and sustainability objectives, for instance feed of unsatisfactory quality is recycled in Skretting's production (Skretting, 2010b). In general, there are common traits in the species composition, as can be observed in figure 4.14. Trimmings and other species make up a considerable share of the ingredients as seen from the graph, and the share of trimmings is believed to increase in future as more fish is destined for consumption (FHL, 2010a).

[16] Species utilized by the three companies are summarized in table 1 in the appendix.

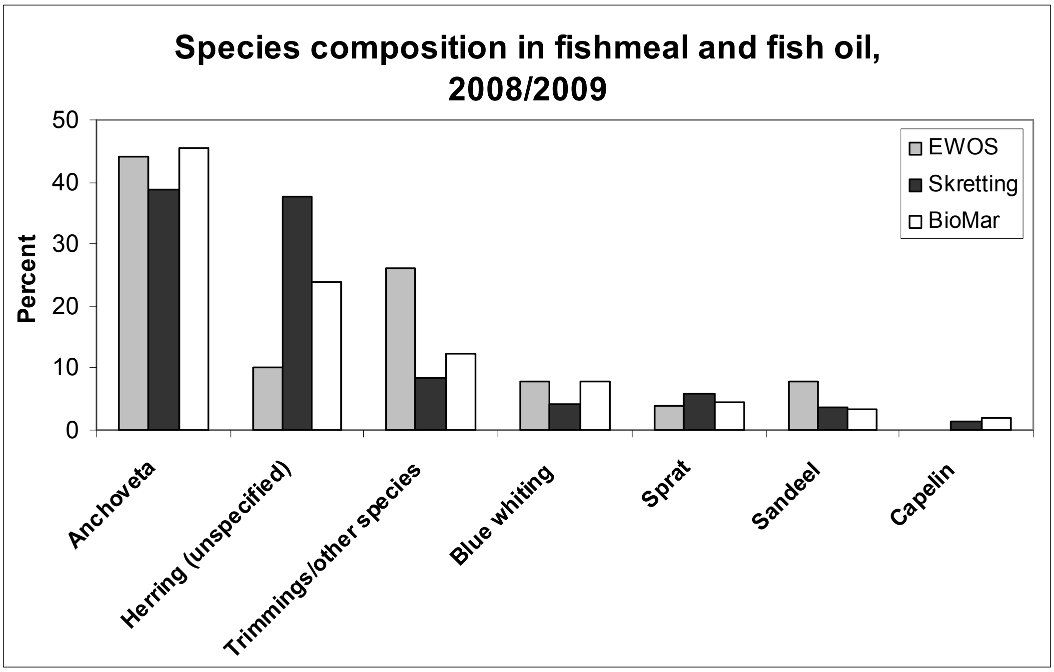

Figure 4.14: Main species in fishmeal and fish oil used by the three main Norwegian producers (adapted from EWOS, 2010b; Helland, 2010; Skretting, 2010b).

4.4 Summary

Norwegian salmon farming has been an exceptional success story with production increasing from 46 tonnes in 1972 to 859,056 tonnes in 2009 (Knapp et al., 2007; Directorate of Fisheries, 2010a).

The structure of the industry has gone through remarkable changes since the start in 1969. What started out as a measure to sustain rural areas has been transformed to one of the most profitable industries in the country. Farms have changed from many and small to larger and fewer. The number of companies has decreased, and it is common to be vertically integrated with control over several of the production stages. Benefits from big-scale operations and a more industrial structure are now characterizing the salmon farming industry. The aquafeed industry has on the other hand not experienced equal dramatic changes, and has had an industrial structure for a long time. Even though the aquaculture industry in Norway is a success story in terms of production and profitability, there are several challenges associated with the operations. One of the challenges is related to the marine resources utilized by the aquafeed industry and is the topic for this study. In the next chapter, I have addressed the management of the forage fish to determine whether management and harvest is sustainable. I have also highlighted the issue of forage fish being a possible source of animal protein for the world's poor.

Chapter 5: Forage fish – status, management and use of catches

Sustaining physical resources is according to Langhelle (2000) the proviso of sustainability, or in other words, the minimum requirement for development. Three aspects of sustainability are covered in this study. Two of them will be addressed in this chapter, namely sustainable management and harvest, and whether destination of catches (food or feed) is deemed sustainable. Species used for fishmeal and fish oil are so-called forage fish, which are characterized by being short-lived, small and fast growing (Fréon et al., 2005). Such species are in general pelagic[17] and move in large schools. Forage fish are not that prone to overfishing as for instance benthic fish because of their short lifespan and population doubling time (Shepherd et al., 2005). Forage fish are in general not perceived suitable for human consumption because they are small, bony, soft, fragile, prone to rancidity and spoil easily[18] (James, 1995). However, there is potential for some of the species to be destined for consumption markets. In most cases it is not economically sustainable with processing because forage fish calls for rapid handling and processing which requires heavy infrastructure (James, 1995). This is the second aspect of sustainability and will be discussed in the end of the chapter.

From the previous chapter, the most common species employed in Norwegian salmon feed were established to be: anchoveta - *Engraulis ringens*, blue whiting - *Micromesistius poutassou,* capelin - *Mallotus villosus,* herring - *Clupea harengus*, sandeel - *Ammodytes spp.* and sprat - *Sprattus sprattus*. On a global basis, these are also quite common, as seen from table 5.1.

Table 5.1: Common families of fish utilized by the global fishmeal and fish oil industry (adapted from Peron et al. 2010).

Main families of small pelagics used in the global fishmeal and fish oil industry	
Family	Main Species
Engraulidae	Anchoveta
Clupeidae	Menhaden, European sprat, herring, sardine
Gadidae	Blue whiting, Norway pout
Ammodytidae	Sandeels
Osmeridae	Capelin
Scombridae	Mackerel
Caranguidae	Horse mackerel, jack mackerel

[17] Sandeel has hibernation periods and hides from predators in the sand. Sandeel is harvested with trawls.
[18] Enzymes present in the fish and content in the gut can lead to the belly bursting, thus deteriorating the quality of the resource.

Five of these species are harvested in the Northeast Atlantic, where 71-80% of all fish stocks are fully exploited. This is the highest proportion on a global basis (FAO, 2009). The anchoveta stock is harvested outside Peru and is also defined as fully exploited (FAO, 2009; Tacon and Metian, 2009a). A fully exploited fish stock is not necessarily undesirable, provided it is the result of an effective and precautionary management regime (FAO, 2009). However, a more cautious and closely controlled approach to development and management is still a necessity and is of larger importance at present, because capture fisheries on a global scale have stagnated around 90 million tonnes (FAO, 2009). Forage fish destined for fishmeal and fish oil processing represent 20-30% of total fish landings (Pèron et al., 2010).

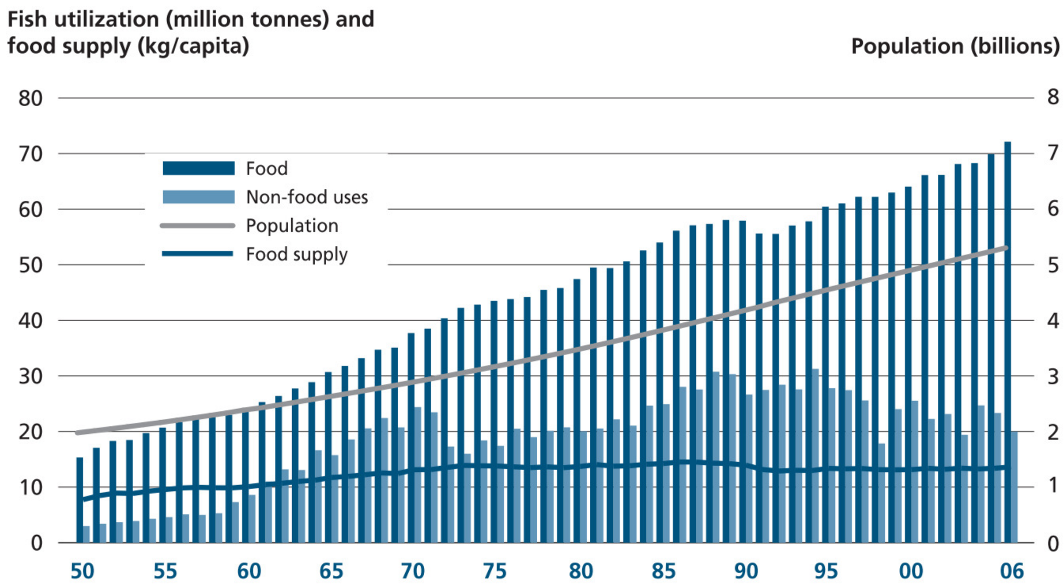

Figure 5.1: Fish utilization and global food supply 1950-2006, excluding China (FAO, 2009).

Most exploited fish stocks have stagnated and some are decreasing and need time to recover. This is a negative development and a reality that needs to be tackled in a world where total seafood consumption is increasing. An immediate consequence is that more of the world catches will be destined for human consumption with increasing prices. This will again have effects for industrial purposes like the production of fishmeal and fish oil (Ellingsen and Aanondsen, 2006). Figure 5.1 demonstrates that catches destined for non-food uses reached its peak in 1994, and has been decreasing since (FAO, 2009).

5.1 Management[19] and stock status

All fisheries in the North East Atlantic are subject to total allowable catch quotas (TAC), and other management measures such as closed areas, catch limitations in certain areas, seasonal bans, by-catch limits, gear restrictions, minimum mesh size and minimum landing size (Shepherd et al., 2005).

The anchoveta fishery in Peru is the largest single-species fishery in the world (Frèon et al., 2008), with average landings of more than 5 million tonnes annually. In the early 1970s, the stock collapsed due to El Niño[20] and heavy fishing pressure, but the stock has recovered since. Today, the fishery is regulated through seasonal quotas, but it is argued by Frèon et al. (2008) that in practical terms access to the fishery is open for all (open-access).

Certain tools are needed to assess the state of a stock: A target reference point (TRP) is representing management objectives and designates the optimal position for a stock. TRPs can be defined in terms of stock size or other relevant parameters (King, 2007). Similarly, a limit reference point (LRP) is a defined threshold or a minimum value, and indicates an unfavorable position for the fish stock in question (King, 2007). After a management objective has been translated into a TRP, and a LRP has been established, an indicator is needed for monitoring and evaluation of the fish stock.

For this thesis I have chosen to operate with reference points and indicators referring directly to the state of the stock: B_{lim} is the lowest acceptable spawning stock biomass (SSB) level, and B_{pa} is the spawning stock biomass set as a target under the precautionary approach. SSB is the indicator assessing the health of the stock. The health of the stock is measured with the sustainability scale presented in chapter 2, and degrees of sustainability are determined accordingly.

The respective stocks are managed sustainably if harvest rules are set according to scientific advice and management is in accordance with the assessment tree. This implies that there are two separate ways of perceiving sustainability of forage fisheries: A quantitative measure of the health of the stocks and a qualitative measure of management.

Due to non-existing indicators of a socio-economic character, biological parameters are applied in this study. I will argue that these are sufficient for the purpose of this study, as they are in agreement with the proviso of sustainability (Langhelle, 2000). Nevertheless, the sustainability concept is concerned with socio-economic as well as biological aspects and

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[19] I have operated with the current management advice at the time of writing the thesis. Advices have been updated on a continuous basis.

[20] El Niño is a climatic phenomenon leading to unfavorable conditions for the anchoveta (Freon et al., 2005).

should therefore be included. Due to limited time, the framework for assessing the forage fish stocks is purely biological, but for later studies, socio-economic indicators and parameters should be developed and incorporated. It is important that this delimitation is considered when discussing the results.

5.1.1 Anchoveta - *Engraulis ringens*

The anchoveta fishery is the largest in the world with catches varying between 1.7 million tonnes in 1998, to a maximum of about 10 million tonnes in 2000 (PRODUCE, 2009). The fishery is of large national importance as the anchoveta makes up about 90% of the total Peruvian catches (Durand and Seminario, 2009). The stock is prone to environmental variations; especially the El Niño Southern Oscillation (ENSO) affects spawning in summer and has caused large variations in stock abundance (IMARPE, 2009). Great fluctuations in stock size are illustrated by figure 5.2, and as seen from the figure, the decrease in biomass in 1992 and 1997 was the result of an El Niño period. A phase of rapid growth follows the ENSO periods, and the stock was "back to normal" in 2001 (Durand and Seminario, 2009). The stock is deemed to be fully exploited and overexploited in periods by FAO (FAO, 2009). IMARPE on the other hand states that the condition of the stock is satisfactory, and that a fishing mortality (F) of 0.4 is sustainable (IMARPE, 2009).

At present, the management goal is to maintain the spawning biomass above 5 million tonnes at the onset of each spawning period (August and February) (Frèon et al., 2008). There are no official reference points presently established for the stock (Sustainable Fisheries Partnership, 2009). However, for the purpose of this study, I have chosen to utilize the management objective as a limit reference point, B_{lim}. In this way, it will be possible to assess the stock according to the sustainability scale. Freon et al. (2005) argue that such steady state management is not suitable for highly variable resources like pelagic fish. These stocks do not fulfill the assumptions of the models, and the reference points applied are therefore erroneous (Fréon et al., 2005). Adaptive management is more suitable due to the regular monitoring limiting the risk of overexploitation. This regime has been implemented for the Peruvian anchoveta, and quotas are set accordingly (Frèon et al., 2008). Two or three surveys are conducted each year for abundance estimations of both the anchoveta and its predators, and if abundance is low, the commercial fleet performs a real time 48 hours estimation (IRD/IMARPE, undated). Other tools like plankton and egg surveys are also utilized in deciding quotas.

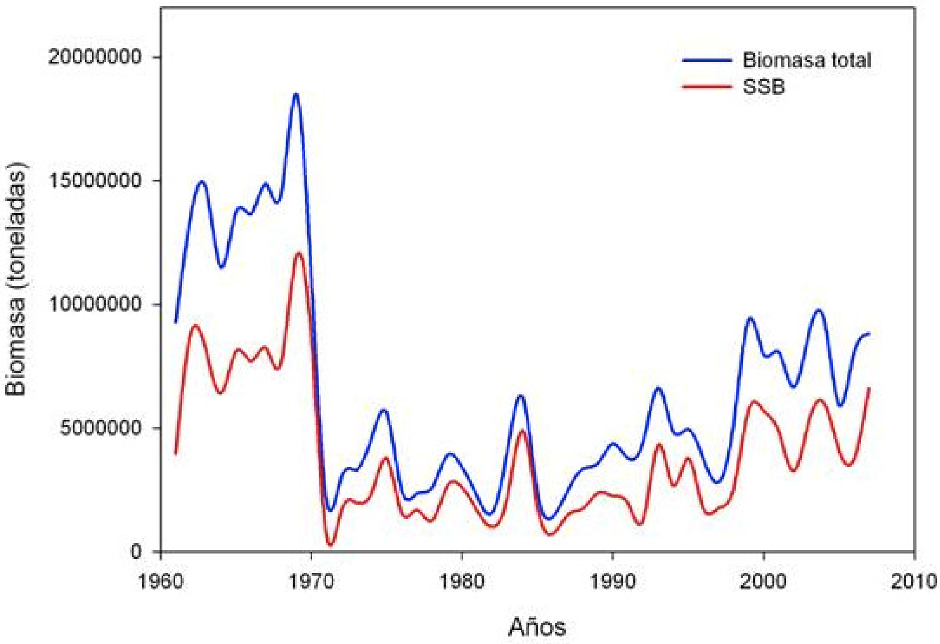

Figure 5.2: Total biomass and spawning stock biomass of the Peruvian anchoveta 1960-2010 (Oliveros-Ramos et al., 2010).

Quotas are set prior to the fishing periods, and for the first period in 2010, 2 million tonnes were allocated (IMARPE, 2009). No continuous information of set quota, nor advice, for the last ten years has been obtainable online. Recent catches illustrated by figure 5.3, are available online (PRODUCE, 2009), but differs greatly from the statistics provided by FAO (FAO, 2010a).

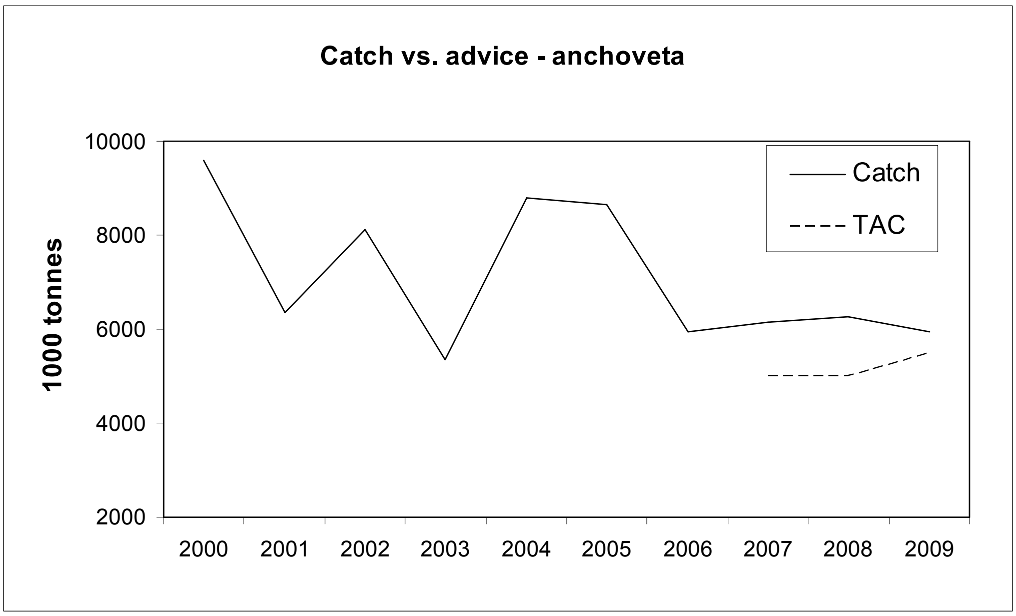

Figure 5.3: Catch of anchoveta 2000-2009 with TAC from 2007 (PRODUCE, 2009).

Finding recent information about the Peruvian anchoveta has proved difficult, and the methodology used for this particular stock is therefore different from the North Atlantic species. Information about the SSB for the last ten years (2000-2009) is inadequate as indicated by figure 5.4.

