The Environmental Status of Norwegian Aquaculture

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Preface

The Bellona Foundation has always focused on the marine environment - and marine industries. Pollution of the oceans has always been central, whether our efforts have focused on manufacturing, radioactivity, oil and energy, shipping or fisheries and aquaculture. The struggle for clean oceans is the struggle to preserve nature's diversity for our descendants and produce food to sustain the world's future population. Although the oceans' potential for food production is enormous, it is threatened by radioactive contamination, oil spills, environmental toxins and climate changes. Clean oceans are absolutely essential to marine food production. Bellona intends to fight with all available resources so that we meet this requirement in the future as well. On board the eco-activist ship the S/S Kallinika, Bellona's environment patrol will be active anywhere the thoughtless decisions of politics and industry risk jeopardising marine environments and resources.

Closeness to nature and the sea has helped to mould the Norwegian national character. The recognition of the fact that we humans live from harvesting nature's bounty comes naturally to Norwegians. This recognition is the basis of Bellona's environmental protection efforts. It is also why Bellona is positive towards aquaculture as an idea. Aquaculture has quickly developed into one of Norway's most important export industries. Even though low prices and financial difficulties have dampened the optimism that marked the aquaculture debate only two years ago, we believe nevertheless that in the future old and new forms of food production based on marine resources will be a growing factor in the Norwegian economy. At the same time, we see that the industry has a considerable environmental impact, in the form of pollution as well as effects on Norway's unique wild salmon stocks.

Our aim with this report, The Environmental Status of Norwegian Aquaculture, is to create a sober-minded, scientifically-based factual groundwork that is intended to set the agenda for the debate on the environment and aquaculture in Norway. This report is meant to help to dispel misunderstandings and myths so that we can instead focus on the important challenges.

We have tried to include all the important environmental aspects of aquaculture, examining it from all angles and taking a look at resource use, pollution and the impacts on biodiversity and food safety.
We feel certain that this report is one of the most thorough and most integrated on the topic of aquaculture and the environment that exists between two covers.

Bellona's next step in its efforts in aquaculture will be to take part in the hunt for new solutions, new resources and new products that will take place in the years to come. We believe that pure and safe food from the ocean will play an ever more important role in the Norwegian economy.

Our ambition is to set the agenda for the political and scientific debate in the area of marine food production. With a scientific approach to environmental challenges, in partnership with research, the industry and the government, Bellona intends to stake out the course for the future.

Frederic Hauge

photo: Bellona archive

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Summary

The impact of salmon farming on wild salmon
In 2002, over 600,000 escapes from Norwegian fish farms were reported. A considerable percentage of these escapes were due to technical malfunctions and propeller damage. Bellona reports such incidents to the police, since the farms do not meet statutory requirements for proper technical standards and operation.

In certain fjord areas and salmon rivers, more than half of the salmon are escaped farmed salmon. If the percentage of escaped farmed salmon in the river is high compared with wild salmon stocks, the farmed fish can affect the wild salmon ecologically and genetically.

Salmon lice pose a serious problem to wild salmon. If the salmon lice are not under control in fish farms, the high density in fish farms on the salmon's route from the river to the sea may be a major source of infestation.

Discharges from fish farming
Pharmaceuticals used to combat salmon lice in fish farms are potentially harmful to animals and other organisms in the water and on the bottom around the cages being treated. Although the various substances have various environmental properties, the common denominator is that they are toxic to some species, though the harmful impact is limited to a relatively small area around the fish farms. Although the pharmaceuticals degrade slowly, they do degrade.

Previously there was widespread use of antibiotics in Norwegian fish farming, but vaccines, improved tending routines and better locations have reduced this problem to a minimum. Use has been cut from 50,000 kilograms to about 1,000 kilograms in 15 years. In Chile, the use of antibiotics is still high. The addition of antibiotics to the marine environment can lead to the development of resistance to antibiotics and delay the decomposition of organic material.

Fish farming in open cages causes the release of nutrient salts and organic material, in the form of feed spills and fish excrement. Such discharges can result in local pollution problems if the releases exceed the fjord area's carrying capacity. This may be the case if the farm is operated in areas with poor water exchange. In Norway, fish farming is done today largely in good locations, so that the release of nutrient salts and organic material is quickly diluted and dispersed in the ocean, where they do not pose an environmental problem.

To prevent the fouling of fish farm nets by shellfish, algae and other organisms, it is common to impregnate them with copper compounds. Eighty per cent of the impregnating material is dissolved while the net is in the water. Fish farming in Norway releases about 200 tonnes of copper per year. Since copper is considered an environmental toxin, any releases are undesirable. There are alternatives to copper impregnation, and Bellona would like copper impregnation to be phased out eventually.

Growth opportunities in marine food production
Farmed salmon are fed with pellets made of fish oil, fishmeal, vegetable oil and vegetable protein. It has been discussed whether farming salmon is a proper use of resources, since the feed used can feed people. A special focus has been on the use of fishmeal and fish oil. Here it is important to note that these resources are largely used for animal feed in any case. With this in mind, salmon farming is an efficient use of resources, since salmon utilize the feed more efficiently than chickens or pigs, for example.

If salmon farming is ever to be called sustainable, an important criterion is that the resources used for feed are harvested in a sustainable manner. The fish stocks in the world that go into fish feed today are as of today being fully utilised, and there is no room to tax them further. Any growth in global production in fish farming will therefore have to be based on sources of feed other than fish oil and fishmeal. Currently, various vegetable ingredients are increasingly being used. Other possible alternatives for the future are proteins produced with the aid of natural gas, marine resources harvested on lower trophic levels and the cultivation of algae, for example.

Even though the primary production of biomass is almost as high in the oceans as on land, only a small percentage of the food we eat comes from the sea. The reason is that we primarily harvest from the top of the marine food chain, whereas we have based our food production on land on the cultivation of plants and the raising of herbivores. The immense production of biomass in the sea constitutes an enormous potential for food production, which can be exploited with the aid of cultivating and harvesting at lower levels of the food chain. Such developments should be based on knowledge and respect for the balance and carrying capacity of marine ecosystems.

Food safety
Environmental toxins like heavy metals, PCBs and dioxins from previous and current discharges accumulate in the marine food chain and may therefore present a problem to fish farming based on raw materials from fish. Strict monitoring of raw materials and products is therefore necessary to ensure safe seafood. In Norway, test results from the National Institute for Nutrition and Seafood Research show levels of environmental toxins in farmed salmon below stipulated threshold values, and farmed salmon is therefore safe for consumers to eat.
The dyes that are added to fish feed to give salmon fillets their desired red colour are carotenoids equivalent or similar to those found in the natural diet of wild salmon and pose no health risk to consumers.

Cod farming
Rapid growth is expected in cod farming. There are reasons to expect similar problems with parasites and diseases seen in salmon farming, for example, even though cod farming is able to benefit from experiences gathered from salmon farming.

Mussel farming
Farming filtering species such as mussels is a potentially green and not very resource-intensive method of food production. Mussels feed by filtering seawater and thus require no additional feed. Although the potential is great, the availability of suitable locations may be limited.

Introduction

In three decades the Norwegian aquaculture industry has grown from almost nothing to a production of nearly 500,000 tonnes. With such rapid growth, it is no surprise that environmental considerations have not always been addressed. In the eighties the use of antibiotics exploded, and local pollution problems with eutrophication arose when the location's carrying capacity was exceeded. Much has improved since then, and the problems with antibiotics and eutrophication have been virtually eliminated. At the same time, a higher production volume has meant a greater need for resources for fish feed, and the problem of fish escaping from fish farms has not diminished.

This report aims to describe the environmental status of Norwegian aquaculture, as it appears today. The main focus is on salmonid farming, since as of today this is the predominant industry in aquaculture. Nevertheless, many of the issues discussed are relevant for the farming of other fish species that are in the starting gate for commercial farming. At the same time the farming of new species raises new environmental questions, and we have included a brief review of cod and mussels in Chapters 5 and 6, respectively. New farmed species beyond these have not been given priority at this time.

Chapter 1 addresses the impacts of salmon farming on wild salmon. The chapter discusses the problem of escaping from fish farms in terms of causes and scope before giving a thorough introduction to the ecological and genetic impacts on wild salmon. This section probably assumes previous knowledge of biology by the reader, even though we believe that anyone interested will derive great benefit from the material. Finally, Chapter 1 outlines the problem of the spread of salmon lice from farmed salmon to wild salmon.

Chapter 2 addresses discharges from fish farming into the marine environment. Three pharmaceuticals to combat salmon lice are evaluated for environmental impacts. We would have liked to include all such pharmaceuticals here, but owing to insufficient capacity have had to limit our survey. In this chapter we have also made room for a review of integrated combat strategies and alternatives to the use of pharmaceuticals, where especially the use of wrasse is discussed in detail. The chapter then discusses the environmental impacts of antibiotics use and what has made the sharp decline in use possible. Finally in Chapter 2 we examine the environmental impacts of discharges of nutrient salts and organic material and how adapting to the local carrying capacity is crucial for the condition of the environment in the fjord surrounding the fish farm.

Chapter 3 examines growth opportunities in marine food production in a relatively broad perspective. Here we attempt to present a picture of the oceans' potential for increased food production. The chapter begins with a discussion of whether salmon farming is an efficient use of resources and continues with an evaluation of the sustainability of the fish resources used for fish feed. Chapter 3 ends with an examination of various ideas for new sources of feed and reports on the state of research on how these are utilised.

Chapter 4 addresses food safety and reproduces test results for selected heavy metals, PCBs and dioxins. The test results are compared with threshold values. This chapter also addresses dyes used in salmon feed to give salmon fillets the desired red colour and considers whether these present a health risk to consumers.

As mentioned above, Chapter 5 provides a brief review of the problems that can arise if cod farming becomes widespread. Discussed in particular is the spread of parasites and diseases specific to cod and thus not covered by the other chapters.

Chapter 6 covers shellfish farming, a form of food production Bellona is highly favourable to. This chapter focuses more on the potential and limitations of shellfish farming than on adverse environmental impacts.

Chapter 7 gives an account of the government regulations that cover Norwegian aquaculture. Key to this are the Aquaculture Act and the Operation and Diseases Regulations. Here a particular focus is on criminal sanctions in connection with escaped fish from fish farms.

One of the authors of this report on board Kallinika - the Bellona crusade ship - on his way to a protest action in Sweden.
photo: Bellona archive

Chapter 1
Impacts of salmon farming on wild salmon

photo: Per Eide

1.1 Salmon escape from fish farms

The Norwegian government's long-range paramount goal is that the volume of escaped fish from fish farms should not represent a threat to the maintenance of Norwegian wild salmon stocks (Directorate for Nature Management, 2000). In 2002 a total of 614,000 salmon and trout were reported as escaped from Norwegian fish farms (Directorate of Fisheries). Statistics show that, except for 2002, the number of reported escapes has fallen in recent years. At the same time there is reason to suspect considerable underreporting. Some producers may fail to report out of fear of criminal sanctions and bad publicity. Farmers may find minor escapes not really worth reporting, since the value is too low for insurance payments to be profitable. Nevertheless, the figures reproduced here are taken from Statistics Norway and the Directory of Fisheries' annual statistical survey, in which escape figures are included in the data submitted by fish farmers. Since the data on which the statistics are based are confidential and cannot be used for monitoring purposes, fish farmers have little to fear in submitting correct escape figures.

1.1.1 Causes and liabilities

Figure 1 shows the most common causes of escapes broken down by cause (Vannebo *et al*., 2000). The categories "propeller damage", "handling", "installation mal-

Landing the fish mechanically, a common reason for fish escapes. photo: Per Eide

function" and "technical malfunction in hatchery" all together comprise 53.1 per cent of the number of escaped fish and 63.2 per cent of insurance events. What these four categories have in common is that these escapes can chiefly be blamed on the fish farmer and/or supplier of equipment and services such as transport (wellboats) nets, vessels, smolt and the like.

Bad weather included in the category "installation malfunction" was in the period 1994-1999 responsible for 30 per cent of the number of escaped fish and 12.5 per cent of insurance events. Although the weather cannot be blamed on fish farmers, questions may be raised about fish farms located in the sea that do not withstand bad weather. In the statistics for 2002 the Directorate of Fisheries eliminated the heading "bad weather" and replaced it with "installation malfunction". Damage by predators, responsible for 20.5 per cent of escapes, may also be discussed in this manner. Assuming that the installations that are common in fish farms as of today are defined as legal, both bad weather and predator damage can be placed in the same category as collisions because the escape is due to circumstances over which the producer has no control.
In many cases Bellona has reported producers to the police in connection with serious escapes. The fish farming companies were reported for violation of Section 16, first paragraph, cf. Section 25, of the Aquaculture Act and Section 3 of the Regulations of 18 December 1998 relating to Establishment, Operation, and Disease Prevention Measures at Fish Farms. Pursuant to Section 16, first paragraph, of the Aquaculture Act, fish farms shall meet "adequate technical standards", and Section 3 of the Operation and Diseases Regulations (of 18 December 1998) and fish farming activities shall be operated in such a manner that ".... they are technically, biologically and environmentally acceptable".

Producers have a vested interest in preventing escapes. An escaped fish is a lost fish, and regardless of the insurance scheme, escapes are bad for business. That is why Bellona does not suspect anyone of deliberately letting fish escape. But in light of the requirements of the Aquaculture Act for environmentally sound operation and technical standards for fish farms, in individual cases we choose to report escapes to the police anyway. In other words, Bellona believes that incidents of salmon escaping are criminal acts when they are due to deficiencies in routines or malfunctioning installations. Bellona's interpretation was confirmed by a ruling against Dåfjord Salmon in the Hålogaland Court of Appeal. It makes no difference that the escape is caused by an accident. If an accident can lead to thousands of salmon escaping, the operation is not environmentally acceptable and in violation of the requirements of the Act. However, Bellona's experience with the escape issue has told us that the problem is taken very seriously by the industry itself, and there is a growing focus on escape-prevention measures. Research projects on new technology, training courses for employees and other actions have been implemented.

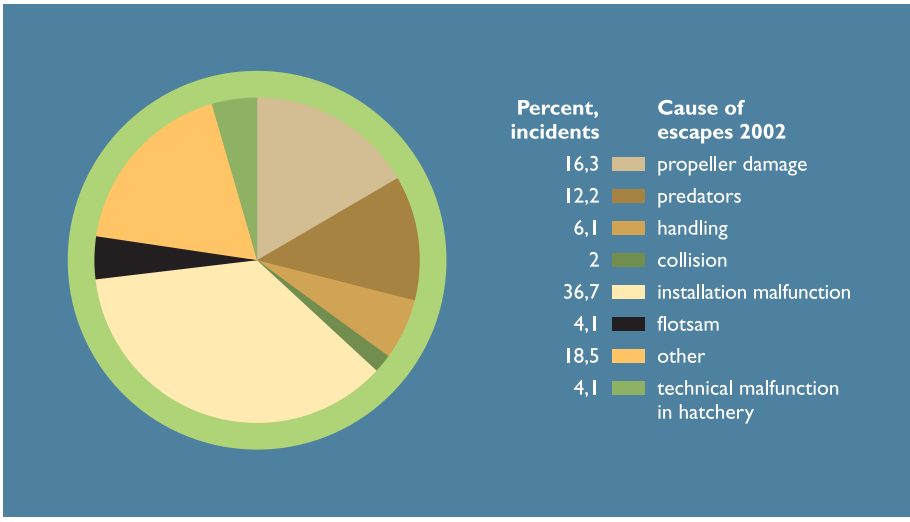


Figure 1:
Cause of escapes 2002, number of fish
(Directory of Fisheries, 2003)

1.1.2 NYTEK - Technical standard for fish farms

The general requirements of the Aquaculture Act for adequate technical standards are now being fleshed out with a new regulation relating to "technical standards for installations used in fish farming activities". If adopted, the draft regulation means that all fish farms have to meet the proposed standard NS: 9415, Floating fish farming installations - Requirements for design, dimensioning, production, installation and operation. The proposed

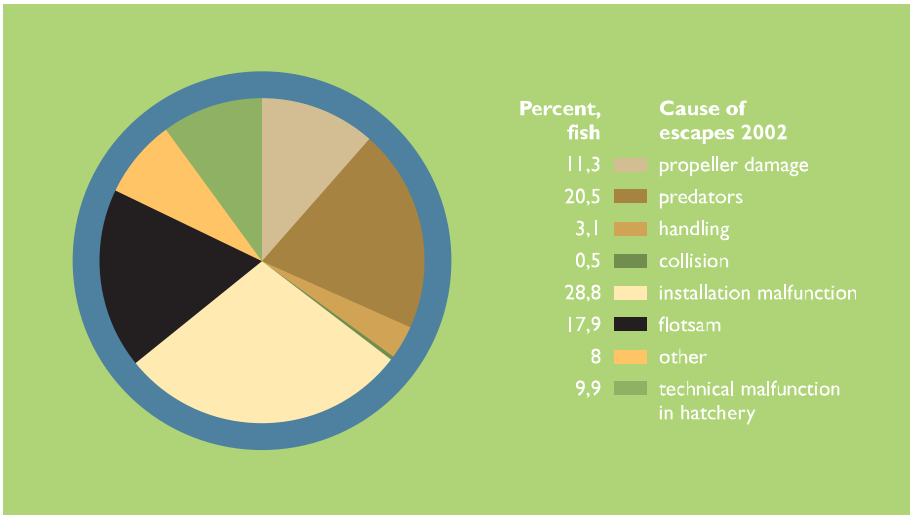
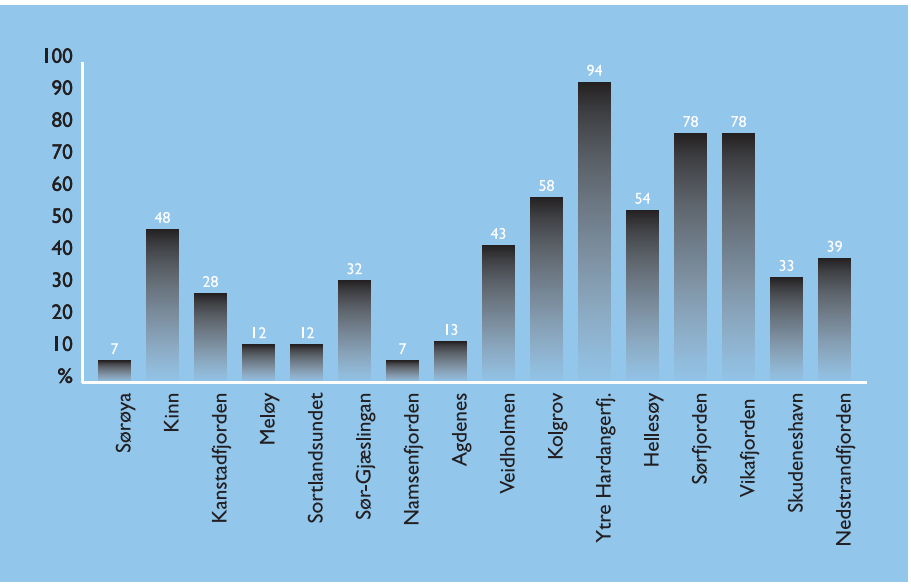


Figure 2:
Causes of escapes 2002, by number of incidents
(Directory of Fisheries, 2003.)

Handling netpens with a crane may cause damage to the net and, in turn, fish escapes. photo: Per Eide

standard, which is under discussion, was drawn up by a committee consisting of representatives of the authorities, industry, suppliers and other resource persons. The design requirements cover all main components, i.e. nets, mooring, floating collars, rafts/barges and any extra equipment. Competency requirements will be set in accordance with the natural constraints of the location in question. To address this, the standard will include a system for classifying locations by the environmental impacts the installation will be subjected to. If the regulation is adopted, the requirements will apply to new installations effective 1 April 2004. For existing installations there will be a transitional scheme featuring a so-called certificate of fitness based on the same requirements that apply to new installations.

Figure 3:
Share of escaped farmed salmon in salmon catches at different locations, 2002. (NINA, 2002)



1.1.3 Occurrence of escaped fish in rivers and the sea

The overview of the number of farmed fish that escape serves as an indicator of where the industry stands in its escape-prevention efforts. To measure the environmental impacts of escapes, it makes more sense to look at the quantities of escaped fish found in areas crucial to wild salmon, both in rivers and in the sea. The Norwegian Institute for Nature Research (NINA) does test catches in various places, and with the aid of scale samples the percentage of escaped salmon can be determined. Figure 3 shows that escaped farmed fish completely dominate some fjord areas.

1.2 Impacts of escaped farmed salmon

Every year large numbers of farmed salmon escape from Norwegian fish farms. The official escape figures from Norwegian fish farming for 2002 is over 600,000 and has been between 1.6 million and 272,000 in the past ten years (Fiske *et al*., 2001; Anon., 2002). What then is the problem? How can the addition of more salmon to the rivers actually be harmful when many of these populations are critically small? The answers to these questions are not obvious. Escaped farmed salmon is a relatively recent phenomenon, and research into this problem is time-consuming, so that the answers have not begun to emerge until now. Nor have concerns been always equally well justified and were partly based on assumptions regarding the connection between the decline in many wild salmon stocks and large escape figures. This has provided incentives to research in this field, and the following is an attempt to summarise and draw conclusions based on what we know today. A number of technical terms used in the text are explained in a separate glossary at the end of the chapter.

Escaped farmed salmon can affect wild salmon on several levels, both ecologically and evolutionarily/genetically (Blaxter, 1997). Escaped farmed fish appear together with wild fish in the sea as well as in rivers, thus constituting an (ecological) competitor to wild salmon in addition to being a spreader of parasites and contagion. Escaped farmed salmon can also breed with wild stocks, supplying the wild population with genetic material carried by the farmed fish and genetically altering the wild population. The ecological impact of escaped farmed salmon on wild stocks may also indirectly affect the genetic material of wild fish in that stocks are reduced and wild fish have to adapt to the high number of farmed salmon (Mork *et al*. 1999). Likewise, genetic changes result in a change in ecological and behavioural traits.

1.2.1 Ecological impacts

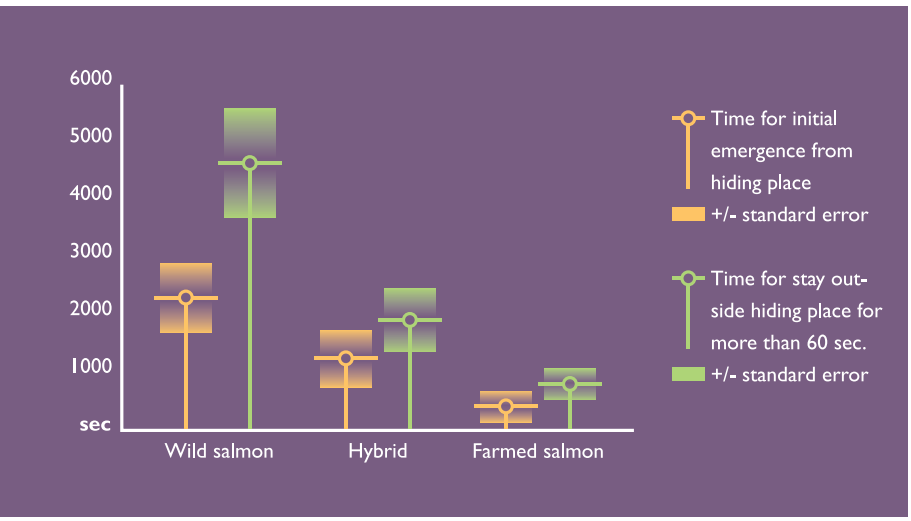
Impacts in the ocean

Numerous studies have shown that the percentage of farmed fish in the ocean can be up to 50% several places (e.g. Fiske *et al*., 2001). This can have implications for wild stocks in two areas: transmission of disease and competition for food. However, problems with designing studies that can demonstrate this quantitatively mean that to Bellona's knowledge there are currently no data on this.

The Neiden-river, far east in Finnmark, is known to be a great salmon river
photo: Bellona archive

Later migration

Farmed salmon migrate up rivers later than wild salmon (Lura & Sægrov, 1991; Fiske *et al*., 2001). The reason for this is partly environmental and partly genetic: being raised in hatcheries and sea cages make the fish less imprinted by location. They often migrate back to the area that they escaped from, and from there up adjacent rivers. This delays farmed salmon compared with wild stocks. In addition, selection for late sexual maturity (see Table 1) will have a reinforcing effect outside the fish farm, which affects wild salmon populations in many ways. Furthermore, as a rule, the angling season tends be concentrated around the time before most of the farmed salmon migrate (Fiske *et al*., 2001). This means that it is primarily wild salmon that are subject to being caught by anglers. Another consequence is that the farmed fish ruin spawning beds where wild stocks have already spawned. Fleming *et al*. (1996; 2000) showed that farmed fish largely display spawning behaviour that yields highly unsuccessful attempts at spawning and spawning beds.



Figur 4:
Tid lakseyngelen gjemmer seg etter eksponering for en modell av en predator. (etter Einum & Fleming, 1997)

Growth in the river

Einum and Fleming (1997) conducted laboratory experiments as well as stocking tests with parr (salmon up to two years old). They compared farmed salmon from the Aqua Gen breeding station in Sunndalsøra with first-generation descendants of wild stocks from the rivers Imsa and Lone as well as hybrids from crossings between farmed fish and wild salmon. In sum, the laboratory experiments concluded that the farmed parr behaved differently compared with the wild salmon, and that the hybrids were somewhere in between.

In the experiments with parr, the farmed fish were shown to dominate wild stocks from Imsa. Again, the hybrids were somewhere in between. For the Lone fish, the hybrids were dominant. This shows that all the dominant fish had at least half of their genes from farmed fish. An estimate of aggression yielded a corresponding result.

It may seem paradoxical that a breeding programme has selected for aggressive fish. Unintentional selection of behavioural traits is known from a number of animals; for instance, the breeding of animals such as lions and tigers in zoos has selected for less aggressive individuals (Gilligan & Frankham, 2003). That the opposite has been the case for salmon makes sense, since rapid growth in an environment with a nearly unlimited supply of food and the absence of predators (discussed in Fleming & Einum, 1997). Fleming & Einum (1997) conclude that farmed fish have altered many traits that make them poorly adapted to a natural environment compared with wild stocks.

In another experiment (Einum & Fleming, 1997) fish were exposed one at a time to a model that was supposed to resemble a potential predator fish. The fish were subjected to a simulated attack from a predator in a tank with only one hiding place. The time before they emerged from hiding, as well as the time they stayed for longer periods (more than a minute) outside the hiding place, was recorded (see Fig. 1). The experiment yielded significant differences between farmed fish vs. hybrid fish and hybrid vs. wild fish. Similar findings have been made for rainbow trout Onchorhynchus mykiss (Johnsson & Abrahams, 1991; Brejikian, 1995). This may indicate that this type of behaviour in salmonids has a strongly heritable component and that several genes are involved.

Fleming & Einum (1997) used the same farmed line from Sunndalsøra, while they took wild fish from the river Namsen, which has provided most of the genetic basis for the original parent fish for this farmed line (Gjøen & Bentsen, 1997). The results of Fleming & Einum (1997) are also supported in the literature (Johnsson & Abrahams, 1991; Brejikian, 1995; Einum & Fleming, 1997); farmed fish are significantly more aggressive than wild fish.

Ever since 1975, growth speed has been selected for in farmed fish (see Table 1). All studies Bellona is familiar with show that farmed fish and their progeny grow faster than wild fish. Fleming *et al*. (2000) showed that that progeny of farmed fish and wild stocks compete for habitats and food in the river. Domineering and aggressive progeny of farmed fish will therefore give wild stocks keen competition.

From experiments in the wild (McGinnity *et al*., 1997; Fleming *et al*. 2000) we know that wild salmon's production of emigrating smolt is sharply reduced when they

grow up in a river together with the descendants of farmed salmon and hybrids. In Fleming *et al*., (2000) the reduction was greatest for the progeny of wild female salmon; more than 30% fewer than expected. In this study, salmon fry and smolt grew up without competition from older generations, and the result may therefore be an underestimation of the problem. Nevertheless, this shows that the productivity in a salmon stock drops when farmed salmon infest the river during the previous generation. The apparently paradoxical result shows that wild salmon populations are expected to shrink in the following generation when individuals are added that originate from fish farms.

Reduced success in spawning in escaped farmed fish

Fleming *et al*. (2000) released wild and farmed salmon in a restricted area in the river Imsa. Parallel with this, farmed and wild fish were kept in an artificially created spawning area inside a laboratory. From this experiment they discovered that farmed salmon had poorer success in spawning than wild salmon (the farmed males had just over 20% of the success in spawning of the wild males. For the females, success in spawning was over 30% of that of wild fish.); the farmed fish displayed unsuitable spawning behaviours; made fewer spawning beds; the farmed females did not use up the milt (most remained, even after spawning); and the roe was both smaller and had lower survival rates than those of the wild salmon. In addition they saw that the descendants of farmed fish migrated earlier out to sea and were smaller in size.

In the study of Fleming *et al*. (2000) the wild fish, farmed fish and hybrid fish were marked and then allowed to migrate to the sea. The fish were then recaptured when they returned to the river as sexually mature. On the basis of this, the lifelong fitness of the farmed salmon was calculated at 16% of that of wild stocks.

The percentage of sexually mature parr is lower in the farmed salmon (about 20%) compared with the wild salmon (about 45%) (Fleming & Einum, 1997). Although this is a natural change in the life history resulting from selecting for late sexual maturity (see Table 1), at the same time this will change the balance between these two life histories that are both evolutionarily stable strategies (ESS). How this will change the population sizes in the wild has, as far as we know, not been investigated, and what the impact will be is therefore uncertain.

Einum & Fleming (1997) conclude that farmed fish outcompete wild fish at certain life stages and thus displace the locally adapted wild stocks. At other stages of the lifecycle, however, farmed fish will be less well adapted than wild stocks, and the population will thus decline. The results of this study may indicate that the risk of population reduction is greatest in populations with a lot of predation and slow growth.

1.2.2 Indirect genetic effects

A situation mentioned by many researchers (*e.g.* Mork *et al*., 1999), is that the subsequent "natural evolution" of salmon in the wild may be influenced by the presence of escaped farmed salmon and their progeny. As of this writing, Bellona is unaware of any concrete data that quantify this problem, and designing studies to test this is difficult. Nevertheless, it makes sense to imagine changes in at least two areas:

a) increased genetic drift if farmed salmon reduce and displace wild populations
b) altered selection regime due to competition from farmed fish and altered disease picture

1.2.3 Genetic interactions

There has long been concern that escaped farmed salmon may harm the various wild fish populations through hybridisation and altering the gene pools of wild populations (Hansen *et al*. 1991). There are several problems that can arise in this connection. If the farmed salmon have different characteristics and adaptations from wild salmon populations, gene flow may cause the wild salmon populations to lose characteristics that are crucial in a natural environment, while they adopt more of the farmed salmon's characteristics. On the other hand, if the escaped farmed salmon have less genetic variation than wild stocks, gene flow to the wild population will cause individual populations to lose variation (Tufto & Hindar). Variation is essential for two reasons (Hedrick, 2000), evaluated from both a short-term and a long-term perspective. A population that loses variation and thus becomes genetically uniform will be less resistant to disease and parasites. Or put another way: it is easier for a parasite to adapt to a population of genetically similar individuals (few polymorphic loci in the population and low heterozygosity) and where the individuals themselves have little variation (the individuals have few heterozygous loci). Additionally, in theory some of the harmful, recessive alleles will increase in frequency and produce less viable individuals (inbreeding depression). Studies just out (Reed & Frankham, 2003) empirically show that there is a good connection between fitness and heterozygosity, population size and quantitative genetic variation. Heterozygosity explains about 20% of the variation in fitness. In the long term, a population with little polymorphism will not have as great an evolutionary potential as a population with a lot of genetic variation. All escaped

farmed fish will come from a small number of farmed populations, which will lead to different populations becoming more like one another. It has also been claimed that coadapted gene complexes may dissolve. The following is an attempt to clarify relevant concepts and summarise empirical studies.

Evolutionary forces: mutation, selection, migration and drift

From modern evolutionary theory we know that there are four key forces that induce a population to change over time. These forces are selection, mutation, drift and migration. Even if all alleles originate in mutations, such events are all too rare to be an important force in ordinary evolution. It is therefore disregarded as a cause for fixing an allele or trait in a population. Drift is the random selection of gametes with different sets of alleles. The potential for evolution caused by drift is therefore inversely proportional to population size. Selection is probably the best-known evolutionary force and is caused either by survival and reproduction ("natural selection"), breeding ("artificial selection") or sexual selection. Migration (gene flow) means that individuals from a donor population reproduce in a recipient population. Migration results in the recipient population becoming more like the donor population. Although the donor and recipient populations will at the outset normally differ from each other in several characteristics and genes, unlike drift, migration will necessarily impact all these characteristics simultaneously. Like selection, migration is both deterministic and directional.[1] For its part, drift is deterministic, but not directional. Selection can counteract migration, drift and mutations; if drift or migration has increased the frequency of alleles that produce low rates of survival and reproduction in earlier generations, natural selection can reduce them. Nevertheless, modern evolutionary theory says that migration is a very important evolutionary force, which can override selection and lead to less adapted populations (Graur & Li, 2000; Tufto, 2001; Lenormand, 2002).

Breeding and evolution

Traditional livestock breeding and evolution in the wild have several similarities. The biggest differences are that natural and sexual selection are more important in the wild, whereas artificial selection is more important in breeding programmes. In addition one can say that unlike natural selection, artificial selection has a goal. The fact that these mechanisms have certain similarities does not mean, as we try to elucidate in this chapter, that bred organisms are necessarily "natural" or harmless if introduced into the wild. Genetic drift is an important evolutionary force in small populations. A general rule of thumb[2] says that populations of fewer than 500 individuals will lose genetic variation. After many generations, the genetic variation will no longer allow adaptations to the environment. A population of fewer than 50 individuals will after a few generations suffer from inbreeding depression.

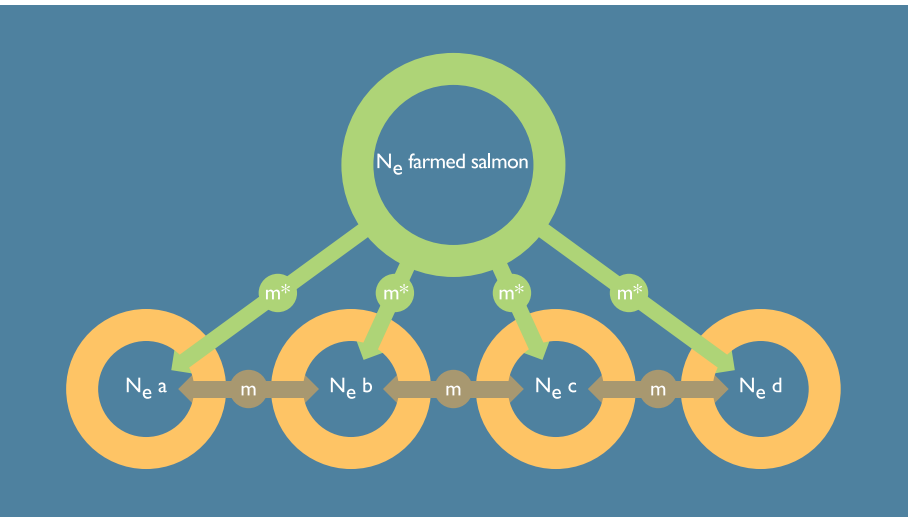
Practically all traits have a genetic component. In addition, many traits have an environmental component, which is not inherited in the same manner. In an evolutionary perspective, only the genetic component is interesting. A trait may be physiological, behavioural, anatomical etc, and one or more genes may be controlling the trait. Most genes have a specific location in the genome. This place is called a locus. When a mutation occurs, a new variant of the gene arises. Such gene variants on the same locus are called alleles. All alleles once arose by a mutation, but mutations are so rare that they cannot be an evolutionary force. Many of the alleles can be found in a population's overall "genetic library", its gene pool.

Gene flow from farmed salmon to wild salmon

With a higher than 95% probability, wild salmon will return to the river they grew up in. The probability of migrating to the wrong river is greatest for geographically close rivers (Bentsen, 2000). This means that the salmon populations along the Norwegian coast are structured essentially according to what in ecology is called a "steppingstone model" (Kimura & Weiss, 1964.).

Figure 5 illustrates the observation that wild populations in geographical proximity engage in little genetic exchange, but that selection and migration work together and maintain local adaptations for fitness-related traits. The homogenisation that takes place naturally will be of a different degree and intensity than the kind that escaped farmed fish bring about. First, migration from farmed

Figure 5:
Figure 5: A model for gene flow in salmon. The circles represent the gene pools of the "population" of farmed salmon and of wild populations [B, C, D and E]. The arrows represent gene flow between the populations, m is the migration rate between two geographically near salmon populations, m* is gene flow from the farmed fish populations to the wild populations. Note that the gene flow from the farmed population to the wild populations is one-way, while there is gene flow both ways between two close wild salmon populations. The farmed fish are not affected by wild stocks, whereas the wild salmon populations affect one another. For Norwegian salmon, m < 0.05 is a likely estimate. For many wild salmon populations, m* will be far greater, some places 20-30% (Fiske *et al.*, 2000; Fleming *et al.*, 2000). The effective population size (Ne) for farmed salmon would be from 30 to 125 (Bentsen, 2000). For wild salmon populations, it will normally be greater and much greater in the major salmon rivers.



salmon only goes one way. This means that wild populations are supplied with more or less that same alleles or allele frequencies in each generation. Second, farmed fish share the same gene pool or a very few gene pools. Drift will cause the various farmed lines to "drift" apart. Regardless of where the fish escape from, it has the same genetic basis or it shares the same gene pool with many other farmed fish. This results in differences between the various wild populations shrinking due to gene flow from escaped farmed fish.

In the section "ecological impacts" we saw that the success in spawning and the life-long fitness of escaped farmed fish are reduced compared with wild fish (Fleming *et al*., 2000). Nevertheless, this yields a migration rate (m) equal to 0.19, which shows that there is a not unsubstantial gene flow to the wild population, even though the farmed salmon are poorly adapted to natural conditions. With a ratio of farmed salmon of about 50%, which was the case in this experiment, the genetic dissimilarities between the farmed population and the wild population was cut in half in 3.3 generations (Fleming *et al*., 2000).

Year	Trait
1975	Growth (slaughter weight)
1981	Age of sexual maturity
1993/(94)	Resistance to disease[3]
1994	Colour of flesh
1995	Shape
1995	Fatcontent and distribution

Table 1: Selected traits in the Norwegian breeding programme for salmon. (Modified according to Gjøen & Bentsen, 1997.) Year indicate when selecting for the various traits began.

Hybridisation with other species

Norwegian salmonids are good biological species with well-developed pre- and postzygotic barriers where they coexist. Although prezygotic barriers are greatest where the various species live together naturally (Youngson *et al*., 1993; Verspoor, 1988), hybrids may appear that are not completely sterile. This means that gene flow between species (introgression) can occur. However, the percentage of hybrids is very small, especially where the species live together naturally as they have done in Norway since the ice receded at the end of the last Ice Age. There is reason to believe that there is no extensive gene flow between wild populations of the species salmon (*Salmo salar*) and trout (*Salmo trutta*) in Norway. However, it has been shown that escaped farmed fish hybridise with trout to a greater extent than wild fish do: in individual stocks with a lot of farmed fish up to 7.5% hybrids between salmon and trout has been recorded (Hindar & Balstad, 1994; Youngson *et al*., 1993; 2001). In the short run this will lead to a decline in the stocks, while the long-range consequences of increased introgression are impossible to predict.

The breeding programme behind Norwegian farmed salmon

The basis population of the Norwegian breeding programme[4] was taken from Norwegian salmon rivers in 1971 - 1974 (Gjedrem *et al*., 1991) and consisted of fertilised salmon ova from forty Norwegian rivers (Gjøen & Bentsen, 1997). Approximately twelve "full-sibling-groups" were taken from each river (Gjøen & Bentsen, 1997). The material gathered was divided into four lines where the fish were only crossbred internally. In addition to the breeding programme described above, breeding was also done at private aquaculture stations, and the total number of breeding lines has been between eight and fifteen (Gjøen & Bentsen, 1997). There were attempts to cross individuals from the private breeding lines into the national programme, but this led to a reduction in one or more of the traits that had been selected for, and these "hybrid lines" were therefore not further crossed into the breeding lines. Later, individuals from the Norwegian breeding programme were to varying extents included in smolt production in countries such as Australia, Canada, Chile, the Faeroe Islands, Iceland, Ireland, Scotland and the US (Fleming *et al*., 2000), though here fish originating in other countries were also included.

Beginning in 1975, artificial selection for increased weight began by using the trait "slaughter weight" (Gjøen & Bentsen, 1997). Subsequently other traits were added, and (as of 2001), five traits are selected for (see Table 1). Experiments have also begun to investigate the genetic component to resistance against salmon lice (Soppeland, 2002), the purpose of which is to investigate possible heritability for eventual inclusion in the breeding programme.

N_e for the Aqua Gen lines where such data are available is between 30 and 40 (maximum 125) (Bentsen, 2000). This is far below what is recommended for the long-term maintenance of a population (N_e = 500). It is also below what is recommended for short-term preservation (N_e = 50). Of course, these are not hard and fast rules. Further, it is reasonable to believe that N_e is greater for the Aqua Gen breeding programme than it is for the private breeding lines. The best way to find answers to whether the breeding system is resulting in the loss of genetic variation is to investigate assumed neutral loci by using molecular markers. If there is less heterozygosity in the private breeding lines, this type of genetic contamination will be greatest from these lines.

1 In nature the direction of selection will not necessarily be constant over long periods of time.

2 The rule of thumb cited here is the somewhat controversial "50/500-rule". On the one hand it has been argued that this is too low an estimate. Opponents of this view attach special importance to structured populations. On the other hand, some claim that even smaller populations manage fine. An example of this is the Chattam Island black robin, whose population was down to one female and two males (Ardern & Lambert, 1997). After a comprehensive rescue operation, this species has now grown to several hundred individuals. Nevertheless, critics have two objections to such examples. First, the fitness of individuals in today's population may be lower compared with individuals from the original population. Second, a population with little genetic variation can more easily be weakened by a future parasite, disease or other environmental change.

3 "Research on resistance against furunculosis was initiated in 1990 and implemented in the breeding programme in 1993. One year later ISA was also implemented in the programme."

4 "The Norwegian breeding programme" means the lines that AKVAFORSK, NLA and Aqua Gen have bred in Sunndalsøra and Kyrksæterøra (after 1986). Although other private lines have been bred at the same time, AKVAFORSK has been responsible for most of the Norwegian salmon production.

1.2.4 Reduction in genetic variation

Mjølnerød *et al.* (1997) compared the genetic variation in neutral markers for wild salmon from Tana, Numedalslågen and one of the four farmed breeding lines from Aqua Gen. They used three types of genetic markers that are well suited for studying genetic variation at the population level: twelve polymorphic allozymes, three single-locus minisatellites and one multilocus minisatellite. The comparison showed that the number of alleles had been reduced for all the markers in the farmed breeding line. In addition, several of the allele frequencies diverged from what was expected. In sum, this indicates that drift has greatly impacted the farmed salmon's genetic material and that the farmed salmon have lost genetic variation as a result, which is supported by other literature in the field (*e.g.* Norris, *et al.*, 1999). Loss of genetic variation has several unfortunate consequences; see 3.1.

Physiological/anatomical changes in farmed fish

Fleming & Einum (1997)[5] showed that the farmed fish from Sundalsøra's population 1 (sensu Gjedrem *et al.*, 1991), which has the preponderance of its genetic material from the river Namsen, displayed many anatomical differences compared with wild fish from the river Namsen. Fin lengths were shorter in the farmed fish, whereas the body form was more robust and less streamlined. The studies of Johnsson *et al.* (2001) showed that the heart rates of farmed salmon have become lower on average than in wild fish, and that these fish had poorer endurance and a weakened ability to flee from predators and migrate to suitable spawning beds. Furthermore, Johnsson *et al.* (1996) revealed that the production of growth hormones is higher in farmed salmon than in wild salmon. Besides the behavioural changes, this is probably one of the reasons for the rapid growth of farmed salmon (Fleming *et al.*, 2000). Such characteristics may be a good adaptation in smolt facilities and cages, but are in all probability maladaptations in the wild. Singer *et al.* (2002) found that the smolt's ability to react/adjust in the transition from fresh water to salt water was poorer in farmed fish than in wild fish. In this study, fish from population 1 (sensu Gjedrem *et al.*, 1991) were compared with wild fish from the Imsa. The reason for the farmed fish's relatively poorer ability to adjust may therefore be either the result of the breeding programme or the expression of characteristics in the base population of the farmed fish. However, the reason is not so important, since regardless of the origin of the alleles, this will reduce the fitness of wild populations in the event of hybridisation.

Coadapted gene complexes

Many phenotypic traits are controlled by more than one locus. This implies that adaptations are founded on genes in more than one place in the genome. For such traits, selection has selected for allele combinations rather than alleles. Such selection works slowly and will not be able to counteract as high migration rates as single-locus traits can. Although to Bellona's kno wledge, no studies have been published that have been able to identify this problem in Atlantic salmon (*Salmo salar*) in light of escaped farmed salmon, recent studies from Ireland (for the time being unpublished) point in this direction. Nonetheless we have strong circumstantial evidence from a study of a species of Pacific salmon (*Oncorhynchus gorbuscha).* This Pacific salmon species has a strict two-year life cycle. This means that in all rivers there are actually two populations, an odd-year and an even-year population, that are temporally isolated and therefore never spawn during the same season. Such population pairs will necessarily be adapted to identical conditions, whereas the gene flow between them is minimal. Gharrett *et al.* (1999) and Gharrett & Smoker (1991) cryopreserved milt and fertilised roe of the sister population the following year. The first hybrid generation evinced a good re-catch rate, but at the same time showed greater variation in size. The second-generation hybrids showed a low return migration rate. In general, it is not unusual for first-generation hybrids to show good or increased fitness. The reason for this is often that these individuals have a very high percentage of heterozygous loci. It is not until the second hybrid generation that the problems begin to become evident. The most obvious interpretation of this study is that there is more than one gene controlling many of the fitness-related traits in this species, in addition to the fact that the odd-year and even-year generations had coadapted gene complexes that were broken up in the second hybrid generation. This species is a relative of Atlantic salmon, and there is nothing that suggests that Atlantic salmon have genetics that are substantially different from Pacific salmon in this area. However, any difference may be due to different evolutionary histories, especially migration rates and how long the populations have been isolated.

1.2.5 Summary:

- Farmed fish have lower genetic variation than wild fish.
- Farmed fish have altered fitness-related traits that include anatomy, physiology, behaviour and life history.
- Farmed fish hybridise with wild fish.
- Hybrids between wild fish and farmed fish are generally intermediary forms.
- The fitness of wild populations is reduced by immigration of farmed fish.
- For the time being it is difficult to test the consequences of reduced genetic variation in and between wild populations.

5 In several of the following studies, farmed fish are compared with wild fish. It is obvious that comparing fish taken directly from cages with fish caught in the wild would yield results where it would be impossible to distinguish between genetic dissimilarities and environmental effects. Researchers have tried to avoid this problem by having eyed ova from both groups grow up under identical conditions. Although it may be debated whether maternal effects may be a contributing factor (discussed in Fleming and Einum, 1997, for instance), this is probably not decisive since the fish used in these studies are older than one year.

The salmon population in Tana is the most important population of Atlantic salmon. Several hundred tons are being landed annually. photo: Bellona archive

- Escaped farmed fish destroy, and compete with wild fish for spawning beds.
- The progeny of escaped farmed fish out-compete wild fish in the competition for resources in the river, both as fry and as parr.
- Farmed salmon increase the hybridisation between salmon and trout
- Coadapted gene complexes are likely to disappear from local salmon populations
- The size and fitness of the populations of Norwegian salmon stocks will be reduced if the percentage of farmed salmon continues to be high.

Glossary:

(based on Lawrence [1995] unless otherwise indicated.)

abiotic of a non-biological nature, e.g. salinity, temperature etc.

allele gene variant

anadromous life history in which reproduction takes place in fresh water while portions of the years of growth take place in the sea

coadapted gene complexes (= coadapted gene pools) a population or set of populations in which the genotypes are composed of alleles on two or more loci which in combination provide higher fitness compared with hybrid individuals and/or their progeny

fitness (w) a measurement of individuals' potential for survival and reproduction[6]

gamete haploid germ cells (with n alleles)

gene pool total quantity of genes in a population

genetic drift evolutionary force in which alleles are lost as a result of chance. Increases as the effective population size shrinks

heterozygosity percentage of heterozygous loci in a population

inbreeding depression condition of a population caused by inbreeding in which fitness is reduced as a consequence of recessive, negative genes are found in an abnormally high percentage of heterozygotes

locus (pl. loci) area on a chromosome where a gene is located

maternal effects inheritance that is not directly coded for in genes, transmitted from mother to child but not necessarily to subsequent generations, e.g. ovum size/nutritional value and disease[7]

N_e effective population size

neutral locus locus with more than one allele, where the various alleles have identical fitness. Selection cannot affect such. Thus they can provide important information on the other evolutionary forces: genetic drift and migration

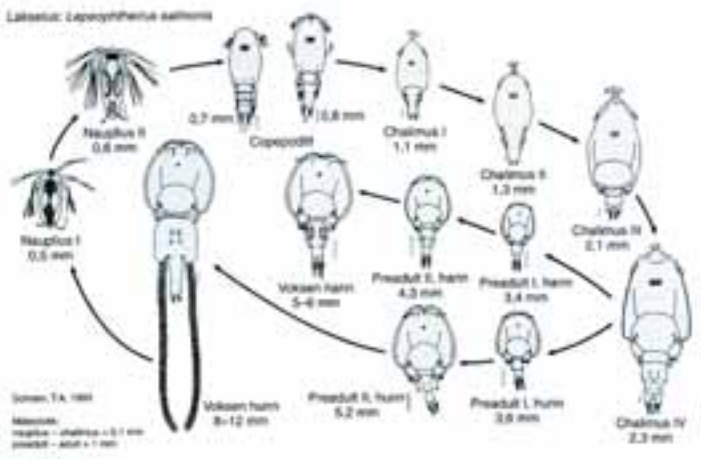
phenotype characteristic(s) of an organism caused by one or more alleles

6 Graur and Lie 2000, p. 41

7 Futuyma, 1998

1.3 Salmon lice (*Lepeophtheirus salmonis*)

The salmon louse is a parasite that uses salmonids as a host. Although always present on wild salmonids in Norwegian waters, since the explosive growth of the aquaculture industry, the louse has gradually become a major environmental problem. As a consequence of fish farming the number of potential hosts for salmon lice has multiplied, and as a result the louse population has become so large that we see adverse effects on wild salmonid stocks in Norwegian coastal areas.



The life cycle of the salmon lice. illustration: Scram

The salmon louse, *Lepeophtheirus salmonis*, is the ectoparasite that today constitutes the biggest problem in Norwegian aquaculture. Vast resources nationally and internationally are devoted to research on combating salmon lice. The salmon louse appears on most species in the genera *Salmo* (salmon and trout) and *Oncorhynchus* (Pacific salmon and rainbow trout) (Kabata 1979).

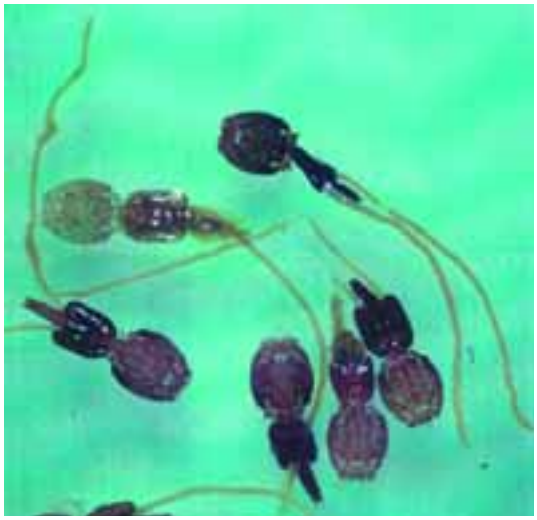
Ten different stages have been described in the life cycle of the salmon louse. Each stage is separated by a moult (two naupliar stages, one copepodite, four chalimus, 2 pre-adult and one adult stage) (Johannessen 1978; Johnsen & Albright 1991a, b; Schram 1993).

We can further divide the louse's life cycle into two phases, a free-swimming planktonic phase and a parasitic phase (Tully, O. *et al.* 2002). The two naupliar stages and the copepodite stage swim freely in the water, thus spreading the parasite. The fish is infested by the copepodite, which attaches itself with two pairs of antennae and then with a chitin thread, before it moults and becomes a chalimus 1 (Heuch P.A. *et al.*, 1999). During the four chalimus stages the parasite clings tightly to the fish with the aid of the chitin thread. The pre-adult and adult stages can move freely on the fish. A female can make at least eleven pairs of egg strings, each with several hundred eggs, after a fertilisation. In experiments, females were seen living for 140 days after reaching the adult stage (at 7oC), and everything indicates that they overwinter on the host and cause new infestations in the spring (Heuch & Schram, 1999). In female *L. salmonis* researchers have observed that the egg strings were replaced already 24 hours after having released the previous brood of naupliar larvae (Johannesen, 1978).

1.3.1 Potential for spreading

The Institute of Marine Research has created a numerical model for calculating the spread of salmon lice. Salmon lice spread during the first three stages of the louse's life cycle, before the copepodite becomes parasitic and has to attach itself to a host to survive. The salmon louse's potential for spreading is therefore a function of current, wind and the time it takes for the louse to pass from the free-swimming planktonic phase to the immobile parasitic phase. The time it takes before the parasitic phase begins is highly dependent on water temperature. In general, colder temperatures will lead to slower development (Jonson *et al.*, 1991a) and a greater potential for spreading over longer distances.

At 8°C it will take approximately 4.5 days from hatching until the salmon louse is infectious, after which they can be infectious for up to 23 days. For 12°C, the corresponding figures are approx. 2.5 and 13 days (Boxaspen, K. *et al.*, 2000). That is, at 8°C the salmon louse can spread for almost a month, whereas at 12°C the potential spreading period is cut in half. Given the typical current



Swimming salmon lice. photo: Alpharma AS

speeds in Western Norwegian fjord areas, this means that the salmon louse can be carried several hundred kilometres from where it hatched and still be capable of infesting salmon (Asplin, L. *et al*., 2002).

1.3.2 Explosive growth in the number of hosts for the salmon louse

Heuch & Mo (2001) have devised a model for the production of salmon lice in Norway from Vest-Agder up to Troms. The model operates with threshold values: (1) the level of lice in 1986-1987 (before disconcerting effects on sea trout were observed) and (2) a level that implies a doubling of estimated natural infestation pressure. The thresholds imply a production of salmon louse eggs of between 50 billion and 5.2 billion.

The number of louse eggs produced by wild salmonids was estimated at 2.6 billion. With a limit in accordance with the current salmon lice regulation (0.5 lice per fish), the number of eggs produced from farmed fish is estimated at 29 billion in 2000. As a result of a continued increase in the number of farmed fish in the sea, Heuch and Mo operated with an increase in louse production from fish farms in 2005 to 46 billion eggs. Given the current escape situation, the contribution from escaped farmed fish is on the order of 15 billion eggs. Salmon louse production from escaped farmed fish is thus six times higher than the total production from wild salmonids. (Heuch, P.A. *et al*., 2001)

In 2000, the official threshold was supposed to have been 0.6 lice per farmed fish, assuming a threshold of 50 million eggs. If all fish farmers had followed the official order that year, total louse production would be close to 50 billion eggs.
In order not to exceed the limit for a doubling of the natural infestation pressure, with the production in 1999, we would have had to lower the limit of lice per fish to 0.05 (Heuch, P.A. *et al*., 2001).

1.3.3 Effects on salmonids

The salmon louse lives on the fish's mucus, skin and blood. A salmon smolt with more than 10-15 salmon lice is so weakened that it is not likely to survive its sojourn in the sea before returning to the river to spawn (Asplin, L. *et al*., 2002). Besides the fact that salmon lice can produce directly lethal effects on salmonids, harm has been observed at lower infestation rates. Bite injuries from lice on the fish give pathogens a better foothold and can cause disease in the fish. In addition to the bite injuries, low non-lethal infestations will induce stress responses in the fish. Fish under stress have problems with their salt balance, reduced immunity and are more at risk of infections (Tully, O. *et al*., 2002).

Before fish farming activities began in earnest along the Norwegian coast, winter was a bottleneck for the salmon louse due to the low number of hosts at that time. The explosive growth of salmonid farming in Norway changed this situation drastically. Today there are large quantities of salmonids in the sea all year round. This makes it possible to sustain a large population of salmon lice and high infestation pressure all year.

In some years we have seen very serious salmon lice infestations on emigrating salmon smolt. The Institute for Marine Research's counts of lice in Sognefjord in 1999 were unsettling. That year the infestation was 104 lice per fish and a conservative estimate of 86% mortality. The following year the infestation fell to 36 lice per fish and an estimate of at least 65% mortality (Holst J.C. *et al*., 2001). The fish farmers' defence has been to focus on this being a year with optimal temperatures for lice and little supply of fresh water due to a winter with little snow. This provided good conditions for lice with subsequent major infestations of wild salmonids. Nevertheless, the situation in 1999 is within natural fluctuations, and there will be more years with low snowmelts and temperatures that suit the salmon louse. These scenarios in which the salmon louse obtains favourable conditions must be decisive for the extent fish farming that may be permitted in an area.

Since 1991 serious infestations of wild stocks of sea trout have been observed. Studies from sixty-three different rivers and streams showed that in fifty-seven of these, the sea trout had problems with salmon lice infestations. An average of 250 salmon lice per fish counted was observed for 1992 (Consulting biologists, 2003). However, the situation has improved since the early 1990s, though the Institute for Marine Research still considers the situ-

Close-up of a salmon louse feeding on fish.
photo: BioSmart AS

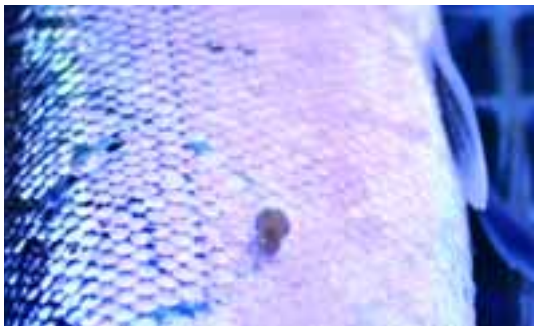
ation of the sea trout unsatisfactory and probably critical in many places (Holst J.C., 2003). Even though the number of infestations seems to have been reduced, it is still clearly higher than in regions far away from salmon farming, where an infestation level is estimated that is similar to that in western Norway before fish farming was established (Consulting biologists, 2003).

Unless we stop farming salmonids or make all facilities land-based, the likely scenario according to the Institute for Marine Research is for salmon lice, wild salmon and farmed salmon to coexist on the Norwegian coast for the foreseeable future. However, in this scenario the authorities ought to be able to require that salmon lice levels in fish farms be maintained that are sustainable with regard to the salmon and sea trout stocks in the individual fjord system.

1.3.4 Fighting salmon lice

Existing treatments for salmon lice can be roughly divided between biological methods, *i.e.* the use of wrasse, and chemical treatment of salmon infested with salmon lice (Roth *et al*., 1993; Costello, 1993). Both methods are discussed in detail in their own chapters in this report. Among other important measures, coordinated delousings may be mentioned.

In the salmon lice regulation laid down by the Ministry of Agriculture on 1 February 2000 pursuant to Sections 16 and 29 of Act no. 54 of 13 June 1997 relating to measures to counteract diseases in fish and other aquatic animals (the Fish Diseases Act), threshold limits were introduced for obligatory delousing of fish farms. If in the period from 1 December to 1 July a count shows an average per fish of 0.5 or more adult female lice, or a total of 5 or more adult female lice and mobile stages, in individual cages, treatment for salmon lice is to be performed for the entire locality. In the period from 1 July to 1 December, the entire locality is to be deloused if there is an average of 2 or more adult females, or a total of 10 adult females and mobile stages per fish in an individual cage (Lovdata).



Close-up of a salmon louse feeding on fish. photo: BioSmart AS

In 1996, work began on the "National Plan of Action to Combat Salmonid Lice". The working group had representatives from the Norwegian Animal Health Authority, the Norwegian Directorate of Fisheries, the Directorate for Nature Management, the Norwegian Fish Farmers' Association (NFF) and the Aquaculture Veterinarians' Association. Together they formulated several goals in combating salmon lice. The plan of action's long-term objective is to reduce the harmful effects of lice on farmed and wild fish to a minimum. Five short-term objectives were also defined:

1. measures are to be planned and coordinated in regional collaborations.
2. the prevalence of lice in at least 95% of the localities is to be documented.
3. the prevalence of lice on wild fish is to be documented.
4. measures used to combat salmon lice are to be documented in at least 95% of the fish farms.
5. organised delousing is to be planned and carried out during the cold season.

In the most recent performance report (National Plan of Action to Combat Salmonid Lice Performance Report 2000 and 2001), some of the defined goals for 2001 could not be met, unfortunately. However, performance was better than for 2000.

1.3.5 Wild salmon and salmon lice: conclusion

Salmon lice continue to represent a significant problem for the stocks of wild salmonids in Norway's coastal and fjord areas. The number of hosts is steadily rising, and absent a change in current strategies for combating salmon lice, this will lead to ever-increasing production of salmon lice in the years to come.

At a threshold of 0.5 lice per fish, increased fish farming activities will lead to increased salmon lice production. To stop the growth of production of salmon lice and prevent increased infestation pressure on wild stocks, the threshold for the permitted number of lice per fish must continually be reduced. A lower limit for obligatory delousing, however, seems to many to be difficult to implement. The alternative would be to stipulate a carrying capacity for what a fjord area can tolerate of salmon lice. In that case fish farming activities must be adjusted on the basis of how much salmon lice the individual system tolerates.

We see that escaped salmon contribute heavily to the production of salmon lice along the Norwegian coast. Measures to reduce the escape of farmed fish will in this way help to reduce the infestation pressure on stocks of wild salmonids.

Chapter 2
Discharges from fish farming

photo: Norwegian Seafood Export Commission

2.1 Discharges of pharmaceuticals for combating salmon lice

Various parasites cause considerable health problems and mortality in farmed salmon and wild salmon alike (see separate chapter). In this section we shall address the environmental impacts of the various forms of treating parasites. We shall concentrate on salmon lice, *Lepeophtheirus salmonis*, and sea lice, *Caligus elongatus*, which both belong to the family *Caligidae* in the class copepods (*Copepoda*), hereafter called simply lice. Treatments of lice-infested farmed fish can be divided into three main categories, which are usually used in combination: wrasse, delousing baths, and medicated pellets. The first, wrasse, has few environmental drawbacks, but certain limitations on practical use. The two others subject the fish and the marine environment to toxic substances, and must therefore be thoroughly evaluated with a view to environmental impacts. In addition, it was previously common to treat the fish with hydrogen peroxide, which relatively easily breaks down into oxygen and water. The problem, however, is that this treatment only removes the lice from the salmon without necessarily killing them. Thus, the parasites can return to the cages, or worse, infest wild salmon. In Norway, hydrogen peroxide has fallen into complete disuse (Treasurer and Grant, 1997).

Since the spread of salmon lice from fish farms to emigrating wild smolt is reckoned to be a central environmental problem in fish farming, two different environmental problems need to be weighed against each other. For now an important part of the solution to the louse problem is effective chemotherapeutic treatment, which in turn creates another environmental problem, namely, pollution of the marine environment. In the following we shall review documented and assumed environmental impacts of the most common salmon delousing agents, and on the basis of available research findings, give the reader a picture of how the chemicals behave in the environment, especially in view of their toxicity, persistence and health effects. Further, the chapter will describe the potential of biological methods for combating lice using wrasse as well as give an account of how the use of pharmaceuticals can otherwise be curbed. The chapter concludes with a discussion of the difficult balancing act that delousing involves.