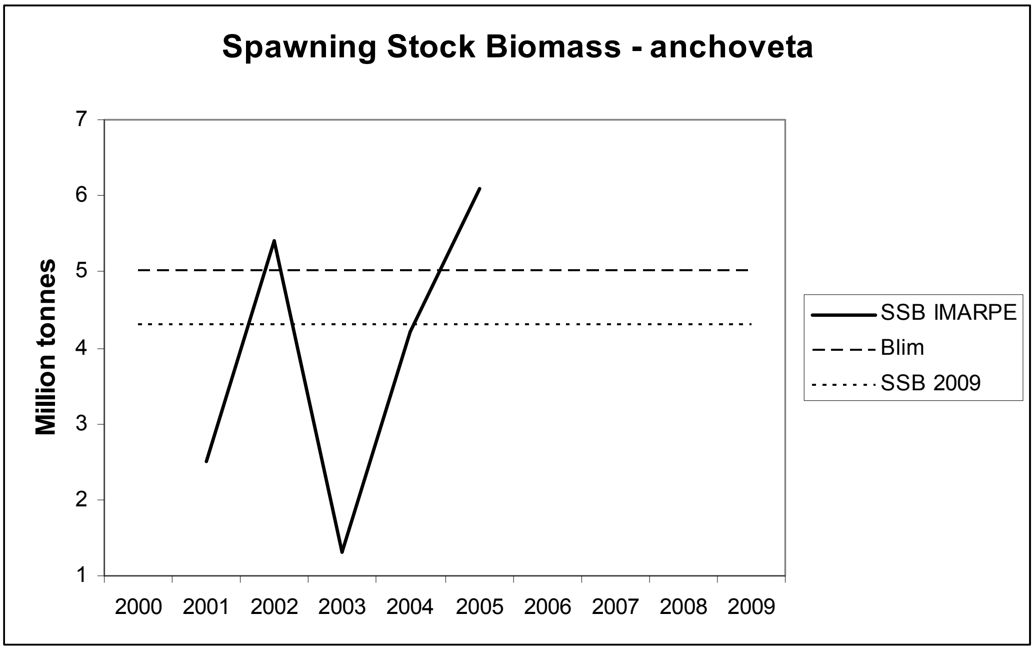

Figure 5.4: Spawning stock biomass, anchoveta 2000-2009 (adapted from IMARPE, undated-a; IMARPE, undated-b; IMARPE, 2001; IMARPE, 2004; IMARPE, 2009).

Conclusion: The anchoveta scores 2/10 on the sustainability scale, the years where information about SSB is lacking are given a score of zero. According to the assessment tree, I will argue that improvements have been made in terms of a more holistic management. Effort applied in the fishery has been decreasing (Paredes, 2010), which implies that the resource base will experience less pressure in the future. Peru has attempted to apply the ecosystem approach (Frèon et al., 2008) which is positive. The adaptive management regime is comprehensive, but corruption in the fisheries and in processing is occurring, which is a source of bias for the whole sector. Data collected from The Ministry of Production and IMARPE's web pages also differ from other sources[21], which makes assessment difficult. Information regarding quota advice is also lacking, with information only about the years 2007-2009. Overall, assessing the sustainability of the management regime is difficult due to inadequate information about several aspects.

[21] Cahuin, S.M et al. (2009) Climatic regimes and the recruitment rate of anchoveta, Engraulis ringens, off Peru. In addition to statistics provided by FAO; http://www.fao.org/fishery/species/2917/en

5.1.2 Blue whiting – *Micromesistius poutassou*

The blue whiting fishery is a fairly new fishery that developed in the 1970s, and it was not until 2006 that a proper management regime was imposed on the fishery (Ministry of Fisheries and Coastal Affairs, 2010a). The participating states conducted what has later been termed an "Olympic fishery" to secure fishing rights prior to implementation of the TAC. Today, the TAC has been set in accordance with the ICES' advice at 540,000 tonnes for 2010 (IMR, 2010). In previous years the TAC has been higher than the advice from ICES. For instance in 2009, the actual TAC was 590,000 tonnes, but the advice was less than 384,000 tonnes (ICES, 2009a; IMR, 2009). The ten last years of catch and advice by ICES are compared in figure 5.5 and it is evident that there has been a large gap between advice and actual catch. For 2011, the quota has been significantly reduced to 40,100 tonnes (Jensen, 2010a).

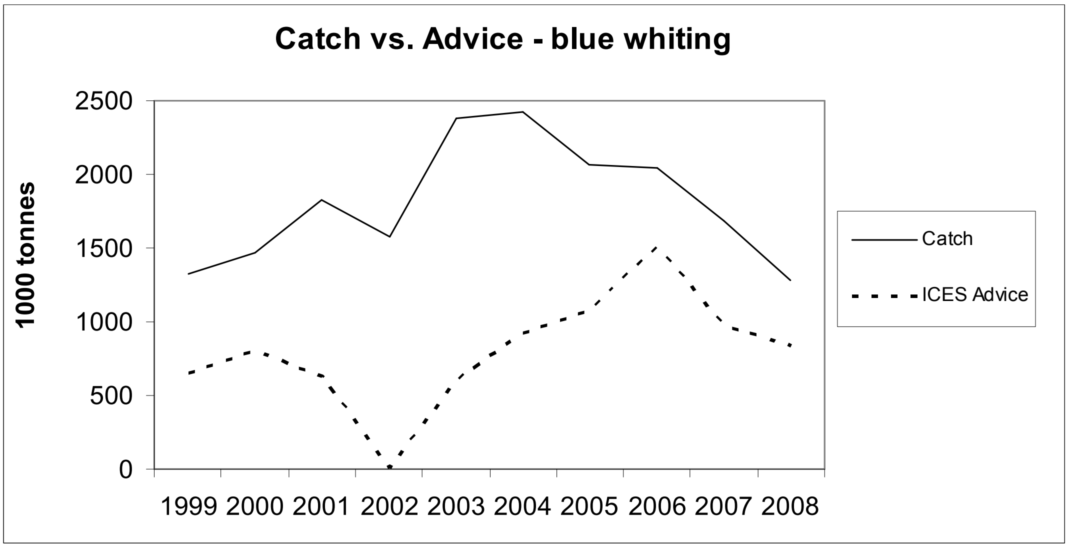

Figure 5.5: Total catch of blue whiting compared with ICES advice 1999-2008 (adapted from ICES, 2008b; FAO, 2010b).

Development of the spawning stock biomass in figure 5.6, shows an evident decrease after its peak in 2003-2004. FAO (2009) claims that the blue whiting is fully exploited, and it is stated by ICES (2009a) that fishing mortality is above target, and that the stock is overfished in a long-term perspective. According to IMR (2009), the stock is also experiencing low recruitment and is comprised mostly of adult fish.

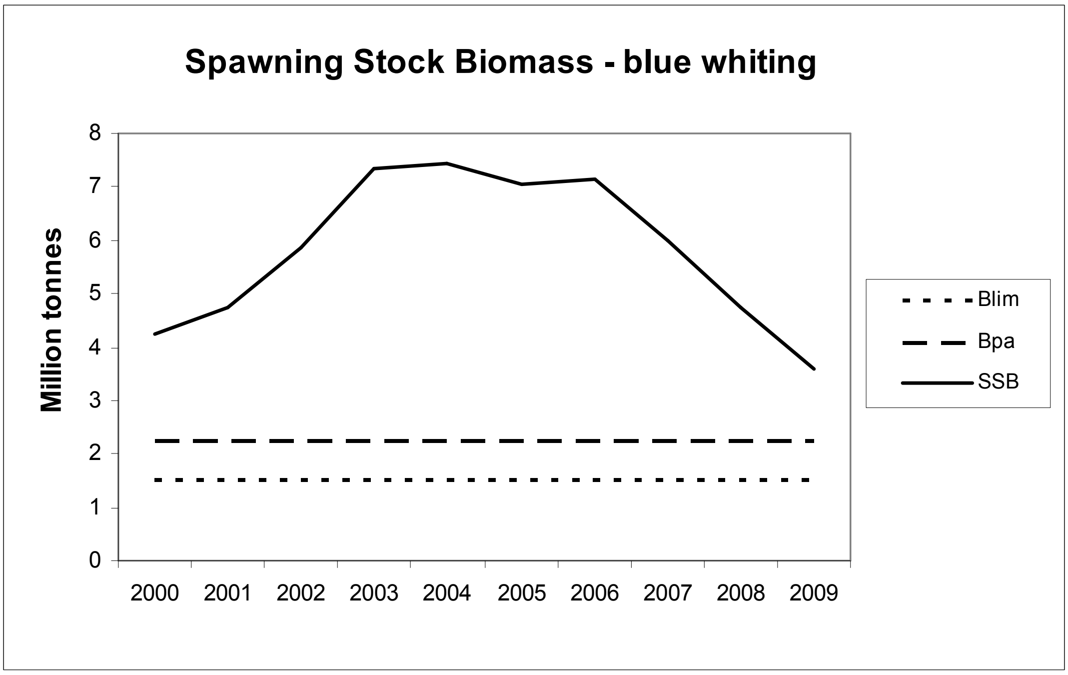

Figure 5.6: Blue whiting Spawning Stock Biomass 2000-2009 (adapted from ICES, 2009a).

Conclusion: Based on the last ten years, the stock is above B_{lim}, with a 10/10 score on the sustainability scale. The trend is however a clear decrease in SSB and the 2011 quota for blue whiting is dramatically reduced from previous years (Jensen, 2010a). This might be the result of ignoring harvest advice and higher catches than what seems appropriate by ICES. The stock was not subject to a management plan until 2006, and is therefore not managed sustainably according to the assessment tree.

5.1.3 Barents Sea capelin – *Mallotus villosus*

The Barents Sea capelin fishery is shared between Norway (60% of the quota) and Russia (40% of the quota) (IMR, 2009). There have been three recorded collapses of the Barents Sea capelin since the assessments began in 1972 (IMR, 2009). Norwegian spring spawning herring (NSSH) feed on capelin, and the large cohorts of NSSH in 1983, 1998-1999, 2002 and 2004 caused the collapses of the Barents Sea capelin (IMR, 2009). 2009 was the first year since 2003, with a commercial fishery on Barents Sea capelin, see figure 5.7 (IMR, 2009).

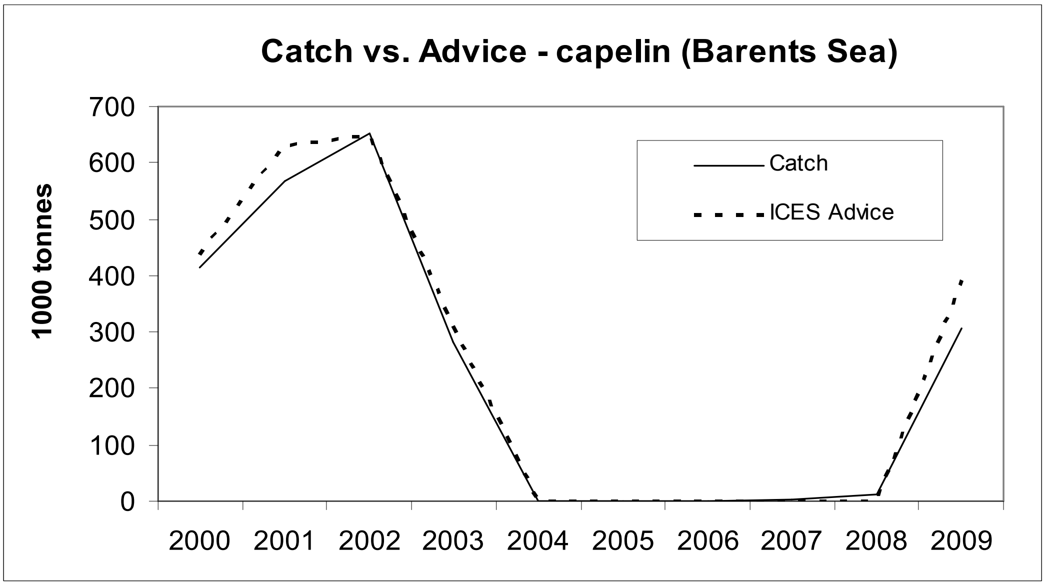

Figure 5.7: Total catch of Barents Sea capelin with ICES advice the recent ten years (adapted from ICES, 2009c).

A TAC of 390,000 tonnes in 2009, is in accordance with the precautionary principle (ICES, 2009c). Spawning stock biomass in the end of 2009 was left at 517,000 tonnes (figure 5.8), well above the B_{lim} of 200,000 tonnes (ICES, 2008d). Catches in 2009 were lower than the TAC (306,000 tonnes) and SSB in 2010 is therefore believed to increase further (IMR, 2009).

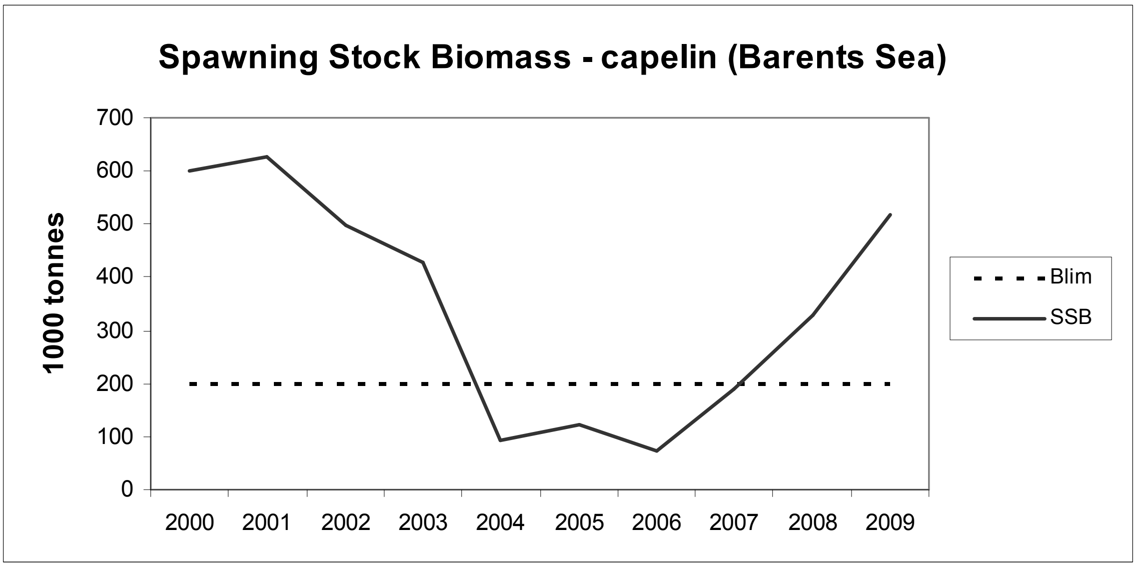

Figure 5.8: Spawning stock biomass of the capelin Barents stock 2000-2009 (adapted from ICES, 2009c).

Conclusion: The Barents Sea capelin SSB, has been below B_{lim} for four years, and the stock therefore scores 6/10, which is moderately sustainable on the sustainability scale. The stock has suffered from predation pressure and limited fishing has therefore been undertaken. However, in the few periods of fishing, the TAC has been set relatively similar to the advice, with the exception of 1992 when the TAC was set 266,000 tonnes higher than the advice (ICES, 2009c). This is outside the timeframe of this study, and I conclude that the TAC has been following the advice the last ten years. The capelin in the Barents Sea is not managed sustainably due to a lacking precautionary biomass level (insufficient information). The management regime is therefore not considered sustainable on the basis of the criteria applied in this study.

5.1.4 Icelandic capelin - *Mallotus villosus*

Harvests of Icelandic capelin is mainly performed by Icelanders who are responsible for 78% of the quota, Norway in comparison holds 11% of the quota (Matthìasson, 2003), which made up 28,431 tonnes in 2010 (ICES, 2009d; ICES, 2010b). In 2008, it was impossible to estimate spawning stock biomass and abundance of juveniles, but it is known that the 2006 cohort was weak. ICES advised that the fishery should be closed, but actual catches were 15,100 tonnes in 2008/2009[22], as seen from figure 5.9.

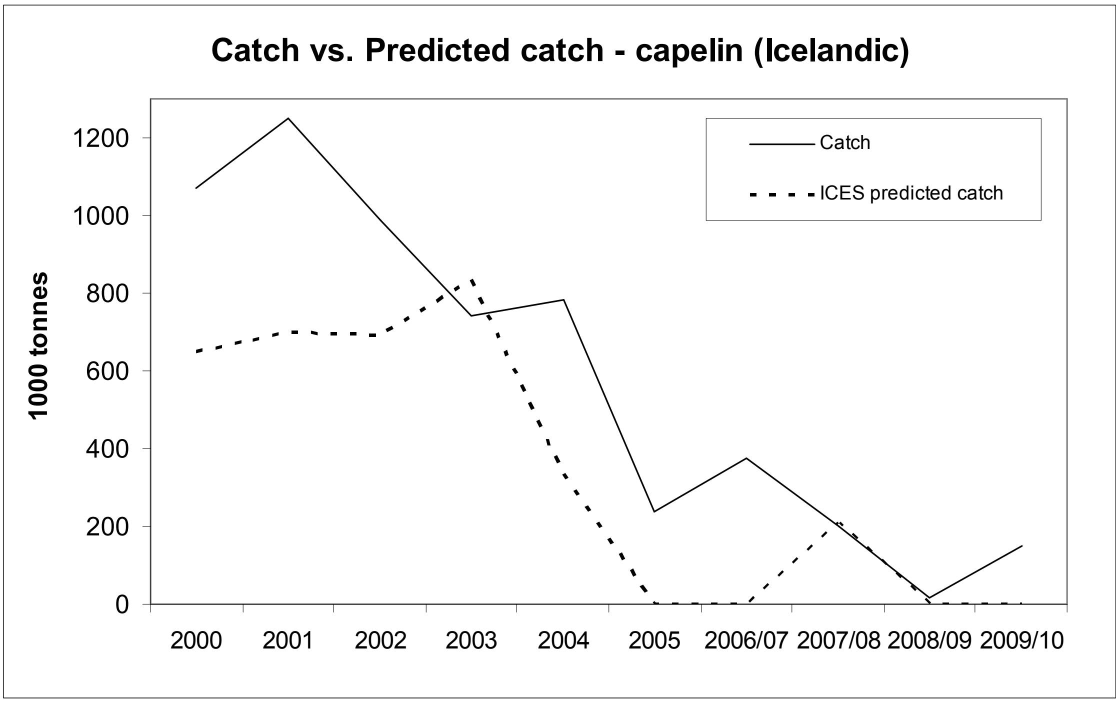

Figure 5.9: Total catch of Icelandic capelin the last ten years compared to the ICES predicted catch corresponding to advice (adapted from ICES, 2010b).

[22] Norwegian vessels did not take part in the 2008/2009 fishery and were complying with the regulations.

The management objective for the Icelandic capelin is to maintain a spawning stock at 400,000 tonnes, which was successful until the start of the 2009 season, see figure 5.10. However, ICES advised that the fishery should have been closed from 2005, but TACs were established until the 2007/2008 fishing season (ICES, 2009d). Assessments by Icelandic scientists in January 2010 provided positive results with a SSB of 530,000 tonnes, which resulted in a total quota of 130,000 tonnes, where Norway holds a share of 28,431 tonnes (IMR, 2010).

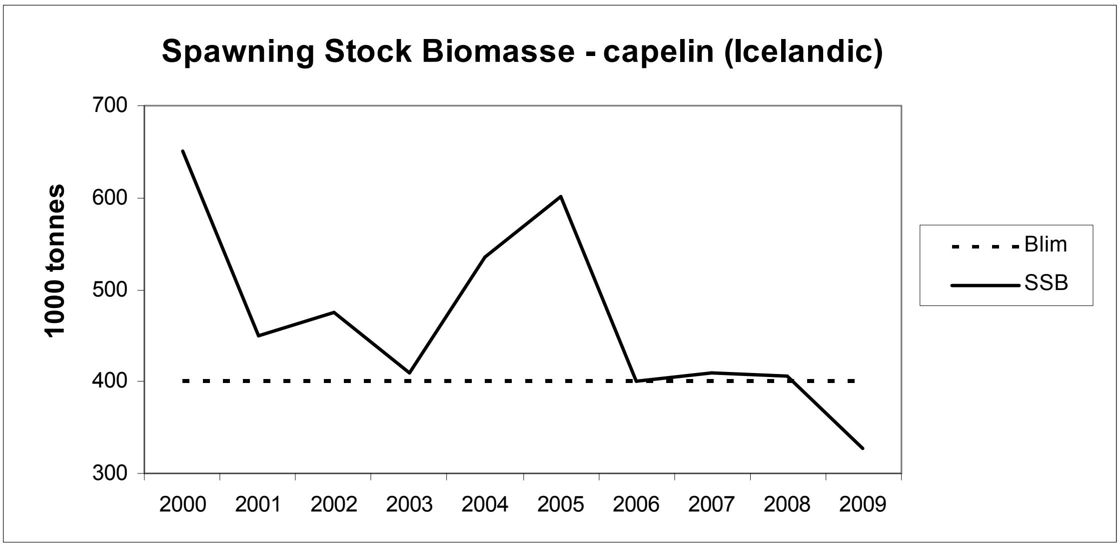

Figure 5.10: Spawning stock biomass of Icelandic capelin 2000-2009 (adapted from ICES, 2009d).

Conclusion: The Icelandic capelin scores 9/10, which is deemed sustainable. Even though the present fishing mortality seems appropriate for staying above 400,000 tonnes (ICES, 2009d), the spawning stock biomass seems at risk of falling below the B_{lim}. Additionally, precautionary reference points for the stock does not exist and the state of the stock has therefore not been evaluated (ICES, 2009d). The stock is not deemed to be sustainably managed according to the assessment tree in chapter 2.

5.1.5 Norwegian spring spawning herring (NSSH) – *Clupea harengus* L.

The NSSH is a valuable resource shared by Norway (61%), Iceland (14.5%), Russia (12.8%), EU (6.5%) and the Faroe Islands (5.1%) (IMR, 2009). NSSH biomass has not been this large since the 1950s, and that is believed to be the result of a comprehensive and effective management plan (IMR, 2009). A large biomass facilitates large revenues, and catches have been larger than a million tonnes since 2007 (figure 5.11) (ICES, 2009a).

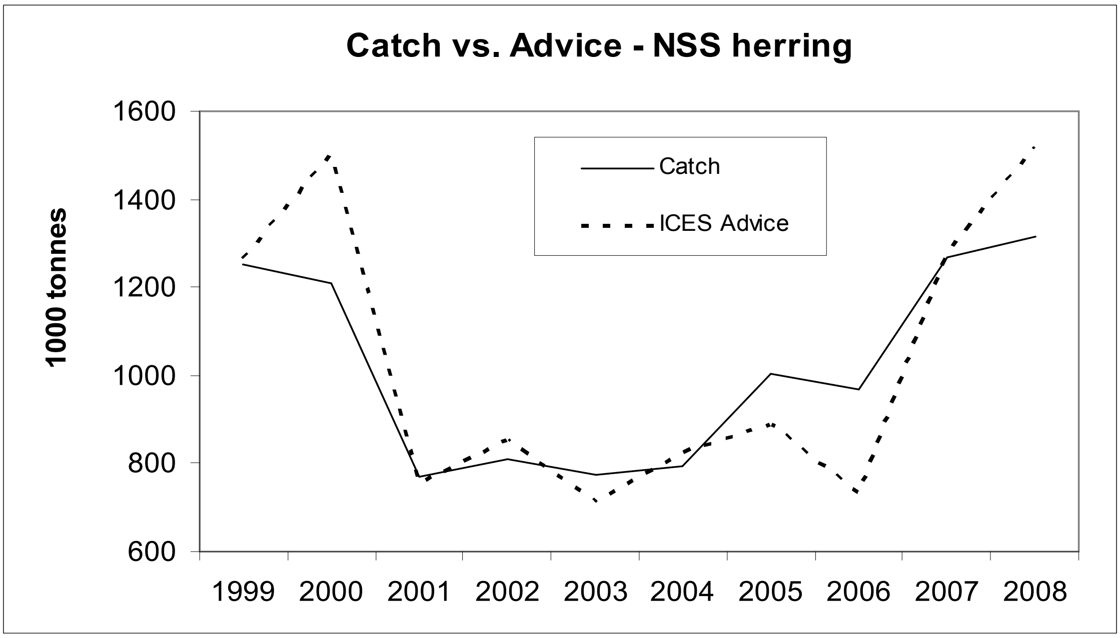

Figure 5.11: Total catch of NSSH compared to ICES advice the last ten years (adapted from ICES, 2009a).

The management plan for the NSSH is well developed with B_{lim} of 2.5 million tonnes and B_{pa} of 5 million tonnes. If the precautionary reference point is reached, an action plan is in place to ensure that the stock level does not decrease to the limit reference point (ICES, 2009a). This is in accordance with the precautionary approach, and from figure 5.12 it is evident that the SSB level is currently well above the reference points.

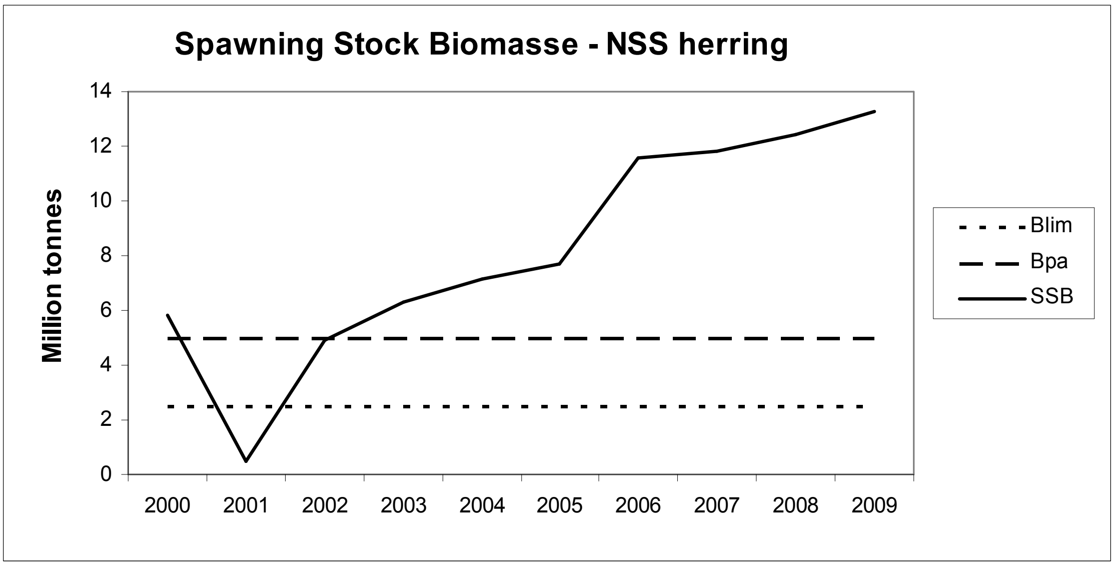

Figure 5.12: NSSH spawning stock biomass 2000-2009 (adapted from ICES, 2009a).

ICES consider the stock to be in a very good condition with full reproductive capacity. However the stock is believed to decrease in the coming years due to weak cohorts after 2004 (ICES, 2009a). NSSH is according to ICES (2009a) classified as being harvested sustainably.

Conclusion: The NSSH scores 9/10 on the sustainability scale. In relation to the assessment tree, the NSSH stock is at present the best-managed stock relative to this study.

5.1.6 North Sea herring – *Clupea harengus* (autumn spawners)

In 2008, the autumn spawning herring stock in the North Sea was at risk of not being harvested sustainably, and the stock was experiencing reduced reproductive capacity and a spawning stock biomass below precautionary levels (ICES, 2008c; IMR, 2009). A new revised management plan agreed upon by the EU and Norway has improved the situation, and the stock was, as of June 2010, considered to be harvested on a sustainable basis (ICES, 2010a; IMR, 2010).

The spawning stock biomass was at its peak in 2004, as illustrated by figure 5.13, with the largest landings the following year (within the ten year timeframe). The harvest rule was a fishing mortality of adults and juveniles set according to the precautionary principle. However, the SSB continued to decrease, and in 2007, ICES stated that SSB must increase to levels above B_{pa} (ICES, 2010a).

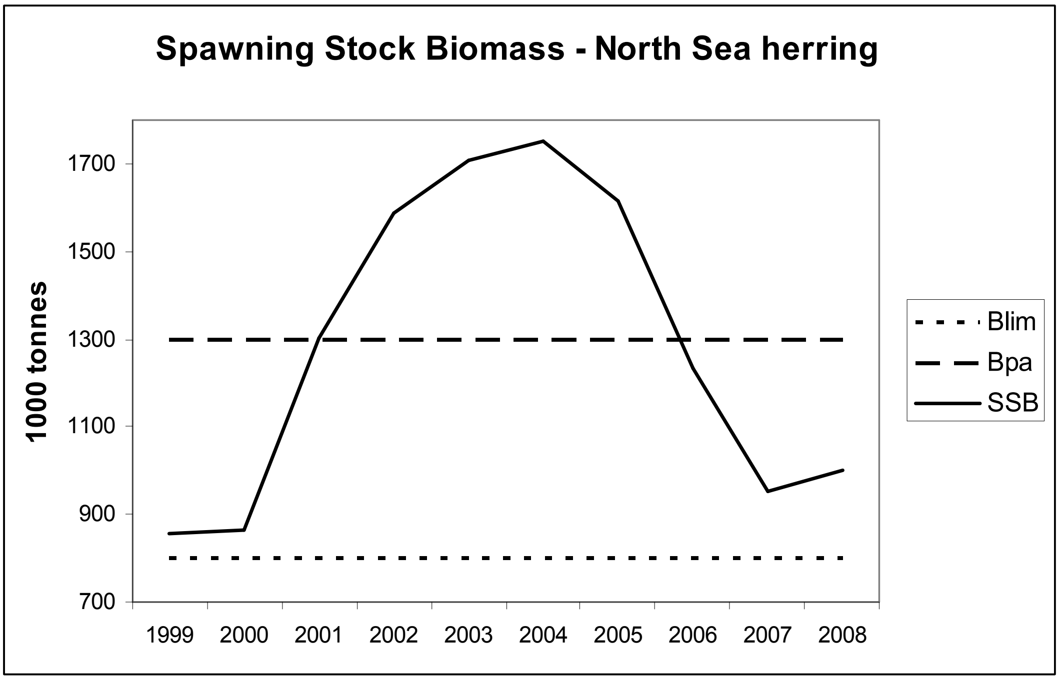

Figure 5.13: North Sea herring, spawning stock biomass 1999-2008 (adapted from ICES, 2009b).

Harvest rules are based on scenarios, which makes it difficult to illustrate catch compared with advice, the same way as the preceding stocks.

Conclusion: The SSB is above B_{lim} the whole period and scores 10/10, as the only stock with full score, on the sustainability scale. In despite of this, the stock was not managed according to precautionary principles prior to the establishment of the new management plan. The revised management plan was implemented late in 2008 (IMR, 2010). According to the assessment tree, the stock has therefore not been managed sustainably until this year.

5.1.7 Sandeel – *Ammodytes spp.*

The health of the sandeel stocks is currently of concern and has led to discussions surrounding the management regime. The Institute of Marine Research (IMR) has questioned ICES after stating that the conditions of the stock was promising and within safe biological boundaries, while local populations were in reality overfished and depleted (Johannessen, 2010; Lindbæk, 2010). A trial fishery with TAC 20,000 tonnes has been performed in the Norwegian Exclusive Economic Zone (EEZ) in 2010. The results from this trial fishery and acoustic assessments demonstrate that the state of the sandeel stocks in the North Sea has in fact improved since 2009, both regarding abundance and distribution. Still, it is emphasized that the stock continues to be under regeneration and locally depleted stocks must be given the opportunity to build up local sustainable spawning stocks. Therefore a quota of 30,000 tonnes to be harvested on certain areas is implemented for 2010, totaling 50,000 tonnes of sandeel (Johannessen and Johnsen, 2010).

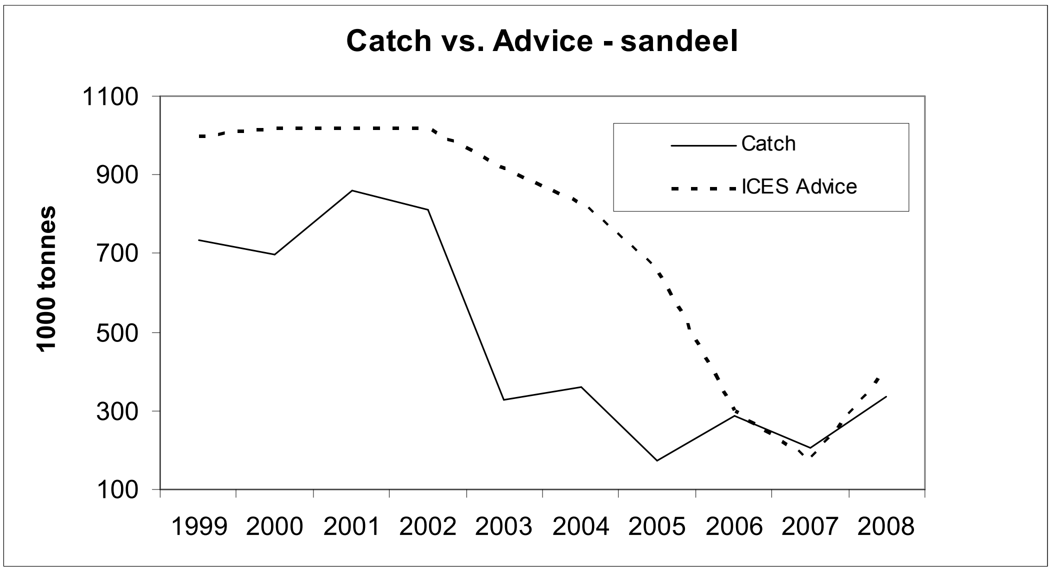

Figure 5.14: Total catch of sandeel compared to ICES advice 1999-2008 (adapted from ICES, 2008c).

The above graph is illustrating a different situation than the rest of the species; the catches are actually below what is advised by ICES. In 2006, ICES advised a closed fishery until the SSB reached B_{pa} (ICES, 2009b). In the period 1999-2008, the SSB was at its peak in 2000 with about 463,992 tonnes, as seen from figure 5.15, just above the limit reference point, B_{lim}, set at 430,000 tonnes (ICES, 2009b). The stock decreased until 2007 when the stock level almost doubled from the year before. ICES also that information about fishing mortality, F, is lacking, and therefore the state of the stock cannot be evaluated with regard to sustainable management (ICES, 2009b).

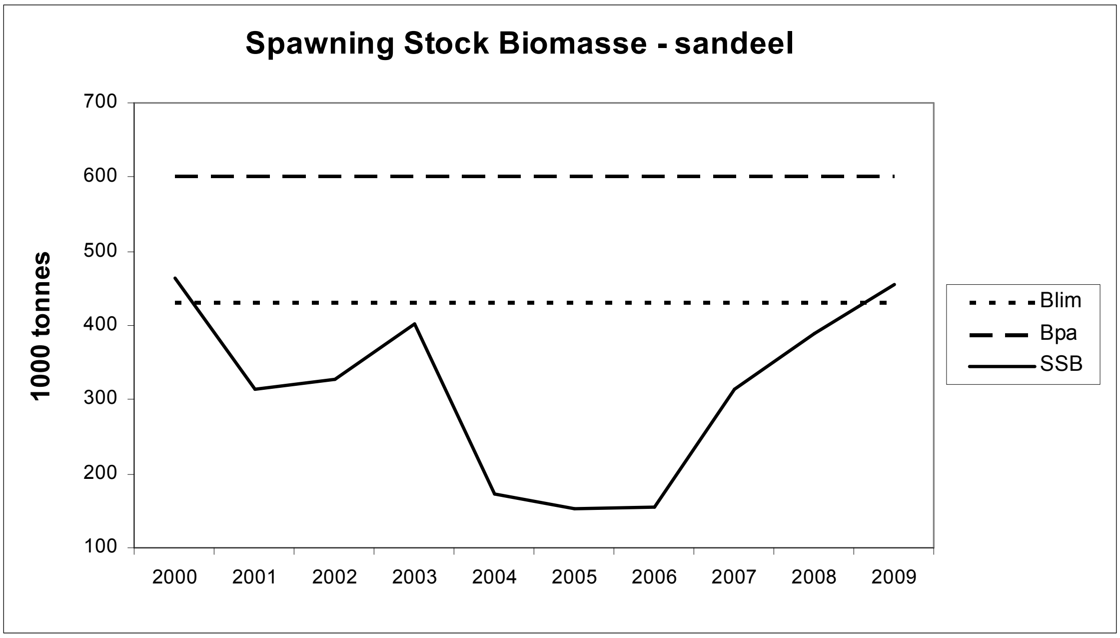

Figure 5.15: Sandeel spawning stock biomass 2000-2009 (adapted from ICES, 2009b).

There was no fishing in the Norwegian EEZ in 2009 (IMR, 2010). A new area-based management plan is to be implemented by 2011 (Ministry of Fisheries and Coastal Affairs, 2009a). In this plan it will be ensured that local stocks will be sustained at a level where spawning will be successful.