2.1.1 Assessing environmental impacts of pharmaceuticals used to combat salmon lice

Assessing the environmental impacts of the various pharmaceuticals used to combat salmon lice is no easy task. There is no standardised method for experimental design and measuring of the substances' biodegradability, and several experiments with the same substance may therefore yield different half-life periods. It is thus very difficult to compare different substances in respect of environmental characteristics. When pharmaceutical manufacturers apply to have their products approved by the Norwegian Medicines Agency, the agency obtains an environmental assessment of the substance from the Norwegian Pollution Control Authority. The Norwegian Pollution Control Authority gains access to the manufacturer's environmental documentation and writes up a brief evaluation based on this. Due to a lack of standard procedures for testing and documentation, the Norwegian Pollution Control Authority must in each case use discretion in judging whether the documentation submitted is sufficient, and if not, request additional documentation. In consideration of the manufacturer's needs for protection against competitors' possible copying of the actual product or copying the documentation, the Norwegian Pollution Control Authority returns the documentation without disclosing it in any way. Thus, it is completely up

Underwater picture of salmon.
photo: Villakssenteret

to the manufacturers what they want to make public, and as a non-governmental organisation, Bellona is at the mercy of the manufacturers' disclosure policies in its quest for documentation. In this chapter this may be reflected in the fact that some substances are described in more detail than others. To a certain extent we have had to base our evaluations on secondary sources, such as the Norwegian Pollution Control Authority or Scottish authorities' evaluation of environmental documentation, as well as presentations from pharmaceutical manufacturers. Recently the new "Environmental Data Act" came into force. Its purpose is to give everyone access to companies' environmental documentation regarding products, emissions or discharges.

Pharmaceuticals for use against salmon lice in Norway (Norwegian Medicines Control Authority, 2000):

Classification	Active ingredient	Trade name
Pyrethroids	Cypermethrin	Excis vet. (Grampian)
	Cis-cypermethrin	Betamax (Vericore)
	Deltamethrin	Alpha Max (Alpharma)
Pyrethrum	Pyrethrum extract	Py-sal vet. (Norwegian Pyrethrum)
Organophosphates	Azametiphos	Salmosan (Novartis)
Chitin synthesis inhibitors	Diflubenzuron	Lepsidon vet. (Ewos)
	Teflubenzuron	Ektobann (Skretting)
Avermectins	Emamectin	Slice vet. (Schering-Plough)

In this report we will review the environmental and health documentation of deltamethrin, emamectin and teflubenzuron.

2.1.2 Alpha Max (deltamethrin)

The description of the health and environmental effects of deltamethrin is based on information presented by the manufacturer Alpharma. As part of the product approval process, the manufacturer obtained documentation that was submitted to the authorities for evaluation. This documentation has not been made public. Alpharma's justification for not making the documentation public is its desire to protect its investment and prevent competitors from copying their documentation and getting an easier toehold in the market.

Therefore, Bellona has no independent sources beyond the Norwegian Pollution Control Authority's remarks on Alpharma's documentation (Brendgren and Vike, 2001). Bellona is not comfortable with using information from the manufacturer only, but has no reason to believe that the manufacturer is withholding data.

Netpens in the sommer. photo: Norwegian Seafood Export Commission

Description

Alpha Max is a bath treatment for combating salmon lice. The active ingredient is deltamethrin, an insecticide in the pyrethroid group. The chemical formula for deltamethrin is $C_{22}H_{19}Br_2NO_3$.

Treatment with Alpha Max involves reducing the volume in the sea cage by pulling up the netting walls or "sewing them up". The cage is wrapped up, either in a skirt with an open bottom or a completely closed tarpaulin. Alpha Max is added, and the treatment ends after 30-40 minutes by removing the tarpaulin so that the water is replaced. In this way the substance is dispersed to the marine environment.

Action

Deltamethrin kills salmon lice by blocking the transmission of impulses on its neural pathways.

Biodegradation

The biodegradation time for deltamethrin has been studied in a laboratory at a temperature of 10 C, which is a relevant temperature for the environment in Norwegian fjords. For sea water, the tests showed that less than 10% of the quantity added persisted after 10 days and less than 2% after 181 days. For sediment taken from the seabed under a fish farm, a half-life was discovered of 140 days. 90% had biodegraded after less than one year. For sediment taken from another location, the biodegradation time was faster, with a half-life of 90 days. The reason for this difference is probably the unique composition of the sediment, for instance a higher percentage of organic material from feed spills and faeces under the fish farm. The biodegradation time is so long that there may be a risk of accumulation in the sediment from frequent

treatments. However, this is hardly likely, due to the fact that the discharges will be diluted and distributed over large areas of the seabed by being dispersed in the water (effects of currents and waves). It is unlikely that differing current speeds and directions in connection with subsequent treatments will result in exposure to the same sediment. The biodegradation of deltamethrin forms substances that are less toxic and the substance degrades all the way to CO_2.

Deltamethrin has little potential for bioaccumulation in fish. Experiments performed on the American catfish (*Ictalurus punctatus*) show that for fish continually exposed to deltamethrin, the substance bioaccumulates for 10-15 days. That is, the quantity in the fish increases day by day. After 10-15 days, the substance is converted in the fish, and the amounts of deltamethrin residues fall, despite continued exposure. When the test fish is transferred to clean water, deltamethrin will be excreted quickly.

When fish are exposed to deltamethrin for a brief period, which is the most comparable with the effects of salmon lice treatment, experiments on American catfish (*Ictalurus punctatus*) and salmon (*Salmo salar*) show no signs of bioaccumulation.

Dispersion

Tests conducted by SINTEF have shown that the substance does not sink to the bottom after treatment, but is dispersed out and down the water column. It is not until the properties of Alpha Max that enable it to be mixed with water stop working that deltamethrin precipitates. The dispersion of Alpha Max from the fish farm means that treatment should be avoided if the direction of the current carries the substance in towards the littoral zone, where various species of crustaceans thrive.

Toxicity

- Acutely toxic to crustaceans (salmon lice, copepods, shrimp, crab)
- Less toxic to fish and invertebrates (except for crustaceans)
- Non-toxic to microorganisms, birds and mammals.

Field studies

Alpharma has conducted field studies to compare observed effects with model estimates.
Laboratory tests showed that deltamethrin is acutely toxic to prawns (*Palaemon elegans*). Then prawns were placed in cages in and around a fish farm in Rogaland county. After treatment with Alpha Max at twice the recommended dose, 100% mortality was seen in the prawns in or right up against the cages containing the fish. Prawns placed at a distance of 5 metres from the cages had 70% mortality at a depth of 1 metre and 50% mortality at depths of 3-5 metres. A distance of 30 metres yielded 5% mortality at a depth of 1 metre, 40% mortality at depths of 2-3 metres and no mortality 2 metres from the bottom. 50 metres away an average mortality of 8.6% was found, which does not deviate significantly from the control location, where the average mortality was 5-6%.

Human health

Deltamethrin has a NOEL (No Effect Level) of 1 mg deltamethrin per kilogram of body weight per day. This value is based on toxicological tests of blood chemistry, hematology, organ weight, histopathology, tumour development and reproductive health studies over several generations. The tests were performed on mice, rats, dogs and rabbits.

Based on NOEL, a threshold has been set for the acceptable daily intake (ADI). In calculating ADI a high safety factor is used, which for deltamethrin is set at 100. This means that the ADI is one-one-hundredth of NOEL, which is the highest intake that did not show signs of toxic effects in chronic animal tests. The ADI for deltamethrin is thus 0.01 mg per kilogram of body weight per day (10 µg/kg body weight/day).

Deltamethrin is also used as an agricultural insecticide. The breakdown of the intake of deltamethrin residues between veterinary medicinal use and pest control is crucial for determining the magnitude of the residues of the substance that can be approved in fish, the maximum residue limit (MRL). The breakdown of the ADI on which the MRL is based, is as follows:
Pest control: 85% of ADI
Veterinary medicine: 15% of ADI = 1,5 µg/kg/day

Thus, a person weighing 60 kilograms may ingest 1.5 µg x 60 = 90 µg of deltamethrin from veterinary medicinal use per day. Based on these calculations, the EU has set an MRL value for fish at 10 µg deltamethrin/kg of fish (EMEA, 2001). To prevent fish to be slaughtered from having deltamethrin residues exceeding the MRL, there is a retention period of three days. Residue concentration tests show that two hours after treatment there are no deltamethrin residues of the MRL (10 µg deltamethrin/kg fish). In other words, the Norwegian authorities have used an extra margin of safety when setting the retention period for deltamethrin in fish at three days after treatment.

2.1.3 Emamectin

Emamectin benzoate belongs to the avermectin group and is administered to the fish through feed. This preparation

Circular netpens in the winter. photo: Norwegian Seafood Export Commission

is manufactured by Schering-Plough Animal Health and is marketed under the name Slice® vet.
Unless another source is given, the information comes from McHenery (1999), a report prepared on behalf of Schering-Plough.

Action

Avermectins bind with high affinity to glutamate-regulated ion channels in invertebrates. Avermectins cause increased diffusion of chlorides through the cell membranes in the salmon louse and nerve impulse disruptions. The result is that the parasite is paralysed and dies. Emamectin benzoate is effective against several stages of the salmon louse, the copepodite, chalimus, motile pre-adult and adult stages. Due to the spread of infectious salmon anaemia (ISA), it is desirous for the treatment to kill the salmon louse at all stages of its life, since the salmon louse can function as a carrier of ISA (Nylund *et al*., 1994).

Treatment regime

Effective treatment of salmon lice is achieved by administering 50 µg per kilogram fish, per day for seven days.

Biodegradation in the environment

When giving feed with emamectin added, a small amount will fall to the bottom as feed spills, while most of it is added to the environment through excrement and is thus incorporated into the sediments. Dispersion will depend on local current and depth conditions. Various models have helped researchers estimate that feed spills and excrement disperse over an area of between 10,000 and 20,000 sq. m after treating twelve 15x15 m cages.

Biodegradation in seawater

The half-life of emamectin in water was found to vary between 0.7 days during summer conditions to 35.4 days during winter conditions. The difference is due to light-sensitivity, not temperature.

Biodegradation in sediments

Laboratory tests in which medicated pellets containing emamectin were added to anaerobic marine sediment samples showed than 66-68% of the administered dose had not biodegraded after 100 days. On the basis of this datum, a half-life in these samples was estimated to be between 164 and 175 days.

Modelling indicates that the concentration of emamectin in sediments is at 76 µg/kg directly beneath fish farms that have been medicated, falling to 1.7 - 16.7 µg/kg 75 metres away along the tidal axis. 100 m downstream from the fish farm, the concentration drops to 0.2-1.7 µg/kg. Field tests have established emamectin residues in one of ten sediment samples. The positive sample was taken ten

Manual handling of the net.
photo: Marine Harvest

metres downstream from the fish farm. The other nine samples yielded no traces. The likely reason that the field tests showed less residue than the modelling results is that the substance was quickly diluted in large quantities of seawater.

Toxicity

The toxicity of avermectins in general and emamectin in particular has been tested for a large number of organisms. In the following we will review examples of various categories of organisms, but for a complete survey, we refer to McHenery (1999).

Microorganisms and plants

Avermectins have neither antibacterial nor fungicidal properties, and no effect on microbial fauna in the soil has been recorded at concentrations of 5 mg/kg. Nor have microalgae been found to be sensitive to avermectins, with tests on *Selenastrum capricornutum* over 5 days at concentrations of up to 3.9 µg/litre showing no effect. Gibbous duckweed *(Lemna gibba*) exposed to concentrations of up 94 µg/litre over 14 days was not affected either. However, toxic effects were found for tomato roots that were dipped in a solution with a concentration of 192 mg/litre (McHenery, 1999).

Invertebrates

Since emamectin is meant to kill salmon lice, which is a crustacean (subphylum: *Crustacea*), it is not surprising that this substance is also toxic to other crustaceans. The most vulnerable is *Mysidopsis bahia* (mysid shrimp), which had a mortality of 50% (LC50) after 96 hours in water with a concentration of emamectin of as little as 0.04 µg/l. At the opposite end of the scale we find *Crassostrea virginica* (a species of oyster, not relevant in Norway), which had an estimated mortality of 50% at a concentration of 665 µg/l. Similar results have been found in a number of other molluscs. Field tests in which mussels were placed near fish farms during treatment with emamectin showed no signs of toxic effects up to 4 and 12 months after treatment.

For *Crangon crangon* (common shrimp, sand shrimp) and *Nephrops norvegicus* (Norway lobster, ocean crayfish) mortality of 50% was registered after 192 hours at concentrations in the water of 166 µg/l and 572 µg/l, respectively. Such high concentrations will not be found under realistic conditions. No significant effect or mortality was seen in the same species after they were fed fish food with concentrations of 69.3 and 68.2 mg/kg, respectively.

Fish

Salmon that have ingested doses of emamectin through medicated feed of 356 µg/kg fish/day over 7 days, showed no mortality, and the No Effect Limit (NOEL) was found to be 173 µg/kg fish/day.

Mammals

Tests of toxic effects on mammals have been done with regard to human health (see below).

Human health

A score of toxicological studies have been done on mice, rats and beagles. Mortality of 50% (LD50) occurred at doses varying from 22 to 120 mg/kg. In the study yielding the lowest NOEL, an experiment based on neurotoxicity with daily doses over 15 days in mice, a NOEL of 100 µg/kg body weight was found.

Based on the NOEL and a safety factor of 100, the acceptable daily intake (ADI) has been set at 1 µg/kg body weight. Thus, a person weighing 60 kg has an ADI of 60 µg/kg body weight. On this basis, the MRL has been set at 100 ?g/kg fish (EMEA, 1999).

Based on residue concentration tests in salmon, researchers in many countries have found no need for any retention period. This applies to the EU and Chile, for example. Nevertheless, the United Kingdom and Chile have a rule that fish may not be treated more than once during the 60 days before slaughtering, which is not really relevant in any case. In Norway there was once a requirement of zero residue instead of an MRL, and therefore a retention period of 120 days. The Norwegian system with the zero threshold was justified on the basis

of marketing considerations whereby Norwegian fish would be able to be marketed as "completely" pure. In practice this meant that the detection threshold of the testing method in question was the applicable threshold. This has now been abolished and replaced with an MRL.

2.1.4 Teflubenzuron

Teflubenzuron is a salmon delousing agent that is added to medicated pellets at a concentration of 2g/kg of feed. The dosage is 10 mg/kg body weight each day over seven days. Teflubenzuron is marketed in Norway by Skretting under the name Ektobann. Teflubenzuron is for the moment not being used in Norway, which partly is due to the negative focus in 1998 on possible environmental effects and partly doe to the introduction of the product Slice, with emamectin as the active ingredient. Unlike teflubenzuron, Emamectin is effective against all stages of salmon lice. Owing to fears of the development of resistance in salmon lice against emamectin in particular, Skretting sees a certain possibility for a resumption in the use of teflubenzuron, even though the manufacturer does not currently have a commercial interest in this. This substance is approved for use in Norway, the United Kingdom, Ireland, Canada and Chile (Richie, 2002).

Action

Teflubenzuron is a chitin synthesis inhibitor, that is, it disrupts chitin synthesis in shellfish and kills the louse by preventing moulting. The substance is effective on moulting on the larval stage and pre-adult lice, but has no effect on adult lice.

Fate in the environment

Teflubenzuron enters the environment chiefly via excrement and, to a certain extent, feed spills. The substance binds to particles and has low water-solubility. This leads to low concentrations in the water and there is no effect on aquatic organisms. Sedimentation of the particles is relatively rapid below and around the fish farm, with the result that high concentrations can be recovered only in a limited area.

Biodegradability in the sediment

Teflubenzuron biodegrades relatively slowly, and according to laboratory tests, has a half-life in sediment varying from 35 to 100 days. However, a field study that took place over a year in a location in Scotland showed a half-life of six months. The discrepancy with regard to the expected degradation time is attributed to the fact that the test location was a "worst-case" location in respect of water exchange and being burdened by organic material (SEPA, 1999).

Toxicity

Since teflubenzuron works on crustaceans by preventing moulting, the deleterious effects on crustaceans around the fish farm will be greatest if a lot of animals are moulting during and in the period following treatment.

Several field studies have been done to assess the effect that teflubenzuron use has on crustaceans such as crab and lobster. In an experiment conducted in Norway, three groups of crabs (*Cancer pagarus*) were set out. One was placed next to the fish farm, one 70 metres away and one was a control group. Mortality was 17.1 per cent next to the fish farm, 14.5 per cent 70 metres away and 17.5 per cent in the control group. Thus, mortality in crabs exposed to teflubenzuron does not deviate significantly from the control group. Nor were any significant differences found in the percentage of individuals that moulted successfully during the experiment.

In a similar Canadian experiment on lobster (*Homarus americanus*), mortality of 10% was found in lobster located under the fish farm and 13% in the group located 50 metres away. A group located 100 metres away had zero mortality, as did the control group. Here the difference in mortality is significant.

A Scottish study of lobster (*H. gammarus*) yielded significant differences in mortality between the control groups and the groups of lobster placed under the fish farm and 25 metres away from it. In this study there was also high mortality in the control group, which is attributed to high levels of organic material in the sediment.

Human health

A number of studies of toxic properties have been done to uncover possible risks to human health. The studies were reviewed by EMEA (1999b). No NOEL has been set, because the lowest dose studied, 487.3 mg/kg body weight/day, yielded effects in the form of increased liver size in mice and rats, for instance.

The carcinogenicity tests cited conclude that there is no significant difference in tumour development between treated rodents and the control group, and negative results of mutagenicity studies were cited.

Owing to a lack of knowledge of the NOEL a safety factor of 200 was used to set the ADI, which on the basis of dose-related effects in tissue from the carcinogenicity studies has been set at 0.01 mg/kg body weight. On the basis of residue concentration studies, the MRL has been set at 500 µg/kg fish.

2.2 Measures to reduce discharges of salmon delousing agents

2.2.1 Wrasses

The use of wrasses to control lice is an effective means of control that does not add pharmaceuticals to the marine environment. Wrasse is an umbrella designation of fish in the wrasse family (*Labridae*) that can feed on ectoparasites, i.e. parasites that are attached to the outsides of farmed fish. The most relevant wrasse species are the goldsinny or salmon wrasse (*Ctenolabrus rupestris*) for salmon under 2 kilograms, and the ballan wrasse (*Labrus bergylta*) for larger salmon. Other species that can be used for louse control are the corkwing wrasse (*Crenilabrus melops*), the rock cook (*Centrolabrus exoletus*) and cuckoo wrasse (*Labrus bimaculatus*) (Andreassen and Kvenseth, 2000; Nogva, 2000).

Wrasse eat salmon lice from the fish. Wrasse is an environmentaly sound treatment against salmon lice. photo: Per Gunnar Kvenseth

An experiment conducted at Villa Miljølaks AS's fish farm in Vestnes in Møre og Romsdal county shows that wrasse can provide an effective treatment against lice (Kvenseth *et al*., 2002). During the period of the experiment, the farm was subjected to repeated infestations of salmon lice. Every time, the lice were eaten up by the wrasse before they reached sexual maturity. The advantage of this form of treatment for salmon lice is that the wrasse perform continuous control of the louse situation. For their part, medications or delousing baths are incapable of keeping louse infestations down between treatments. The wrasse's appetite increases as the louse grows. Used correctly, a female louse with eggs is a rare sight in a well-run salmon farm that actively uses wrasse.

Practical limitations

Despite its benefits, the use of wrasse has, according to the Directorate of Fisheries' figures, fell from 2.6 million fish in 1999, to 1.8 million in 2000. There may be several reasons for this decline. One reason may be that medicated pellets and bath treatments have become more competitive. Furthermore, several fish farmers have experienced a number of problems with getting wrasse to work, and some have seen high rates of mortality among the wrasse. Other animal technicians point out that the temperature and aquatic environment are not always suitable for wrasse use, especially in northern areas. The use of wrasse requires adequate tending of the fish. Protocols and guides have been developed for attaining good results by using wrasse. A primer for using wrasse is available at www.leppefisk.no.

Once the wrasse have cleaned the nets and the salmon, they can do damage by biting the fin rays or the eyes of the salmon. Therefore it is essential to monitor the development of the total food available to the wrasse. If such a situation arises, the number of wrasse in the cage needs to be adjusted, for example with the aid of a modified fish pot baited with mussels (Kvenseth *et al*., 2003).

Another limitation is the supply of wrasse. The need is estimated to be six million goldsinny, if all fish farmers used these on salmon under 2 kilograms. From Møre og Romsdal county southward the supply of wrasse caught in the wild is good, whereas in Trøndelag and northward, the supply is limited. Transfers of fish from southerly areas are therefore necessary. For salmon larger than 2 kilograms, the ballan wrasse is a more suitable species, but here the supply of fish caught wild is a much clearer stumbling block. Farming wrasse may therefore become a possibility (Kvenseth *et al*., 2002). The Institute of Marine Research has succeeded in producing ballan wrasse fry at the Aquaculture Station in Austevoll. Raising wrasse may make stable year-round delivery possible, and the wrasse will be able to be delivered ready-vaccinated with a health certificate. However, challenges remain in respect of spawning and mortality (Skiftesvik and Bjelland, 2003).

Costs of using wrasse

According to Kvenseth *et al*. (2002), the costs connected with this type of treatment are the same as for using feed with a delousing agent added. For large salmon, the numbers turn out very positive for wrasse. Purchasing ballan wrasse, at a 1% mixture (ratio of wrasse to farmed fish in the cage) with large salmon, costs on the order of 1/10 of the cost of purchasing pharmaceuticals for equivalent louse control in large salmon 2 - 7 kilograms. Recent research (S. Øvretveit, 2003) shows that the number of delousings with pharmaceuticals has a negative impact on the feed conversion ratio (FCR). For an ordinary fish farm the extra costs will amount to between NOK 1 and 2 million for a generation. With the effective use of wrasse, these costs will be on the order of NOK 0.1 million in all.

A positive added effect of the use of wrasse is that they also nibble at the fouling of the fish farm nets. Fouling otherwise clogs the mesh so that water exchange is poor. To prevent fouling, impregnation using copper compounds has traditionally been used. This is discussed below in this chapter.

Potential problems

Transporting wrasse between parts of the country or between fish farm sites potentially spreads fish diseases. Contagiousness experiments were conducted on farmed goldsinny (*Ctenolabrus rupestris*) in Scotland. In various experiments the fish were exposed to the viral diseases infectious pancreatic necrosis (IPN) and pancreas disease (PD). Goldsinny do not appear to be able to spread the latter disease (PD) to salmon. The researchers found that goldsinny was likely as susceptible to the IPN virus as salmonids, but that the goldsinny had a greater ability to recover. The virus was also found in the faeces of goldsinny that had been exposed to high doses of the virus. Therefore, faeces can be a continuous source of infection in a salmon farm that is infected with IPN (Gibson and Sommerville, 1996). IPN was considered one of the most serious infectious diseases in Norwegian fish farming, causing annual economic losses of up to NOK 400 million in 1994 and 1995 (Biering, 1999). Nevertheless, the goldsinny's potential as a source of infection for the IPN virus should not prevent it from being used for combating parasites, but transporting wrasse between different locations and the re-use of wrasse with different cohorts of salmon should be avoided (Gibson and Sommerville, 1996).

Diseases can also affect the wrasse themselves. Mortality in the wrasse can reduce their effectiveness on the louse infestation. In goldsinny and ballan wrasse the bacterial disease atypical furunculosis can cause problems. The illness is triggered by stress and may occur in the fish farm in connection with handling nets or fish. In corkwing wrasse bacterial infections like *Vibrio splendidus* and *V. tapetis* can cause problems. Such infections manifest themselves as ulcerations, listlessness and poor appetite. Viral infections are yet to be found in wrasse caught in the wild, but this may be due to a lack of a diagnostic method. While no parasites have been found in wrasse that can cause problems for salmon, there are parasites that can cause high mortality in wrasse (Kirkemo *et al*., 2003).

Several instances of high levels of mortality in wrasse in salmon farms have raised questions about whether the use of wrasse is an ethical use of animals. The Norwegian Council on Animal Ethics has considered the issue and concludes that the use of wrasse in salmon farming is desirable, but points out that fish farmers need to understand that the wrasse are living beings and not input factors on par with pharmaceuticals. The wrasse's biological needs have to be met in the form of access to food, availability of suitable hiding places and adequate wintering (Norwegian Council on Animal Ethics, 2000)

2.2.2 Other measures against salmon lice

Lights in the cages may mean fewer lice

There is an established connection between how deep the salmon go in the fish farm and how many lice the salmon get. The deeper the salmon go, the smaller the infestation. Experiments have shown that submerged lights in the cages lure the salmon down into deeper water, with lower louse infestations as an outcome. This method is most relevant during the late autumn and winter. In the spring and summer the natural light will override the artificial light (Hevrøy, 1998 and Boxaspen, 2001), making the method relatively less interesting under Norwegian conditions.

Stimulating the salmon's resistance

Tests performed at a fish farm in Scotland have shown that the salmon's resistance against lice was strengthened when the feed product Respons Proaktiv, an amino acid-based feed that contains glucanes and extra vitamins, was added. Glucanes are polysaccharides that consist of glucose from yeast cell walls. Glucanes' positive impact on the salmon's immunity and general health has been documented. The group of salmon fed glucanes had on average 24.4 per cent fewer lice than the control group, a statistically significant difference. It is not completely clear how glucanes help the fish against infestation by salmon lice (Ritchie, 1999).

Vaccines against salmon lice

The "Eukaryotic Parasites in Fish" project is working to develop preventive measures against salmon lice. One approach is building on the fact that the lice suck and digest blood from their host. If vital components of this blood digestion can be characterised, they may conceivably be used as antigens in a vaccine against salmon lice. Researchers believe, however, that there is far to go before such a vaccine is available. (Institute for Marine Research website, www.imr.no).

Therapy recommendations of the Norwegian Medicines Agency

In 2000 the former Norwegian Medicines Control Authority, now the Norwegian Medicines Agency, published therapy recommendations for salmon lice. The purpose of the recommendations is to ensure the effective treatment of farmed fish, minimise the spread of salmon lice to wild salmon, limit eco-toxic effects and prevent the emergence of resistance against pharmaceuticals in salmon lice. These recommendations are divided according to the size of the fish and, in part, by the season in which treatment takes place. The recommendations would probably look somewhat different today, because it is now known that emamectin is also appropriate on large fish. The most important thing is alternating between different treatments, so as to avoid the development of resistance.

Fish smaller then 500g:

Treatment - summer:

1. Wrasse
2. Oral treatment (medicine pellets), preferably emamectin
3. Synthetical pyrethroids

Tratment - winter/early spring

1. Syntetical pyrethroids

Fish between 500 - 1000g:

1. Wrasse (spring/summer)
2. Syntetical pyrethroids
3. Oral treatment

Fish over 1000g:

1. Syntetical pyrethroids

In addition to following the Norwegian Medicines Agency's therapy recommendations, proper routines for prevention and treatment will help to reduce louse infestations on the fish as well as the use of pharmaceuticals. For example, letting sites lie fallow will keep different generations of fish apart, and general good care of the fish will reduce the need for treatment. Players in the fish farming industry have specified such an integrated approach to the louse problem with the concept "integrated pest management" (Richie, 2002). We can also note that wrasse were not included as part of the recommendations for large fish. The Norwegian Medicines Agency should update its recommendations if wrasse can be successfully obtained for large fish.

2.2.3 Conclusion - treatment of salmon lice

Common to all pharmaceuticals intended to combat salmon lice is that they are toxic to a number of organisms, especially crustaceans, which are the subphylum salmon lice belong to. However, the toxic effects of the substances are relatively local, in the sense that individuals located a distance from the fish farm are not exposed to toxic doses of the agents. How large an area around the fish farm that is affected will vary with the type of substance and local environmental conditions, such as currents and aquatic chemistry.

The pharmaceuticals are also relatively persistent, with half-life periods of several months in sediment, though they are biodegradable, unlike heavy metals and other environmental toxins.

From an environmental perspective, salmon delousing may be viewed as a necessary evil. Failure to act against large infestations of salmon lice in fish farms will not only create health problems for the farmed fish, but also create an untenable situation for emigrating wild salmon. Wrasse have the potential to render the use of antiparasitic drugs superfluous, but until this potential is realised, using these agents cannot be avoided.

The use of wrasse against salmon lice can and should be a more central form of treatment, but several challenges remain before the use of chemicals can be replaced by a non-polluting louse treatment. A greater effort especially in disseminating knowledge about routines for this non-polluting form of treatment is therefore imperative. Bellona will evaluate the policy instruments that in an appropriate and cost-effective manner can force the increased use of biological methods to combat salmon lice.

2.3 Antibacterial agents in fish farming

Like land-based forms of raising livestock, where large numbers of animals are placed in a very limited space, intensive fish farming provides various diseases and parasites ideal conditions to spread. Infectious diseases like furunculosis were previously treated with large quantities of antibiotics added to feed. In our discussion of the environmental impacts of antibacterial agents in fish farming, we would remind the reader that the use of antibiotics in the Norwegian fish farming industry has fallen from 50,000 kilograms to 500-600 kilograms in fifteen years (Grave *et al*., 2002).

Current levels are low enough not to pose any environmental problem. Nevertheless, there are two reasons why we wish to focus on this issue. First, the use of antibiotics is still high in other countries where salmonids are farmed. This applies to Chile, for example, a country not as advanced in preventive fish health as Norway. There is no vaccine against the disease piscirickettsiosis, the disease causing the greatest losses in Chilean fish farming (Olsen, 1999). Antibiotic use in Chile is estimated at fifty tonnes (Jensen, 2002; Nutreco 2002). Second, we fear that consumption in Norway will rise if the farming of other species such as cod reaches significant production volumes. The reason for the rapid decline in Norwegian antibiotic use is primarily due to the availability of effective vaccines against the chief bacterial infections, as well a generally better fish health as a result of more suitable operation locations, less stress and improved hygiene against contagions (Poppe, 1999).

New farmed species will pose new health challenges, and the development of new vaccines may take time (Bleie, 2002). New salmon diseases and new variants of known diseases may also help to reverse the favourable trend in Norway. In 2002 consumption increased to about 1,000 kilograms, especially due to problems with winter ulcers (Norwegian Animal Health Authority, 2003; Rasmussen, 2002).

2.3.1 Environmental impacts of antibiotics in fish farming

Antibacterials are administered to fish through medicated feed that is mixed at feed plants. Antibacterials enter the marine environment when some of the feed is not eaten and sinks to the seabed or is eliminated in fish excretion (Smith, 1996). Three effects of the spread of antibiotics to the marine environment are highlighted:

- Antibiotic resistance
- Spread to wild fish
- Retarded decomposition of organic material

Antibiotic resistance

After intensive, repeated medication using the same antibacterial agent, reduced efficacy is often seen after a time against the disease in question. Before vaccination programs largely eliminated furunculosis outbreaks, oxolinic acid was chiefly used to treat it. After repeated treatments, it was noted that the efficacy was reduced, and in 1999 an investigation showed that 36% of the furunculosis bacteria were resistant against one or more antibiotics (Sørum, 1999). As a consequence of the emergence of resistance, treatments must be repeated or new agents employed. However, antibiotic resistance is not purely a problem of fish health. Resistance can develop in other bacteria in the marine sediments and in the water, thereby spreading to other organisms in the marine environment (Sandaa *et al*., 1992). The total burden of resistant bacteria people are subjected to is growing and may create new problems for human health.

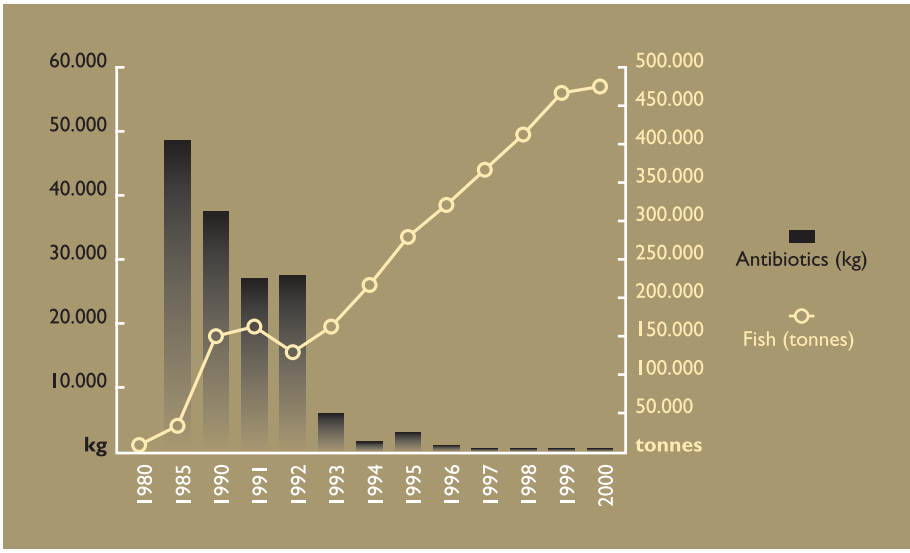


Figure 6:
Antibiotic use, compared with production volumes in Norwegian fish farming.

Spread to wild fish

Antibiotics are also spread to wild fish directly when cod, for example, eat medicated feed that falls through the cages. This fish, in turn, may be caught and eaten by people, who thereby ingest limited doses of antibiotics (Røstvik, 1997). This is undesirable, when one considers the development of resistance in people. Since the use of antibacterial agents is currently so small, the quantity that wild fish ingest from feed spills will be practically equal to zero.

Retarded decomposition of organic material

Antibacterial agents, as the name indicates, are meant to kill bacteria. But as was mentioned above, parts of the

Dissection of salmon.
photo: Norwegian Seafood Export Commission

doses of medication end up in the marine environment, especially in the sediments beneath and around the fish farm. The consequence of the spread is that the number of bacteria in the sediments is also reduced. Hansen *et al.* (1992) found that the total number of bacteria in the sediment after the addition of the antibacterial agents oxytetracycline, oxolinic acid and flumequine by 50-70% respectively. A fish farm has considerable discharges of organic material in the form of unutilised fish feed and excrement (see below in this chapter). A sharp decline in the bacterial flora around the farm retards the decomposition of the organic material and contributes to accumulation.

The biodegradation of antibacterial agents in sediments
The biodegradation of antibacterials in the sediments goes relatively slowly (a half-life of up to 150 days in the topmost sediment layer, 0-1 cm), but varies substantially among the various agents and among types of sediment. A study in which samples were taken up from under various fish farms indicates that Florfenicol has a half-life a fraction of that of the other common agents (Hektoen *et al.*, 1995)

2.3.2 Summary - antibiotics

The environmental impacts of high levels of antibiotic use in fish farming will be substantial and unwanted. Therefore, it is good news that the use of antibacterials in the Norwegian fish farming industry has nearly been eliminated in fifteen years, from 50 tonnes to about 1,000 kilograms. Nonetheless it is important to keep the focus on this issue in countries where the development of vaccines and general preventive health efforts have not come as far, and where considerable antibiotic use continues to be maintained.

	0-1 cm		5-7 cm	
Agent	**Half-life**	**r2**	**Half-life**	**r2**
Oxytetracycline	151	0.923	>300	0.137
Oksolin acid	151	0.671	>300	0.087
Flumequine	60	0.917	>300	0.064
Florfenicol	1,7	0.976	7,3	0.684

Table 2: Half-life of various antibiotics in sediment at two different depths. (Hektoen *et al.*, 1995)

2.4 Discharges of nutrient salts and organic material

2.4.1 Introduction

Fish farming is a significant local source of discharges of nutrient salts. The vast majority of Norwegian aquaculture production takes place in net cages in the sea. Feed spills and excrement are not collected but are released directly into the water (State of the Environment Norway). This produces a fertilising effect in the waters, and if the discharges are too large in proportion to what the waters carrying capasity, water quality will decline. This will have consequences for the surrounding environment and the environmental condition of the fish farm. Discharges of nutrient salts, primarily nitrates and phosphates, and organic materials come from feed spills, fish excrement and dead fish.

Reduced oxygen content

Organic material from fish farms sinks to the bottom and is decomposed by bacteria. This biodegradation process requires oxygen. The discharges thus reduce the oxygen content of the surrounding water, and in extreme cases we may see a total lack of oxygen in the water at the bottom. Discharges of nutrient salts of nitrogen and phosphorus lead to increased algae growth and biomass production in the surrounding water. This increased biomass production leads to a further addition of organic material to the bottom of the fjord, which in turn requires increased amounts of oxygen for bacterial decomposition.

Nitrogen and phosphorus

Two types of nutrient salt, those of nitrogen and phosphorus, represent most of the nutrient salt discharges connected with fish farming (Braaten, 1992). Generally it is salts of phosphorus that are mostly responsible for eutrophication in fresh water, whereas nitrogen salts normally will be more important in salt water (Braaten, 1992). Many of the fish farms are located in fjords and in areas with a large inflow of fresh water, and detailed knowledge is required of the area in question in order to say anything about which nutrient salts are limiting primary production. A fish farm that produces 500 tonnes of salmon, that is, a small farm, releases nutrient salts equivalents to a town of 5,000 to 7,500 inhabitants (State of the Environment Norway). According to the Norwegian Institute for Water Research (NIVA), aquaculture is responsible for 60% and 25%, respectively, of discharges of phosphorus and nitrogen salts along the coast from Lindesnes northward.

Organic material

From fish feed, it is proteins, fats and carbohydrates that constitute nearly all of the organic material (Einen & Mørkøre, 1996). When the organic material hits the bottom, it can be "biodeposited" on the surface of the sediment. Biodeposition means that the sedimentated material is taken up by benthic fauna that are nourished by filtering particles from the water (such as mussels), and the excrement from such fauna is deposited on the seabed (Wasermann, 1994). To prevent a reduction in water quality due to high consumption of oxygen for decomposition we are dependent on adequate currents that can spread the organic material over a larger area. The energy content of the organic material is crucial for the quantity of oxygen that must be added to the water to decompose the organic material (Åsgård & Storebakken, 1993). That is why organic material is converted to energy content in the table below.

Year	Discharge of nitrogen		Discharge of phosphorus		Discharge 10 MJ	
	Pr. ton fish	Total	Pr. ton fish	Total	Pr. ton fish	Total
1992	56,20	8.855	11,10	1.749	18,80	2.962
1993	49,60	13.358	9,90	2.666	16,50	4.444
1994	46,54	11.933	9,60	2.461	16,51	4.233
1995	47,64	16.174	9,80	3.327	16,91	5.741
1996	49,83	20.398	9,60	3.930	17,10	7.000
1997	48,16	19.829	10,10	4.158	19,28	7.938
1998	50,08	21.554	10,40	4.476	20,03	8.621
1999	45,10	21.684	9,80	4.720	20,03	9.630

Table 3: Discharges of nutrient salts and organic material (Source: Klev, 2000)

2.4.2 Discharges of nutrient salts and organic material

Since the beginning of the 1990s we have seen a steady increase in discharges of nitrogen and phosphorus salts and organic material from Norwegian aquaculture. Despite some reductions in discharges per tonne of fish produced, the growth in volume leads to a continuous increase in total discharges.

If the assumed increase to 1,050,000 tonnes of salmonids produced in 2010 comes about (Almås, K. *et al*., 1999), the discharges of nitrogen and phosphorus will climb to 47,355 tonnes and 10,290 tonnes, respectively - an increase of 118.4% and 188%, respectively. This assumes, however, that fish farming is conducted in the same manner as today (2000), and that the nutrient content of the feed is the same as in 1999 (Klev, S.M., 2000).

2.4.3 Impacts of discharges

The impacts of the discharges from fish farming are largely local and correspond to the impacts of other forms of organic environmental load (Frogh & Schanning, 1991; Braaten. 1992; Tvedten, 1996).
Organic material that is deposited on the seabed is decomposed by bacteria that use oxygen. As the oxygen level in the surrounding waters falls, local biodiversity is reduced (Tvedten *et al*., 1996). If the seabed is overburdened, when the oxygen has been used up and because toxic hydrogen sulphide is formed in the bottom sediments, a so-called "rotten" seabed without animal life develops. Rising hydrogen sulphide gas may harm the fish in the fish farms. In Norway, damage has been shown to fish gills assumed to be due to gas formation in sediments.

Any adverse impacts due to eutrophication from a location are reversible. Studies done by Frogh & Schanning (1991) show that locations to which large quantities of organic material were previously added and had highly anaerobic sediments can recover to an almost natural state after a rehabilitation period of between three and five years. The length of the rehabilitation period that is necessary will depend on local topographical conditions.

It has been shown that the currents with dissolved nutrients from aquaculture discharges go out into the Norwegian Sea and thence end up in the Barents Sea. However, the contribution is so small that changes in concentration are not measurable (Hillestad *et al*., 1996).

Good locations important

In the case of nutrient salts and organic material, the carrying capacity of a location, i.e. how much the location can tolerate of a type of environmental load, is dependent on depths, current, seafloor conditions and what is defined as acceptable environmental conditions.

The depth conditions at a locality are important. Aure and Ervik (2002) have discovered that the quantity of fish in a standard fish farm can be increased from 60 to 250 tonnes when the depth is increased from 30 to 80 metres, i.e. that carrying capacity quadruples. The favourable depth conditions along the Norwegian coast are also one of the main reasons for the success that aquaculture has had in Norway.

The design of the fish farms is also important with regard to the carrying capacity of a location. The difference between a compact fish farm (a farm where the cages are in rows on both sides of a central walkway and a free-standing fish farm is relatively big. Based on a current speed under the cages of 4 cm/sec., calculations show that the local carrying capacity increases from approximately 100 to 300 tonnes when using free-standing cages as opposed to compact fish farms. (Aure, J. *et al*., 2002)

2.4.4 The MOM system

A system is under development for environmental monitoring of fish farms. The system is called MOM - a Norwegian abbreviation translated as Modelling - Ongrowing Fish Farms - Monitoring. This model includes a simulation program and monitoring program. The simulation program simulates the effect of hypothetical discharges. Depending on the utilisation ratio of the location relative to the fjord area's carrying capacity, various studies can be performed. These may be ordered by the county governor, though they are not generally required. The system has four utilisation ratios and distinguishes between A, B and C studies. At locations where the utilisation ratio is high, more frequent and more comprehensive studies have to be conducted. At lower utilisation ratios the requirements of studies are less stringent.

An A-study is a simple measurement of the rate of sedimentation on the seabed under the fish farms and primarily uncovers heavy environmental loads. A-studies are particularly useful in combination with B-studies. They are voluntary and may be conducted by the fish farmers themselves.

Condition of location	A-studies	B-studies
1 Low impact	every 3rd month	every 2nd year
2 Medium impact	every 2nd month	every year
3 High impact	every month	every 6th month
4 Overloaded		extended B-study

Table 4: The MOM System. Modelling - Ongrowing Fish Farms - Monitoring (Hansen *et al*., 2001 and Ervik *et al*. 1997)

A B-study monitors trends in seabed conditions under and near a fish farm. The frequency of the studies increases in step with the load, and the dividing line between acceptable and unacceptable impact goes where benthic fauna disappear. These studies cover three groups of sediment parameters, presence or absence of fauna, pH

and redox potential and sensory sediment parameters such as gas bubbles, odour, consistency, colour and volume of the sample and thickness of the sludge deposited from the fish farm.

C-studies chart the seabed conditions from the fish farm and outward towards the recipient. The most important part of the C-study is a quantitative investigation of benthic fauna populations. This investigation can only be conducted by specialists in benthic fauna studies and is normally conducted after being ordered by the county governor.

The increase in the scope of production and the growing local concentration of fish farms may result in greater local discharges. The new system for modelling and monitoring fish farms (MOM) will perhaps be able to give the government and the industry a better basis for tailoring production and discharges to the location's carrying capacity.

Methods to reduce feed spills and discharges of organic material

Measures to reduce discharges of nutrient salts and organic material from fish farms may be divided into two categories: (1) Steady improvements in feed and (2) Collection of feed spills, faeces and dead fish.

Much of this the aquaculture industry itself has begun to deal with. Feed costs represent about half of the production costs of farmed salmon, and it is clear that the industry will save a lot of money by developing better feed and reduce feed spills when the fish are being fed. Underwater cameras to monitor feeding are becoming increasingly common. This enables the technician to stop the feeding when he sees that the fish have stopped eating, whereby less feed is wasted. Improvements of feed and feeding routines, considered the most important discharge-reducing measures, have led to a steady reduction in the feed factor, which has now stabilised at about 1.2.

A number of systems have also been developed for collecting dead fish in the cages. This not only reduces the discharges of organic material, but is also a crucial measure for ensuring good health in the fish farm. The reason is that dead fish that are not removed can lead to a rise in pathogens and thus cause outbreaks of disease in the fish farm.

2.4.5 Conclusion

From Lindesnes and northward, aquaculture contributes heavily to the total discharges of nitrogen and phosphorus salts. The discharges of these nutrient salts and organic materials have increased in step with the growth in volume of Norway's farming of salmonids. Even though the industry's measures to improve feed quality and reduce feed spills have reduced the discharges per tonne of fish produced, this reduction has been counteracted by an increased production volume. Continued growth in the farming of salmonids in addition to scaling up the production of other farmed species will lead to increased discharges of nutrient salts and organic material to Norway's coastal and fjord areas. Even though fish farming is responsible for a large part of these discharges, these discharges do not necessarily constitute a large addition of nutrients compared with natural levels, and compared with what is added by ocean currents from foreign discharge sources.

These discharges are harmful only if they exceed the carrying capacity of the area in question. As long as the discharges do not exceed this, they may have a positive impact on the productivity in the area and not inflict any harm on the environment.

The challenge linked to discharges of this type is therefore to calculate the carrying capacity of the location and adjust fish farming activities accordingly. The MOM system (Modelling - Ongrowing Fish Farms - Monitoring) will be an important tool in these efforts.

Figure 7:
Changes in feed factor in Norwegian aquaculture. The feed factor is the number of kilograms of feed that provides one kilogram of growth in the fish.

2.5 Copper impregnation of nets

Installations in the sea will always be subject to fouling by shellfish, algae, barnacles and hydroids. Impregnation is used to reduce this fouling on the actual net, but also has other functions such as making the net stiff so that it is kept extended in the water, prevent UV radiation from ruining the net and reducing/filling in the gaps between the filaments in the net so that these areas are not fouled. Vannebo *et al*. (2000) estimated that 80-90% of discharges take place through leaching into seawater, whereas 10-20% takes place from net cleaning facilities. Total copper discharges in Norway arising from net impregnation are about 200 tonnes per year. That is, about 1 gram of copper is discharged for every 2 kilograms of farmed salmon produced.

Leaching of copper from fish farm nets and discharges of copper from net cleaning facilities comprise aquaculture's chief addition of environmental toxins to the marine environment. Studies show that the discharges from net cleaning facilities, which constitute 10-20% of total copper discharges from aquaculture, lead to considerable excess concentrations of copper in sediments and biological material in areas near the cleaning facilities. Experiments have shown that copper discharges from net cleaning facilities are bioavailable for some evertebrates and have a markedly adverse impact on planktonic algae (NIVA, 1996). On the basis of this knowledge, it was wise of the authorities to set a requirement for zero discharges from net cleaning facilities. This was adopted in the form of a regulation in 2002, with effect from 2006 for existing facilities.

2.5.1 The environmental effects of the leaching of copper from fish farm nets

On the basis of figures from the Norwegian Pollution Control Authority, leaching of copper from fish farm nets in the sea amounts to about 160 tonnes of copper per year. Although the environmental effects of these diffuse discharges are not thoroughly documented, in light on its extent, thorough analyses ought to be performed of the effects that copper from fish farms has on benthic fauna, phytoplankton and other organisms. Copper ions are released into the open water and sink to the bottom. Copper compounds in the nets are also taken up by macroalgae and fauna that grow on the actual nets and sink to the bottom with them.

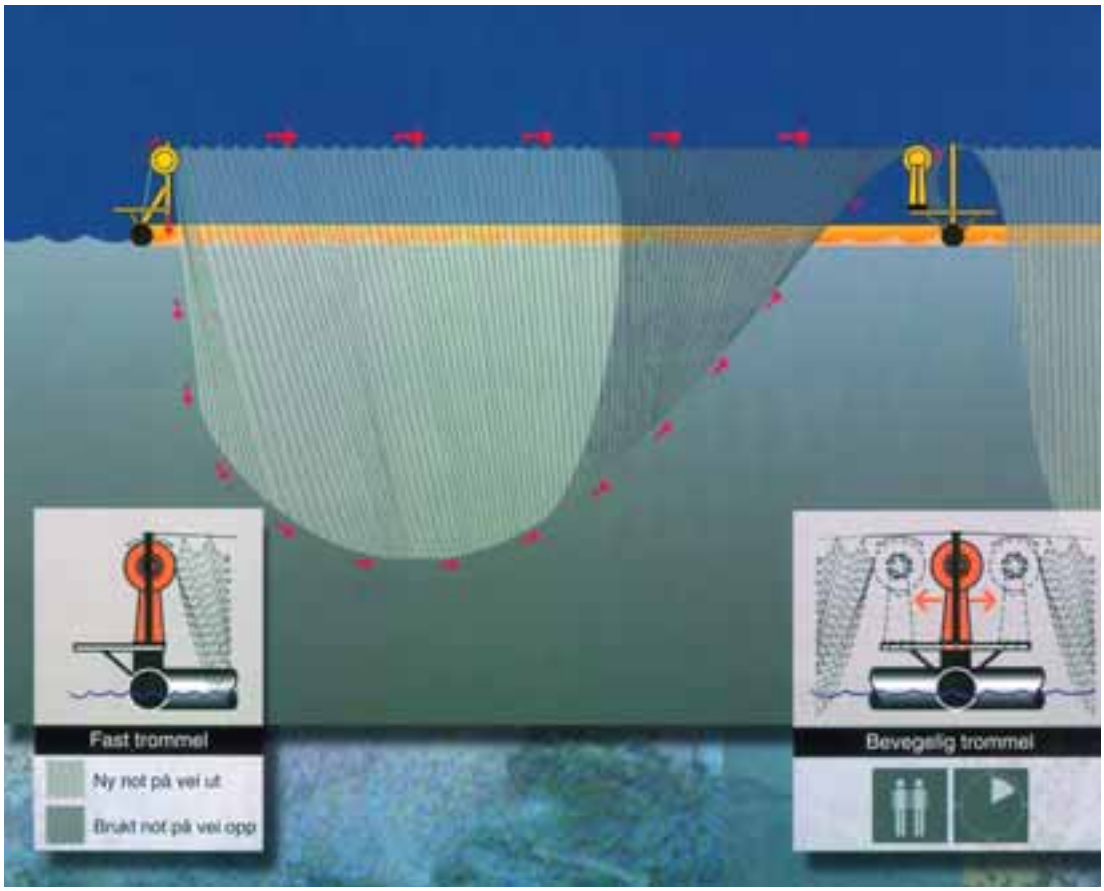
Harmful concentrations

Although relatively few studies have been done to test the effect of heavy metals on marine species in a satisfactory manner, there are some studies that test acute toxicity. On the basis of these, tolerance thresholds can be calculated, but this produces estimates only and is not a sure way of establishing exact knowledge.

Marino-Balsa *et al*. (2000) tested acute mortality for three economically important and widespread species: lobster, spider or toad crab (Atlantic lyre crab) and the common prawn when exposed to the metals mercury, cadmium and copper. LC50 values were calculated after 48 hours for lobster and 72 hours for the other two species. Lobster was the most sensitive species. Marino-Balsa *et al*. conclude that the maximum concentration without a biological effect is 0.5 micrograms per litre of seawater for copper and mercury and 0.3 micrograms for cadmium. Bond *et al*. (1999) observed anatomical abnormalities in the ova of spiral wrack right after fertilisation that interfere with the cell division and development of the zygote. The threshold value for the changes was 10.6 nM. If the concentration was below 10.6 nM, the changes were reversible. Low tolerance thresholds for copper are also known from groups of organisms such as tunicates (Bellas *et al*. 2001). Anderson & Kautsky (1996) found that salinity affects the tolerance threshold for copper pollution. The most wide-ranging study so far, Hall and Anderson (1999), calculated an average tolerance threshold from a sample of 65 species in very different categories of organisms and found a value for copper of 5.6 micrograms per litre. On the basis of available studies there is reason to believe that many species will be unaffected by copper concentrations under 5 micrograms per litre, whereas some species that are rather important economically such as lobster may be harmed at even lower copper concentrations, possibly down to 0.5 micrograms per litre.

Copper concentrations around fish farms and net cleaning facilities

Despite proven hazardous effects, Bellona has not been able to find data on copper concentrations in water near fish farms and net cleaning facilities. However, it is easier to measure copper concentrations in sediments, and in this area there are a number of studies. Wilken (2001) found copper concentrations of over 800 milligrams per kilogram of sediment under fish farms in Denmark. However, fish farm sites in Norway almost always have better water exchange, so that conditions are not comparable. Similar figures were obtained in Scotland: 725 milligrams per kilogram (Miller, 1998).



The draft shows the Enviro drum's manner of operation. The Environmental drum is one of many alternatives to copper impregnated seines.
illustration:
Rabben mekaniske verksted AS

2.5.2 Technological developments

Technological developments in aquaculture are proceeding very rapidly, also in respect of measures to prevent fouling of nets. This is amplified by the fact that impregnating nets constitutes a considerable cost in fish farming, which thus has a strong incentive to develop better solutions. The environmental gains are hailed by fish farmers, which view pollution of the fish farm site as a potential threat to their own business. The implementation of policy instruments against copper impregnation by the authorities may reinforce and hasten the implementation of better solutions.

Examples of alternatives to copper impregnations

Double net bags: Especially prominent as of today are various solutions based on frequent changing of the nets. Systems with double net bags, where one bag can be pulled up and wiped off while the other remains in the water, have become quite popular, not only because fish farmers want to reduce pollution, but because such investments have proven to be cost-saving. The Nor-Mær company delivers a system that it calls the "environment-friendly system". According to the company's website, www.normaer.no, the system is based on the use of double, unimpregnated nets. These are installed so that one net will always be hanging to dry on special net pillars. When the net in the water begins to be fouled, it is changed quickly and efficiently with the net that is hanging to dry. Nor-mær has developed special net winches for this use, allowing two people to change a net in one to one-and-a-half hours. Another vendor that has specialised in such solutions is Rabben Mekaniske Verksted, which markets its product under the name "Enviro Drum". A video presentation of the technology is posted at www.rabbenmek.no. With such systems, there is no longer any need for cleaning and impregnating the nets. However, it requires that the nets are changed before fouling "gets the upper hand". By the very fact that users have to avoid serious fouling before changing nets, this type of cage means that the water exchange in the cage is good all the time, which in turn is important for health, quality and feed consumption.

In most cases, a system of double net bags makes copper impregnation superfluous, because the fouling falls off the net bag after drying. The dried organic material that sinks to the bottom in this instance hardly constitutes an environmental problem, since it contains

Circular netpens, commonly used in Northern Norway, make the use of copper impregnation hard to avoid. photo: Bellona archive

neither copper nor other toxins. There is also reason to highlight a positive side effect of this technology. Frequent net changes allow the fish farmer to do adequate inspections of the nets, which may thereby prevent escapes of farmed salmon, considered to be the industry's most serious environmental problem. This assumes that mechanical solutions for changing nets do not put too heavy a strain on the nets. So far, however, such systems have some limitations in locations especially subject to bad weather, where simpler circular plastic structures dominate.

Flushing nets

Although high-pressure flushing of fish farm nets has long been in use, it is taxing. The challenge is to develop mechanical solutions that make it possible to flush without using divers to go underwater, which is very expensive.

Biocides

At the Department of Mathematical Sciences and Technology (formerly the Department of Agricultural Engineering) of the Agricultural University of Norway, experiments are being conducted on impregnating nets with biodegradable compounds that can replace copper. So far, no results have been published of such experiments.

Wrasse eat fouling

In addition to the positive effect that wrasse have on fighting salmon lice, they have yet another benefit. It turns out that the wrasse nibble away at fouling from the nets. In combination with the mechanical methods mentioned above, wrasse can make fish farming nets without copper impregnation a more competitive alternative.

2.5.3 Conclusion

Bellona believes that the authorities should put pressure on aquaculture to encourage a phase-out of copper impregnation of nets. Long-term policy instruments should be implemented to provide for a gradual change-over to copper-free alternatives, with a predictability and long-range nature that gives fish farmers the best possible basis for deciding on future investments in technology.

Chapter 3
Growth opportunities in marine food production

photo: Bjørn Winsnes

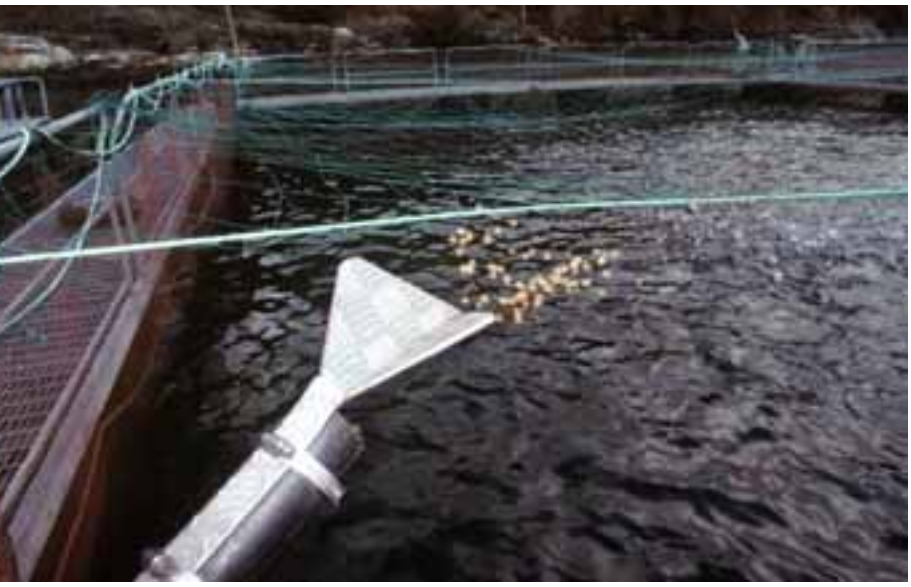
3.1 Feed accounts for farming of salmonids

Aquaculture is growing faster than any other means of animal food production in the world. Globally, production has increased by an average of 9.2 per cent per year, against a 1.4 per cent increase in fishing. In 2000 the total production volume in aquaculture was 35.7 million tonnes, compared with 91.3 million from fisheries (FAO, 2002). The UN Food and Agriculture Organization, FAO, predicts that the production volume in aquaculture will increase by 54,000 tonnes each year until 2030.

Today we obtain more than 95 per cent of our food from the soil despite the fact that the primary production of plants in the ocean is almost equally large. The difference is because nearly all food production on land is cultivated, i.e. by means of agriculture or livestock production, at a low level on the food chain. We utilise primary producers, plants and herbivores. At sea, fishing accounts for the bulk of food production, and catches are taken to a large degree from the upper level of the food chain: large carnivores such as cod. At each level of the food chain 90 per cent of the energy is lost. If we can increase utilisation of the ocean's biomass production by harvesting or cultivating at a lower trophic level of the ocean's food pyramid, the ocean's contribution to global food production could be substantially larger than it is today (Åsgård, 2000).

Can salmon be part of such a development? Indeed, salmon is a predator high up on the food chain. Is it right to use fish protein to make fish protein? The claim that "five kilograms of wild fish becomes one kilogram of farmed salmon" has been the main ingredient in the debate as to whether it is a good or poor use of resources to farm carnivorous species of fish like salmon. In this part of the report we will show that farmed salmon is in the process of moving down a step on the food chain. We will see how efficiently salmon farming utilises resources compared with other livestock production, and review some new potential sources of feed. Furthermore, we will describe the management and status of the most important stocks of fish used as feed.

Automatic feeding facilities ensure an effective feeding process with a minimum of waste. photo: Marit Hommedal



Suitability of feed resources as food for humans

If we wish to maximise access to food in the world, we can move human beings down the food chain. This becomes a thought experiment about the earth's theoretical potential to feed a growing human population, which quite unrealistically presupposes political supranational control of all market mechanisms. It is nevertheless a supposition attracting a certain amount of interest in the political debate. In raising livestock that are fed "human food", a large share is lost along the way because the farm animal uses energy to move, maintain life functions and body heat, reproduce, etc. The amount of food available to the world's population would consequently be greater if we turned the feed resources directly into food for humans. The land used to produce feed for farm animals could to a much greater degree than today be used to produce food for humans. At the same time, the need humans have for protein can largely be met by soya and other lentils instead of meat. The same principles apply to the sea. Forage fish, which to a large degree are used as feed in fish farming, are small and full of bones, but are still nutritionally suitable as food for humans. The species that taste good and are in demand in the various markets are discussed in detail by Strøm (2002). All things considered, the vast majority of fish are suitable food for humans. We can also go lower down the marine food chain and use zooplankton or small crustaceans such as copepods as a source of protein for humans. The demand will hardly make harvesting of such products for food production profitable, but from a nutritional standpoint this resource could conceivably have potential. It is probably more relevant to use these alternatives as a new source of feed for aquaculture - an opportunity discussed later in the section on alternative sources of feed.

Allocation of resources in the market

It is mainly the market - subject to different political operating conditions - that decides how the various food resources are utilised. To increase the share of soya meal used directly as food for humans, the willingness to pay

for soya as food must rise so that farmers can achieve higher prices for their crops from food processors than they do from feed producers. The same applies to forage fish. If fishmeal manufacturers receive more money for the meal from, for example, fish cake producers than they do from manufacturers of fish feed, more fish cakes and less feed will be produced. The result of economic development is, however, usually the opposite. Greater prosperity creates higher demand for "exclusive" meat, both from land-based livestock production, fisheries and fish farming (FAO, 2002). On the world market, the richest countries account for the demand for such products. Poor people who would be happy to eat both soya and fishmeal have less purchasing power than the feed industry in the Western world. Should a global food shortage occur that hits more than just the poorest, higher demand for food will yield higher production of food based on what we currently use as feed.

Unless we want to introduce a new economic world order, there is little we can do with the fundamental mechanisms in the market. Through development aid, reduction of various trade barriers and forgiveness of debt, however, the imbalances can be evened out, but this is a completely different debate for which there is no space to discuss here. Theoretically speaking, we can entertain various means to achieve a more "efficient" utilisation of resources. For example, a global prohibition against using fish raw materials as feed for fish or farm animals, would mean a reduction of the demand for this raw material, thereby precipitating a drop in prices. The adjustment of producers (including commercial fishermen) to this new market would in the long term yield a lower production volume. The smaller the demand for the species of fish in question, the smaller the supply on the market will become. If we assume that a prohibition would reduce the production volume to under a third, this would cause a loss of food resources exceeding the loss seen by letting the raw material go through salmon farming, taking into consideration that only 30 per cent of the protein in the feed recurs in the salmon fillet. (See the section "Feed utilisation in salmon compared with other farm animals").

Forage fish are food for other species of fish

So-called forage fish, which are used in the production of fishmeal and fish oil, are also food for other species of fish in the sea - species that are higher up on the food chain. Harvesting of forage fish can thus reduce the availability of food to major species of edible fish, particularly cod. Cod and other species of edible fish are predatory fish in the same way as salmon, and they are found on the same trophic level on the food chain. In theory, we get more out of forage fish when they are taken out of the sea and fed to salmon than when we let them be food for wild cod because feed utilisation is optimised in aquaculture. But such reasoning is too simple. The sea's ecosystem is complex. You cannot mathematically calculate which species and which level on the food chain will provide the biggest yield, and manage the stocks only by this. Marine biomass production is dependent on a well-functioning interaction between the species and to prevent an imbalance, the harvesting of individual stocks must be viewed from a comprehensive perspective. On land, however, we have accepted complete alternation of the ecosystems. Cultivation of land has displaced wilderness, livestock have displaced wild grazing animals and wild predators have been exterminated to protect livestock. Should we then exterminate the cod to protect more productive species lower down the food chain? Bellona does not think so, and through the Storting's discussion of Report no. 12 (2001-2002) to the Storting, Rent and rikt hav (A Clean and Rich Ocean), the principle of ecosystem-based management of the ocean has been adopted as Norwegian policy (Ministry of the Environment, 2002). Management of fish stocks included in fish feed production is discussed in more detail later in this chapter.