Conclusion: The stock is not considered to be sustainable due to a SSB level lower than B_{lim} in most of the ten-year period. With a score of 2/10 the sandeel has the lowest in this study, where information is available for assessment. Based on insecurity regarding current management and the implementation of the new management plan in 2011, the stock is not deemed to be sustainably managed.

5.1.8 North Sea sprat – *Sprattus sprattus*

There are two populations of sprat relevant for this study: the North Sea sprat and the Skagerak/Kattegat sprat. These populations are managed differently, but have in common that too little information is available about stock status (ICES, 2009b). There is no management objective for this stock, reference points are not established, and ICES has not sufficient information to give advice. ICES has, however, made catch predictions, but they are not of significant value for the purpose of this study. Recent catches can be seen from figure 5.16.

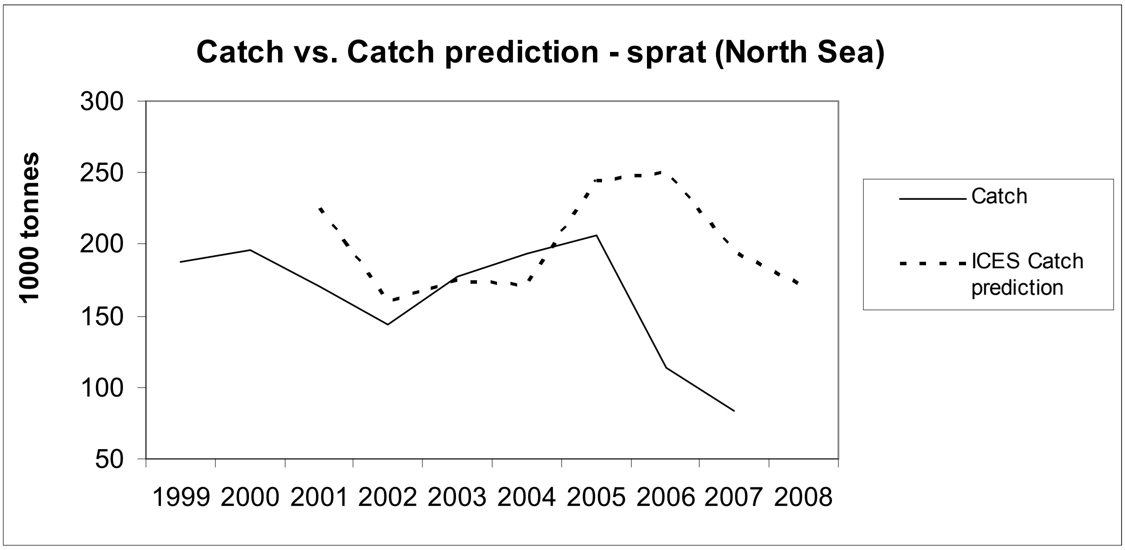

Figure 5.16: North Sea sprat, total catch compared to ICES catch prediction 1999-2008 (adapted from ICES, 2008c).

Conclusions: There is no information regarding SSB and the stock scores 0/10 on the sustainability scale due to no information. Based on this it is concluded that the sprat is not managed sustainably. There is too little information about the stocks, and management is inadequate. Inadequate information implies lacking management and also insecurity in terms of stock health.

5.1.9 Skagerak/Kattegat sprat – *Sprattus sprattus*

The Skagerak/Kattegat sprat is fished together with juvenile herring, and the harvest of sprat is limited by the restrictions on juvenile herring (ICES, 2009b). Catch estimates have been provided by the ICES Advisory Committee on Fishery Management and are illustrated in figure 5.17. ICES advice is not available due to lack of information.

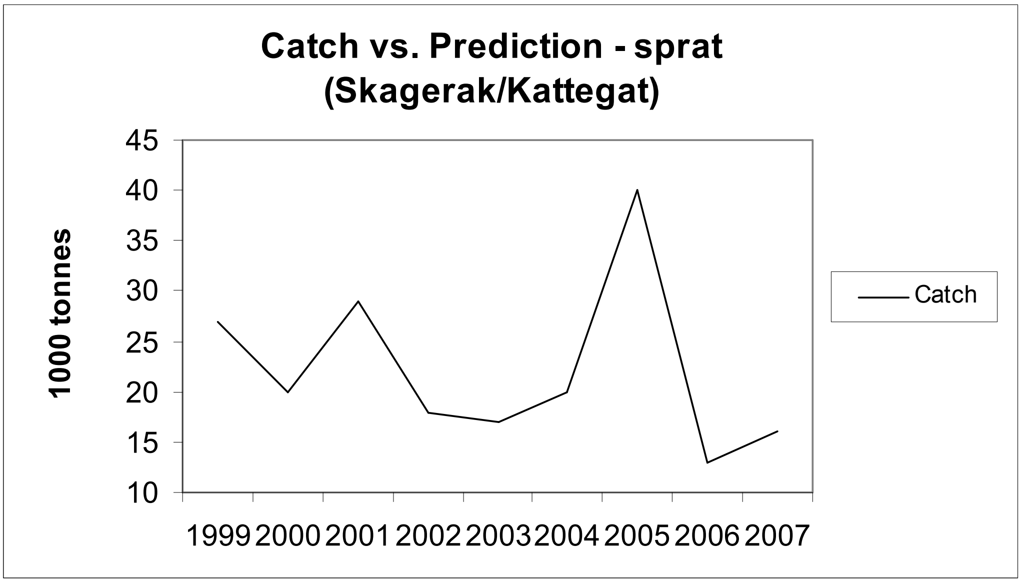

Figure 5.17: Total estimated catch of Skagerak/Kattegat sprat (adapted from ICES, 2008c).

Conclusion: As the North Sea sprat, this stock score 0/10 on the sustainability scale due to inadequate information. Inadequate information implies lacking management and also insecurity in terms of stock health. According to the assessment tree, the Skagerak/Kattegat is not managed sustainably. A summary of the species assessed in this study is provided in table 5.2.

Table 5.2: Sustainability of species assessed, according to the tools applied in this study.

Sustainability of species according to sustainability scale, scientific organ and assessment tree			
Species	Score	ICES/IMARPE	Assessment tree
Anchoveta	2 of 10	Sustainable if F = 0.4	Not sustainable (N/A)
Blue whiting	10 of 10	Overfished in a long-term perspective	Not sustainable
Barents Sea capelin	6 of 10	Consistent with the precautionary approach	Not sustainable
Icelandic capelin	9 of 10	SSB at risk for falling below Blim	Sustainable
NSS herring	9 of 10	Sustainable	Sustainable
North Sea herring	10 of 10	Sustainable from 2010	Sustainable from 2010
Sandeel	2 of 10	N/A	Not sustainable
North Sea sprat	N/A = 0 of 0	N/A	Not sustainable
Skagerak/Kattegat sprat	N/A = 0 of 0	N/A	Not sustainable

5.1.10 Characteristics of forage fish

The assessment tree in chapter 2 highlights several aspects that should be considered when determining the sustainability of using forage fish in feed. Ecosystem considerations, by-catch levels and levels of waste will be shortly addressed here. For later studies, these aspects should be given further attention.

Freon et al. (2008) states that in management of the anchoveta, ecosystem considerations are included. Anchoveta is important as food for other fish species, birds and mammals. In the North Atlantic, capelin and sandeel are pointed out as important prey species, and in both cases fishing is only permitted when the stock can handle fishing pressure and predation, and still manage to reproduce (ICES, 2009b; ICES, 2009c).

Purse-seiners are mainly employed in the harvest of forage fish. However, pelagic trawls target blue whiting and capelin, and sandeel is targeted with trawls due to its burrowing behaviour (IMR, 2010). Normally, purse-seiners targeting schooling species are "clean", meaning that the catches are mostly consisting of the target species, by-catch levels are low compared to e.g. trawl catches. Even though sandeel is harvested with small-meshed trawls, by-catch levels are reported to be lower than 3% of the total catches (IMR, 2010). Compared to the anchoveta fishery with by-catch levels of about 5% in a purse-seine fishery (Frèon et al., 2008), I will claim that the sandeel fishery is performing satisfactory.

Capture of forage fish produce little waste due to the fact that the whole fish is processed into fishmeal and fish oil. If the fish is destined for consumption, trimmings and by-products are utilized. Herring trimmings for instance, make up a large percentage of raw materials in fishmeal and fish oil (Skretting, 2010b).

5.2 Other species and trimmings

The above species are the main components of the marine resources in Norwegian salmon feed. However, other species and in particular trimmings and in some cases by-catch are also included. In Ewos' production, jack mackerel and menhaden made up a smaller part of the marine raw material (EWOS, 2010b). Skretting used a small amount of boarfish in their fishmeal and horse mackerel, sardine and South Pacific mackerel in their fish oil (Skretting, 2010b). BioMar utilized a small amount of Norway pout in their fishmeal and fish oil (Helland, 2010). What is interesting to notice here is that trimmings make up quite a large percentage in salmon feed. Skretting for instance utilized 11% trimmings in fishmeal, and 17% of the fish oil was made from trimmings (Skretting, 2010b). This is an important aspect of the whole sustainability discussion, and it can be seen as recycling of marine resources.

The trimmings are mostly from herring processing and this demonstrates that processing itself can generate valuable by-products for the aquaculture industry.

5.3 Feed or food?

The second aspect of sustainability (figure 5.18) is that the use of the marine resources in Norwegian salmon feed does not conflict with the prioritizing of the poor. Satisfying the needs of the poor is the goal of development, and it is stated by Langhelle (2000) that WCED implies that the poor should be given overriding priority.

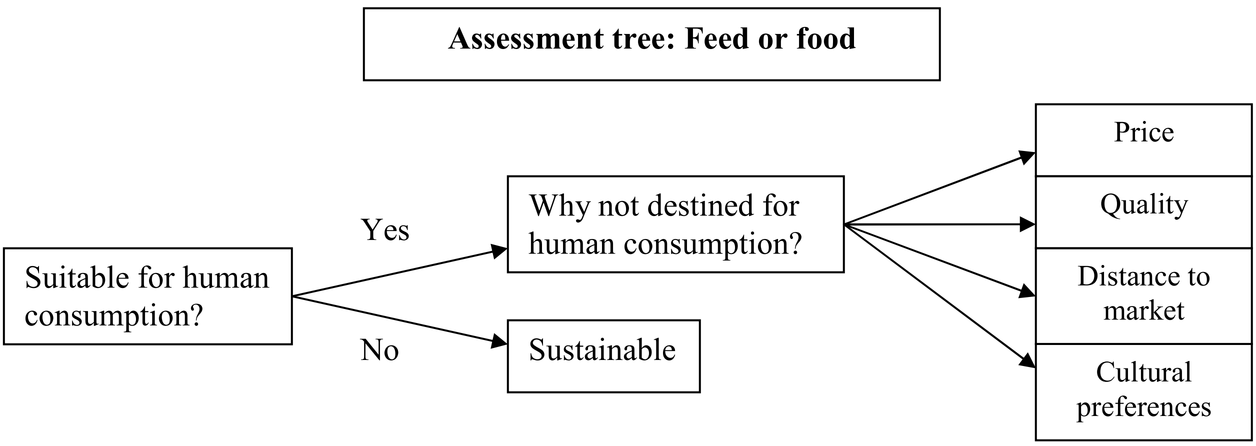

Figure 5.18: Assessment tree considering the utilization of forage fish, developed for this study.

The assessment tree is demonstrating reasons for the non-food use of forage fish. The alternatives on the right hand side influence the amount of forage fish destined for consumptive markets. Wijkström (2009) states that the poor in most parts of the world do not obtain more or less cheap fish because forage fish is utilized in aquafeed. In Asia, the practice of feeding farmed fish with wild fish, harms some of the poor, but is beneficial for others. It is also pointed out that the main problem in this area is the use of by-catch or trash-fish in aquaculture operations. This reduces the amount of fish available for food and also the chances of creating employment (Wijkström, 2009). The transition from feedfish to foodfish is purely economically constrained. Preserving fish and transporting it from the area of harvest to the poor, will require capital investments in the fleet, and cause the products to increase significantly in price (James, 1995; Wijkström, 2009). International agreements creating subsidizing policies might be able to provide foodfish for the poor. However distributing food in this way seems more suitable for people in need due to disasters of different kinds. Employment has proven to be the best tool in poverty alleviation, which goes hand in hand with improving nutritional status (Wijkström, 2009). Therefore, it seems more beneficial for international agreements to aim for establishing employment opportunities for the rural poor.

Another argument is that the forage fish utilized in Norwegian salmon feed is located in areas away from the people in greatest need of cheap animal protein. In figure 5.19, fish as percentage of total animal protein intake is illustrated.

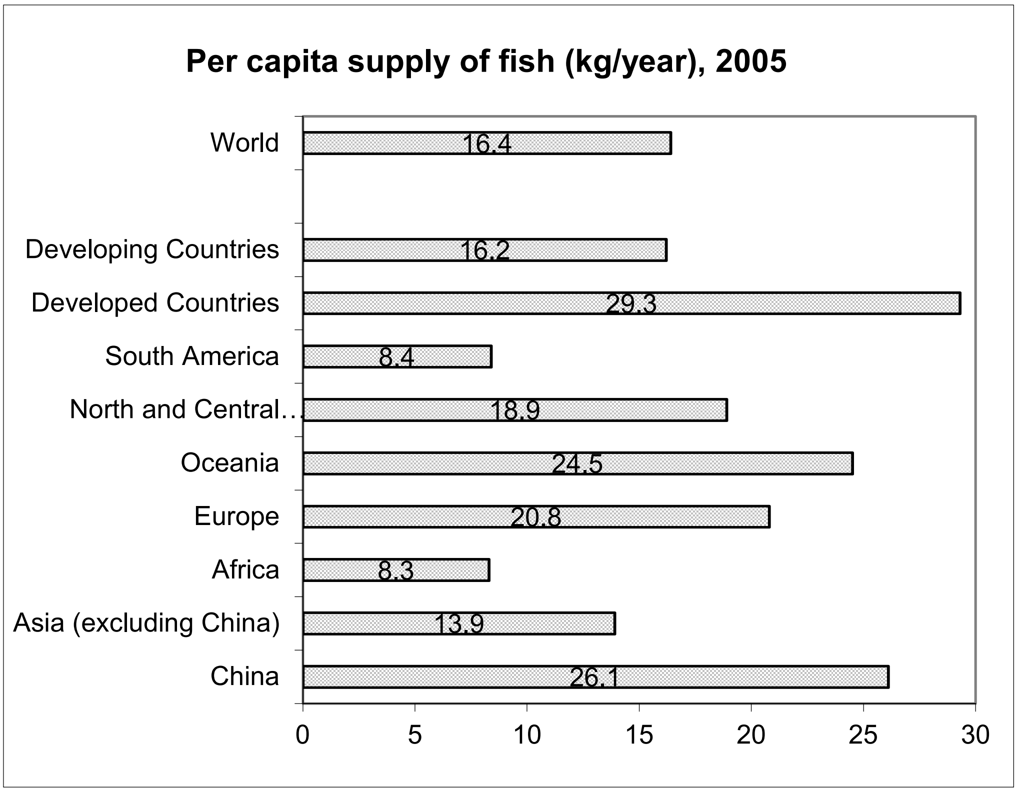

Figure 5.19: The importance of fish as a source of animal protein between continents (adapted from FAO, 2009).

In Norwegian salmon feed, the resources are from North Atlantic fisheries and from the anchoveta fishery outside Peru. The continents where fish is most important as food are Asia and Africa, and there is no conflict between these continents and resource components applied in salmon feed. Looking back at the perishability issue, there are currently few opportunities of transporting small pelagics to these areas. If doing so, another sustainability issue occurs, namely the one of climate change and the use of fuel and energy during transport.

Nonetheless, there are changing uses of North Atlantic species, and the trend is that larger quantities are destined for human consumption. Mackerel is a pelagic species suitable for making high quality fishmeal and fish oil, but 99-100% is destined for human consumption (Kontali Analyse, 2010b). The trend has been the same for herring with an increasing percentage destined for human consumption as indicated by table 5.3. In the last ten years, the situation has varied mostly due to varying degrees of fish quality. Herring of bad quality is destined for fishmeal and fish oil. Herring trimmings also make up a large percentage of ingredients in aquafeed (EWOS, 2010b; FHL, 2009a; Helland, 2010; Skretting, 2010b).

Table 5.3: Development of herring utilization (adapted from Kontali Analyse, 2010b).

Development of herring utilization in Norway						
	NSS Herring			North Sea Herring		
Year	Catch (Tonnes)	Consumption %	FM/FO %	Catch (Tonnes)	Consumption %	FM/FO %
1999	707 918	72	28	73 532	75	25
2000	811 069	79	21	57 159	92	8
2001	572 771	96	4	87 688	97	3
2002	530 003	93	7	83 927	80	20
2003	478 589	95	5	123 407	76	24
2004	470 847	100	0	148 347	94	6
2005	571 083	100	0	169 173	98	2
2006	584 665	94	6	146 443	83	17
2007	746 553	86	14	107 262	89	11
2008	1 046 400	92	8	65 754	96	4

* Consumption refers to human consumption. FM/FO means fishmeal and fish oil.

Blue whiting has potential as a food fish, and larger quantities have recently been destined for surimi[23] production, but the project was unsuccessful due to a dark color of the surimi (Sørensen et al., 2003; Pelagisk Forum, 2006). Research on the possibility of further processing of the blue whiting has been conducted with promising results. To be able to utilize larger quantities (table 5.3) than previously for human consumption will require that the fish must be of better quality. To achieve better quality, the fleet harvesting blue whiting must improve handling practices and storage onboard (Sørensen et al., 2003).

Increasing quantities of blue whiting for human consumption is currently on the agenda and an objective of important research institutions and it is believed that market opportunities will expand (Sørensen et al., 2003; Pelagisk Forum, 2006). Based of the above, it seems like the blue whiting in the future will experience the same situation like herring. In 2007, all landings were destined for fishmeal and fish oil, but in 2008, 8% was destined for consumption and increasing to 21% last year (Kontali Analyse, 2010b). Blue whiting of lower quality and trimmings (if processed in Norway) will be destined for fishmeal and fish oil, while the fish of good quality will be destined for human consumption.

[23] Surimi is a Japanese loan word referring to a fish-based food product intended to mimic the texture and color of the meat of lobster or crab, commonly referred to as crabsticks.