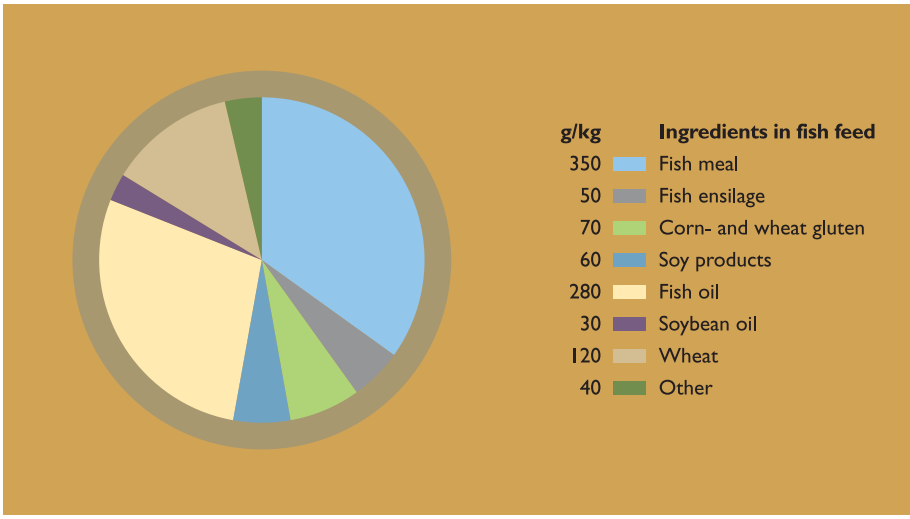


Figure 8:
Composition of "traditional" fish feed. Today, the percentage of vegetable raw materials is usually higher.

Diet of farmed salmon

Figure 8 shows the traditional breakdown of the ingredients in salmon feed (Waagbø *et al.*, 2001). In practice, the composition will vary between different feed products and manufacturers. The percentage of vegetable raw materials has increased since this overview was compiled. Among other things, an average of 20 per cent of the oil content in feed from Skretting in Norway is from vegetable oils, and percentages of 30 per cent are becoming common (Skretting, 2003). Trials have shown that

the percentage of vegetable oil can be increased to 40 per cent without impacting productivity or consumers' perception of taste. With the right combination of vegetable and marine oil, the same content of the healthy and sought-after omega-3 fatty acids is largely achievable as with the use of 100% marine oil (Williamsen, 2002). The major fish feed manufacturers are consequently replacing an increasing share of the fish oil in the feed with vegetable oils (Williamsen, 2002). The reason is that limited and unstable production of fish oil leads to higher prices and uncertainty about availability of supplies, which in turn helps make other raw materials competitive. Vegetable oils and fats are produced in a much larger volume than fish oil, and the markets are more predictable. In addition, vegetable raw materials provide greater food safety, because the problem of some environmental toxins that accumulate in the marine food chain is avoided (Rosenlund, 2001).

Utilisation of feed in salmon compared with other livestock.

Compared with other feed concentrate-based livestock production, salmon farming is extremely efficient in terms of the utilisation of energy and protein in the feed. The efficiency of the salmon is attributed to several factors. Fish are poikilothermic (cold-blooded) and do not use energy on keeping their body temperature stable like land animals such as pigs and chickens. Because salmon have up to several thousand offspring very few breeding pairs are needed. Feed consumption for recruitment is thus extremely low, compared with, for example, pigs, which usually have 12-14 offspring in each litter. Furthermore, the slaughter yield in salmon is high. The percentage of muscle, or pure flesh, in salmon is 65 per cent (Austreng, 1994). Relatively little thus goes to waste as offal, and much of the offal can also be used for food or in feed production.

Figure 9:
Utilisation of feed in salmon, compared with other livestock (Austereng, 1994)

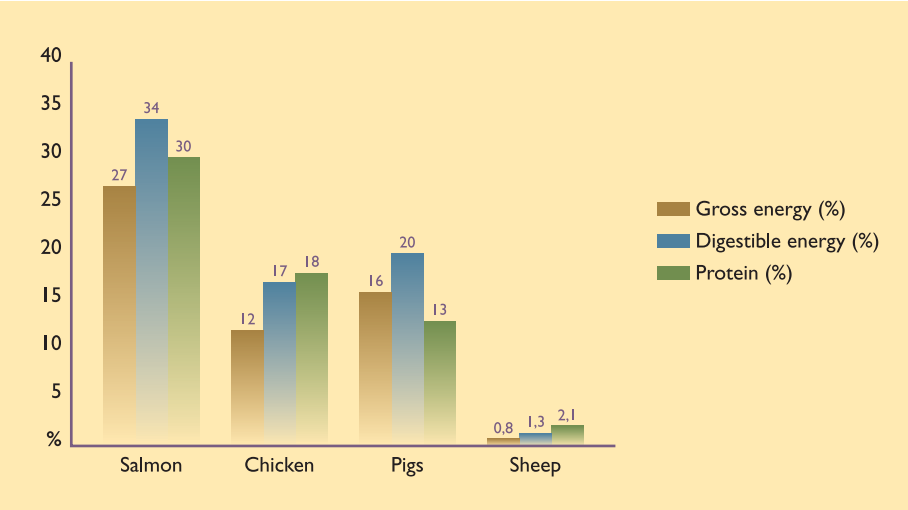


Figure 9 provides an overview of the utilisation of feed in salmon, chickens, pigs and sheep (Austreng, 1994). (Sheep sets itself apart in this company because it is a ruminant. Their utilisation of feed is low, but ruminants can live on roughage (fresh or preserved grass), and can consequently utilise resources that are neither suitable for human consumption nor as feed for poultry and pigs. In Norwegian agriculture, a lot of feed concentrate is also used in sheep farming, but we will not go into that here.)

We see from figure 9 that salmon utilises the energy in the feed twice as efficiently as chickens, and 70 per cent more efficiently than pigs. For protein the ratio is similar: Salmon utilise protein 70 per cent more efficiently than chickens, and twice as efficiently as pigs. Such a comparison between different types of livestock becomes most relevant if they compete for the same sources of feed. Traditionally, salmon have mainly been fed marine raw materials, which in the production of chickens and pigs has only been used in smaller amounts as an appetiser. The positive effect of having a small percentage of fishmeal in chickenfeed means that we can expect continued higher demand for this raw material in agriculture. When farmed fish and terrestrials are increasingly being fed the same raw materials, the comparison of feed utilisation is extremely relevant, and we see that it is more beneficial in salmon farming instead of other types of livestock production.

From raw material to meal and oil

Depending on the type of fish in the raw material, 1,000 kg of fish yields approximately 200 kg of fishmeal, nearly 120 kg of fish oil and 680 kg of water (FAOa). To make 1 kg of fishmeal and 0.5 kg of fish oil you consequently need 5 kg of fish. In theory, from unprocessed fish to processed meal and oil, only the water content disappears. In practice, however, waste can occur due to technical factors. Poor handling of raw material en route from the ocean to the fishmeal factory can reduce the quality to such a degree that it cannot be used as feed. A huge quantity of fish is also lost during the fishing of major species of edible fish. Just in Norway, 140,000 tonnes of fish in the form of fish entrails and the like are thrown overboard from fishing vessels (www.rubin.no).

Fish and plants - current diet of salmon

Based on the current salmon diet we can estimate how many kilograms of fish are used in producing one kilogram of salmon. The percentage of vegetable raw materials in the feed has as mentioned increased considerably in recent years, and it is not unusual that up to a third of the oil content in salmon feed is vegetable oil and two-thirds is fish oil. Feed composition differs greatly over the course of a year, because the price of the raw materials

Hand feeding.
photo: Bjørn Winsnes

fluctuates widely. Feed manufacturers constantly adjust their output to the market, so that the percentage of marine raw materials can be extremely high at times and low during other periods. We make the following assumptions for the estimate (it is important to bear in mind that these prerequisites are not met in all cases.)

- The feed factor is 1.2 (number of kg of feed/kg of growth)
- 26 per cent fish oil in the feed (two-thirds of an oil content of 40 per cent)
- 35 per cent fishmeal in the feed
- 8.4 kg of fish yields 1 kg of fish oil (1000 kg of forage fish yields 120 kg oil and 208 kg meal)
- 4.8 kg of fish yields 1 kg of fishmeal

(1) 1 kg of salmon x 1.2 kg of feed/kg of salmon
= 1.2 kg of feed
(2) 1.2 kg of feed x 0.26 kg of fish oil/kg of feed
= 0.32 kg of fish oil
(3) 0.32 kg of fish oil x 8.4 kg of fish/kg of fish oil
= 2.66 kg of fish

Production of 1 kg of salmon with two-thirds fish oil and one-third vegetable oil in the feed thus requires oil from 2.66 kg of fish.

It is normal that fish feed contains approximately 35 per cent fishmeal (Waagbø *et al.*, 2001). The equation for fishmeal is thus as follows:

(4) 1.2 kg of feed x 0.35 kg of fishmeal/kg of feed
= 0.42 kg of fishmeal
(5) 0.42 kg of fishmeal x 4.8 kg of fish/kg of fishmeal
= 2.0 kg of fish.

In this equation we have shown that 2.66 kg of fish yields enough fish oil and more than enough fishmeal for the production of 1 kg of salmon, under the above assumptions. Consequently, 5 kg of fish, which was previously usual, is not necessary.

Because Norwegian salmon farming is regulated through feed quotas specified in kilograms, it is profitable to have high energy density in the feed. Regulation thus produces a skewed effect, because adjustment to the regulation can produce a feed composition other than one that is nutritionally optimal. The proposal has therefore been made to change the feed quotas from weight given in tonnes per licence to energy given in kJ per licence. This change could result in lower fat content in the feed, thereby further reducing the need for fish oil.

3.2 Fisheries ceiling reached

In intensive fish farming, such as farming of salmonids in Norway, fishmeal and fish oil are used in the fish feed. This chapter provides an overview of the world's largest manufacturers of fishmeal and oil. The main emphasis is on the stocks that are mainly used in this production, the condition of these stocks and an evaluation of whether their management can be viewed as sustainable.

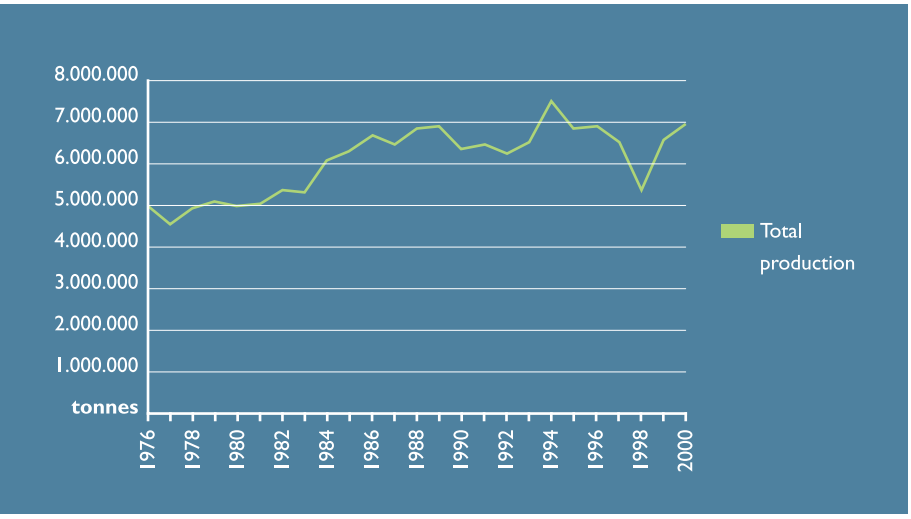
The world's total catch of fish

In the period from 1950 to the end of the 1980s catch statistics show a gradual increase from approximately 20 million tonnes up to approximately 90 million tonnes. From the end of the 1980s up to today we have also, according to FAO statistics, seen an increase in the catch. If we are to believe the statistics, the increase in the last 20 years is solely due to China's fishing industry. However, several doubt the country's reports (Watsen & Pauly, 2001). Disregarding China's catch, the world's total fish catch has declined from the end of the 1980s until today. The last 10-15 years can indicate that the world's total catch of fish has reached a level of approximately 100 million tonnes annually. Bearing in mind that 75 per cent of the world's fish stocks are fully taxed, overtaxed or need time to rebuild after collapsing (FAO, 2002a), there is little to indicate that we can expect an increase in the total catch. It is more natural to ask whether the current catch level is sustainable or whether we will see a decline in the fish stocks in consequence of too high fishing pressure.

One-third of the catch is ground

Fishmeal and fish oil are important protein and fat sources for the fish farming industry. Of the world's total catch of fish, approximately 30 per cent goes to produce fishmeal and fish oil. In 2001, 29.4 million tonnes of a total catch of 91.3 million tonnes were used for this purpose. In recent years this percentage has varied between 25-35 million tonnes (FAO, 2002a). Fishing activities in the Southeast Pacific and Northeast Atlantic are the main sources of the world's production of fishmeal and oil. On the west coast of South America, Peru and Chile fish the Peruvian anchovy (*Engraulis ringens*), sardines (*Sardinesops sagax*) and Chilean mackerel (*Trachurus murphyi*). In Europe, capelin (*Mallotus villosus*), blue whiting (*Micromesistius poutassou*), herring (*Clupea harengus*), small sandeel (*Ammodytes tobianus*), lesser sandeel (*Ammodytes marinus*), horse mackerel (*Trachurus trachurus*), mackerel (*Scomber scombrus*), Norway pout (*Trisopterus esmarkii*) and European sprat (*Sprattus sprattus*) go in varying degrees for the production of fishmeal and oil (FIN, 2003).

Figure 10: Development of the world's fishmeal production (tonnes/year)



3.2.1 Production of fishmeal and fish oil on a world basis

Since the early 1980s, the annual production of fishmeal has remained at around 6.5 million tonnes. Peru is completely dominant with its fishmeal production of more than 2.2 million tonnes, equivalent to approximately 30 per cent of the world's output.

Country	Tonnes
Peru	2.241.529
Chile	880.744
China	806.423
Denmark	388.685
Thailand	387.416
Japan	386.869
USA	335.194
Norway	265.000
Iceland	253.238
Russia	125.623

Table 5: The ten largest manufacturers of fishmeal, and their production volume.

Annual production of marine oil has varied at around 1.2 million tonnes. In certain years, the meteorological phenomenon El Niño has dramatically reduced production, particularly in 1998 (FAO, 2000a). With approximately 45 per cent of the world's output, Peru is also the leader in the production of marine oil.

Fishmeal and fish oil are important sources of fat and protein for farmed fish, although other industries also use these resources. The trend, however, is clear: more and more of the world's fishmeal and oil is used in aqua-

Land	Tonnes
Peru	587.312
Chile	180.199
Denmark	140.254
Norway	87.817
USA	87.249
Iceland	78.533
Japan	59.974
Spain	19.000
China	15.790
Canada	9.702

Table 6: The ten largest manufacturers of fish oil, and their production volume.

	1988	2000	2010
Aquaculture	10 %	35 %	56 %
Poultry	59 %	24 %	12 %
Pigs	20 %	29 %	20 %
Ruminants	3 %	3 %	0 %
Other	8 %	9 %	12 %

Table 7: Distribution of the different usages of fishmeal, and forecast for 2010 (Source: IFFO).

	1990	2000	2010
Aquaculture	16 %	57 %	98 %
Consumption	76 %	31 %	1 %
Industry	8 %	10 %	0 %
Pharmacy	0 %	2 %	1 %

Table 8: Distribution of the different usages of fish oil, and forecast for 2010 (Source: IFFO)

culture. In 2000, 35 per cent of the fishmeal and 57 per cent of the fish oil were used in aquaculture. IFFO expects that this will increase, respectively, to 56 per cent and 98 per cent in 2010.

3.2.2 South America

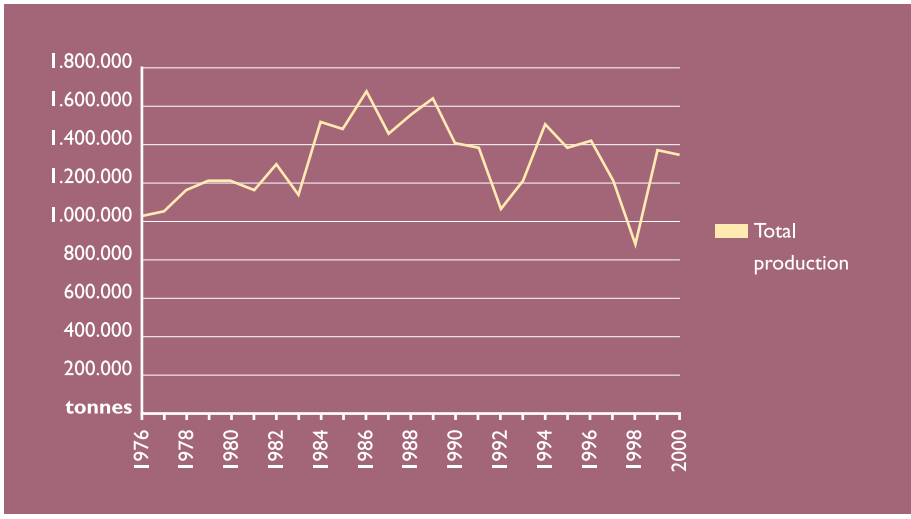
The west coast of South America has one of the world's most productive ocean areas. Landward ocean currents make it a so-called "up-welling" area, i.e. huge amounts of nutrient-rich cold water flow up from the depths to the surface. Here the nutrients become available, and in combination with sunlight they cause rapid growth of algal blooms. The algae provide good growing conditions for small pelagic fish, which are fished in abundance. El Niño reverses the current pattern, weakening the up-welling of nutrient rich water. This in turn leads to reduced algal growth and smaller stocks of fish that graze on them.

Peru is the dominant fisheries nation in the area, with Chile in a good second place. In good years the fishing of anchoveta (*Engraulis ringens*) accounts for around 10 per cent of the world's total catch volume. Peru is dominant in the fishing of this species. In addition, Peru accounts for the largest harvest of sardines (*Sardinesops sagax*) in the area, while Chile traditionally has fished most of the mackerel species jack mackerel (*Trachurus murphyi*). All three species are used to produce fishmeal and oil. In 2001, the pelagic fisheries in the Southeast Pacific (FAO area no. 87) were described as fully taxed (WRI), and it is consequently not probable that the harvesting of fish can increase without adverse effects on the stocks of pelagic fish and the ecosystem as a whole (Cury, P. *et al.*, 2000).

A purse seine like this is essential in the catching of industrial fish. photo: Vidar Vassvik

Peru is the world's largest producer of fishmeal and fish oil, most of which is exported. In 2000, Peru exported 2.2 million tonnes of fishmeal and 456,000 tonnes of fish oil. Chile, the world's second largest producer, previously

Figure 11: Development of the world's fish oil production (tonnes/year)



exported the vast majority of its production of fishmeal and oil, but the country's intense focus on fish farming has changed this. Chile still exports large quantities of fishmeal, approximately 540,000 tonnes, but has become a net importer of fish oil. After Norway, Chile is now the world's second largest fish oil importer, with an import of 95,000 tonnes in 2000.

Regulation of fishing in South America

Fisheries management along the coast of Chile and Peru is mainly based on restrictions on fishing in certain geographic areas and to periods of fishing activities. There is no TAC (Total Allowable Catch), as we are used to in our waters. When the fish stocks show signs of decline, fishing bans are introduced. In Peru, all fishing boats are now equipped with a satellite tracking system that provides the authorities an opportunity to continually monitor the position of the boats. Furthermore, the authorities in Peru have introduced fishing moratoriums in February-March and August-October to protect growth in recruitment and spawning stocks of anchoveta and sardines.

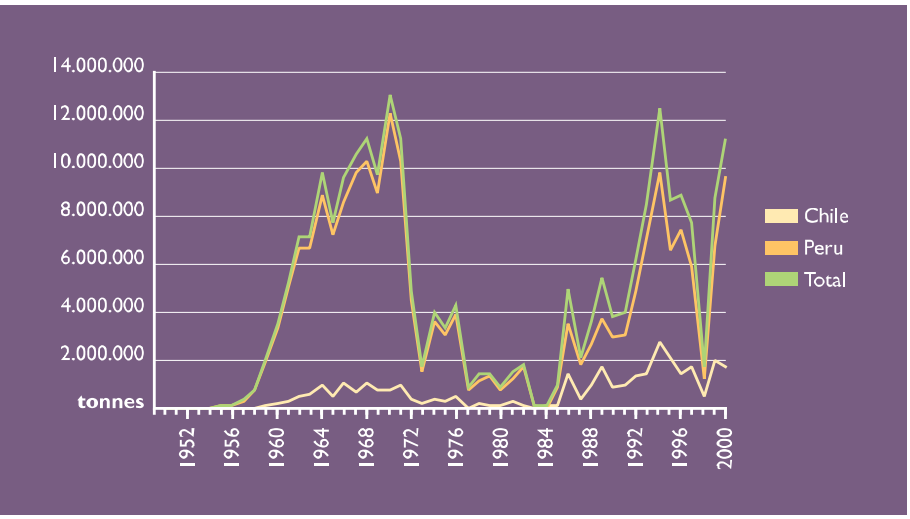
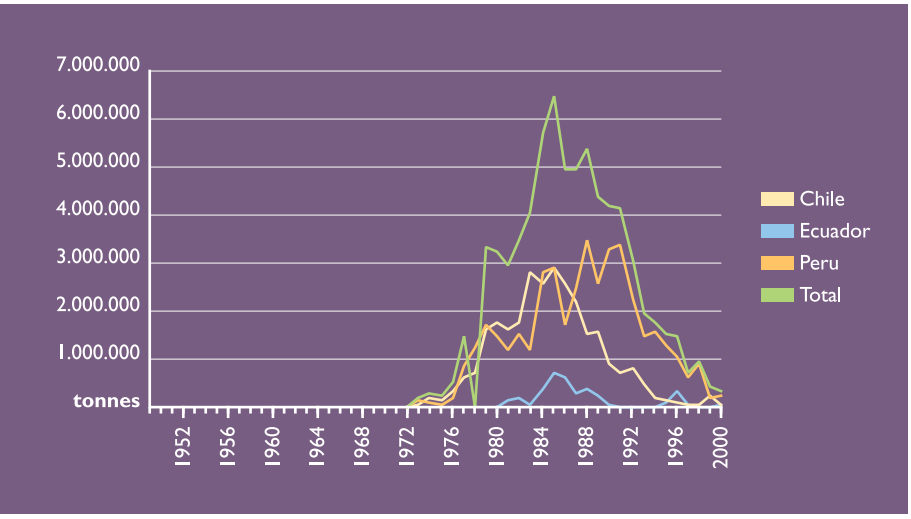


Figure 12: Catch of Anchoveta (tonnes/year)

Figure 13: Catch of South American Pilchard (tonnes/year)



In Chile the authorities have introduced maximum quotas for the annual catch of each fishing company. In the northern part of Chile there is a fishing moratorium on anchoveta and sardines in August-September to protect the spawning stocks. Furthermore, they have stopping fishing for anchoveta in December-February. In the central and southernmost part of Chile, fishing for anchoveta and sardines is shut down during spawning, which usually takes place in July-August and during the period from mid-December to mid-January. For Chilean mackerel a fishing moratorium is put into effect in periods when many small fish are recorded in the landings. Like the system in Peru, all large Chilean fishing vessels are equipped with a satellite tracking system. This makes it possible for the authorities to monitor the position of the boats and prevent fishing activities in areas closed to fishing. Both countries have begun programmes to measure the stocks of their most important species of fish.

Since the industrialisation of fishing in South America, the three species anchoveta (*Engraulis ringens*), sardines (*Sardinesops sagax*) and Chilean jack mackerel (*Trachurus murphyi*) have been under severe pressure. Varying climatic conditions and fishing activities have at times led to collapse of the stocks. The largest fishing nations, Peru and Chile, have introduced restrictions in fishing, and control has improved. The fish stocks are fully taxed. An increase in harvesting will not be sustainable and will in the long term lead to lower catch volume.

Anchoveta - *Engraulis ringens*

The Peruvian anchovy *Engraulis ringens* is the most fished fish in the world. It has a short life cycle, and the stocks vary widely depending on both natural conditions and fishing pressure. This year, with the absence of El Niño and good access to food, fishing of this one stock alone has accounted for around 10 per cent of the world's total catch volume. As the result of a powerful El Niño in 1997/1998 stocks plummeted, and the catch was reduced from 7.7 million tonnes in 1997 to approximately 1.7 million tonnes the year after. This had consequences throughout the world, because the shortage of fish oil in particular led to a dramatic price increase. Stocks did, however, rapidly recover and in 2000 the catch was 11.2 million tonnes.

Sardines - *Sardinesops sagax*

Catches of the sardine *Sardinesops sagax* have fallen dramatically since the mid-1980s. Peru fished most of this

species in 2000, at just over 226,000 tonnes. Chile accounted for 60,000 tonnes, Ecuador 51,000 tonnes. The catch statistics show a reverse correlation between stocks and catches of the species anchoveta and sardines in the Southeast Pacific. Periods of strong recruitment of anchoveta come at the expense of recruitment of sardines (Espino, M)

Chilean Jack Mackerel

Fishing of this mackerel species is led by Chile, which landed over 1.2 million tonnes in 2000. Peru and Ecuador landed 296,000 and 7,000 tonnes, respectively. From 1995's record catch of 5 million tonnes the catch fell to around 1.5 million in 2000. This species is primarily used for consumption, but some also goes for the production of fishmeal and oil.

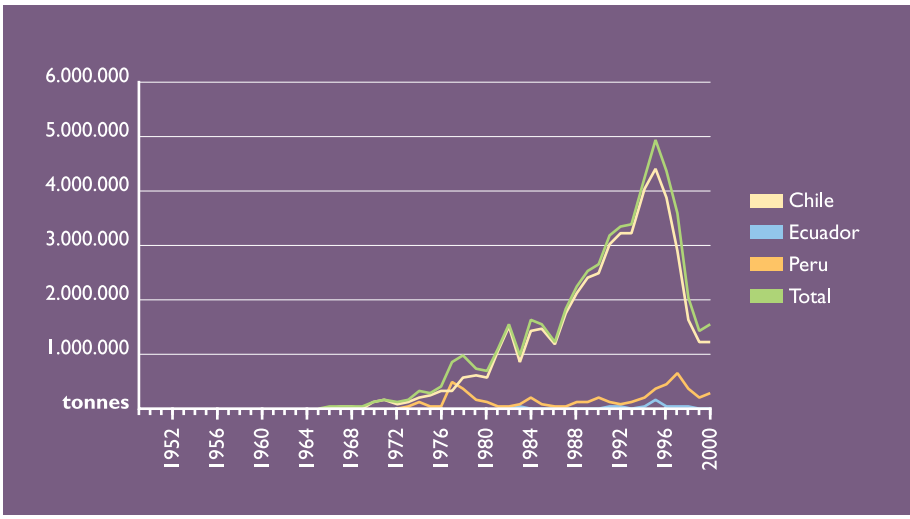


Figure 14:
Catch of Chilean jack mackerel (tonnes/year)

3.2.3 Europe

Europe has no "up-welling" area like that found in South America. The rich fishing in our waters is attributed to a wide continental shelf providing good growing conditions for fish.

Several species are used for the production of fishmeal and oil. In industrial trawler fishing, it is mainly Norway pout (*Trisopteirus esmarkii*), small sandeel (*Ammodytes spp.*) and blue whiting (*Micromesistius poutassou*), in addition to capelin (*Mallotus vollosus*) and European sprat (*Sprattus sprattus*), that go for grinding. To a lesser degree this also includes herring (*Clupes harengus*), mackerel (*Scomber scombrus*) and horse mackerel (*Trachurus trachurus*) in the production of fishmeal and oil.

Denmark is Europe's largest producer of fishmeal and fish oil, with 389,000 and 140,000 tonnes, respectively in 2000. Denmark exports most of its production to nations with large fish farming operations such as Norway. By European standards Norway and Iceland are also major producers of fishmeal and oil.

Norway produced 265,000 tonnes of fishmeal and 87,000 tonnes of fish oil in 2000. Because of the steadily growing fish farming industry our need for meal and oil is much larger than what we manage to produce ourselves. Norway is a net importer of both fishmeal and oil, with most coming from the large fisheries off the west coast of South America. Based on the production, export and import of fishmeal and oil in Norway we can estimate the amount of fishmeal and oil used in Norway in 2000. The bulk of this is used in the production of fish feed for salmon and rainbow trout farming. Based on these estimates, Norway's need for fishmeal was 362,000 tonnes, oil 259,000 tonnes.

Lesser sandeel and small sandeel (tobis)
- Ammodytes marinus & A. tobianus

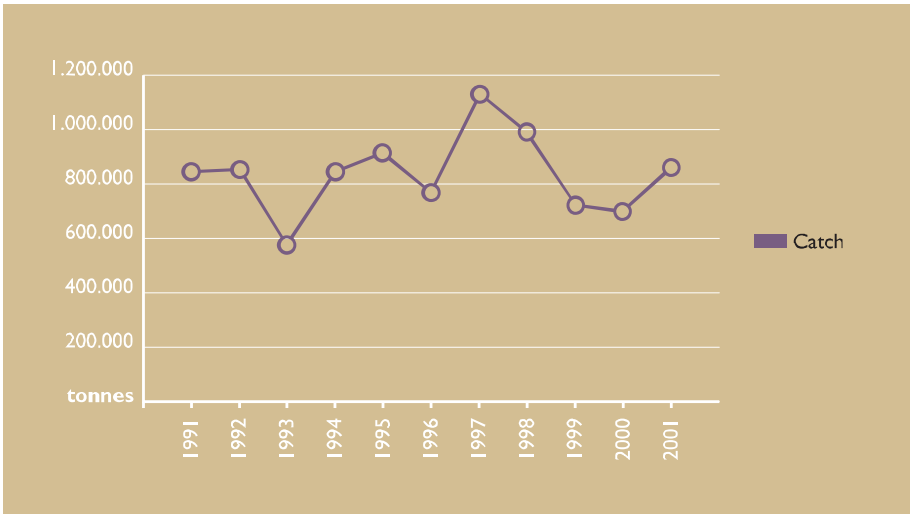
Because of a high fat content that provides good quality fishmeal, small sandeel is the most sought-after resource. Denmark dominates the fishing of small sandeel in the North Sea with a 2001 catch of 630,800 tonnes out of a total 858,100 tonnes. Norway's catch in 2001 was 179,200 tonnes.

Small sandeel stocks are believed to be within safe biological limits. No total quota (TAC) has been agreed for fishing this species, just a division between Norway and the EU of quotas in each other's areas. Assessments made by the ICES Advisory Committee on Fishery Management (ACFM) indicate that the stocks of small sandeel can tolerate the current fishing pressure.