The Peruvian government has also initiated campaigns to increase consumption of anchoveta, but the quantities are quite large and it does not seem possible for it all to be utilized for human consumption (Frèon et al., 2008). In 2009, approximately 190,000 tonnes (3%) were destined for human consumption (Jackson, 2010a).

Regarding the other species, the capelin is attractive in the Asian markets, especially in Japan. Roe from capelin is regarded as a luxury product, and whole capelin is eaten as a snack. In spite of this, the establishment of capelin in these markets has been difficult due to the unpredictable supply of the resource (Boge, 2010). Capelin can increase its value sevenfold from raw material to finished product. Currently, Nofima[24] is carrying out a project investigating the possibility of a market-based harvesting regime for capelin. Such a regime would be beneficial in economic terms, but constitutes challenges for the fishing fleet (Nofima, 2010).

Sprat fished in fjords and along the coast is destined for canning. Requirements from the canning industry regarding quality, determines when and where the fishery is opened (IMR, 2010). Canned sprat is referred to as anchovy or sardine and is a common commodity.

The remaining species, sandeel, is very small and the filet yield would be too small to utilize for human consumption as the situation is today. It could be possible for canning like with sprat, but there are no current existing markets. It is purely economic considerations and established markets that decide where the forage fish is destined. With today's situation, I would say that the forage fisheries supplying the Norwegian salmon feed are not conflicting with the world's poor. However, this is a dynamic situation subject to changes in prices, quality of the resources, distance to markets and consumers' preferences.

This chapter has dealt with the management of forage fish and the implications these harvests may have on the world's poor. The next chapter will address the third aspect of sustainability, namely how the resources are utilized in feed production and their effectiveness as feedstuffs.

[24] Nofima is the Norwegian Institute of Food, Fisheries and Aquaculture Research.

Chapter 6: Salmon feed – opportunities and challenges

On a global basis, aquafeed production is minor compared to the total production of animal feed. In 2006, the total production made up 4% (about 1 million tonnes) of the total animal feed production of 25.4 million tonnes (Tacon and Metian, 2008). The fishmeal and fish oil industry receives around 20-33 million tonnes of fish annually together with 4-6 million tonnes of by-products and trimmings (Shepherd et al., 2005; FHL, 2009a; Ministry of Fisheries and Coastal Affairs, 2009b). From these raw materials, production of fishmeal varies between 4.5 and 7.5 million tonnes, while fish oil production fluctuates between 0.85-1.67 million tonnes (Tacon and Metian, 2009a). Global landings of forage fish, and hence, the supply of fishmeal and fish oil have been fairly stable the last 25 years, as indicated by figure 6.1. The global aquaculture sector consumes 68% and 88% of total fishmeal and fish oil production (Naylor et al., 2009).

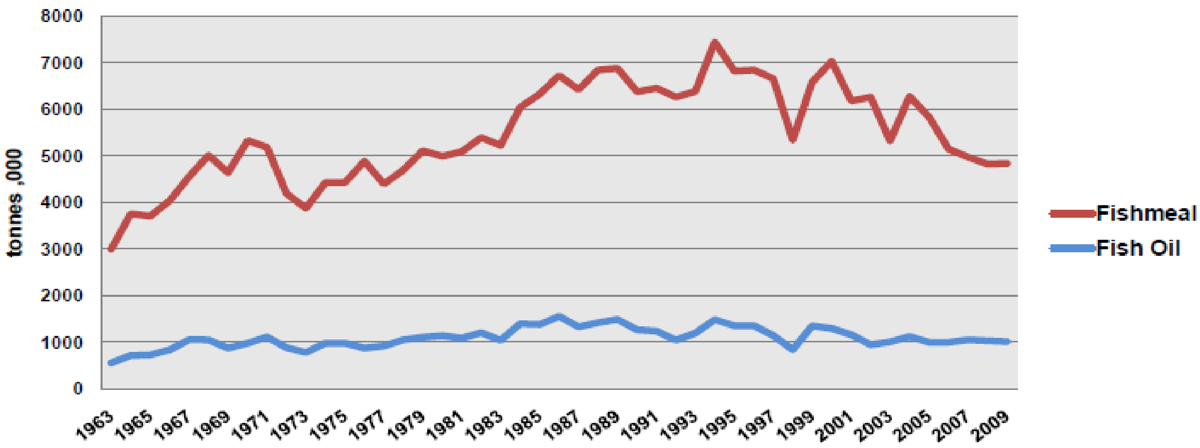

Figure 6.1: Global production of fishmeal and fish oil 1963-2009 (Jackson, 2010a).

On the other hand, there has been a shift in the distribution; from a market dominated by agricultural use and hardeners, to a market where most of the meal and oil is used in aquafeed for carnivore farmed fish and shrimp (Shepherd et al., 2005). Increasing demand follows this development and hence, the value of these commodities is increasing, as seen from figure 6.2.

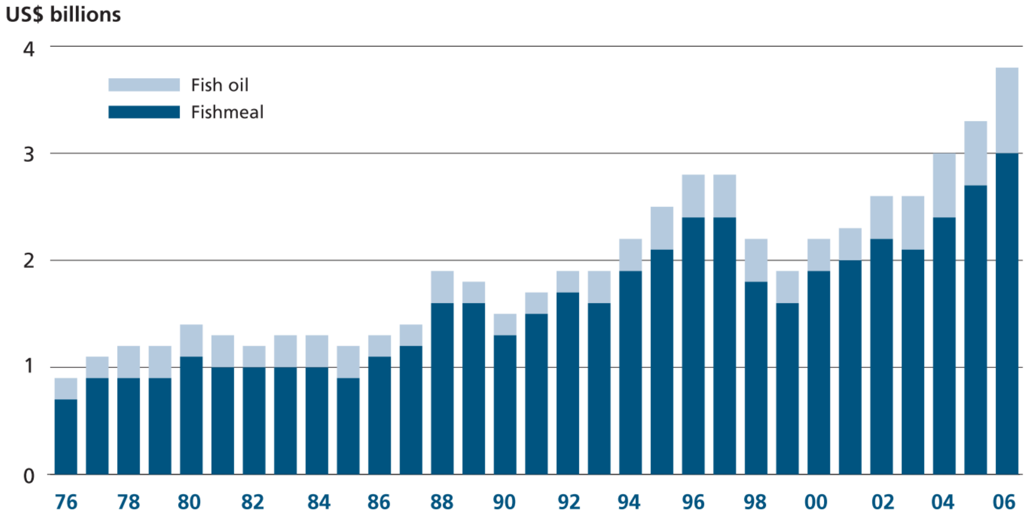

Figure 6.2: Increasing value of globally exported fishmeal and fish oil (FAO, 2009).

Salmon farming worldwide consumes 15% and 43% of the global aggregate fishmeal and fish oil production (Tacon and Metian, 2008), and the share has been increasing together with production. In spite of this, inclusion levels in salmon feed have on average decreased in the period 1995-2006; fishmeal content from 45% to 30% and the fish oil content from 25% to 20% (ibid.). Tacon and Metian (2008) predict a further reduction of in near future. The average inclusion levels of fishmeal and fish oil in Norwegian salmon feed is 31% and 21% respectively (Tacon and Metian, 2008). In 2007, salmon farming in Norway consumed about 7% of the world's fishmeal production and 22% of the fish oil production (FHL, 2009a).

Salmon is an attractive commodity because of its palatability and positive health effects (NIFES, 2010). Omega-3 or polyunsaturated fatty acids have a documented positive effect on heart and vascular diseases. Eating fish rich in omega-3 is believed to have a range of beneficial effects in addition to the ones mentioned above; on obesity, diabetes, osteoporosis and mental illnesses (NIFES, 2010). The increasing awareness concerning physical health has also led to an increasing interest in utilizing fish oil as a dietary supplement. Pharmaceutical companies are filling this niche, as they are becoming increasingly important in the fish oil market. In 2010, it is estimated that 15% of the global use of fish oil is destined for producing omega-3 pills (Sandvik, 2010). Pharmaceutical companies are believed to make up about 1/3 of the fish oil market share in the future (Skretting, 2010a).

6.1 Present status

Salmon feed has traditionally been dominated by marine raw materials; fishmeal has made up 40-60% of the aquafeed, while fish oil has had an inclusion level of about 20-30% (Gillund and Myhr, 2010). These resources have satisfied the nutritional requirements of salmon, while at the same time provided high levels of the beneficiary marine fatty acids (omega-3). In later times however, it has been necessary to move towards a more plant-based diet due to the restricted supply of these marine resources.

Fish oil is extracted from whole fish, the skin and liver of certain species, or waste from processing (New, 1995). Fish oil is rich in polyunsaturated fatty acids, especially eicosapentaenoic acid (EPA) and docosahexanoic acid (DHA), commonly referred to as omega-3 (Blanco et al., 2007). This essential fatty acid profile is what makes fish oil essential in salmon feed, but essential vitamins, available phosphorus and phospholipids are also of importance (New, 1995).

Fishmeal is generally composed of 70% protein, 10% minerals, 9% fat and 8% water, with essential vitamins, minerals and trace elements (Blanco et al., 2007). Amino acid profile, digestibility and palatability can vary depending on the raw material used and how it is processed (Blanco et al., 2007). These differences and the general quality of the fishmeal can affect growth and feed conversion ratio (FCR) of the farmed fish. Thus, fresh raw material produces the best quality fishmeal and inclusion of trimmings and by-products affect the quality in terms of a lower protein level and a higher level of ash, reducing the crude protein digestibility.

Salmon diets in Norway are currently based on about 40% vegetable raw materials and about 60% marine resources, illustrated by figure 6.3 (Gillund and Myhr, 2010). Marine inclusion levels will vary among companies and regions due to prices, policies and availability. For instance, Skretting through its Sustainable Economic Aquafeeds program, avoids illegal, unregulated and unreported (IUU) fish and threatened species to enter production through requirements of documentation at delivery (Skretting, undated).

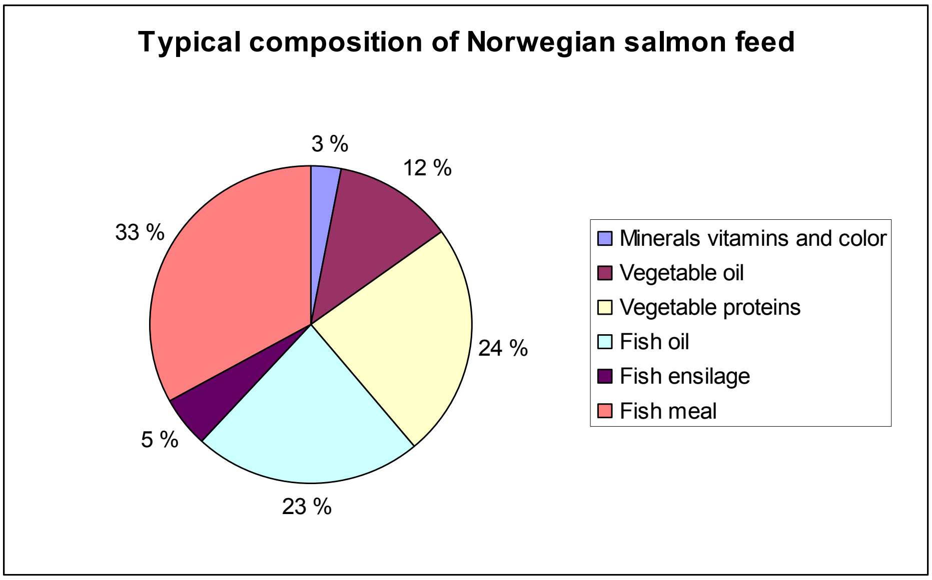

Figure 6.3: Typical composition of salmon feed (Gillund and Myhr, 2010).

As seen from figure 6.3 and figure 6.4, by-products and trimmings are included in aquafeeds, in the form of ensilage or protein-concentrate (RUBIN, 2009). 30% of herring trimmings and by-products are made into ensilage, but the majority is reduced to fishmeal. Protein-concentrate from herring is used in feed for salmon (RUBIN, 2009).

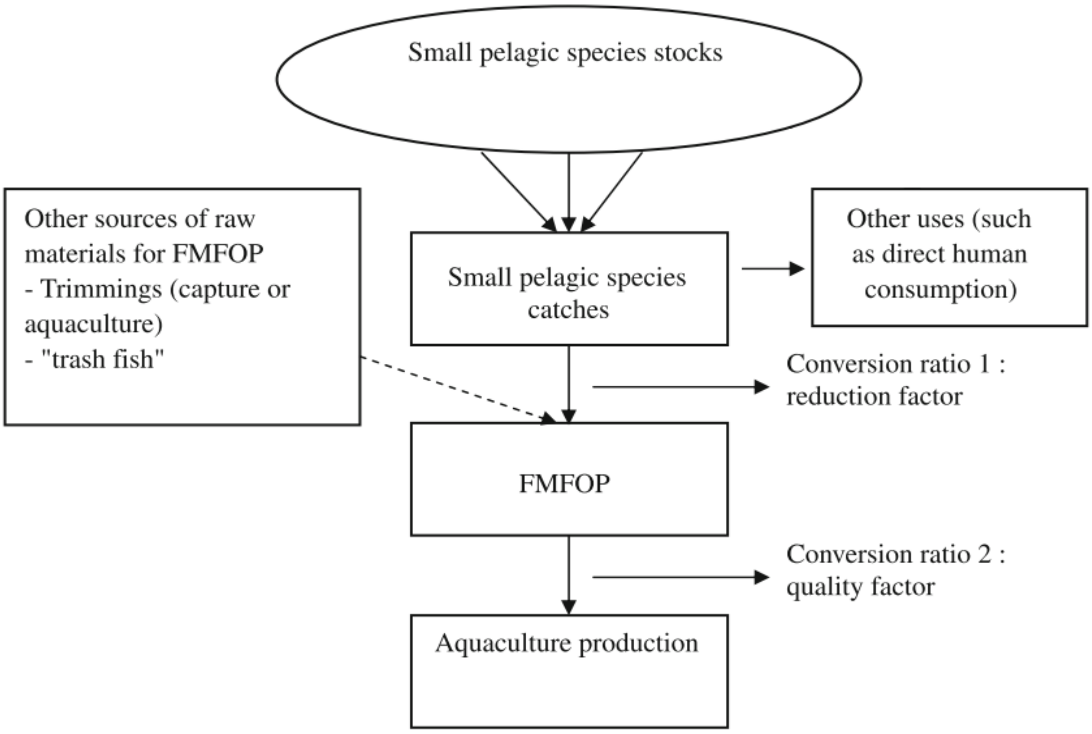

Figure 6.4 Origin and potential use of small pelagic fish stocks (adapted from Peron et al. 2010).

Pèron et al. (2010) illustrate the origin and potential uses of ingredients included in fishmeal and fish oil production, demonstrated by figure 6.4. Of notice here is that there are two reduction factors or conversion ratios in fishmeal and fish oil production. The first denotes how much fishmeal and fish oil is generated through the processing of a certain amount of wet fish. This reduction factor is assumed constant, because processing of forage fish uses fairly simple industrial techniques, without significant improvements (Pèron et al., 2010). The second is the feed conversion ratio, or how much compound aquafeed is needed to produce one kilo of salmon. Together the two ratios form the Fish In – Fish Out (FIFO) ratio, which refers to how many kg of wet fish is needed to produce one kg of salmon.

6.1.1 Feed conversion ratio (FCR)

FCR in Norwegian salmon production presently ranges from 1.0-1.4:1 with an average of 1.2:1, which is lower than the global average of 1.2-1.3 (Tacon and Metian, 2008; FHL, 2009a). The average FCR have gradually been reduced from 3.5:1 in 1975, to the current ratio of 1.2-1.3:1 (Tacon and Metian, 2008; FHL, 2009a). Feed composition has changed during this period; protein and carbohydrate levels have been reduced while fat and energy levels have increased. On average, 35% protein and 40% energy was retained in salmon in 1993 compared with energy retention levels of 10-20% in the wild (Åsgård and Austreng, 1995). Wild salmon must in comparison to farmed salmon, consume 10 kg fish to grow 1 kg (Norsk Fiskeoppdrett, 2009).

There are individual differences in FCR among companies, depending on the feed itself, the quality of the site (water flow, salt level, temperature), quality of smolt, and efficiency during feed operations (Skretting, 2010a). Salmon experiences an optimal growth when the temperature is 10-15° Celsius, and growth will be affected negatively if the temperature rises above 15° Celsius (Skretting, 2010a).

6.1.2 Fish In – Fish Out (FIFO)

Tacon (1995) points out that all intensive fish farming of carnivorous finfish reduces net fish protein, rather than being net producers of protein. Net producers are semi-intensive farming systems employed by farmers within developing countries producing omnivorous or herbivorous fish (Tacon, 1995). On a global scale the aquaculture sector is a net protein-producing sector with an overall FIFO ratio of 0.70 (Tacon and Metian, 2008). This is possible because farmed species represent different ecological niches, and herbivore fish will compensate for the net loss of marine protein and fat caused by carnivorous species. Yet, the amount of raw material or whole fish required in production of carnivorous species is decreasing, from 7.5:1 in 1995 to 4.9:1 in 2006, and with predictions of a FIFO ratio of 1.5:1 in 2020 (Tacon and Metian, 2008). The salmon will then be more of an herbivore species than what is the case of wild salmon living on a natural diet.

The FIFO ratio varies considerably in existing literature, from 1-2 kg to 5 kg to produce one kg of salmon (Ellingsen and Aanondsen, 2006; FHL, 2009a). FCR influence the FIFO ratio as seen from figure 6.5. With less aquafeed needed to produce a kg salmon, the FIFO ratio will also decrease. Naylor et al. (2009) state that salmon currently is experiencing a FIFO ratio on a global average of about 5:1.