Capelin - *Mallotus villosus*

Capelin is mainly used for the production of fishmeal and oil, but some is also used for consumption. Stocks of

Figure 15:
Catch of small sandeel in the North Sea (tonnes/year)



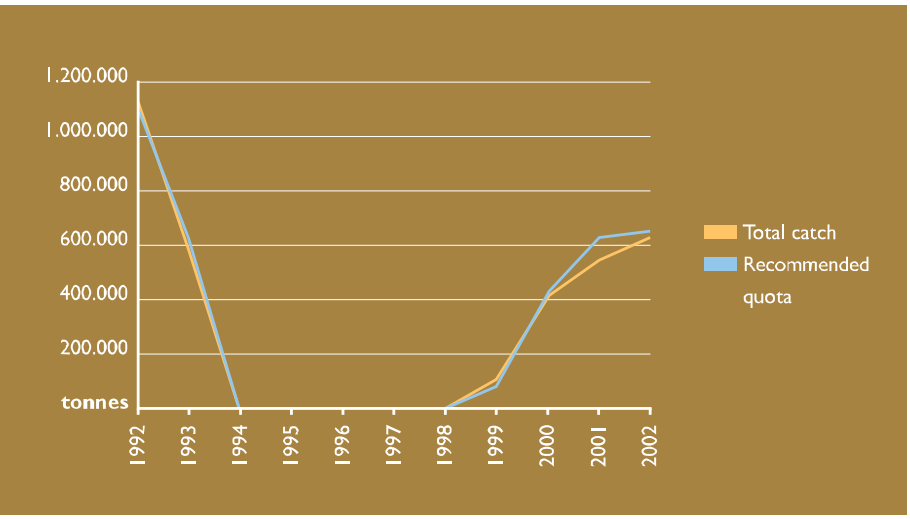
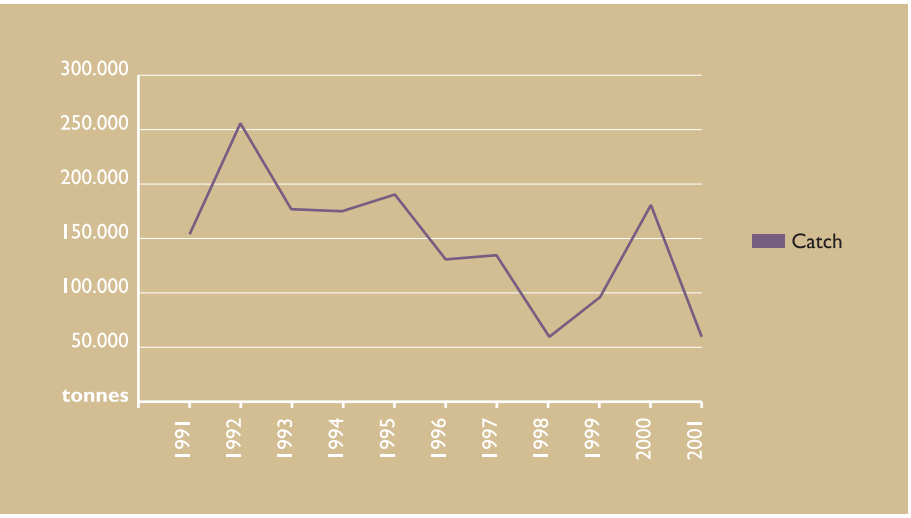


Figure 16: Catch of Capelin in the Barents Sea (tonnes/year)

Figure 17: Catch of Capelin by Iceland - East Greenland - Jan Mayen (tonnes/year)

Figure 18: Catch of Norway pout in the North Sea (tonnes/year)



capelin in the Barents Sea peaked in 1975 with total stocks of 7.15 million tonnes. In 1991 stocks had sunk to 5.71 tonnes. Because of low stocks a ban was placed on fishing capelin in the Barents Sea in 1994. Fishing was resumed in 1998.

In the Barents Sea, Norway and Russia are the dominant forces in fishing for capelin, with 383,000 and 228,000 tonnes, respectively. The stocks are diminishing and were estimated at 2.2 million tonnes in the autumn of 2002. The decline is due to small cohorts in 2000 and 2001. ICES has recommended a quota for 2003 of 310,000 tonnes. At its autumn 2003 meeting, the Norwegian-Russian fisheries commission voted to follow the scientists' recommendation, and set the total quota at 310,000, with 60 per cent to Norway and 40 per cent to Russia. The extent to which the decline in the stocks is short-term or whether the stocks will have a prolonged period of low stock sizes depends on the result of spawning in 2002 and 2003.

The largest capelin fishery takes place in the area by Iceland, East Greenland and Jan Mayen. Iceland is the biggest fishery nation, with a catch of 1,051,000 tonnes in 2002. According to scientists, stocks of capelin by Iceland, Greenland and Jan Mayen are in good condition.

Norway pout - *Trisopterus esmarkii*

Fishing for Norway pout is part of industrial trawler fishing in the North Sea. The catch is used to produce fishmeal and oil. Denmark accounts for the largest harvesting of Norway pout in the North Sea, with 40,600 tonnes in 2001. Norway fished 17,600 tonnes that same year.

After hitting bottom at the end of the 1980s, stocks have shown a generally positive trend, and ICES regards the stocks as being within safe biological limits. No total quota (TAC) is agreed for fishing of Norway pout, only a division between Norway and the EU of quotas in each other's areas. Assessments made by the ICES Advisory Committee on Fishery Management (ACFM) indicate that stocks of Norway pout can tolerate the current fishing pressure.

Blue whiting - *Micromesistius poutassou*

The majority of the blue whiting catch (*Micromesistius poutassou*) is used for the production of fishmeal and oil. Some is also sold fresh or frozen for human consumption (Fishbase). Annually, 13-15 nations fish for blue whiting. Norway, the Faroe Islands, Iceland and Russia normally take 75-85 per cent of the total catch (Institute of Marine Research, 2003). According to the Directorate of Fisheries, the Norwegian fleet took approximately 536,700 tonnes in 2002.

The strong cohorts in 1999 and 2000 are now sexually mature and comprise the largest part of the spawning biomass. Nevertheless it is disconcerting that the spawning stocks are made up of extremely young fish - fish older than three years make up barely 20 per cent of the spawning stocks - which is due to extremely high fish mortality. The rapid stepping up of the fishery, particularly of young fish, has given a new dynamic to the stocks that makes it difficult to assess their condition.

There are not yet any agreed quotas among the countries for blue whiting fishing in international waters, which has led to virtual "free fishing". The individual countries have set their own quotas based on their view of percentual rights of recommended maximum catches (TAC) from ICES. The countries have not agreed on an international regulation of the stocks.

The stocks are below safe biological limits, and disagreement on how large quotas the individual countries are entitled to fish, will probably lead to a continued high harvest of blue whiting. According to the Institute of Marine Research, a decline in stocks will be unavoidable if recruitment is "normal", and taxation continues to exceed the recommendations from ICES (IMR 2003).

European sprat - *Sprattus sprattus*

European sprat is used for both feed and human consumption. Denmark is clearly the biggest actor in the fishing of European sprat in the North Sea and the Skagerrak/Kattegat area. In 2001 the Danes fished 157,200 tonnes of a total of 170,100 tonnes in the North Sea.

The recruitment measurements are extremely unsafe and no scientific quota recommendations are being issued at this time. According to the Institute of Marine Research European sprat stocks nevertheless seem to be satisfactory, with an increase in catches and biomass.

Herring - *Clupea harengus*

Herring is primarily used for human consumption. Some lower quality herring is, however, used for the production of fishmeal and oil. Herring fishing can be divided into two stocks: Norwegian spring-spawning herring (NVG herring) and North Sea herring.

Stocks of Norwegian spring-spawning herring are estimated by ICES to be within safe biological limits. ICES has recommended a TAC of 710,000 tonnes for NVG herring in 2003.

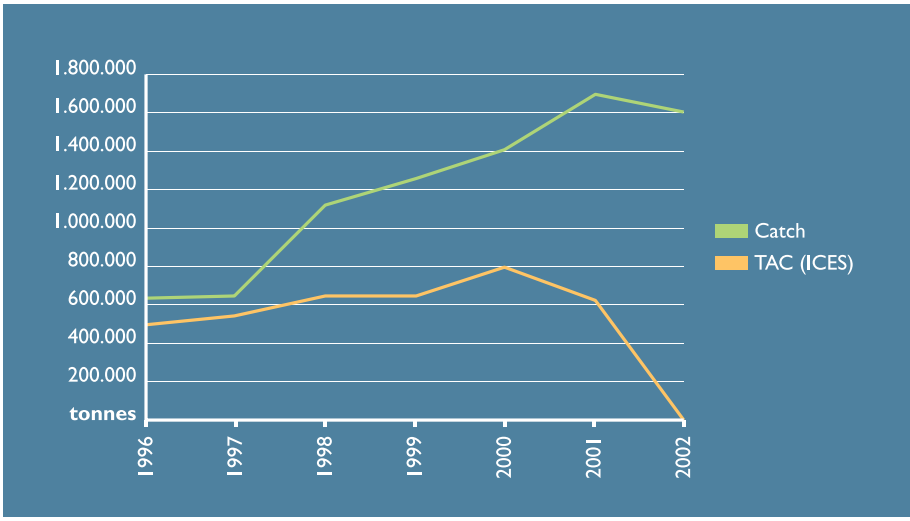


Figure 19: Catch of blue whiting (tonnes/year)

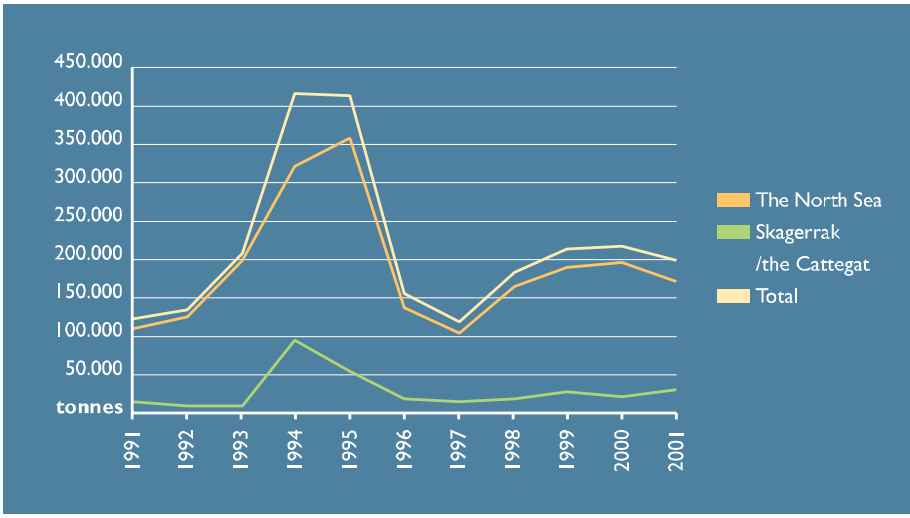


Figure 20: Catch of European sprat (tonnes/year)

Figure 21: Catch of Norwegian spring-spawning herring (tonnes/year)

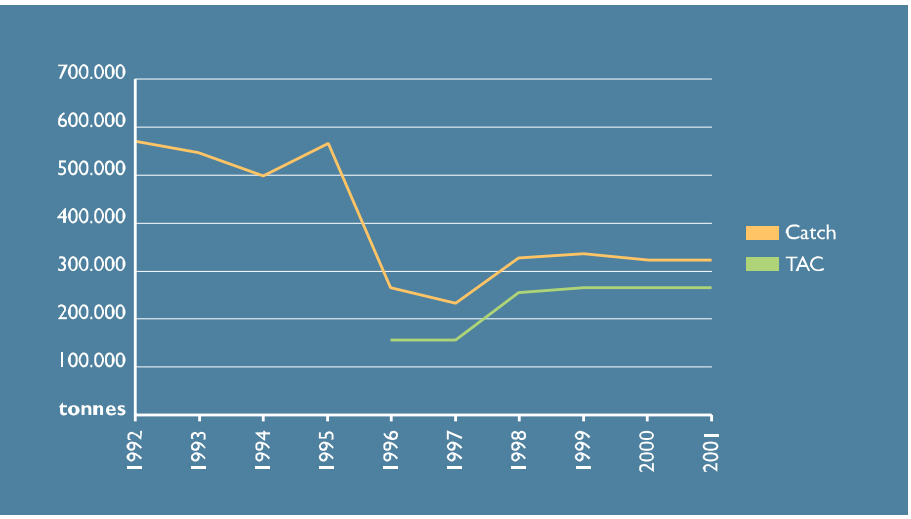
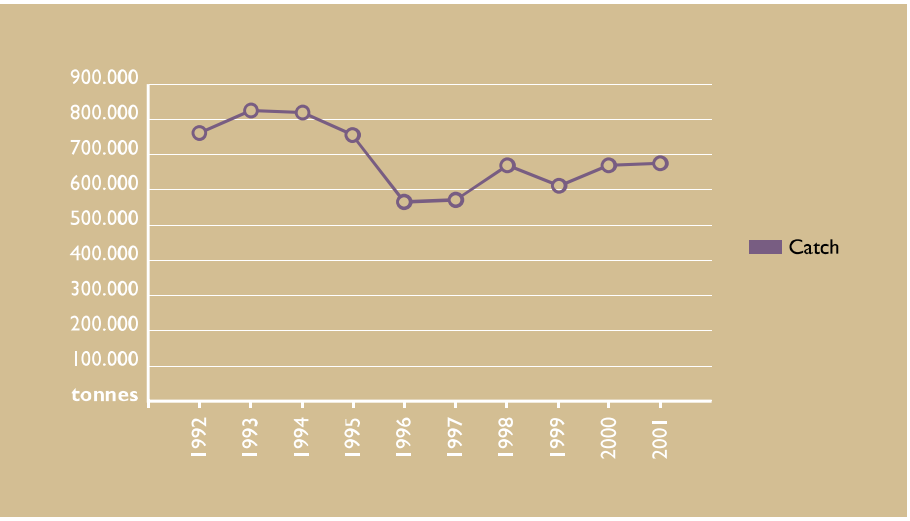


Figure 22: Catch of herring in the North Sea (tonnes/year)

Figure 23: Catch of horse mackerel (tonnes/year)

Figure 24: Catch of Atlantic mackerel (tonnes/year)



Stocks of North Sea herring are growing well and are viewed as being within safe biological limits with spawning stocks of just over 800,000 tonnes.

In addition, around 100,000 tonnes of herring are fished annually in the Skagerrak/Kattegat area. Herring in Skagerrak/Kattegat are caught partly through direct herring fishing, partly through forage fishing for young herring and European sprat and as bycatch in industrial trawler fishing.

Horse mackerel - *Trachurus trachurus*

Horse mackerel is primarily used for human consumption, only limited amounts are used for the production of fishmeal and oil. Previously, most of the Norwegian catch of horse mackerel was ground, but in recent years the major portion has been exported to the consumer market in Japan. Catch statistics show a Norwegian catch of 32,000 tonnes in 2002.

Spawning stocks have declined dramatically since 1995 and were estimated at 760,000 tonnes in 2001. To maintain the catch level, steadily younger cohorts have been fished. This practice is not sustainable. It is particularly the catch of small horse mackerel in the English Channel and in the Atlantic Ocean south of Ireland that has increased. The biological recommendations in recent years have been to reduce fishing dramatically. The Institute of Marine Research recommends that the total quota for 2003 be kept at the same level as in 2002. This means a total catch of 98,000 tonnes, which is considerably below the current harvest of horse mackerel.

Mackerel - *Scomber scombrus*

Northeast Atlantic mackerel stocks consist of three spawning components: southern and western mackerel and North Sea mackerel. Stocks of western and southern mackerel are at a high level while the North Sea stocks are still at a low level, though with growth tendencies (IMR).

Mackerel catches go by and large for human consumption. In 2002 the Norwegian catch was 182,000 tonnes, and nearly all went for consumption. Only 200 tonnes were delivered for grinding. In 2001, 180,000 tonnes were fished, of which 99 per cent went for consumption, i.e. 1,800 tonnes went for grinding.

In the period before 2001 there have been several years where the catch has been up to 100,000 tonnes higher than scientist recommendations. The ACFM recommends a quota of 542,000 tonnes for 2003.

The small smacks of Lofoten.
photo: Kjell Storvik

3.2.4 Summary - The fishery ceiling has been reached
One-third of the world's fish catch goes to grinding and production of marine meal and marine oils. According to the FAO, fish stocks used for this purpose are currently fully taxed. We therefore cannot base ourselves on the future need for these resources being covered by an increased harvest of the listed species of fish. Continued growth of aquaculture therefore requires that other sources of raw materials be found for the production of fish feed.

Stocks used as fishmeal and oil in South America have been the subject of wide fluctuations, both in consequence of overfishing and natural variations in the availability of food. Anchoveta stocks have recovered since the last great El Niño in 1998. Sardine stocks have, however, plummeted, and Peru, Chile and Ecuador should reduce fishing for this species to a minimum to get stocks up to a more sustainable level.

In our waters fishing for blue whiting is far higher than recommended by scientists. The lack of international agreements and conflict about how many parties are entitled to fish have led to virtual "free fishing" of this species. In addition to the fact that the harvest of blue whiting is way too high, increasingly younger cohorts are being fished. This represents improper and unsustainable fishing. If the fishing pressure is not reduced in relation to the level recommended by scientists, we will see both a huge reduction in stocks and an enormously smaller economic dividend from the blue whiting fishery.

According to the Institute of Marine Research, fishing for horse mackerel in certain areas is alarming. A far too high harvest of younger fish does not represent sustainable fishing. To ensure stocks and maintain financial earnings the catch of horse mackerel must be reduced in relation to scientists' recommendation of a total of 98,000 tonnes.

3.3 Alternative sources for feed

3.3.1 Bycatches and discards

One source of major quantities of fish raw materials is found among what is already fished, but for various reasons is thrown back into the sea. Today's fisheries are largely based on selective fishing where certain species are fished. In addition to the desired species, large amounts of fish are caught as bycatch. Some of the bycatch is landed and recorded, while the rest is dumped into the sea. Alverson *et al.* (1994) has estimated the global discarding of fish at 27 million tonnes. This means that millions of tonnes of protein are dumped annually into the ocean.

In addition to being an enormous waste of resources this practice also leads to an underestimation of world fishing pressure. For stocks that according to official landing statistics are already taxed to the maximum, bycatching with subsequent discarding will be the factor that, overall, will push stocks into an unsustainable condition.

The reasons for discarding are plainly economic. In some cases discarding will also be a result of directly illegal activities during fishing. Clucas (1997) lists several reasons for discarding from the world fishing fleet:

- Wrong fish, wrong size, wrong sex or injured fish.
- The fish cannot be stored with the rest of the catch.
- The fish are inedible or poisonous.
- The fish do not keep well.
- Lack of space on board.
- "High grading" (Low-value fish are dumped to make room for fish of higher value.)
- The quota has been reached (leads to high grading where the small fish are dumped to fill up the quota with larger fish of higher value).
- Catch of prohibited species in a prohibited area, in a period with closed fishing grounds or with prohibited gear.

According to the FAO (1997) the amount of discarded fish was reduced from the mid-1980s until the mid-1990s. The organisation is now operating with an estimate of around 20 million tonnes of discards annually. The reduction is due to a) a decline in the fishery, b) a fishing moratorium for periods/areas, c) the development of more selective fishing equipment, d) greater utilisation of bycatch for consumption and for feed for aquaculture and livestock farming, e) the introduction of a ban on discarding in certain countries and f) greater focus and willingness by governments and interest groups to reduce the amount of discarded fish.

In Norway, the authorities have adopted a zero discard policy. It is illegal for commercial fishermen to throw back any of the catch to the sea. This is an incentive to fish more selectively by avoiding fishing in certain periods and areas where high bycatches can be expected. The prohibition is also a driving force behind the development of equipment that reduces bycatches (Hall *et al.* 2000). The EU countries have a law that is nearly the exact opposite of Norway's. They have introduced a prohibition against keeping, or landing, fish where a TAC (Total Allowable Catch) or quota has been reached (Alverson *et al.* 1996). In many cases this means that the EU requires the fishing vessels to dump fish. Most of the fish thrown back in the sea are already dead. The fish that are still living have little chance of surviving (Hall *et al.* 2000).

Fishery and species	Discards in tonnes	Percent of total
Pelagic (consumption)		
Herring	22 140	0,87
Sardines	4 480	0,18
Mackerel	11 220	0,44
Horse mackerel	7 380	0,29
Sprat	10 360	0,41
Subtotal	55 580	
Fish for fishmeal		
Capelin	15 380	0,6
Blue whiting	5 220	0,21
Sandeel	17 380	0,68
Norway pout	3 980	0,16
Other pelagic fish	2 240	0,09
Subtotal	44 200	
Fish for consumption		
Atlantic cod	816 000	32,08
Haddock	230 000	9,04
Pollock	163 000	6,41
Norway haddock	248 000	9,75
Whiting	67 500	2,65
European plaice	153 000	6,02
Other demersal fish	766 000	30,12
Subtotal	2 443 500	
TOTAL	**2 543 280**	

Table 9: Estimate of discards from fisheries in the North Sea and Northeast Atlantic. (Source: Clucas 1997)

3.3.2 Transgenic plants (GMO)

The possibility of modifying the genes of oil-rich plants to produce a vegetable oil with a fatty acid profile that covers the needs of salmon has been aired. In addition, a substantial percentage of today's production of, for instance, soya and maize is based on transgenic plants.

The policy of the fish farming industry in Norway is to avoid transgenic plants in fish feed. The main reason is consumer scepticism towards such products. In this chapter we will show why the fish farming industry should continue its restrictive attitude, and perhaps expand the reason from market-related concerns to a real concern for considerable environmental problems.

Modern transgenic technology involves inserting genes from one organism into another. Opposition to and attention to transgenic plants has been massive, particularly in Norway and other parts of Europe, but not to the same degree in the United States. The arguments against have been that the technology goes against nature and that the consequences can be dire (Thakur, 2001). Bellona does not share the view that the technology is wrong per se, we believe the arguments should be based on the possible impact of the cultivation of transgenic plants, and the technology should be met with an extremely cautious precautionary approach.

Bellona is not generally against gene manipulation for research purposes or in controlled production of chemical compounds in secure laboratories. For example, the production of insulin by the use of transgenic bacteria or yeast cells is unproblematic. The precautionary principle must, however, apply within all the areas of use in this technology, and it is important that scientists in fields that use transgenic organisms are critical in view of the future use of research results. New technology should not be adopted before the risks to human health and environmental safety are properly evaluated. In our opinion no satisfactory environmental impact assessments have been established for releasing genetically modified (GM) organisms in the environment. This is largely due to scientists knowing too little at this time about the objective of the technology, namely DNA. It is important that scientists and other decision-makers acknowledge that knowledge about genetic material is still at a "kindergarten level". It is crucial that science has good knowledge of how genes work before GM organisms are released. This is a prerequisite for any realistic determination of long-term ecological effects. Based on the knowledge that is available today, all releases of transgenic organisms into the natural environment are unacceptable.

What are the consequences?

The problems of releasing transgenic plants into the environment is by and large associated with three factors: resistance to antibiotics, pesticides and herbicides, and Bt genes. The latter two are properties transferred to many transgenic plants because the plants will then tolerate pesticides and herbicides or will produce Bt toxin in the plant tissue, which kills certain types of insects. (Bt prototoxin is produced naturally by a group of bacteria called *Bacillus thuringensis,* and is converted to Bt toxin if it comes in contact with a digestive enzyme found in some groups of insects. The resistance to antibiotics is only a marker gene that with current technology can be cut out again. Antibiotic resistance genes are currently a large problem in most of the transgenic plants grown today, but can most likely be eliminated in the future.

Several problems are associated with herbicide resistance and Bt toxin genes. The Bt toxin in plant tissue that is ploughed under could have a great impact on the soil fauna and also kills species that naturally combat pests or species that have no direct effect on agriculture but otherwise have functions in the ecosystem. In contrast to traditional spraying, transgenic plants that express Bt genes constantly subject insects to Bt toxin. This will increase the probability that the pests will develop resistance. If transgenic plants with herbicide resistance cross-pollinate with wild-growing relatives, herbicide resistance could make it impossible to spray for weeds. We know that such cross-pollination will take place in several of the plants that are used, or could be used in aquaculture feed, such as maize or rape. This has been one of the opponents' main arguments, although for a long time there was no concrete evidence. In recent years, however, it has been proven that transgenic elements have spread to cultivated plants in other fields and relatives growing in the wild (Quist & Chapela, 2001). The other main problem with herbicide and insect-resistant plants is that they lead to increased and indiscriminate use of pesticides and herbicides. Because of the fact that the plants in question are resistant to herbicides and/or pesticides, an attitude has evolved that it does not hurt to spray the crop an extra time or two.

Reproduction and heredity among bacteria is very different from what we find in higher organisms. Among other things, they can absorb DNA from their surroundings and exchange small DNA fragments with each other. In this way DNA from rotting plant parts can be transferred to soil bacteria (Bertolla & Simonet, 1999) or from food in the digestive system and to intestinal bacteria (Martin-Orue *et al*., 2002). It was recently discovered that DNA from transgenic plants has been transferred via pollen to bacteria and yeast in the intestines of bee larvae (Kaatz *et al*., 2002 -in the process of being published). This shows that the artificially introduced genes are spreading in the environment, not only by normal cross-pollination with closely related species, but that they actually invade the genomes of completely non-related species.

A number of concerns are also related to some of the vectors (particularly viruses) used to transfer foreign DNA in the stem cells of the new transgenic organism. Such vectors will incorporate other genes in addition to those whose expression is desired, and could cause the transgenic element to form a new virus particle that can infect new hosts or change the expression degree of other genes.

Gene modification can also cause changes in the biochemical processes of the transgenic organisms. These can have an expression that given today's knowledge is impossible to predict. Damaging concentration of toxins, mutagens (substances that cause potentially damaging genetic changes) and carcinogens (substances that stimulate the development of cancer) can be formed.

So far it looks as though there is limited risk associated with eating transgenic organisms. Studies, however, have shown that the digestive system can be affected by food from transgenic plants (Ewen & Pusztai, 1999). Ewen and Pusztai (1999) showed a change in the morphology of the intestines of rats fed a type of transgenic potato. When these results became known, the transgenic potato was withdrawn and further research was prohibited. It has also been demonstrated that DNA from GM crops have been transferred to intestinal bacteria in humans (Gilbert *et al*., 2002). The people taking part in the trial were given milkshakes and hamburgers containing GM soya with a herbicide resistance gene. This gene was subsequently found in the intestinal bacteria of the trial participants. The trial was carried out on people who have had a colostomy. It is surprising that DNA from the transgenic soya variant can survive the passage through the stomach and stay more or less intact in the small intestine.

It is also important to note that gene pollution cannot be cleaned up afterwards. The effects may thus be irreversible. Based on currently available knowledge Bellona regards transgenic plants as an unacceptable source of feed for the fish farming industry.

3.3.3 Fossil fish feed

Protein for feed can be produced from natural gas. Norferm at Tjeldbergodden in Norway has developed a product called BioProtein, which is now being used on an experimental scale in Norwegian salmon feed. Norferm describes the process as follows: "The production of BioProtein takes place when the microorganism *Methylococcus capsulatus* and a few other auxiliary organisms grow and divide continuously with a regular supply of methane gas, oxygen, ammonia, various nutrient salts and minerals. How quickly the cells grow and divide depends on the amount of nutrients added per unit of time" (www.norferm.no). The composition of the product Basic BioProtein is given in table 10.

Nutrient content	Percent
Protein	70,6
Fat	9,8
Ash (minerals)	7,1
Fibre	0,7
N- free extract	11,8

Table 10: Composition of BioProtein.

Trials have been conducted to replace part of the fishmeal in feed with BioProtein. Various percentages of BioProtein were tested, and a diet consisting of 20 per cent BioProtein turned out to give the best result. The trials also showed that BioProtein contributed to a higher growth rate and more efficient utilisation of feed in salmon (EWOS, 2001).

Metabolising of nutrients

When nutrients are metabolised in the cells, CO_2 is formed, which all animals exhale. In an environmental policy context this "emission" is not considered to be an emission of greenhouse gases because the carbon is usually part of the natural cycle. Through photosynthesis, plants take up just as much CO_2 as they subsequently give off during metabolisation in the cells of animals. When part of the carbon metabolised in the cells comes from fossil sources, as is the case with BioProtein, this involves a net addition of CO_2 to the system. Consequently, it must be evaluated whether this CO_2 emission should be included in the accounts for emissions of greenhouse gases into the atmosphere. The CO_2 emissions from the respiration of salmon do not, however, go directly into the atmosphere. Some of the carbon is bound in the flesh of the fish and subsequently released when the fish is eaten. The carbon exhaled by the fish can to a varying degree be taken up in the photosynthesis of microorganisms, algae and other plant material under water, and is bound in this cycle over time, so that a potentially extremely long-term delay in the emission occurs. There are divided opinions among scientists about how long-term such binding of CO_2 is. High density of fish, as found in a fish farm, will regardless lead to a higher concentration of CO_2 locally. This creates higher CO_2 pressure against the water surface so that CO_2 is emitted into the air. The division between CO_2 that is bound under water and CO_2 that is emitted into the air, will depend on local environmental factors such as the degree of water exchange and the amount of organisms taking up CO_2. Calculation of this division at each fish farm will require extensive modelling.

Consumption of natural gas

Consumption of natural gas in the Norferm process is 2.3 standard cubic metres (Sm^3) per kilogram BioProtein (Huslid, 2003). One standard cubic metre of gas (CH_4) yields 2.27 kg CO_2 when burned.

If we assume a feed factor of 1.3, which means that 1.3 kg of feed yields 1 kg of growth in the fish, and presuppose that fish feed contains 10 per cent BioProtein, the consumption of BioProtein will be 0.13 kg per kilogram fish. The production of 1 kg BioProtein consumes 2.3 Sm^3 of gas. The consumption of gas per kilogram of fish is thus:

(1) 0.13 kg/kg of fish x 2.3 Sm^3/kg = 0.3 Sm^3/kg of fish.

Combustion of 0.3 Sm^3 gas yields a CO_2 emission of:

(2) 0.3 Sm^3/kg of fish x 2.27kg CO_2/ Sm^3
= 0.7 kg CO_2/kg of fish

To put this figure into perspective we can compare the emissions of cars. A VW Golf with a 1.6 litre petrol engine has an emission of 166 gram/km (www.volkswagen.no). Net addition of fossil CO_2 to the natural cycle from the production of 1 kg of salmon is thus equivalent to the emission from a car driven 4 km.

If all Norwegian salmon receive 10 per cent BioProtein in their diet, the annual addition of fossil CO2 will be:

(3) 500,000,000 kg of salmon x 0.7 kg CO_2/kg of salmon
= 350,000,000 kg CO_2, or 350 thousand tonnes of CO_2.

Similarly, 20 per cent BioProtein in the diet would yield an emission of 700,000 tonnes CO_2.

By comparison, total CO_2 emissions from road traffic in Norway in 2001 totalled approximately 9 million tonnes (SSB, 2002). 350,000 tonnes CO_2 is equivalent to 9-10 per cent of what we must reduce in relation to current emissions to meet the Kyoto obligations.

If the use of BioProtein becomes widespread, a climate policy assessment should be undertaken as to what extent a new source of fossil carbon should be permitted while simultaneously expending major resources on eliminating other sources.

3.3.4 Harvesting zooplankton

The research programme *Calanus* at the Norwegian University of Science and Technology (NTNU) is aimed at identifying the opportunities for harvesting zooplankton in Norway. The objective of the programme is to map the sustainable harvesting potential, develop efficient harvesting techniques and industrial processes for processing, and evaluate the nutritional properties of raw materials with respect to fish feed. The project must be regarded as basic research. There is extremely limited knowledge about this area at this time (*Calanus* - project description).

What is known, however, is that the quantity of zooplankton in the ocean is enormous. In the Norwegian Sea, the quantity of zooplankton varies between 5 and 11g dry weight per m^2 (Ellertsen *et al*., 1999), while for the Barents Sea it varies between 8 and 13 g dry weight per m^2 (Hassel, 1999). The production of different types of herbivore zooplankton, e.g. the calanoid copepod *Calanus finmarchicus,* is so large that if only 10 per cent of the production is harvested, it would be equivalent to the entire ocean's biomass production in the first level of carnivorous species on the food chain including herring, capelin and carnivore zooplankton. This biomass is particularly interesting because it is highly similar to the salmon's natural diet. In addition to small fish, salmon eat lots of copepods, e.g. *Calanus finmarchicus*. It is therefore assumed that *Calanus finmarchicus* is a well-suited source of protein for farmed salmon. At the same time this biomass is food for economically important fish, which places strict requirements on management, both in relation to ecosystem and society.

The biggest practical challenge is to find cost-effective catch methods. If you can imagine a trawler with a type of pelagic net so fine-meshed that it takes copepods measuring only 1-2 millimetres, energy consumption would be dramatically high. In addition, a fine-meshed active implement has the capacity to take a bycatch consisting of virtually everything in its path. A form of passive filtering would perhaps be more realistic. Another possible approach is to produce protein by cultivating phytoplankton as a food source for copepods or other similar types of animals.

3.3.5 Algae as fish feed

Various types of microalgae produce fatty acids suited to the nutritional needs of the farmed fish. At the Agricultural University of Norway, a research project funded by the Research Council of Norway has been initiated to develop production methods for microalgae as a fat-rich source of feed for fish. In order for microalgae to be commercially interesting as fish feed, quick-growing algae with a high content of the desired polyunsaturated fatty acids must be selected. The production process itself must be developed so that the product can be competitive in price. Today, microalgae is produced for health food purposes at a production cost of NOK 200 per kg of dry material. These costs have to drop to NOK 50 per kg for fish feed production to be profitable (Hjukse, 2003). The fatty acid composition and the potential for use in aquaculture have been studied in Duerr *et al*. (1998), Renaud *et al*. (1998) and Browna *et al*. (1997).

3.4 Conclusion

In this last chapter we have shown that 2.66 kg of fish provides enough fish oil and more than enough fishmeal to produce 1 kg of salmon under the given assumptions. Globally speaking, there is a considerable variation in how much vegetable oil that is used, but because of adequate access (annual production: 100 million tonnes (FAOSTAT)) to such raw materials, there is reason to expect that this will be a growing trend. We can consequently establish that the claim "Five kilograms of wild fish becomes one kilogram of farmed salmon" no longer fits with reality. Of course, the vegetable raw materials come in addition to the fish, but the point is that salmon are in the process of taking a step down the food chain, virtually to the same trophic level as pigs and chickens. Consequently, they are competing for the same feed resources, and, as we have shown, salmon farming consequently provides better resource utilisation than grain-based livestock production on land.

Even though the proportion of fish in the feed has been reduced to 2-3 kg per kg of salmon, and developments in feed composition mean that we can increase the production of salmon on the basis of a given quantity of wild fish, access to forage fish sets a limit on how much farmed fish we can produce. And that limit, as we have shown, has already been reached, and has in fact been exceeded for some stocks. When the potential for increasing the percentage of vegetable raw materials has been exhausted, other resources will have to be sought if production is to continue to increase.

The nutritional needs of the salmon make it impossible to use one feed consisting only of vegetable raw materials, unless there is a concentrated effort to change vegetable fatty acid and amino acid profiles with the aid of gene technology. Due to the risk of major, adverse environmental impacts associated with transgenic plants in agriculture, this is a development path Bellona is extremely sceptical of.

We have shown that the potential for harvesting new types of biomass from the ocean is huge. Today, the land produces more than 95 per cent of our food, even though the primary production of the sea is almost as large. In the sea we harvest at the top of the food chain, and cultivation of the ocean is only at the starting gate. We have pointed out the ecological, practical and economic conditions that place limits on the development of the ocean's food production. Comprehensive documentation remains before we can draw conclusions about the way forward.

Chapter 4
Food safety

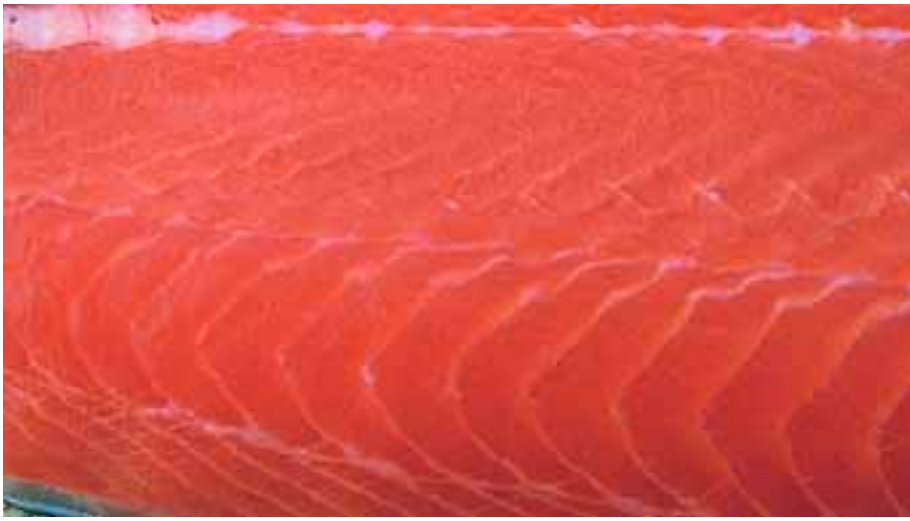


photo: Marit Hommedal

4.1 Foreign substances in fish

Environmental toxins in the ocean are concentrated in the marine food chain and accumulate in fat. This means that predatory fish can have a high content of environmental toxins. Particularly large pike (*Exos lucius*) fished in polluted lakes have a high content of, e.g., mercury (SNT, 2002), and are humorously referred to as "hazardous waste". But farmed salmon can also acquire a considerable content of environmental toxins if the feed contains much marine fat from polluted ocean areas. To reduce the content of environmental toxins in fish feed the content of raw materials close to the sources of pollution (particularly European waters) has largely been reduced in favour of raw materials from South America, which at the outset is the biggest producer of fish oil and fishmeal.

Table 11:
Content of dioxins and dioxin-like PCB compounds. Test results from 35 samples of Norwegian farmed salmon taken in 2002-2003. PgTEQ/g is an abbreviation for picogram toxic equivalents per gram. (Nifes, 2003. Unpublished data)

	Number of samples	PCDD	PCDF	Sum PCDD/F	non-orto PCB	Sum TEQ PCDD/F+non-orto
		(pg TE/g)	(pg TE/g)	(pg TE/g)	(pg TE/g)	(pg TE/g)
Mean value	35	0,19	0,40	0,58	0,97	1,56
Min - max	35	0.06-0.51	0.19-0.68	0.25-1.19	0.71-1.47	1.05-2.16

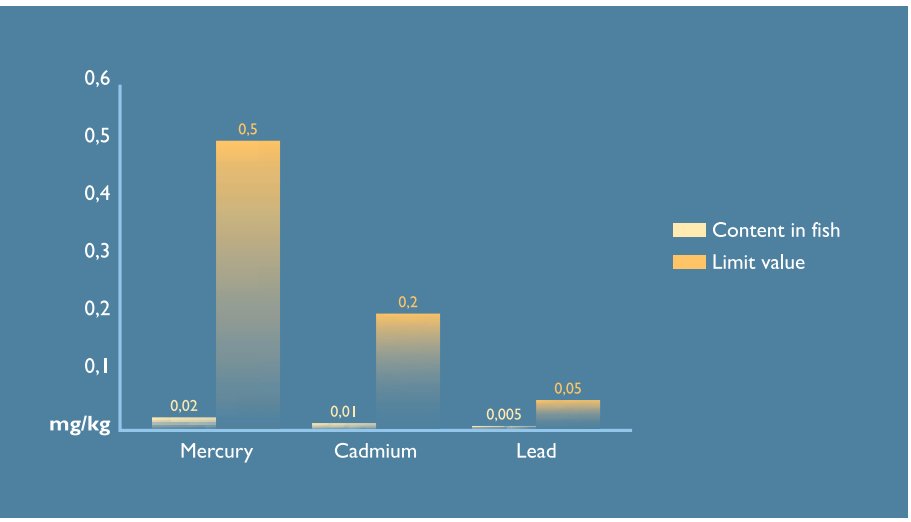
In Norway the concentrations of environmental toxins in farmed salmon are carefully monitored by National Institute for Nutrition and Seafood Research (NIFES), through an annual testing programme (Julshamn *et al.*, 2002). Threshold values for many environmental toxins are set by the EU, CODEX (UN) and individual nations to protect the health of their citizens. NIFES monitors alien substances in fish according to EU directive 96/23-2003. The programme includes 64 different chemical compounds divided into 13 groups of substances. Farmed salmon is monitored with respect to heavy metals, PCB, dioxins, dioxin-like PCB compounds, residues of pharmacological substances, residues of hormonal substances, pesticides and brominated flame retardants among other substances.

4.1.1 Heavy metals

The most recent monitoring results (Haldorsen *et al.*, 2003) show that the content of heavy metals in Norwegian farmed salmon lies under threshold values by a good margin.

Figure 25 compares observed levels of heavy metals in Norwegian fish with threshold values set by the EU, and clearly illustrates that the heavy metal content of Norwegian salmon does not provide grounds for concern about the health of consumers. The mercury content has fallen from 0.04 mg/kg in 1995 to 0.02 mg/kg in 2001. For lead and cadmium the figures represent the detection values of 0.01 and 0.005 mg/kg, respectively, so that actual values may be lower.

Figure 25:
Content of heavy metals in Norwegian farmed salmon, compared with threshold values.



4.1.2 Dioxins

Dioxins (Polychlorinated Dibenzo-para-Dioxins (PCDD) and Polychlorinated Dibenzo Furans (PCDF)) are chlorinated organic environmental toxins, which are formed as a byproduct in various industrial processes and by combustion. Dioxins that accumulate in fatty tissues are hard to break down and become concentrated in food chains - in that respect the marine food chain is particularly vulnerable. People are exposed to dioxins via their diet, and the main sources are animal products such as fish, dairy products and meat.

Content of dioxin in food is given in picograms WHO-TE/g (or nanograms/kg). TE stands for toxic equivalents and is calculated from toxic equivalency factors (TEF) or weighting factors that have been established for a number of dioxins and dioxin-like PCB compounds.

The table shows test results for 35 samples of Norwegian farmed salmon from 2002 and 2003 (NIFES, unpublished data). The EU has set an upper limit for dioxin (PCDD and PCDF) in fish of 4 pg WHO-TE/g. Test results for Norwegian salmon show 0.58 pg WHO-TE/g on average,

The research center Centre for Aquaculture Competence, at which Bellona function as an observator, is situated in Langvika close to Hjelmeland.
photo: Marius Holm

with a range from 0.25 to 1.19 pg WHO-TE/g. The trend is a reduction in content of dioxins in Norwegian farmed salmon. The last six years represents a reduction of 39%, from 0,95 pg WHO-TE/g (SNT. 1997) to 0.58 pg WHO-TE/g.

According to a American study (Hites et.al., 2004) the average concentration of dioxin and dioxin-like PCB compounds in Norwegian farmed salmon was found to be 2.3 picograms/gram (pg/g) fresh weight. Moreover, the dioxin-like PCB compounds are given to be 75% of the total figure. The values of dioxins (PCDD/PCDF) found in this study commensurate with Norwegian surveys showing values of about 0.6 pg/g fresh weight. The EU threshold limit of 4 pg/g relates to dioxins only, and does not include dioxin-like PCB compounds.

4.1.3 PCB

PCB stands for polychlorinated biphenyls and is a collective term for a group of 209 different substances. The use of PCBs is prohibited today in the Western world, but continues to enter the environment via leaks from landfills and other sources. Because there are so many different PCBs, a measurement standard has been arrived at in which 7 different PCB congenes (PCB7) are measured and used in estimating pollution. For Norwegian farmed salmon the sum is 0.016 mg/kg. The EU does not have any threshold value here, but a threshold of 0.6 mg/kg has been set in the Netherlands.

Even though salmon is within this threshold value, particularly vulnerable individuals such as small children and foetuses are conceivably at risk. Jacobs *et al.* (2001) found that high consumption of farmed salmon by children under 5 could lead to a higher intake of PCBs than the tolerable daily and weekly intake. Jacobs (2002) reiterated that there is reason for concern for heavy consumers of farmed salmon, unless producers are careful about their selection of raw materials. Her concern was particularly true of heavy consumers of salmon who are pregnant or nursing.

The EU has set a limit for tolerable weekly intake of dioxin (PCDD and PCDF) and dioxin-like PCB compounds of 14 pg WHO-TE/kg body weight. Test results for Norwegian salmon show 1.56 WHO-TE/g on average, with a range from 1.05 to 2.16 pg WHO-TE/kg. For example, a person weighing 70 kg could ingest 980 pg WHO-TE per week without exceeding the EU's threshold value. A 200 g salmon fillet yields, with values from the study of Norwegian fish, 312 pg WHO-TE per meal. Concerned with risk assessment of carcinogenic agents, the guidelines for the EU and the WHO show that differentiation between substances that harm the genetic material directly and substances that do not, is scientifically accepted. For substances that do not harm the genetic material directly, like PCB and dioxins, threshold limits for effect are commonly given. Values below this threshold limit should imply no risk.

As the fish stock used in the production of fish oil and fishmeal is fully taxed, the farming industry has been forced to find substitutes for the marine fats in the fish feed. The increase in the use of vegetable oils - such as rapeseed oil - cuts back on the use of fish oil, which in turn will lead to reduced levels of environmental contaminants such as PCB and dioxins in fish feed and farmed fish. More vegetable oils in the feed might however lead to higher levels of pesticides.

4.2 Dyes in salmon

Most regard salmonids as a "red" fish. The flesh from wild salmon from oceans and rivers is often red, pink or orange, in varying degrees. The red colour is caused by carotenoids from the diet of the fish. The word carotenoid stems from carrot, *Daucus carota*, which also gave the name to the first carotenoid that was isolated, carotene. Today, scientists know of more than 600 different natural carotenoids. Carotenoids are very widespread in nature and are found in most living organisms, from small microorganisms to higher plants and animals. The dye is only produced in certain types of microorganisms, algae, fungus and plants. Other organisms such as salmon must ingest carotenoids through food.

In salmon, the most common carotenoid is astaxanthin. Astaxanthin is very common in both freshwater organisms and marine organisms, and is released when crayfish and lobster are cooked, which is why they turn red and look attractive on the dinner plate. Other carotenoids common in fish are canthaxanthin and lutein. Wild salmon take in carotenoids by eating small crustaceans or other fish with small crustaceans in their digestive system. Analyses have shown that wild Atlantic salmon have between 3 and 11 mg astaxanthin per kilogram in muscle. In American Sockeye salmon (*Onchorhynchus nerka*) the natural level is higher, from 25 to 37 mg/kg in muscle.

The function of carotenoids

Carotenoids in the diet of wild fish have several functions. In a number of fish species the red colour is important as camouflage, because it makes the fish less visible in deep water, where the red segment of the wavelength spectrum of visible light does not penetrate. In salmonids the red colour also plays a role in mating and spawning behaviour. In mammals an antioxidant function has been found in carotenoids, in that they protect polyunsaturated fatty acids. However, this is not equally well documented in fish, but a connection has been made between the concentration of astaxanthin in the feed and amount of vitamin A in fish.

It has been proven that astaxanthin is necessary in the initial feed of salmon fry. Failure to add astaxanthin in the feed results in low weight and high mortality. The need for astaxanthin in salmon fry is about 5 mg/kg of feed (Christiansen and Torrisen, 1996).

Nor are greater amounts of astaxanthin harmful to salmon. In trials, salmon have been fed up to 200 mg astaxanthin per kilogram of feed without negative effects being reported. This is three times higher than the normal level in feed today. (All above data where the source has not been given: Christiansen, 2001)

Pigmentation of farmed fish

In marketing farmed salmon it has been found that it is necessary for salmon to have a red colour that fits the consumer's image of salmon flesh. To achieve this, carotenoids are added to fish feed, so that farmed salmon ingest it in the same way as wild salmon. In Norway, astaxanthin, the most common carotenoid in the wild salmon's diet, is mainly used. In other countries, such as Scotland, Ireland, Chile and Canada, both astaxanthin and canthaxanthin are used.

Astaxanthin level in farmed salmon

The amount of astaxanthin added to fish feed depends on the desired redness of the flesh, but analyses have shown that the marginal response in concentrations above 50-60 mg/kg of feed is low. This is because absorption of carotenoid is low at higher concentrations (Choubert and Storebakken, 1989). The amount of astaxanthin remaining in the flesh will vary depending on the fat content and the general composition of the feed, but for a 3-4 kg salmon given 50-60 mg of astaxanthin per kg of feed, 6-8 mg of astaxanthin will be found in the fish muscle.

Sources of carotenoids

Synthetic production of carotenoids is currently the most common manufacturing method and widespread colorant products on the market include "lucantin pink" from BASF and "carophyll pink" from Roche, both of which consist of astaxanthin. Similar products are found containing canthaxanthin. Current production forms for astaxanthin are chemical synthesis, fermentation of astaxanthin-producing microorganisms or cultivation of astaxanthin-producing algae.

Before synthetic astaxanthin products came on the market it was common to use different byproducts from the processing of crustaceans, where astaxanthin occurs in esterified or protein-bound form. This makes bioavailability low, and together with factors such as uncertain access this has meant that natural sources of carotenoids are insignificant today.

The chemical structure of astaxanthin and canthaxanthin can vary. Astaxanthin consists of several isomer compounds. The division between *cis*-isomers and *trans*-

Colour standard card.
photo: Marit Hommedal

isomers varies in different aquatic organisms. The division is not necessarily the same in synthetic carotenoids such as in the salmon's natural diet (Torrisen *et al*., 1989). In Canada a discussion is taking place, with possible legal ramifications, as to what extent products containing farmed salmon should be labelled. Canada has considerable economic interests associated with the fishing of wild salmon. By studying the difference in isomers it can be determined whether the salmon have been given synthetic astaxanthin in the feed, and thus whether the fish is wild or farmed (Turujman *et al*., 1997).

Effects on health

No negative effects on health have been reported as a result of astaxanthin use, although canthaxanthin has received a lot of attention because in tanning pills it has produced injuries in the form of crystal deposits on the retina of the human eye. The EU's Scientific Committee on Food (SCF) has found that the lowest intake of canthaxanthin producing a quantifiable effect on the retina is 0.25 mg/kg body weight/day. Since this effect had no significant impact on the function of the eye, a safety factor of 10 was found appropriate. This means that the limit for acceptable daily intake (ADI) has been set at a tenth of 0.25, in this case rounded off to 0.03 mg/kg body weight/day. Based on ADI and an estimate of how much consumers eat of various types of food containing canthaxanthin, threshold value can be set for how much canthaxanthin the feed given salmonids, chickens and laying hens can contain. EU's Scientific Committee on Animal Nutrition (SCAN) has set the limit for canthaxanthin in fish feed at 25 mg/kg of feed. This limit is based on the

Product	Assumed daily consumption
Eggs	100
Poultry - flesh	300
Poultry - skin and fat	90
Poultry - liver	100
Poultry - kidney	10
Fish fillet - flesh	300

Table 12: EU's threshold value for Astaxanthin is based on this intake of different foods.

assumption that the consumer eats 300 grams of salmon fillet every day and other foodstuffs in the amounts shown in the table below. (European Commission, 2002)

In other words, one would have to eat a lot of salmon to come close to the EU's limit for acceptable daily intake. Given in addition that this limit has a safety factor of 10, you can safely conclude that it is safe to eat farmed salmon that has been given canthaxanthin in the feed, both before and after the EU's amendment of the rules. Nor have there been reports of eye injuries resulting from the intake of farmed salmon. It is also worth noting that the retinal injuries that occurred in connection with the use of tanning pills were reversible.

The new limit of 25 mg/kg of feed is lower than what is necessary to achieve the colour that, based on market considerations, the fish farming industry believes is desirable. The result of the regulation is that canthaxanthin will probably be replaced by astaxanthin, which is already the most widespread substance in Norway. Since astaxanthin is the natural carotenoid for salmon, such a change is desirable.

However, it is to be expected that in the future astaxanthin too will be evaluated in the same way as canthaxanthin. While there are no reports of eye injuries from astaxanthin, the fact that the substances are so alike means that similar effects cannot be ruled out. Hypothetically speaking, if the ADI is set at the same as for canthaxanthin, the astaxanthin level in the flesh of farmed fish will be somewhat lower than what is found in wild Atlantic salmon, and substantially lower than what is found in Pacific salmon (O. nerka).

Chapter 5
Farming of cod

photo: Norwegian Seafood Export Commission

The authorities in Norway want to see a strong effort to develop new aquaculture species. Cod is one of the species that shows the greatest potential for aquaculture on a large scale. The market for this type of fish is huge and technologically it is possible in certain areas to draw on 30 years of experience in farming salmon and rainbow trout. There are, however, several challenges that have to be resolved before Norway can be a leading player in cod farming.

Huge potential for cod farming

We have two types of farmed cod in Norway: cod that is artificially hatched as in traditional farming of salmon and growing out small wild cod in fish farming cages. In 2002, 247 tonnes of farmed cod were produced by artificial hatching (Directorate of Fisheries, 2003). THe countys of Møre og Romsdal and Sogn og Fjordane were the biggest with 90 and 87.5 tonnes, respectively. In terms of volume, the feeding of cod captured in the wild is still bigger than pure cod farming. At 475.6 tonnes out of a national production of 1,006 tonnes, Finnmark is the leader in the feeding of cod (Directorate of Fisheries, 2003).

A number of prospects for Norway's future potential in cod farming have been outlined. The Research Council of Norway and the Norwegian Industrial and Regional Development Fund (SND) conclude that in 20 years cod may create value equal to the current production of salmon, i.e. annual exports of around NOK 10 billion (Research Council of Norway and SND, 2001).

Production of fry and fish for consumption

Production of fry has been a major bottleneck in cod farming. Many of the problems have been solved, and fry production has climbed rapidly in recent years. At the end of 2002 there were 21 fry producers. Production has increased from around 0.5 million in 2001 to 3 million in 2002, and annual production will easily reach 10 million over the course of a few years. Total plant capacity in 2002 was approximately 85 million fry, which corresponds to food fish production of 250,000 tonnes (Karlsen *et al*. 2003). In the wake of increasing fry production we will shortly see an increase in the production of fish for consumption. At the end of 2002, 270 food fish licences for cod had been issued. Approximately 50 of these are in operation. An increase of cod in intensive fish farming along the coast will also increase the environmental burden of this industry.

Escapes of farmed cod - Genetic impact on wild cod

Escapes of farmed fish and parasitic copepods are the biggest environmental challenges in the farming of salmonids in Norway. The same issues are also relevant to cod farming. Food fish farming of cod is done in pens in the same way as salmonids are currently farmed. In addition, cod has a behaviour that is more disposed towards finding a way out of the pen. The fish escapes easily, so producers have to constantly check the net bags for tears (Holm, J.C., 1999). According to the Directory of Fisheries 75.000 farmed cod escaped during 2003.

Cod stocks can be roughly divided into migratory and stationary populations. The stationary coastal stocks will probably be more vulnerable than the migratory stocks to the impact of cod farming (Simolin, P. *et al*., 2003). According to the National Veterinary Institute, escaped farmed cod could conceivably have a genetic impact on local stocks. How large this impact will be depends on the size of the escape potential in the industry. Given the cod's behaviour and the similarities between food fish farms for cod and salmonids, there is little reason to believe that escapes of cod will deviate from what we see in today's farming of salmonids.

In contrast to salmonids, cod lives its entire life in saltwater. Cod can therefore spawn in the pens and in that way affect the stationary stocks of wild cod even though they do not escape. Cod normally becomes sexually mature approximately 22 months after hatching, with an average size of two kilograms (Karlsen *et al*., 2003). A first-time spawner can produce 400,000 eggs (Holm, J.C., 1999).

To protect wild salmon, zones have been established in which the farming of salmonids is not supposed to take place. Based on the same model, non-cod farming zones close to important spawning areas for wild cod should be evaluated.

Must expect diseases

Knowledge about cod diseases is limited. There is, however, no doubt that intensive livestock production leads to illness. Experience from both salmon farming and land-based livestock farming demonstrates this. There are a number of bacterial diseases (*Vibrio anguillarum, Vibrio salmonicida,* atypical *Aeromonas salmonicida, Yersinia sp., Mycobacterium sp.,* sores etc.) and viral diseases (viral hemorrhagic septicaemia (VHS), Nodavirus, Infectious Pancreatic Necrosis (IPN), *Lymphocystis*, Cod ulcus syndrome (CUS) etc.) that can have an adverse impact on cod farming (Bleie, H. 2003 and Simolin, P. *et al*, 2003). In addition to these known diseases it has to be expected that new ones will appear in a fish farming situation. The National Veterinary Institute in Oslo says in an intensive fish farming situation a number of unknown diseases will probably surface in addition to the possibility of the emergence of more aggressive variants of already known

Cod is considered to be the next major species for Norwegian fish farming industry.
photo: Norwegian Seafood Export Commission

pathogens (Simolin, P. *et al*. 2003). According to the Institute, the diseases mainly represent a threat to the industry itself, but could also threaten wild stocks of cod.

Several aspects make disease problems potentially greater for the farming of cod in relation to salmonids. In contrast to the farming of salmonids, the farming of cod does not have a natural dividing line between freshwater and saltwater over the course of a life cycle, only one locality per licence yields increased infection pressure, use of wet feed represents a considerable infection risk and feeding of fry with live zooplankton represents an infection risk for bacteria, viruses and parasites.

Rich parasite fauna on cod

In 2001 the National Veterinary Institute found 135 parasites on cod. In addition, they reckon the list of unknown parasites is long. Parasitic copepods can occur on all

species of fish in the sea. In addition to causing reduced growth and probably higher mortality in wild fish stocks, they represent a major problem for farmed fish all over the world (Heuch, P. A. and Schram, T. A., 1999). Cod also has lice, and there is every reason to believe that the copepods in the genus *Caligus* will be a problem for farmed cod as *Lepeophtheirus* (and to some extent *Caligus*) are for salmonids in aquaculture (Simolin, P. *et al*. 2003). Sea lice (*Caligus elongatus*) is a copepod that is not very host-specific. This parasite has more than 80 hosts including both salmonids and cod. An increase in cod farming without effective regulations and good treatment methods for this parasite will therefore lead to higher lice pressure on both wild cod and salmonids.

Increased antibiotics use

It is extremely important to develop adequate and effective vaccines against diseases in farmed cod. The sharp decline in the use of antibiotics in the Norwegian fish farming industry is mainly attributed to the development of good vaccines for salmonids. The problems with diseases in the salmon industry occurred after the volume increased sharply. An increase of farmed cod in cages along the coast without an overview of potential diseases and vaccines will lead to an increase of antibiotics in the Norwegian fish farming industry.

Traditional aquaculture or feeding of cod captured in the wild?

Compared with exclusively farmed cod, around four times as much fed wild cod is sold today. From a purely environmental view, there are both advantages and disadvantages with both methods. Genetically speaking, a fed wild cod will not be different from wild cod and will therefore not lead to any undesired genetic impact on cod stocks in the event of escape. On a large scale, however, it can lead to an explosion of harmful pathogens. In traditional aquaculture it is possible to cultivate desired characteristics. Selection based on disease resistance and better utilisation of feed will give farmed cod advantages over wild-captured fed cod. Breeding criteria such as these and particularly speed of growth mean that pure farmed fish will account for the major volumes in the future.

Conclusion

An increase of cod in intensive fish farming along the coast will doubtlessly also increase the environmental burden from this industry. In particular, problems relating to disease and parasites will entail burdens on both the industry itself, the surrounding environment and wild fish. The lack of vaccines against cod diseases will lead to higher use of antibiotics. Escaped farmed cod have the potential to genetically affect stationary stocks of wild cod in particular. The development of feed has not come as far for cod as for salmonids. This may entail a higher feed factor for cod than for the current farming of salmonids, with subsequent major discharges of nitrogen, phosphorus and organic material. As with the farming of salmonids the use of net impregnation on cod cages will cause discharges of copper to water. These are all problems that to a certain degree can be solved and must be solved before farming of cod reaches major volumes.

Chapter 6
Farming of mussels

photo: Per Eide

Farming of mussels represents a green and resource-friendly method of food production. Since mussels live on phytoplankton and other particles in the water, they do not need to be fed. Up to now, the desired development of the industry has not happened mainly because of problems with algal toxins that make mussels poisonous. In areas with a major supply of nutrient salts and subsequent high primary production the farming of mussels with subsequent harvesting of the biomass can improve water quality.

Ecologically correct

Ordinary fish farming requires large quantities of feed. On the other hand, a mussel farm binds the organic material in the water and by harvesting this is removed from the fjord system. The mussel, which basically lives on "sea grass", is much further down the food chain than farmed species such as cod and salmonids. By harvesting biomass at a lower trophic level the potential food harvest is much larger. For each additional trophic level we go up the food chain, more of the original energy is consumed for movement and life functions and less remains as food.

Everyone who have been by the sea, know that blue mussels easily grow on ropes hanging under water. Underwater ropes are precisely what shell farming is based on. photo: Per Eide

Harvesting level	Organisms	Crop (kg)
4	Cod, farmed salmon	1
3	Herring, capelin	5
2	Mussels, zooplankton	20
1	Algae	100

Table 13: Nutritional pyramid (Hovgaard, 1998)

The table above shows a simplified food pyramid and the trophic level to which the various organisms belong. The example illustrates how large a loss there is in our current use of the ocean when we fish cod and herring: we get only 1 - 5 kg back out of an original production of 100 kg of algae. Farmed cod and salmonids will lie between harvest level 3 and 4 depending on how good the utilisation of feed is. By comparison, on land we largely use primary production directly at harvest level 1 (grain, potatoes etc.) or harvest level 2 (sheep, cattle, dairy products). When we catch cod and halibut in the ocean we are utilising ocean predators. Transferred to the land, this would be analgous to trapping and living on bears, wolves, etc." (Hovgaard 1998)

Current production and growth potential of industry

Algal toxins have been the major bottleneck in the development of the mussel industry in Norway. Future prospects now look brighter, and recent years have seen an increase in sales of mussels raised in Norway. According to statistics from the Directorate of Fisheries, sales of mussels raised in Norway increased from 309 tonnes in 1998 to 913 tonnes in 2001.

In Norway the volume of cultivated mussels is still very small. Europe's leading producer of mussels is Spain, with an annual production of about 200,000 tonnes in the fjords of Galicia. Norway, however, has a large unutilised potential. Along the Norwegian coast and particularly in the fjords there is a huge potential for cultivating mussels.

This potential is laid out in the report "Norges muligheter for verdiskapning innen havbruk" (Norway's value creation opportunities in aquaculture) (DKNVS and NTVA 1999).

Whether we will be producing 1.2 million tonnes of shellfish valued at NOK 16.4 billion in 2030 is of course uncertain, but it is probable that we will see a sharp increase from the current level. Market demand will naturally also place a limit on production.

Mussels as filtration plants?

A mussel can be viewed as a water filter that filters out phytoplankton and other particles in the water. A single

Mussels	2000	2010	2020	2030
Million tonnes	0,0041	0,19	0,6	1,2
Billion NOK	0,031	2,8	8,2	16,4

Table 14: Value creation potential for cultivation of mussels (blue mussels, scallops and oysters) (DKNVS and NTVA, 1999)

mussel that is 6 cm long can filter around 3 litres of water per hour (Haamer 1996). A larger quantity of mussels could therefore function as a "filtration plant" for fjord areas affected by too large a supply of the nutrient salts nitrogen and phosphorus.

Too high a supply of nutrient salts leads to higher production of phytoplankton in the upper water layers of the recipient. This causes increased amounts of biomass to sink to the bottom where oxygen is consumed in the decomposition of the organic material. If the recipient's carrying capacity is exceeded there will be a shortage of oxygen in the bottom water and in anaerobic situations, hydrogen sulphide will form during the bacterial decomposition process. A possible step with excessive primary production in a fjord can be the installation of mussel fleets. Harvesting the mussels removes the biomass from the water and can in that way counter eutrophication and improve the quality of the water.

A project carried out at Agder University College (HiA) in cooperation with the Institute of Marine Research concluded that with sufficient access to food, mussels were capable of removing 56% of chlorophyll (algae), 34.3% of particulate phosphorus and 23.5% of total phosphorus (Liodden, J. A. *et al.* 1998). This fits well with subsequent trials demonstrating that the mussels can remove a maximum of approximately 50% of the algae supplied to a mussel farm (Strohmeier, T. *et al.* 2003). The mussel project at HiA concluded that 365 kg of mussels clean 1 PE (person equivalent) of discharges to the fjord area. A typical small town with a discharge of 10,000 PE thus needs an annual production of 3,650 tonnes of mussels to remove anthropogenic discharges of nutrient salts (Liodden, J. A. *et al.* 1998)

Cultivation of mussels along the coast from the Swedish border to Lindesnes could help reduce the supply of nitrogen and phosphorus to the already eutrophication-plagued North Sea. Because the mussels absorb nutrient salts from the fjord there is an opportunity to "filter" some of the diffuse discharges traditional filtration plants cannot manage to collect.