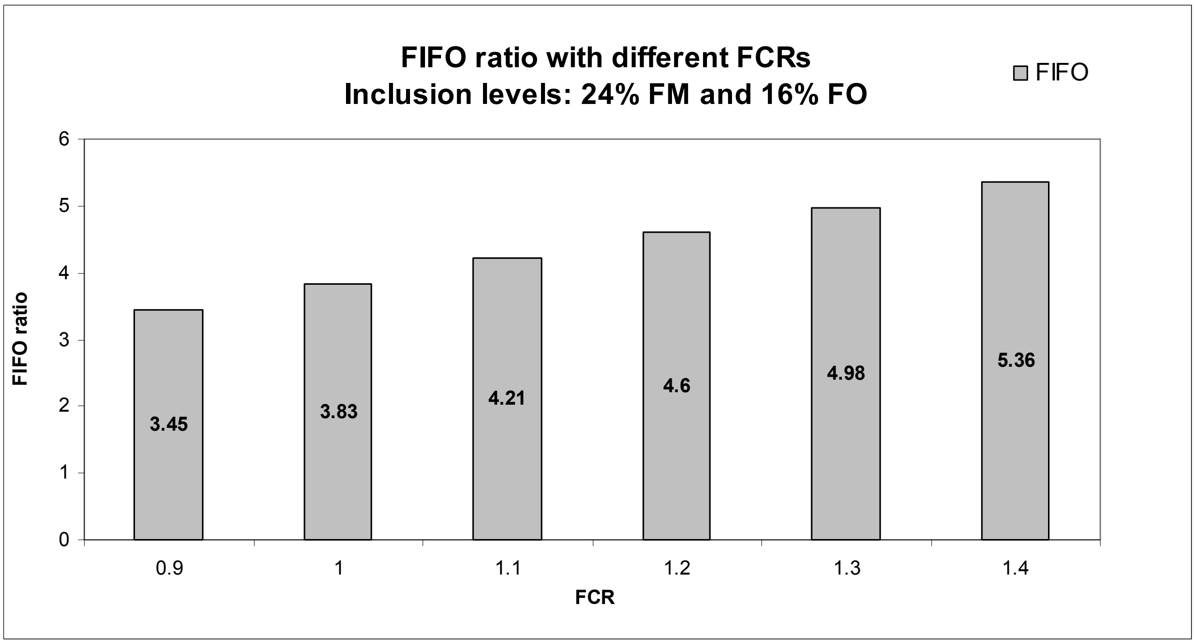

Figure 6.5: FIFO ratios varying with different FCRs with 24% fishmeal and 16% fish oil, which was the global average in 2006 (Naylor et al., 2009).

The FIFO ratio is calculated as follows (Jackson, undated; Tacon and Metian, 2008):

$$\text{FIFO ratio } = \frac{Level\ of\ fishmeal\ in\ the\ diet + Level\ of\ oil\ in\ the\ diet}{Yield\ of\ fishmeal\ from\ wild\ fish + Yield\ of\ fish\ oil\ from\ wild\ fish} \times FCR$$

Behind this formula are certain assumptions; yield from wet fish to fishmeal is assumed to be 22.5%, and wet fish to fish oil is assumed to be 5% (Tacon and Metian, 2008). So, 1000 kg of wet fish, results in 225 kg of fishmeal and 50 kg of fish oil, after processing. Also, by-products and trimmings are increasingly used as raw materials, and will further influence the resulting FIFO ratio. IFFO estimates that 22% of total fishmeal production is made from trimmings and by-products (Jackson, undated).

When making salmon feed, fish oil serves as a bottleneck, and there is leftover fishmeal from production. This is because in the reduction of forage fish (making fishmeal and fish oil) a common proportion between fishmeal and fish oil is 2.8:1 (Norsk Fiskeoppdrett, 2009). This implies that more fish oil is required in aquafeed than what is generated in terms of fishmeal. In other words, more fishmeal than currently in use in aquafeed is produced, which possibly can be applied in other food production (poultry, swine etc). Some species require less fish oil in their diet, for instance shrimp. It is therefore possible to utilize leftover fishmeal in other regions and thereby further reduce the FIFO ratio for salmon (FHL, 2010a). Reducing fish oil content will also lower the FIFO, for instance a 4% decrease leads to a decline in FIFO from 5 to 3.9. The amount of forage fish used to produce feeds for salmon is therefore driven by the need for fish oil (Naylor et al., 2009).

The Norwegian Seafood Federation (FHL) operates with a FCR of 1.2:1, and I have applied the Norwegian average of 31% fishmeal and 21% fish oil (Tacon and Metian, 2008). The formula for Norwegian salmon then becomes:

$$\text{Norwegian salmon FIFO ratio } = \frac{31+21}{22.5+5.0} \times 1.2 = 2.27$$

The magazine Norwegian Fish farming (Norsk Fiskeoppdrett AS) operates with a different way of calculating the FIFO ratio. It is emphasized that the amount of left-over fishmeal as described above must be considered when calculating the FIFO ratio. The amount of fish needed to fulfill the fish oil requirements when inclusion level is 16%, is about 2.2 kg (with fishmeal level of 29% and a FCR of about 1.1:1). However, about 0.7 kg fishmeal is remaining due to the proportion of 2.8:1 between fishmeal and fish oil in the reduction process (Norsk Fiskeoppdrett, 2009). This amount of fishmeal can be utilized in the production of other species or livestock and should therefore not be included in the FIFO ratio for salmon. The resulting FIFO ratio becomes 1.5:1, considerably lower than 2.2:1.

It is pointed out in the article by Gillund and Myhr (2010) that even though the FIFO ratio in current literature varies quite a lot, and is presently decreasing, salmon farming continues to be a *net reducer of marine protein and fat*.

Global fishmeal supplies are likely to remain at around 6 million tonnes per year. Because of the high nutritional value of fishmeal and fish oil it is likely that there will be higher prices and more efficient use of the resource. Critical life stages of animal production will be the major use of fishmeal and fish oil in near future (Shepherd et al., 2005).

Stakeholders explain that it is more important with higher marine inclusion levels in smolt feed and in the feed provided prior to slaughter, than in the grow out phase of the salmon (Skretting, 2010a).

6.2 Salmon compared to other livestock

The feed conversion factor (FCR) is an important parameter for showing how efficient we convert feed into meat (live or gutted/slaughtered weight). With respect to protein and energy retention, fish is much more efficient than other domestic animals. Farming salmon is very efficient (FCR 1.2) compared with chicken and swine, where the FCRs are 2.5 and 3.5 respectively (FHL, 2009a; Liabø, 2009). Total global production of salmonids was in 2008 about 2 million tonnes, while production of chicken and swine was 50 and 90 million tonnes respectively (FHL, 2009a). 142 millions tonnes in total were produced by these three sectors, which required at least 500 million tonnes of feed (Venvik et al., 2009). Salmonid production constitutes 1.41% of the total quantity and utilized only 2.3 million tonnes, or 0.44% of the global feed consumption (FHL, 2009a).

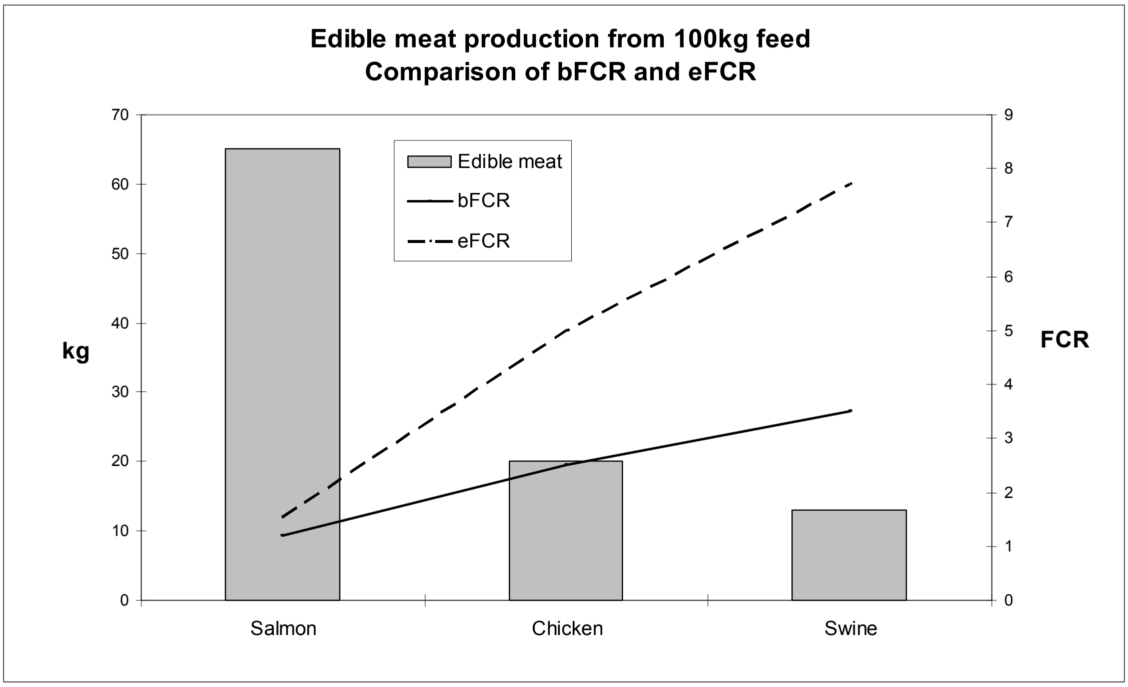

Figure 6.6: Edible meat production from 100 kg of feed, displayed with respective FCRs (adapted from FHL, 2009a).

The production of edible meat from 100 kg of feed is demonstrated in figure 6.6. It is apparent that with a lower FCR, more meat is produced from a certain amount of feed.

Salmon is the most efficient livestock with a biological FCR[25] (bFCR) of 1.2 and in terms of taking into account only the edible meat; the economic FCR[26] (eFCR) is about 1.54:1. bFCR for chicken is 2.5:1, while the eFCR is 5:1. For swine; bFCR is 3.5:1, and eFCR is 7.7:1 (FHL, 2009a). From the figure it is obvious that it is possible to utilize more of the salmon than chicken and swine. Sheep has a particular low efficiency, with only 1.2 kilos produced from 100 kilos of feed (eFCR of 83:1) (Åsgård and Austreng, 1995).

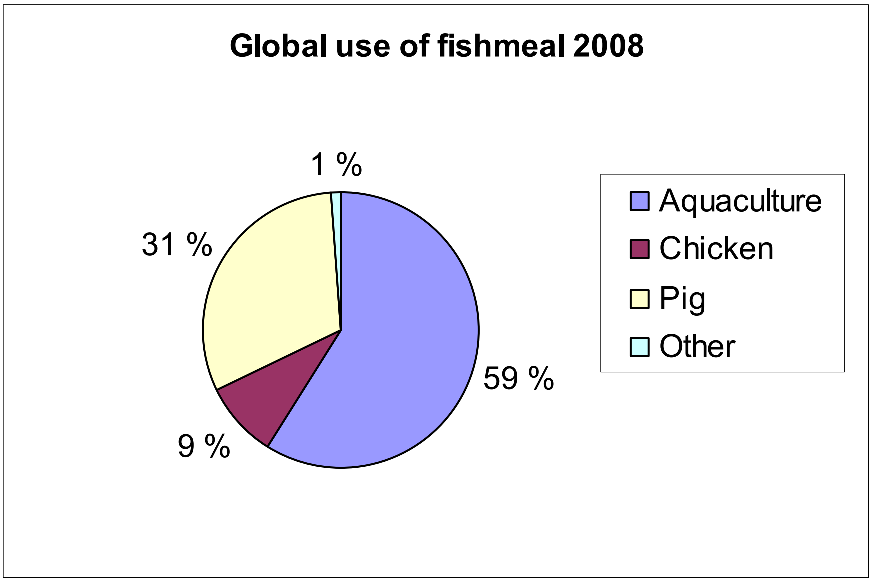

Figure 6.7: Distribution of global fishmeal production, 2008 (adapted from Jackson, 2010a).

Livestock sectors dominate the market for fishmeal (figure 6.7) with aquaculture production representing 59% in 2008 (68% in 2009) (Naylor et al., 2009; Jackson, 2010a). Salmon is the sector with the best competitiveness in the current market situation, and is also dependent on a certain level of fishmeal in its feed (Liabø, 2009). It is believed that with higher demand for marine resources, salmon will increasingly dominate the market. Figure 6.8 indicates price development of both fishmeal and soybean meal in the German and Dutch[27] markets. When fishmeal prices rise, soybean meal prices follow to a certain extent. Flexibility in feed preferences for chicken and swine production makes it possible to substitute fishmeal with cheaper alternative when prices are high; a complete substitution for salmon farming is on the contrary not possible.

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[25] The biological FCR is in live weight.
[26] The economic FCR is the yield after gutting and adjusted for mortality.
[27] These countries were randomly picked as reference countries; however, the price development is similar in the global market.

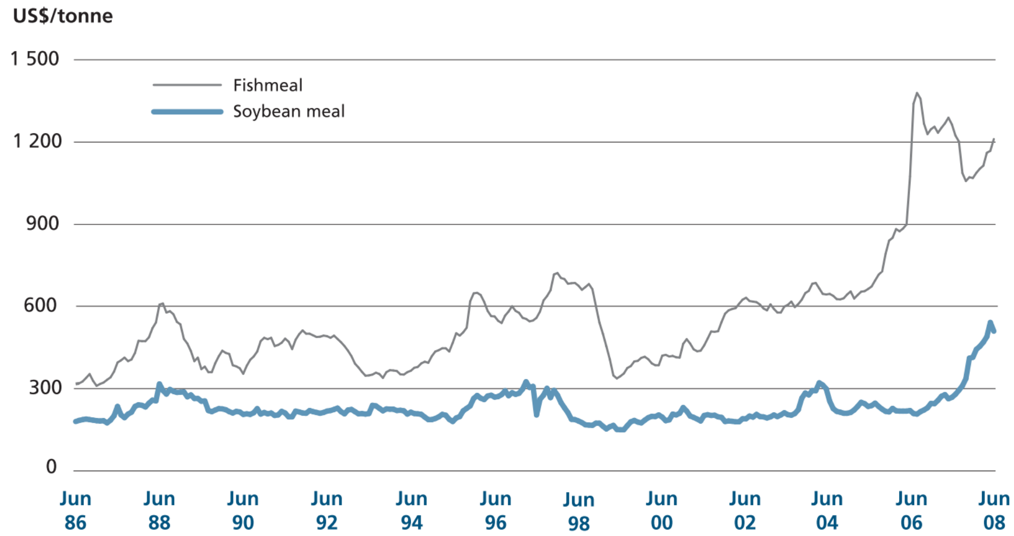

Figure 6.8: Fishmeal and soybean meal prices in Germany and Holland, representing the world market (FAO, 2009).

Aquafeed makes up the largest expense of the aquaculture operation. In the last decade prices of fishmeal and fish oil have increased a lot, 50% and 130% respectively (FAO, 2009). Price, together with the limited availability of these resources, has forced the initiation of a move towards marine independence regarding aquafeed (Gillund and Myhr, 2010). A more plant-protein based diet has not been successful yet and currently salmon farming consumes more marine protein than it produces. However, it is believed that the tools needed to tackle this are already developed by the industry, but that various obstacles have to be addressed before introducing new technology and new salmon diets (BioMar, 2010a).

Research on energy efficiency has also been conducted more recently. Salmon can become more energy efficient and have a lower environmental impact than chicken if more marine raw materials are substituted with vegetable resources (Ellingsen and Aanondsen, 2006). Chicken farming is less energy demanding than salmon farming, mainly because a substantial part of the salmon feed is wild caught fish involving high transportation costs (Winther et al., 2009).

6.3 Alternatives to fishmeal and fish oil

Even though the aquaculture sector does not seem to be immediately restricted by the predictably declining supply of marine resources, it will be a big challenge that has to be tackled by the salmon feed industry at some point in future. There is a need for more alternative sources of raw materials (Shepherd et al., 2005). Fishmeal has traditionally been the principal source of protein in the diet of farmed carnivorous fish and it represents the largest operating costs. This, together with the industry's need for flexibility regarding raw materials, has initiated the work of lowering the marine protein level in feed (Kousoulaki et al., 2008). New resources must possess the optimal makeup as an ingredient in salmon feed, but to fulfill the nutritional requirements is not enough, the feed has to be sustainable[28] and economically viable for the company (Gillund and Myhr, 2010).

A number of potential resources are looked into as substitutes, and will be briefly addressed below. To be a viable substitute for fishmeal and fish oil the alternative ingredient must in addition to be suitable in terms of nutritional characteristics, be readily available, easily stored, handled and used in feed production. Ecosystem considerations and price are also factors of consideration for the application of new feedstuffs (Naylor et al., 2009).

6.3.1 Trimmings and by-products

The share of by-products and trimmings is rising due to increasing processing of fish. Present contribution to fishmeal production is currently around 22% (5.6 million tonnes in 2002) (Jackson, undated; Naylor et al., 2009). By-products and trimmings from fisheries and aquaculture operations in Norway make up about 20% (600,000 tonnes) of the total landings, where 75% is utilized for animal feed. By-products and trimmings from aquaculture are fully utilized. Intra-species recycling is against the law and poses a constraint for utilization of salmon by-products and trimmings from processing (FHL, 2009a). By-products and trimmings can be utilized to a much greater extent than today, and is underrated as a resource for the feed industry (BioMar, 2010a). To develop and extend the use of by-products, the technology and logistics to conserve it must be established (BioMar, 2010a). However, there are some concerns regarding the increasing use of by-products; if a large amount of trimmings in feed substitutes whole fish, the ash content will increase and this can cause mineral deficiencies in farmed fish (Gillund and Myhr, 2010). Another issue is the accumulation of PCBs[29] and dioxins in fish, and some stakeholders have expressed that because of this problem, the use of by-products to a larger degree is not attractive for the industry (BioMar, 2010a). There are scientific studies arguing that there is no risk of disease or transmission of pathogens when using by-products in fish feed (Turchini et al., 2009).

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[28] In this article the definition of sustainable development by the Brundtland commission, is applied, however no further description of what sustainable constitutes is described.
[29] PCBs = Polychlorinated biphenyls, organic toxins.

Silage produced from trimmings and by-products are being used as a supplement in fish feed, and is believed to be an adequate ingredient in a balanced diet, due to the nutritional value determined by the amino acid composition of the feed (Blanco et al., 2007).

In a study by Kousoulaki et al. (2008), stickwater has been proposed as a potential protein source that can enhance fish performance if diets are high in plant protein. Stickwater is the water-soluble fraction of fish and normally represents 20-50% of the fish. Fishmeal production generates coagulated fishmeal and press liquor. Separation of this liquor leaves fish oil and stickwater (Kousoulaki et al., 2008). The study emphasizes the necessity of including components that are present in the water-soluble fraction of marine protein (Kousoulaki et al., 2008), and has demonstrated that stickwater can be an alternative protein source in fish diets and hence adds more flexibility to the feed industry.

6.3.2 Vegetable protein and lipids

Experts estimate that 75% of dietary fish oil can be replaced by vegetable oils in Atlantic salmon without compromising growth performance or fish health as long as the omega-3 requirements are met (Naylor et al., 2009; Turchini et al., 2009). Despite of this knowledge, the industry hesitates to lower the marine inclusion level of oil because consumers around the world seem to be apprehensive regarding the level of omega-3 in the fish. It is therefore desirable with a certain inclusion level to satisfy retailers and consumers. However it is important to emphasize that other factors are equally important for consumers, for example taste, color and availability of the product (FHL, 2010a).

Plants often contain high levels of starch and fiber that has lower digestibility in fish compared to marine resources. Unfavorable amino acids and mineral profiles together with anti-nutritional factors[30] (ANFs) are other features that make various plant protein sources a challenge in fish diets (Gillund and Myhr, 2010).

In salmon feed, sunflower, linseed, maize, coconut, canola/rapeseed, soybean, olive and palm oil is substituting fish oil (Naylor et al., 2009). Substitutes for fishmeal are rapeseed, corn gluten, wheat gluten, barley, pea and lupin meal (Tacon et al., 2006). Some of these resources do not exist in Norway, and will have to be imported.

Soybean meal has been the most common substitution for fishmeal, mainly due to its already established market availability, cost and high nutritional value. Soybean meal is a good source of dietary protein and phospolipids. However, plant proteins cannot fully replace

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[30] Anti-nutritional factors are substances present in food or feed that reduce growth. Examples are phytate, protease inhibitors and dietary fiber.

marine proteins because of reduced nutrient digestibility and the presence of ANFs. They have to be destroyed or biologically inactivated through processing prior to being included in aquafeeds (Tacon, 1995). Fish performance or feed utilization is generally reduced in most species where there has been a significant substitution from marine to plant protein (Kousoulaki et al., 2008).

6.3.3 Land based animal protein (LAP)

Another possible source of protein and lipids are the residues from terrestrial livestock production, such as blood meal, liver meal, meat meal, bone meal, poultry by-product meal and poultry feather meal (Tacon, 1995; Naylor et al., 2009). Meals from invertebrate animals are also likely to be a possibility in the future. However, the same problem as with the use of trimmings and by-products occurs here: the content of ash is high compared to fishmeal from whole fish, because the meal will be comprised mostly of bone and non-muscle parts of the animals. This can be tackled by developing processing practices and thereby improve quality and digestibility of the meal (Turchini et al., 2009). Although it is possible to execute this today, consumer preferences make up a large hindrance, together with concern for disease transmission (Gillund and Myhr, 2010).

6.3.4 Genetically modified organisms (GMO)

Plant genetic research can change features of the plant to a more beneficial structure to suit the nutritional requirements of the fish in question (Gillund and Myhr, 2010). One example of such use of genetics is the successful accumulation of omega-3 in genetically modified plants. This can be a more sustainable source of omega-3 than fish oil in the future (Gillund and Myhr, 2010). However, more research and long-term experiments are needed in this field. Genetic modification of microorganisms have also been undertaken to produce beneficial nutrients like essential amino acids, vitamins, pigments and necessary enzymes to break down ANFs. This is still on the research stage and is not yet commercially available (Gillund and Myhr, 2010).

Concerns are directed to the unknown consequences of adding GMO in food and how this will affect the fish, human health and the environment in the long run. The plant material itself seems to have a larger effect on growth, digestibility, feed utilization and other health parameters than whether or not the plant is genetically modified (Gillund and Myhr, 2010). Consumers in Europe are in general negative towards the use of GMOs in food and feed, not only because of the uncertain effects, but also because GM practices may have unknown and negative socioeconomic effects (Gillund and Myhr, 2010). In EU markets, products that contain more than 0.9% of GMO have to be labeled as GM products, but animal products that have been fed GM feedstuffs are not labeled (Gillund and Myhr, 2010).

6.3.5 Lower trophic-leveled species

Zooplankton, mesopelagic species of fish and some species of squid can be attractive for the feed industry in near future (EWOS, 2010a). Krill is perceived as the most promising resource because of its enormous abundance both in the Antarctic and the North Atlantic. In addition, krill seems to be a satisfactory substitute for fish meal in terms of fish health and quality of the product (Gillund and Myhr, 2010). In spite of this there are concerns regarding the effect of some substances in the exoskeleton of krill on fish health, and further research in this field is needed. Of greater importance is the lack of knowledge regarding the ecology of krill. It serves as food for many organisms and holds up a large share of the lower food web. Krill is also prone to environmental changes. Because of these insecurities, one should take great caution when setting harvest quotas. Scientists and managers know too little to define sustainable catch quotas (Gillund and Myhr, 2010). The harvest quota is currently 6 million tonnes, but actual catches are about 1 million tonnes. The only company operating a krill-fishery in Norway today is Aker Biomarine, and the potential for a big expansion of the fishery is limited. The resource is highly perishable due to autolyctic[31] enzymes and unsaturated fatty acids. It therefore requires the right harvesting methods together with swift processing (Naylor et al., 2009). The pharmaceutical industry is likely to consume most of the harvest, due to the high costs of running the fishing operations.

James (1995) states that mesopelagic fish of the order *Myctophiformes* in the Northern Arabian Sea could substitute fishmeal destined for human consumption in the future. Mesopelagic fish are not suitable for human consumption. The stocks are estimated to be around 100 million tonnes, and have never been subject to commercial fishing (James, 1995). Mesopelagic species are interesting to the aquafeed industry, and it is believed that if an economic exploitation of the stocks could be established, such species can play an important role in the future (EWOS, 2010a).

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[31] Autolysis refers to destruction of cells due to enzymes, and occurs normally in injured or dying tissue.

6.3.6 Microorganisms or single-cell proteins (SCP)

Fermentation of bacteria, yeast and algae with natural gas as an energy source can produce proteins and fatty acids. This is believed to be suitable for aquafeed for two reasons; firstly, it does not change the flesh characteristics of the salmon and secondly, it has a high protein content and no ANFs (Tacon et al., 2006). Still, a slight reduction of the growth rate has been the result when including 20% bacterial protein in salmon diets (Gillund and Myhr, 2010). Tacon (1995) states that SCPs have an ability to genetically modify nutrient limits to fit the dietary needs of the cultured species. SCP might have physiological impacts on the fish and this is a concern regarding these products. Further research is necessary to make SCP more suitable as an ingredient for aquafeed (Tacon, 1995). Additionally, availability is limited due to technical production constraints and the price is therefore high (Naylor et al., 2009).

6.3.7 Substitution challenges

Many stakeholders within the industry are working intensively with the aim of making the farmed salmon a *net producer of protein* by substituting the marine ingredients with vegetable raw materials. The industry states that the biggest challenge is substitution of raw material containing EPA and DHA (Skretting, 2010a). Representatives from the industry further state that the tools to accomplish substitution are being developed, but that legislation hampers the implementation of for example GM plants producing EPA and DHA (EWOS, 2010a). Tacon (1995) points out several challenges in the process of substituting marine raw materials, such as limited availability and high costs being common problems for utilizing single-cell proteins, microorganisms and miscellaneous plant protein sources. Palatability can become less attractive when utilizing vegetable ingredients. Plant lipids and terrestrial by-products can vary in quality and contain ANFs and harmful microbes.

Even though the goal is substitution of a considerable amount of marine raw materials with other resources, there is a limit to how much fishmeal and fish oil it is possible to replace. Research on fish oil replacement shows that with increasing levels of vegetable oil in the diet of salmon, the level of omega-3 in muscle lipids is significantly reduced (Bell et al., 2001; Olsvik et al., 2008). High levels of plant lipids also affect the health of the fish negatively. Bell et al. (2001) emphasize that substituting marine resources in fish feed must not compromise fish health and product quality. It is important to notice that salmon is attractive just because of its high omega-3 content, and if reducing fish oil inclusion levels to the point that it omega-3 levels decrease, it might lose consumers' interest (BioMar, 2010a; EWOS, 2010a).

6.4 Measure the immeasurable?

This chapter has established that there are resources and methods for a partly substitution of marine resources. However, questions and problems still remain; which resource has the greatest potential? Which resource is the most sustainable? Can resources be combined without inflicting new problems? The third aspects of feed resources addressed in this thesis, namely whether use is efficient and sustainable, has proven hard to address. There are no developed indicators denoting sustainable and efficient use (Guldseth, 2010), and I have therefore chosen to elaborate on present status and future outlook. Developing an assessment tree without specific aspects affecting sustainability would not be worthwhile. The complexity surrounding the issue is illustrated by figure 6.9.

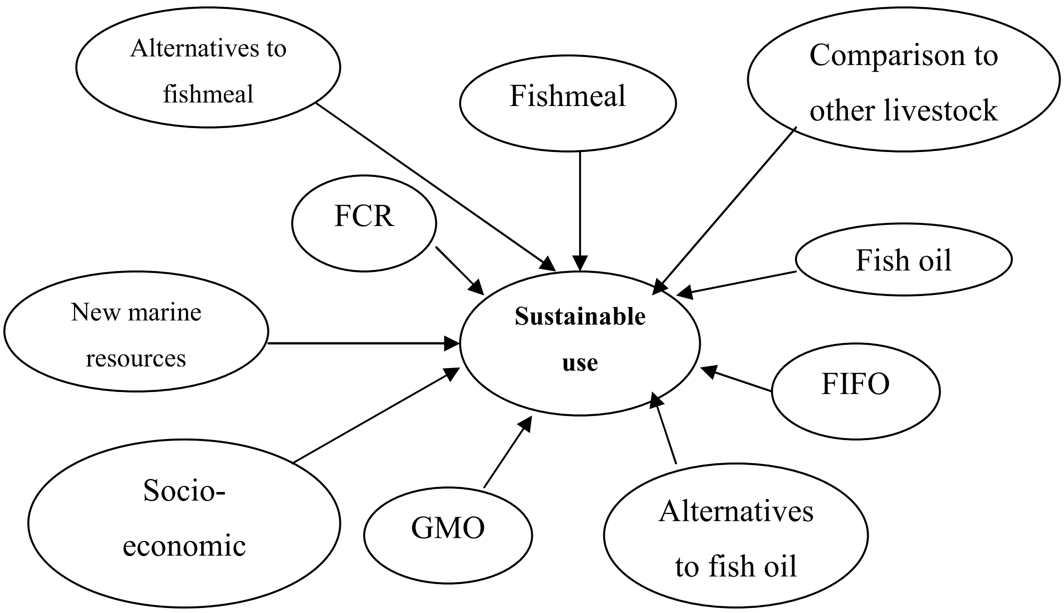

Figure 6.9: Aspects to be included when assessing whether use of aquafeed is sustainable.

Even though the focus is on substituting marine resources due to limited supply, it is important to be aware of the fact that the alternative resources not necessarily are more sustainable than the marine raw materials. Solving this issue would be more constructive if stakeholders were able to adopt a more nuanced and pragmatic view on the matter. This will be further discussed in the next chapter, together with an interlacing discussion of the scope of this thesis, namely the three aspects concerning feed resources; sustainable management and harvest, sustainable destination (therein feed or food for humans) and efficient and sustainable use.

Chapter 7: Sustainability of Norwegian salmon farming

The foundation of the study has been feed resources utilized by the salmon farming industry, and the aspects covered are condensed in figure 7.1.

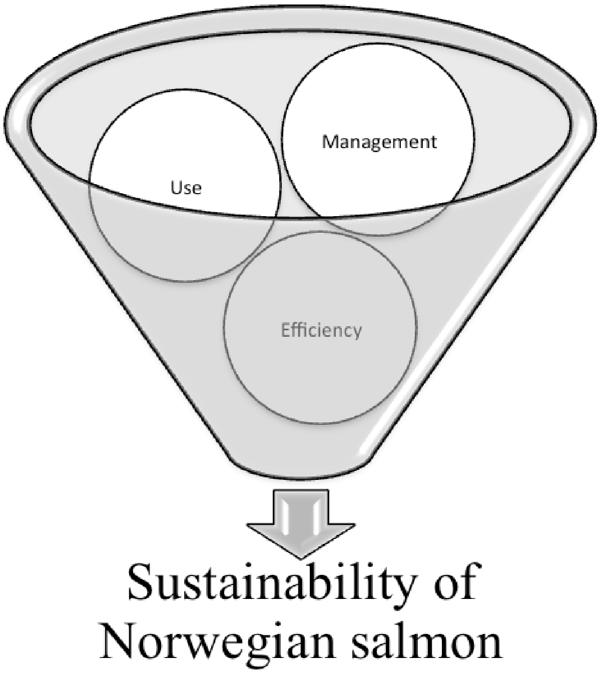

Figure 7.1: The aspects of sustainability covered in this study.

The Brundtland-report made the concept of sustainability gain political footing and credibility (Banik, 2010). The concept has in the course of time evolved from one emphasizing the needs of the poor and social justice and equity across generations, to a slogan misused by several actors in society. Sustainable development and sustainability have recently become about "greenery" or conservationism (Banik, 2010). There is still no clear understanding of what these terms really describe, or what they should entail. Without clear definitions the concept is useless, but it sounds respectable in the ears of the consumer; the buzzword is associated by something *good*.

The proviso of sustainability has been the working concept in this study, and Langhelle (2000) argues that if the proviso of sustainability is not fulfilled, then the goal of development is not achievable. It is stated that satisfaction of human needs depends on the well functioning of ecosystems. Whether the anthropocentric view upon the earth is the ethical correct one is a very interesting discussion, but it is clearly outside the scope of this study. Still, it is apparent that resources must be managed in a way that excludes the risk of detrimental effects. Deteriorating resources will not support further growth of humans. Throughout history, there are several examples of neglecting the proviso of sustainability. Holdgate (1995) argues that because humans are aware of the oceans infiniteness, this explains humans' greed and practice of exploiting the sea. Heavy whaling has been one example of heavy exploitation, and there are present practices as well that grind down future generations' abilities to meet their own needs. Since the industrial revolution we have reduced and are still reducing the oceans ability to support human life (Holdgate, 1995).

7.1 Assessing management of forage fish

Looking back at chapter 5, the stocks that scores 10/10 according to the sustainability scale, are blue whiting and North Sea herring. The blue whiting is however biased because the ICES advice for 2011 is only 41,000 tonnes, which is a decrease from 540,000 tonnes this year (Jensen, 2010b). Such a decrease implies that the health of the stock has deteriorated significantly. The North Sea herring also became subject to a newly revised management plan in 2008, indicating that management was inadequate. In general, management of forage fish can improve significantly. All the stocks are experiencing certain "flaws" in their management regimes. Nonetheless, Norway is deemed as one of the countries with the most advanced management systems in the world (Ministry of Fisheries and Coastal Affairs, 2009b). Worthy of remembering is also that the stocks are pelagic, and small pelagic species are characterized by large variations in stock size, independently of fishing pressure (Fréon et al., 2005). This raises the problem of how to decide on the right indicators of sustainability.

The scale presented in chapter 2 is an attempt of providing a more nuanced perspective on the status of the stock size. A full score on the B_{lim} criterion is 10, which is also the optimum or fully sustainable. Even though a full score is not achieved, a scale like the above mentioned is helpful in stating where along the scale the forage fisheries are at present. The criterion for evaluating the respective stocks according to the scale is that there is information available concerning the spawning biomass stock, and the reference point B_{lim} has been decided on. If information about these parameters is unavailable, a score of 0/10 has been given to these stocks. The nine stocks relative to this study have an overall score of 47.8%, and hence, the resources are moderately sustainable. It is too farfetched to dismiss Norwegian salmon as not sustainable at all; there is no yes or no answer to this problem.

In this study, 33% of the stocks are deemed to be sustainably managed, and it is possible to say that the Norwegian salmon, on basis of feed, is 33% sustainable. This is a lower score than the overall score and raises the question of how results should be interpreted.

In either way, basing sustainability only on feed will be a too narrow perception, because there are other factors than just management deciding if salmon farming is sustainable. There are at least four other indicators that should be developed: For genetic interaction and escape, for pollution and emissions, for diseases and for area utilization. In further research, the methodology should be extended to include these issues as well.

7.2 Feed vs. food

Tacon et al. (2006) argue that the majority of fish used in feeding fish, either in the form of compound aquafeed or non-processed fish, are of potential food-grade quality and could be used for human consumption. One might wonder why it is not so, in a world where decreasing food security is a pressing matter. One important aspect is that dietary traditions and preferences vary among cultures and within cultures. Even though a resource may be plentiful in a country, it is not given that people will eat it. Cultural traditions often determine what is perceived attractive as feed. Contemporary Peruvians for instance, have no tradition of eating anchoveta (Tacon and Metian, 2009b). Anchoveta landings are large; about 5 million tonnes annually (Frèon et al., 2008). About 5% of landings have been destined for human consumption (Tacon and Metian, 2009b) and considering the enormous catch, 5% makes up about 250,000 tonnes, which is quite a large quantity. The anchoveta is a seasonal fishery and there is a limited consumption market and established processing capabilities. Production of fishmeal and fish oil therefore help conserve the catch and spread earnings over a longer period of time (Frèon et al., 2008).

The use of trash-fish constitutes a bigger threat to food security than the use of forage fish (Tacon et al., 2006). Trash-fish is an imprecise term used to describe marine organisms that are unattractive as food due to their small size or nature. Still, these organisms constitute an important source of animal protein for rural poor, especially in large parts of Africa and Asia (Wijkström, 2009). In 2006, trash-fish represented more than 60% of catches in some Asian fisheries. Trash-fish are mostly used in aquaculture practices, and in China about 4 millions tonnes is fed directly to cultured species (Tacon et al., 2006). There is increasing concern of a higher demand for trash-fish which will increase fishing pressure, drive up prices, and thus place the resources outside the economic reach of the poor (Tacon et al., 2006).

In Norwegian salmon farming, the only allowed feed is compound aquafeed and therefore use of trash-fish is not relevant. Nonetheless, the use of trash-fish is an important global problem which places the use of North Atlantic small pelagics and Peruvian anchoveta in a global context.

To state whether the destination of forage fish is sustainable or not is a complex matter requiring a dynamic answer. There are opportunities to increase direct human consumption of forage fish, but technological, economic and market limitations must be overcome (James, 1995; Blanco et al., 2007). It is argued by Tacon and Metian (2009) that forage fish are important in the diet of the poor, and that aquaculture is causing a reduction of this supply. Further, it is recommended that production of fishmeal and fish oil in countries with aquaculture production should be limited for the benefit of the poor (Tacon and Metian, 2009b). I disagree with this statement because, as described in chapter 5, the destination of forage fish is decided mainly by economic reasons, and also restrained by the rancidity of the fish in question. The fish is normally harvested in the open ocean, and when onboard facilities are lacking, the fish is destined for the aquafeed industry because of the lower quality. Needed management measures are therefore those related to infrastructure required to process fish and fish by-products, both onboard vessels and in facilities on land. The high perishability of most forage fish emphasizes the need for conserving the resources in a condition that makes it suitable for further processing. Therefore, it is necessary to establish by-product separation, classification and storage possibilities onboard the fishing vessels (Blanco et al., 2007). If succeeding in implementing such a structure, one will have greater opportunities in utilizing more of the raw material both for human food and for aquafeed. However, in many countries the infrastructure needed to achieve this is too expensive at the moment. Still, if successful in achieving the above, the problem of transport persists. The species utilized in Norwegian salmon feed are geographically located where the distance to rural poor requires special handling and storage of the fish, which inevitably will lead to increased prices. In Peru, the rural poor are located inland (Tacon and Metian, 2009b), and the situation will be similar.

Economic parameters must be fulfilled if more fish is to be destined for human consumption (James, 1995). The *Code of Conduct for Responsible Fisheries* (FAO, 1995:29) argues that “states should encourage the use of fish for human consumption and promote consumption of fish whenever appropriate”. Tacon and Metian (2009b) interpret this in line with the above requirement of a reduction of aquafeed production. My opinion differs from this, due to the fact that the development is market driven. If no consumers exist, and fish was still reserved for these nonexistent consumers, it would be wasting of resources and a clearly unsustainable practice.

However, if the resources were harvested near the poor, for instance in tropical areas where the human population is highly concentrated, it would be beneficial to save a certain amount for the poor. Less purchasing power must be considered and transportation cost kept low. Hunger is a question of buying power, not lack of food (Wijkström, 2009).

Whether or not this discussion is of relevance to the sustainability of Norwegian salmon is another matter. Ingredients utilized by feed companies differ depending on availability and price, and prices in the consumption markets are higher than in the fishmeal and fish oil market (FHL, 2009a; Wijkström, 2009). Because it is purely market mechanisms and economics that drive the destination of the resources, I will argue that this does not accrue to the sustainability discussion. Still, the companies themselves might have special requirements to the resources they employ in their feed. For instance, Skretting's Sustainable Economic Aquafeeds program excludes the use of red listed species in their production. On a general basis, companies only utilize resources subject to TACs (FHL, 2010a). However, TACs are not always in accordance with sustainability principles. What is often the case is that the gap between the ICES' advice and actual TAC, is due to socio-economic considerations. Fishers are dependant on a certain level of predictability in terms of how much they will earn, i.e. how much they are allowed to harvest. For this reason harvest rules have been developed in many fisheries[32].

7.3 Efficiency of feed

In terms of measuring sustainable or efficient use, no practical parameters have been developed. Looking at criterion 2, which accrues to the sustainability of a physical resource category pointed out by Langhelle (2000) and Stryken (2000), this could also be applied to food production. However, if doing so, it would not be very constructive, as all food production *per se* is not sustainable.

Considering what has been presented in this chapter, salmon stands out to be the best overall alternative. Salmon is beneficial for human health, and if it would increase production to such an extent that it excludes other actors from the fishmeal and fish oil market, it might be positive from a health perspective. Another aspect to consider is that once harvested, the forage fish has to be put at its best use. Looking at non-food use alternatives, salmon again

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[32] An example is The Norwegian-Russian Fisheries Commission, which is a bilateral management agreement. The commission operates with a guideline of a maximum 10% change in the quota for cod, *Gadus morhua*, on an annual basis. This rule is valid as long as the spawning stock biomass is above precautionary levels (Hønneland, 2006).

stands out as the best option with the highest proportion of edible meat produced per unit of feed. Market mechanisms decide on what resources are available for the aquafeed industry and this issue can therefore be perceived as not relevant in discussing the sustainability of Norwegain salmon.

The Norwegian FCR was in 2008 between 1.0-1.4 with an average of 1.2. This is a bit lower than the global average of 1.25 (Tacon and Metian, 2008). Change and development of feed conversion rates occur on a continuous basis. The average FCR in 2009 was 1.15:1, a small decrease from 2008 (FHL, 2009b). Some stakeholders state that the FCRs and FIFO ratios are too narrow and provide a perception on reality that is miscalculated (EWOS, 2010a; Skretting, 2010a). They highlight this by the following illustration: When making "smalahove", a traditional Norwegian dish made from a sheep's head, you need one sheep to make the dish, but it is not legitimate to state that a whole sheep is utilized (FHL, 2009a). Further, they argue that it is the same with the aquaculture industry. Fish oil is the bottleneck, and with the current requirements, there is leftover fishmeal and that is ignored in the calculations (FHL, 2009b; Skretting, 2010a). If this had been taken into consideration, the FIFO ratio would have been lower. It is also important to take notice of that FCR refers to the compound aquafeed, consisting of about 50% marine ingredients.

Determining the efficiency of feed is hard to measure without indicators and reference points. Still, looking at the trends, it is evident that the feed is becoming more and more efficient with a gradual decrease from a 3.5:1 FCR in 1975 (Tacon and Metian, 2008).

If comparing farmed salmon to wild, in terms of feed consumption, it will be more sustainable to farm, because a wild salmon has to eat 10 kg of wild fish to grow 1 kg (FHL, 2009b; Norsk Fiskeoppdrett, 2009). However, the relevance of this fact is limited in this study, but it is commonly used as a counter-argument for the accusation of draining the ocean for fish. The global FIFO ratio is currently at an average of 4.9:1 (2006), meaning that 4.9 kg of wild fish is needed to produce 1 kg farmed salmon (Tacon and Metian, 2008). The Norwegian salmon farming in particular, is experiencing a FIFO ratio much lower than the global average at 2.27:1, indicating that salmon from Norway is produced more sustainably than the global average.

Another aspect worth mentioning is the substitutes to marine resources. It seems that the sustainability of these resources is simply being overlooked. A number of these feed resources do not exist in Norway, and will have to be imported. The production and transportation of food crops also have socio-economic effects that should not be neglected.

This issue should also be subject to a sustainability discussion, but is outside the scope of this study.

7.4 The path forward

The preceding discussion has highlighted the difficulty of determining sustainability of Norwegian salmon farming without predetermined indicators and reference points. This is only possible for the forage fish in questions, and only from a biological perspective. For the time being, management of forage fish can be assessed on a quantitative basis and hence it is possible to determine *degrees of sustainability*. Regarding destination of harvest and efficiency of use, only a qualitative assessment is possible, and depending on who is performing the assessment, the outcome will differ. Therefore, I argue that the management and the state of the stock is what should be considered when discussing sustainability of Norwegian salmon. This will most likely change in the future, due to the fact that indicators for efficient use most likely have been developed. However, the trend is clear, salmon production is becoming more and more efficient. It is not possible to be 100% sustainable (not using more resources than produced) in food production. The focus should rather be on the products that are the MOST sustainable, environmentally friendly, and ethically sound.

The supply of fish in the future will depend on the effectiveness of fisheries management and whether aquaculture development is responsible or not. This will be a challenge in the future as more and more people are concerned with the concept of sustainability. A good first step in this process would be the provision of objective information regarding the stocks used for feed production and the impacts of aquaculture. The benefits of a more effective management are many, such as stable yields, larger and more valuable individuals, more selective fisheries leading to reduced discards and waste (Grainger, 1999). Utilizing harvests in the best possible way, reducing discards, better utilization of by-products and the combat of illegal, unregulated and unreported (IUU) fishing are all goals vital to sustainable management (Ministry of Fisheries and Coastal Affairs, 2009b).

Eco-labeling[33] is a possible solution for the determination of sustainability in markets. A fish stock certified by a renowned and legitimate labeling company could ease the decision-making for both the aquafeed industry and the consumers. When consumers decide upon what

[33] For an overview of eco-labels and their criteria: Sainsbury (2010) *Review of ecolabeling schemes for fish and fishery products from capture fisheries.*

they purchase they are concerned not only about the quality and content of the food. Production and environmental impact through the value-chain is also of importance to the consumer (Ellingsen and Aanondsen, 2006). Concerns about eco-labeling has been raised by stakeholders regarding the growing number of eco-labels (Intrafish, 2010). For the industry and the consumers' benefit, a formal code of standards should be established (Mouchly-Weiss, 2010). Formal standards will marginalize the producers who are not able to keep up with development and the requirements of the standard, and the producers who give the industry a poor image. For this to be successful, transparency and compliance are key ingredients (Mouchly-Weiss, 2010). For the consumers, shopping will be easier, because one label will represent legitimate and trustworthy aquaculture production that uses certified raw materials.

The Marine Stewardship Council (MSC) is a well known non-profit certification organization which could be responsible for this task. However, the organization has received a lot of criticism because fisheries under improper management regimes harming the ecosystem have been certified (Pope, 2009). Friend of the Sea is a non-governmental certification body like MSC (Sainsbury, 2010), and provides an eco-label for both fisheries and aquaculture.

The Aquaculture Stewardship Council (ASC) is the equivalent to the MSC for aquaculture operations, and the industry itself believes that the ASC will be the most suitable label for aquaculture products (Smith, 2010). The aim of the ASC is to "accelerate and upscale sustainable trade in mainstream markets" (Smith, 2010). The ASC recognizes that there are a variety of challenges facing the global aquaculture industry, and believes that the ASC as a multi stakeholder organization can be a step in the right direction. The stakeholders themselves state that it will always be focus on the negative aspects of aquaculture, but on the positive side this will drive improvement of the sector (BioMar, 2010a; EWOS, 2010a; Skretting, 2010a).

The International Fishmeal and Fish oil Organization (IFFO) initiated a business-to-business scheme in 2008, aiming to ensure responsible practices in the aquafeed industry (IFFO, 2009; Jackson, 2010b). If fulfilling the requirements[34] the respective companies will become certified with the responsible supply (IFFO RS) label. The trend is a chain of labels from the fishery (Friend of the Sea and MSC), to the aquafeed producer (Friend of the Sea and RS) to the fish farmer (ASC). Today, the NSS and North Sea herring are certified by

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[34] For more information: IFFO (2009) *Global standards for responsible supply: requirements for certification.*

MSC, and the anchoveta is certified by Friend of the Sea (Friend of the Sea, undated-a; MSC, undated-a; MSC, undated-b). 47 fishmeal and fish oil plants in Denmark, Iceland, Peru and USA have been certified by IFFO RS, where the majority are Peruvian (IFFO, 2010) Some fishmeal and fish oil plants are also certified by Friend of the Sea (Friend of the Sea, undated-b). ASC are yet to launch its label, which is expected in mid 2011, but species up for evaluation are among others salmon, tilapia, pangiasus and cobia (Smith, 2010).

ICES is the world's oldest intergovernmental science organization, founded in 1902 in Copenhagen (ICES, undated; ICES, 2008a). The organization was performing in an informal way until the 1960s, when such practice was perceived illegitimate in the light of the establishment of the United Nations in 1942 (United Nations, 1997). It took decades for ICES to reach its current position as an organization responsible for an international standard for assessing fishery stocks. Such a process is required for the aquaculture sector as well; it is essential with a well-established, legitimate and multilateral agreement for responsible aquaculture practices. It is necessary for someone to take the lead in initiation of a process like this, but who is responsible for the sustainability of aquaculture practices? Should Norway, as a pioneer country, establish an organization equivalent to ICES for the global aquaculture sector? Should single companies initiate a process? Or is the answer the Aquaculture Stewardship Council or any other certification agency? The main point is that simple indicators and reference points are needed to evaluate performance, impacts and effects from aquaculture. The ability to demonstrate sustainability could legitimize the Norwegian salmon farming as an environmentally friendly and a future-oriented industry (Guldseth, 2010). Establishing precise criteria would most certainly contribute to innovation and improvement of quality as well.

Chapter 8: Concluding remarks

Sustainable development as it is known from *Our Common Future* is an immeasurable concept. A much narrower and more specific concept is needed for the development of different sustainability indicators. The working concept developed in chapter 2 has proven to be practicable for this study, but the assumptions behind must be considered. My results indicate that Norwegian salmon farming is *moderately sustainable*, and this differ from the perception shared by the government and the industry, who perceive Norwegian aquaculture operations as sustainable (Ministry of Fisheries and Coastal Affairs, 2009b; FHL, 2010a). It is stated in the Aquaculture Act that aquaculture operations must be run in an environmentally responsible manner, but it is not indicated what this means, only that the precautionary principle must be applied at all times (Lovdata, 2010). It is all too diffuse and needs to be concretized.

Aquaculture has been identified as one of the tools to combat uncertain food supply, and buffer against dwindling fish stocks (Smith, 2010). New (1995) states that there are three ways to increase fish availability for human consumption:

1) Aquaculture
2) Fish enhancement or re-stocking
3) Utilization of discards and reduction of processing waste

If fish farming is to play a major role as a food production system, it is imperative that the fish species chosen for mass production should have herbivore or omnivore feeding behavior. Net protein production is possible when production is independent on fishmeal and/or fish oil. Nonetheless, farming of salmon and other carnivores, like shrimp, will continue to exist due to demand from wealthy consumers. Around 30 million tonnes of fish are destined for fishmeal and fish oil production annually (FAO, 2009) and if utilizing these resources in the most efficient way, aquaculture might be a part of the answer to global food deficits. Sustaining these resources must be a top priority. Salmon farming is recycling trimmings and offal, and can itself be recycled by the use of salmon trimmings in the production of omega-3 pills. If scarcity of fish oil becomes a severe problem, salmon trimmings can replace the raw materials used by the pharmaceutical companies and thereby release more raw materials for the use in salmon production. Recycling within the same species is not allowed, and increasing processing in Norway could be a step towards more flexibility in terms of resources for the omega-3 market.

Due to advances within feed technology the flexibility of feed resources are believed to increase in the near future, implying that feed production based on stable marine resources will not hamper a continued growth of salmon production in the short run. The aquafeed company Skretting has succeeded with diets containing only 15% of fishmeal and inclusion of active micronutrients without affecting growth or palatability negatively (Obach, 2010). Norwegian stakeholders also believe that ingredients not allowed in production today, for instance GMO and LAP, will be available in near future (BioMar, 2010a; EWOS, 2010a; Skretting, 2010a). Still, with an increasing demand for marine resources, feed shortage might cause difficulties in the long run. However, it is most likely other factors that will limit growth of Norwegian salmon farming operations on a short term basis: Of immediate concern is the threat sea lice and diseases pose on the industry and regulations might tighten if the proliferation continues. A reduction in biomass or an increasing distance between localities might be a possible response to diseases and lice (Ministry of Fisheries and Coastal Affairs, 2009b). Another factor is the limited supply of suitable locations, and the increasing competition for them between users (Andreassen et al., 2010; BioMar, 2010a). The availability of fishmeal and fish oil does not seem to be a limiting factor for further growth on a short-term basis, but will most likely pose certain challenges in the long term for the Norwegian salmon farming industry.

The Directorate for Nature Management has established a Nature Index[35] with the purpose of getting an overview of the state and development of biodiversity within major ecosystems in Norway. This index is the first of its kind on a global basis, and the project was initiated in 2005, five years prior to its publication. The overall aim of the index is to measure whether Norway will manage to stop the loss of biodiversity by the end of 2010 (Directorate for Nature Management, 2010). This index has been a large project involving many organizations and independent scientists with expertise in different ecological arenas. 309 indicators representing different aspects of biological diversity have been developed together with reference values. These values represent ecologically sustainable levels for the indicators, and when incorporated into the index, a resulting value will demonstrate how far from the optimum the respective indicator is located at a certain point in time (Directorate for Nature Management, 2010).

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[35] Directorate for Nature Management (2010) *Naturindeks for Norge 2010.*

The Nature Index is quite controversial and has received criticism because of the reference points and what they constitute (Skarpaas et al., 2010). The optimum reference values are scientific estimates of the original state of biological diversity, without human influence. These values are useful because it makes it possible to measure the degree of deviation as a result of human impact. It is emphasized by a number of scientists working on the project that the aim is not necessarily to restore biological diversity to a pre-human state, but with indicators and reference values in place, it is possible to discuss the quantitative information and how it should be interpreted (Skarpaas et al., 2010). I will recommend that the aquaculture industry should initiate a similar process; an identification of important indicators, with the aim of monitoring and evaluating effects of aquaculture, both in small-scale regional terms, and with a wider socio-economic perspective. The information generated through such an extensive project might prove more valuable than the actual expenses of conducting it. The discussion about sustainability would be more constructive, and actually mean something specific if an index was in place. As the situation is today, denoting salmon farming as sustainable is at best risky, as no precise manner of measurement to state this exists.

I have through this study implied a way of assessing the state of the stocks included in salmon feed, and highlighted aspects that ought to be included in indicators for assessing the use and efficiency of feed. However, more research is clearly needed, and socio-economic aspects should also be considered in the development of indicators and reference points.

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Appendix

Interview guide – aspects covered

Facts about production:
Species
FCR and FIFO
Share of trimmings and by-products
Share of vegetable fat and protein and its origin
Imports: From where, how much, species and share in feed
Products
Markets: to where and for which species

Management + import:
Responsibility in regards to management, both nationally and globally
Ethical considerations connected to imports
Pressure: consumer → aquaculture → aquafeed producer
Power of the industry to influence management

Sustainability and transparency:
External traceability, relative costs?
Member of the IFFO and the Responsible Sourcing scheme?
Perception of transparency, traceability and labeling.
Environmental report → more credible?
Sustainable if not transparent and traceable?

Media and reputation:
Media coverage
How is the above dealt with internally in the industry?
Cooperation with environmental organizations?
Measures to improve image in the nearby communities?

The future:
Share of trimmings, what will happen when Rubin is wound up?
Share of vegetable fat and protein
Imports
Competitiveness of the industry
Research
Distribution
Consumption vs. Industrial use
Management
Cooperation with NGO's
Certification schemes
Trickle effects due to pressure from consumers
Supply of marine resources
Harvest of lower trophic leveled species

Table 1: Species utilized in fishmeal and fish oil in the three main aquafeed producers in Norway.

Company	EWOS	Skretting		BioMar	
Species	Fishmeal and Fish oil	Fishmeal	Fish oil	Fishmeal	Fish oil/ensilage
Anchoveta	44	45.4	32.2	47	44
Blue whiting	8	7.5	1.1	13	3
North Sea herring				13	20
Trimmings		3.5	1.8	7	14
NSS herring				6	9
Sandeel	8	5.8	1.4	5	2
Sprat	4	4.7	7.2	3	6
Capelin		2.2	0.6	3	1
Norway pout		0.1		2	1
Other	12	0.4		1	
Herring (unspecified)	10	19.1	33		
Herring trimmings		7.5	15.6		
Horsemackerel			2.4		
South Pacific mackerel		1.6	2.4		
Sardine			2.4		
Mackerel		0.2			
Boarfish		2			
Jack mackerel	8				
Menhaden	6				
SUM	100	100	100.1	100	100