Environmental impacts of mussel farms

To avoid the adverse impacts of large-scale mussel cultivation on a large scale it is important to be aware of

photo: Per Eide

photo: Per Eide

the consequences. A major problem is that huge areas will be locked up. It is important to take other user interests into consideration when selecting cultivation areas for mussels. Sediments consisting of excrement from the mussels and the shells that fall down can accumulate underneath a mussel farm. It is important to choose good sites for the placement of mussel farms. Favourable current conditions and deep water will reduce this problem. Regular tending and thinning of mussels will prevent huge deposits of shell debris.

Algal toxins

The algal toxins that can occur along the Norwegian coast are "Diarrhoetic Shellfish Poisoning" (DSP) and "Paralytic Shellfish Poisoning" (PSP) toxins. DSP causes diarrhoea and PSP affects the nervous system, causing paralysis. Each week, the Norwegian Food Control Authority collects water and shellfish samples and evaluates whether it is dangerous in certain districts to eat mussels.

Much work is being invested in solving the problem of accumulation of algal toxins in mussels. Knowledge about localities as well as technology can make a positive contribution to the shellfish industry. The algae causing DSP has shown a strong tendency to accumulate in the inner parts of the large fjords in Western Norway, where there is a large supply of freshwater (Andersen, S. *et al*. 2003). Some of the problem can be solved by using localities in inner fjord areas, where larvae concentrations are the largest, for fry production. The production of mussels for human consumption can be moved to outer fjord areas where there are fewer problems with algal toxins.

A connection has also been observed between the food content and toxin values in the mussels. High food content yielded low toxin values (Strohmeier, T. *et al*. 2003). It will therefore be natural to place the mussel farms in areas with good access to food.

Until now, technological solutions for detoxification of mussels have been mainly based on either lifting deep-water up to the farm or placing the mussels in detoxification tanks.

Conclusion

Farming of mussels is a green and resource-friendly method of food production. In addition, mussels can make a positive contribution to water quality in fjord areas with an oversupply of nutrient salts. The biggest challenge to the growth of the mussel industry has been and still is the problem of algal toxins that poison shellfish.

Chapter 7
Public regulation of fish farming

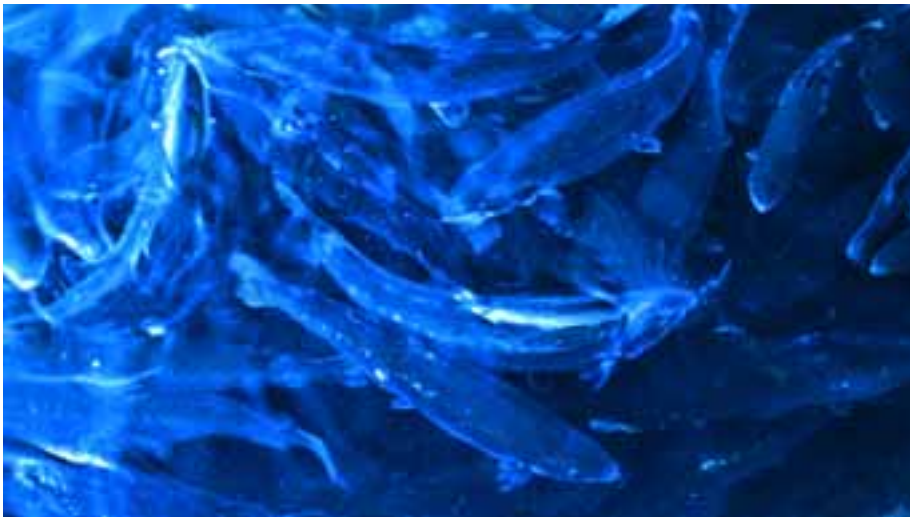


photo: Norwegian Seafood Export Commission

7.1 The Aquaculture Act

Fish farming in Norway is relatively carefully regulated through licensing, feed quotas, density restrictions, health regulations and reporting routines. At the time this chapter was written, the regime for regulating production was being restructured. This review of public regulations will therefore only provide a brief overview of existing rules, and the new rules that are proposed.

The primary law concerning the regulation of aquaculture is Act no. 68 of 14 June 1985 relating to aquaculture (the Aquaculture Act). According to Section 1, "The purpose of the Act is to contribute to the balanced and sustainable development of the aquaculture industry and to its development as a profitable and viable regional industry."

Operation and Diseases Regulations

Environment-related requirements for fish farms are largely specified through the Operation and Diseases Regulations, of which Section 3 states that: "Fish farms shall be established and operated in accordance with the requirements set forth in the licences and relevant rules and in other respects in such a manner that they are technically, biologically and environmentally acceptable".

Licensing requirement

The licensing requirement, or permit, to engage in fish farming is authorised by the Aquaculture Act. Under Section 3, first paragraph: "No person may construct, equip, expand, acquire, operate or own an aquaculture facility without a licence from the Ministry of Fisheries". Section 5 of the Act sets three absolute conditions that have to be met for the licence to be issued. A licence shall not be granted if the facility "will cause a risk of the spread of disease in fish or shellfish", "will cause a risk of pollution", or "has a location which is clearly unfavourable to the surrounding environment, lawful traffic or other exploitation of the area".

- The first subsection of the provision means that in order to get a licence a producer must obtain a permit pursuant to the Fish Diseases Act[8] from Norwegian Animal Health Authority, represented by the Chief County Veterinary Officer.
- The second subsection means producers must obtain a permit pursuant to the Pollution Control Act[9] from the County Department of Environmental Affairs.
- The third subsection that a permit pursuant to the Harbour Act[10] is required. The wording concerning fish farms that "have a location which is clearly unfavour able to the surrounding environment" serves as the legislative basis for the system of temporary exclusion zones, which were meant to protect wild salmon. The temporary exclusion zones will be abolished in 2005 in consequence of Proposition no. 79 to the Storting on the Establishment of National Salmon Fjords and National Salmon Rivers.

Safety and acceptable operation requirements

Section 16, first paragraph, of the Aquaculture Act stipulates that fish farms shall have adequate technical standards. This requirement is detailed in Section 3 of the Operation and Diseases Regulations, which state that: "Fish farms shall be established and operated in accordance with the requirements set forth in the licences and relevant rules and in other respects in such a manner that they are technically, biologically and environmentally acceptable". Consequently, this imposes an acceptability requirement on operations with respect to the technical standards of the facility, the living conditions of the fish and the overall enterprise, including operating routines etc. Work on a Norwegian Standard on the technical standards of fish farms is currently under way (May 2003).
It is important to note that the operation of the facility may be regarded as unacceptable even though the technical equipment is in excellent condition. As mentioned above, the manner in which operations are organised can provide grounds for establishing breach of Section 3 of the regulations. For example, poor routines for preventing escapes or a lack of a contingency plan when risky operations are performed could violate the acceptability requirement.

Qualifications of fish farmers

Section 13 of the Aquaculture Act authorises the setting of standards regarding the professional qualifications of producers. Section 28 of the Operation and Diseases Regulations states that the licence holder and person responsible for the daily operation of fish farms must always have the required professional qualifications to meet the standards of competence that are stipulated for the type of licence in question.

Marking and lighting requirements

Pursuant to Section 4, second paragraph, of the Operation and Diseases Regulations, floating installations must be marked with lights to avoid collisions with ships. The lights must not have a blinding effect on ordinary traffic. Furthermore, the farm must be marked with the licence number visible from the sea and other natural approaches to the farm.

8 See Act no. 54 of 13 June 1997 relating to measures to counteract diseases in fish and other aquatic animals.

9 See Act no. 6 of 13 March 1981 relating to protection against pollution and relating to waste.

10 See Act no. 51 of 8 1984June relating to harbours and fairways.

Land based fish farming.
photo: Norwegian Seafood Export Commission

Keeping records etc.
Section 8 of the Operation and Diseases Regulations states that a management plan giving an account of operations for the next two calendar years must be drawn up and submitted to the Directorate of Fisheries' regional office before 15 December of the current year. Furthermore, records shall be kept of fish farming operations, cf. Section 9. These records shall be kept at the farm for at least five years and must document stocking and stocks of fish, handling of dead fish, consumption of fish feed, pharmaceuticals and chemicals, escapes, etc.

Supervision
According to Section 12 of the Regulations, fish farms, as far as possible, shall be inspected daily and must be inspected immediately after bad weather. Improper supervision can otherwise also constitute a violation of the requirement in Section 3 regarding technically, biologically and environmentally acceptable operation.

Covering of cages etc.
Under Section 18 of the Operation and Diseases Regulations, cages must be covered by a net or similar cover to keep birds out. This is an important measure to prevent possibly infected fish from coming in contact with wild fish.

Use of pharmaceuticals and feed
Under Section 23, special care shall be exercised when using pharmaceuticals and disinfectants at fish farms to prevent releasing these substances into the surrounding environment. Fish farming entails the use of antibiotics, and leakage of them could cause resistance to antibiotics. Furthermore, under Section 22, care shall be taken to avoid unnecessary spills of feed. Fish feed contains medicines, and spills of feed attract wild fish, which in that way may come in contact with infected farmed fish. For this reason, fish farms are usually equipped with collectors to handle feed that is not eaten.
Norway is the only aquaculture nation to impose restrictions on the consumption of fish feed. The restriction is authorised in the regulation on production-regulating measures for farming salmon and trout.[11]

Handling of dead fish
As far as possible, dead fish shall be removed from the production unit daily and subsequently ground and preserved in acid, cf. Section 17, third paragraph. Furthermore, all sick and dying animals, waste originating from fish farming and used packaging shall be regarded as infectious and handled in such a way that there can be no danger of spreading disease. Under Section 6 of the Regulations, fish farms must have a container or other facility for acceptable storage of dead aquatic animals or parts of these.

11 See Regulation no. 223 of 29 February 1996 on production-regulating measures for farming salmon and trout.

7.2 Escapes

Contingency plan

According to Section 25(1) of the Operation and Diseases Regulations, the holder of a licence to breed salmon and trout in the sea must have an up-to-date contingency plan for all sites in use with a view to how future escapes can be limited and how recovery can be carried out most effectively. The contingency plan must also include safety precautions for the towing of sea cages and for the handling of fish during loading and unloading.

Fishing for monitoring purposes

In order to detect any escapes or conditions causing fish to flee, fishing for monitoring purposes must be carried out from 1 October to 30 April, cf. Section 25(2). The fishing is done by placing nets within a distance of 20 metres from the farm. The Directorate of Fisheries points out that the regulation on regular fishing for monitoring purposes does not permit producers to engage in free fishing within the zone. Under Section 47 of the Salmon Act[12], wild anadromous salmonids caught during escape monitoring must be returned to the water.

Duty to report escapes

If farmed fish escape from the facility, the licence holder is required to report *immediately* to the Directorate of Fisheries' regional office, cf. Operation and Diseases Regulations Section 25(3). The obligation also applies if a break out is *suspected,* and applies regardless of whether only a few or many fish are involved.

Duty to recover escaped fish

It is the responsibility of holders of licences to farm salmon and trout in the sea to recover fish that have escaped from the farm, cf. Section 25(4). The duty to recover fish is limited to the immediate vicinity of the farm, which is defined as the sea area up to 500 metres from the farm and no longer applies when it is obvious that the escaped fish are no longer in the immediate vicinity. If the possibilities of recapturing escaped fish so indicate, the Directorate of Fisheries' regional office, in consultation with the county governor, may extend or limit the scope of the duty to recover fish in time and geographic range. Under Section 25(4), third paragraph, the duty to recover escaped fish may be extended when escaped fish are suspected of suffering from an infectious disease.

12 Act no. 47 of 15 May 1992 relating to salmonids and freshwater fish etc.

7.3 Violations of laws

Administrative sanctions

When the Aquaculture Act was amended in 1989 rules were included to enable aquaculture authorities to react to violations of law. The provisions were motivated by a need for the administrative authorities to intervene vis-à-vis violators of the law with effective sanctions and filing complaints with the prosecuting authority. In this way the authorities have been given the opportunity to react against fish farming without a licence and violation of the terms and conditions of issued licences, e.g. exceeding the volume rule, farming species other than those licensed, wrong siting and spreading disease. Through the provisions of the Act, the authorities may issue orders, cf. Section 21, impose coercive fines, cf. Section 22, and revoke licences, cf. Section 24.

Criminal sanctions

Violation of the Aquaculture Act and regulations issued pursuant to it are subject to criminal sanction under Section 25, which sets a penalty for any person "that wilfully or negligently contravenes provisions or conditions set out in or pursuant to this Act". Under the Act, then, there is no difference between intent and negligence with respect to the authority to impose sanctions. Under Section 25, first paragraph, second sentence, aiding and abetting and attempted contravention are also liable to penalty.

In many cases escapes of farmed salmon will constitute violations of the acceptability requirements of Section 16 of the Aquaculture Act and Section 3 of the Operation and Diseases Regulations. Both poor technical standards and operating negligence can constitute criminal offences. Examples of possible criminal violations include[13]:

- Poor procedures for preventing escapes
- Insufficient focus on escapes in the organisation
- Unspecified placement of responsibility in the company and at the establishment (several persons or no one responsible)
- Known defects at the installation are not repaired
- The installation is not suited to the locality
- Lack of preparedness during risky operations

In a recent decision handed down by the Hålogaland Court of Appeal,[14] an aquaculture company was fined NOK 1.5 million for various violations of the Aquaculture Act, Fish Diseases Act and regulations issued pursuant to these laws. Among other things, this conviction included two break out cases where altogether approximately 23,000 salmon escaped.

13 Through an article in the professional periodical Miljøkrim 1/2003, Directorate of Fisheries Assistant Director General Anne-Karin Natås listed a number of conditions believed to violate the acceptability requirement. The bullet points listed above were taken from this article.

14 The judgment of the Hålogaland Court of Appeal was handed down on 26 March 2003. The judgment has been appealed, but no decision has been made whether to approve it for forwarding to the Supreme Court.

photo: Norwegian Seafood Export Commission

References

Alverson, D. L., Freeberg, M. H., Murawski, S. A and Pope, J. G. (1994) A Global assesment of fisheries bycatch and discards. FAO Fisheries Technical Paper 339, 235 pp.

Alverson, D. L., Freeberg, M. H., Murawski, S. A and Pope, J. G. (1996) A Global assesment of fisheries bycatch and discards, reprint.

Andersen, S., Mortensen, S., Strand, Ø., Hovgaard, P. and Magnesen, T. (2003). Skjell - miljøvennlig fremtidsnæring (Mussels - environmentally sound industy for the future). Havbruksrapporten 2003. Institute of Marine Research.

Anderson, S. and Kautsky, L. (1996). Copper effects on reproductive stages of Baltic sea Fucus vesiculosus. Marine Biology 125 (1): 171-176.

Andreassen, J. and Kvenseth, P.G. (2000) Kvalitetssikring ved bruk av leppefisk (Quality assurance for the use of wrasse). Villa Leppefisk AS and KPMG Consulting AS.

Anon. 2002. [Statistics Norway, available at: http://ssb.no/emner/10/05/fiskeoppdrett/

Anon. 2002 Review and synthesis of the environmental impacts of aquaculture. The Stationary Office Bookshop, Edinburgh, UK.

Arden, S.L. and Lambert, D.M. 1997. Is the black robin in genetic peril? Molecular Ecology 6: 21-28.

Åsgård, T. 1999. Har havbruk ei framtid i matforsyninga i verda? (Will aquaculture play a part in global foodsupply?) I: (red?) Havbruksrapport 1999. Institute of Marine Research. Bergen. Norway

Asplin, L., Boxaspen, K and Sandvik, A.D. 2002. Lakselus - en trusel for villaksen (Salmon lice - A threat to the wild salmon). I: Havets miljø 2002. Institute of Marine Research.

Austereng, E. 1994. Fôrutnytting hos laks samanlikna med kylling, gris og sau (Utilization of feed in salmon compared with chicken, pigs and sheep). Norsk fiskeoppdrett, nr 2a 1994.

Bardach, J.E. (ed) 1997. Sustainable aquaculture. New York: Wiley, C. 1997.

Bellas, J., Vazques, E. and Beiras, R. 2001. Toxicity of Hg, Cu, Cd and Cr on early development stages of Ciona intestinalis (Chordota; Ascidiacea) with potential application in marine water quality assesment. Water Research 35 (12): 2905-2912.

Bentsen, H.B. 2000. Et samspill mellom bestander, miljø og forvaltning (Interactions between stocks, environment and management). I: Fisk i ferskvann : / Reidar Borgstrøm and Lars Petter Hansen (red.). Landbruksforlaget - 2nd edition.

Bertolla, F. and Simonet, P. 1999. Horizontal gene transfers in the environment: natural transformation as aputative process for gene transfers between transgenic plants and microorganisms. Research in Microbiology 150: 375-384.

Biering, E. 1999. Infeksiøs pankreasnekrose (IPN). I: Poppe, T. (red.) 1999. Fiskehelse og fiskesykdommer, s. 348-356. Universitetsforlaget, Oslo.

Blaxter, J.H.S. (ed.) 1997. Interactions between Salmon Culture and Wild Stocks of Atlantic Salmon: The Scientific Management Issues. ICES journal of Marine Science Symposium Edition 54(6): 963-1226.

Bleie, H. 2002. Helsesituasjonen 2001 - marine arter i oppdrett (Health staus 2001 - marine species in aquaculture). I: Glette, J., van der Meeren, T., Olsen, R.E. and Skilbrei, O. (red.). 2002. Havbruksrapport 2002. Fisken og Havet nr. 3-2002.

Bond, P.R., Brown, M.T., Moate, R.M., Gledhill, M., Hill, S.J. & Nimma, M. 1999 Arrested development in Fucus spiralis (Phaeophyceae) germlings exposed to copper. European Journal of Phycology 34 (5): 513-521

Borch, O., Kjensli, B., Pedersen, E. 1998. Norsk havbruksnæring mot år 2005: en analyse av fremtidige utfordringer og barrierer for videre vekst (Norwegian aquaculture towards 2005: an analysis of future challenges for further growth). NF-rapport ; nr 14/98 Bodø : Nordlandsforskning

Boxaspen, K. & Næss, T. 2000. Development of eggs and the planktonic stages of salmon lice (Lepephtheirus salmonis) at low temperatures. Contribution to Zoology. Vol 69. (1/2) s. 51-55.

Boxaspen, K. 2001. Nedsenkede lys i merdene kan gi mindre lus (Sunken lights in the netpens can result in less salmon lice). Havforskningsnytt nr 11. 2001. Institute of Marine Research.

Brejikian, B.A. 1995. The effect of hatchery and wild ancestry and experience on the relative ability of steelhead trout fry (Onchorhynchus mykiss) to avoid a benthic predator. Canadian Journal of Fisheries and Aquatic Sciences 52: 2476-2482

Brendgren, A. og Vike, E. 2001. Kommentarer til miljødokumentasjon vedrørende Alpha Max (Comments regarding Alpha Max's environmental documentation). Letter from The Norwegian Pollution Control Authority (SFT) to The Norwegian Medicines Agency. Oslo 5. feb. 2001.

Brown,M.R.; Jeffery,S.W.; Volkman,J.K.; and Dunstan,G.A. (1997). Nutritional properties of microalgae for mariculture. Aquaculture 151: 315- 331.

Choubert, G. and Storebakken, T. 1989. Dose response to astaxanthin and cantaxanthin pigmentation of rainbow trout fed various dietary carotenoid concentrations. Aquaculture, 81: 69-77.

Christensen, T.B. 1998. Slipper vi genteknologien fri - setter vi mennesket i Guds sted (Playing God by releasing gene-technology) . Bellona Magasin 1998(1): 36-37

Christiansen, R. 2001. Fargestoff (Dyes). I: Waagbø, R., Espe, M., Hamre, K. and Lie, Ø. Fiskeernæring: s.141-154. Bergen. Norway.

Christiansen, R. and Torrisen, O.J. 1996. Growth and survival of atlantic salmon, Salmo salar L. fed different dietary levels of astaxanthin. Aquaculture nutrition 2: 55-62.

Chukwudebe, Atkins, R.H., Wislocki, P.G. 1997. Metabolic fate of emamectin benzoate in soil. J. Agric. Food Chem., 45, 4137-4146.

Clucas, I. (1997) A study of the operations for utilization of bycatch and discards from marine capture fisheries. Fishery Industries Division. FAO Fisheries Department.

Cury, P., Bakun, A., Crawford, R.J.M., Jarre, A., Quiñones, R.A., Shannon, L.J. & Verheye, H.M. (2000). Small pelagics in upwelling systems: patterns of interaction and structural changes in "wasp-waist" ecosystems. ICES Journal of Marine Science, 57: 603-618. 2000

Directorate for Nature Management, 2000. Environmental objectives for Norwegian aquaculture: results 1999.

Directorate for Nature Management. Plan of action agains lice on salmonids. Results 2000 og 2001

Directorate of Fisheries. (2003). Statistikk for oppdrett: Rapport (Statistics for aquaculture: Report). www.fiskeridir.no/sider/statistikk/fiskeoppdrett/fiskeoppdrett02.pdf

Directorate of Fisheries. (2003). Rømming av laks og regnbueørret fra oppdrettsanlegg: Årsaksforhold i 2001 og 2002 (Causes for escapes of farmed salmon in 2001-2002. http://www.fiskeridir.no/sider/aktuelt/romming/arsak.html

DKNVS and NTVA. (1999). Norges muligheter for verdiskapning innen havbruk (Norways opportunities for added value in aquaculture). Report from working group established by Det Kongelige Norske Videnskabers Selskab, DKNVS and Norges Tekniske Videnskabsakademi, NTVA.

Duerr,E.O.; Molnar,A.; and Sato,V.(1998). Cultured microalgae as aquaculture feeds. Journal of Marine Biotechnology 7: 65-70.

Easton, M.D.L., Luzniak, D. and Von der Geest, E. 2002. Preliminary examination of loadings in farmed salmon, wild salmon and commercial salmon feed. Chemosphere, vol. 46, s. 1053- 1074.

Einum, S. & Fleming, I.A. 1997. Genetic divergence and interactions in the wild among native, farmed and hybrid Atlantic salmon. Journal of Fish Biology 50: 634-651

Ellertsen, B.; Rey, F. and Melle, W. 1999. Økosystemet i Norskehavet og på Kysten; Plankton og Næringssalter (The ecosystem in the Norwegian Sea and coastal areas; Plankton and nutrients). Pp. 31-37 in: Fisken og Havet, Særnummer 2; Havets Miljø 1999, J. Aure (eds.). Institute of Marine Research

EMEA, 1999. Emamectin - Summary report. The European agency for the Evaluation of medicinal Products

EMEA, 1999b. Teflubenzuron - Summary report. The European agency for the Evaluation of medicinal Products

EMEA, 2001. Deltamethrin (extension to finfish) Summary report (4). The European agency for the Evaluation of medicinal Products

Espino, M. Changes in the southeast pacific by decades: An environmental and fishing resources long-term overview. Notat.

European commission. 2002. Opinion of Scientific Committee on Animal Nutrition on the use of cantaxanthin in feedingstuffs for salmon and trout, layings hens, and other poultry.

Ewen, S, Pusztai, A. 1999. Effect of diets containing genetically modified potatoes expressing Galanthus nivalis lectin on rat small intestine. The Lancet, 354: 1353-1354

Ewos, 2001. Fra gass til fiskefôr (From gas to fishfeed). Perspektiv nr.3 - 2001. Ewos AS.

FAO. (1997). Committee on Fisheries. Twenty-second Session Rome, Italy 17-20 March 1997. Fisheries Bycatch and Discards. http://www.fao.org/docrep/meeting/W3862E.htm.

FAO - Food and Agriculture Organisation "The State of World Fisheries and Aquaculture (SOFIA 2002)

FAO. 2002. State of the world fisheries and aquaculture 2002.

FAOa http://www.fao.org/wairdocs/tan/x5926E/x5926e01.gif

FIN - (Fishmeal Information Network) Sustainability Dossier (in-depth report - January 2003.

FishBase. 2002. World Wide Web electronic publication. 13 November 2002. http://www.fishbase.org

Fiske, P., Østborg, G.M., & Fløystad, L. 2001. Rømt oppdrettslaks i sjø- og elvefisket i årene 1989-2000 (Infusion of escaped farmed salmon in wild salmon fisheries 1989-2000). NINA Oppdragsmelding 704: 1-26

Fleming, I.A. & Einum, S. 1997. Experimental tests of genetic divergence of farmed wild Atlantic salmon due to domestication. ICES Journal of Marine Science 54: 1051-1063

Fleming, I.A., Hindar, K., Mjølnerød, I.B., Jonsson, B., Balstad, T. & Lamberg, A. 2000. Lifetime success and interactions of farm salmon invading a native populasjon. Proc. R. Soc. Lond. B 267: 1517-1523

Forskningsrådet and SND. (2001). Oppdrett av torsk - Strategi for koordinert satsing fra SND og Norges Forskningsråd (Farmed cod - Coordinated strategy from SND and Norges Forskningsråd..

Futuyma, D.J. 1998 Evolutionary Biology 3rd ed. Sinauer Associates, Inc. Sunderland, Massachusettes

Gharrett AJ, Smoker WW, Reisenbichler RR, Taylor SG 1999. Outbreeding depression in hybrids between odd- and even-broodyear pink salmon Aquaculture 173 (1-4): 117-129

Gharrett, A.J. & Smoker, W.W. 1991. Two generations of hybrids between even- and odd-year pink salmon (Oncorhynchus gorbuscha): a test for outbreeding depression? Canadian Journal of Fisheries and Aquatic sciences. 48: 1744-1749

Gibson, D.R. & Sommerville, C. (1996) The potential for viral problems related to the use of wrasse (Labridae) in the farming of Atlantic salmon. In: Sayer, M.D.J., Treasurer, J.W. & Costello, M.J6. (Eds) "Wrasse: Biology and use in aquaculture", 240-250

Gilligan DM, Frankham R 2003. Dynamics of genetic adaptation to captivity Conservation Genetics 4(2): 189-197

Gjedrem, T., Gjøen, H.M. & Gjerde, B. 1991. Genetic origin of Norwegian farmed Atlantic salmon. Aquaculture 98: 41-50

Gjøen, H.M. & Bentsen, H.B. 1997. Past, present and future of genetic improvement in salmon aquaculture. ICES Journal of Marine Science 54: 1009-1014

Graur, D. & Li, W-H. 2000. Fundamentals of Molecular Evolution (second ed.) Sinauer Associates, Inc., Publishers. Sunderland, Massachusetts

Grave, K., Litleskare, I. og Lunestad, B.T. 2002. Forbruksmønsteret for legemidler til oppdrettsfisk i Norge i perioden 1996-2001: Et gullkantet eksportsertifikat for norsk oppdrettsnæring. (Consumption pattern of medicine use in farmed fish in Norway in the period 1996-2001). Norsk veterinærtidsskrift, 114: 52-55.

Haamer, J. (1996). Improving Water Quality in a Eutrophied Fjord System with Mussel Farming. Ambio Vol. 25 No. 5.

Haldorsen, A.-K. L., Julshamn, K., and Lunestad, B.T. 2003. Dokumentasjon av trygg sjømat (Documentation of safe seafood). I: Ervik, A., Kiessling, A., Skilbrei, O. Og van der Meeren, T. Havbruksrapport 2003. Institute of Marine Research, februar, 2003.

Hall, L.W. & Anderson, R.D. 1999 A deterministic ecological risk assessment for copper in european saltwater environments. Marine Pollution Bulletin 38(3): 207-218

Hall, M.A., Alverson, D.L. and Metuzls, K.I. (2000). By-Catch: Problems and Solutions. Marine Pollution Bulletin Vol. 41, Nos. 1-6, pp. 204-219.

Hansen P.K., Lunestad B.T. og Samuelsen, O.B. 1993. Effects of oxytetracycline, oxolinic acid and flumequin on bacteria in an artificial marine fish farm sediment. Canadian Journal of Microbiology, 39 (9): 906-906.

Hansen, L.P., Håstein, T., Nævdal, G., Saunders, R.L. & Thorpe, J.E. (ed.) 1991. Interactions between cultured and wild Atlantic salmon. Aquaculture 98: 1-324

Hassel, A. 1999. Økosystemet i Barentshavet; Plankton (The ecosystem in the Barents Sea). Pp. 18-20 in: Fisken og Havet, Særnummer 2; Havets Miljø 1999, J. Aure (eds.). Institute of Marine Research.

Hektoen, H., Berge, J.A., Hormazabal, V., Yndestad, M. 1995. Persistence of antibacterial agents in marine sediments. Aquaculture. 133, 175-184.

Heuch, P.A. & Mo, T.A. 2001. A model of salmon louse production in Norway: effects of increasing salmon production and public management measures. Diseases of aquatic organisms. Vol. 45: s145-152.

Heuch, P.A. & Schram, T.A. 1999. Crustacea (krepsdyr). I: Poppe, T. (red.) 1999. Fiskehelse og fiskesykdommer, s. 348-356. Universitetsforl., Oslo

Hevrøy, E.M.1998. Effekt av kunstig tilleggsbelysning på grad av lakselusinfeksjon (Lepeophtheirus salmonis) på laks (Salmo salar) i merd (Effects of artificial lights on salmon lice infections). Hovedoppgave i fiskeri- og marinbiologi - Universitetet i Bergen, 1998 I.

Hindar, K. & Balstad, T. 1994 Salmonid culture and interspecific hybridization. Conservation Biology 8: 881-882

Hites, R.A., Foran, J.A., Carpenter, D.O., Hamilton, M.C., Knuth, B.A. & Schwager, S.J. (2004). Global Assessment of Organic Contaminants in Farmed Salmon. Science 303: 226-229

Hjukse, A.V. 2003. Alger - oppdrettsfiskens livrett! (Algea - the favourite food of farmed fish) Forskning.no, 4. mars 2003.

Holm, J.C. (1999). Aktuelle fiskearter i oppdrett (Promesing species for aquaculture). I: Poppe, T. (red.) 1999. Fiskehelse og fiskesykdommer, s. 348-356. Universitetsforl., Oslo.

Holst, J.C., Nilsen, F., Holm, M. 2003. Interaksjoner villaks - lakselus - oppdrettslaks: Hvor står vi, hva er målet? (Interactions wild salmon - farmed salmon: Where are we, what is our goal?) I: Ervik, A., Kiessling, A., Skilbrei, O. Og van der Meeren, T. Havbruksrapport 2003. Institute of Marine Research, februar, 2003..

Holst, J.C., Nilsen, F., Holm, M., Jacobsen, P. & Asplin. L. 2001. Lakselusen dreper villaksen. Kan vi spore effekter av tiltakene så langt? (Salmon lice kills wild salmon - what are the effects of the preventive measures so far?) I: Ervik, A., Kiessling, A., Skilbrei, O. Og van der Meeren, T. Havbruksrapport 2003. Institute of Marine Research, februar, 2003.

Hovgaard, P. (1998). Kompendium om dyrking av blåskjell (Compendium for mussel farming). Høgskolen i Sogn og Fjordane.

Huslid, J.M. 2003. Personal email to Marius Holm, Bellona.

IMR, (2003). Havforskningsinstituttet - Havets ressurser 2003

Jacobs, M., Ferrario, J. og Byrne, C. 2002. Investigation of polychlorinated dibenzo-p-dioxins, dibenzo-p-furans and selected coplanar biphenyls in Scottish farmed Atlantic salmon (Salmo salar). Chemosphere, vol. 47 (2002) s. 183-191.

Jensen, B.A.: Høyt Antibiotikaforbruk i Chile (High consumption of antibiotics in Chile). Intrafish, 11.06.2002.

Jensen, P.M. 2003. Laks med torsk eller skjell i samme anlegg (Salmon together with cod or mussels in the same farm). Norsk fiskeoppdrett nr. 9 2003: s. 40-41.

Johannessen, A. (1978). Early stages of Lepeophtheirus salmonis (Copepoda Caligidae). Sarsia 63, 169-176.

Johnson, S.C. & Albright, L.J. 1991a. Development, growth, and survival of Lepeophtheirus salmonis (Copepoda: Caligidae) under laboratory conditions. Journal of the Marine Biological Association of the UK 71, 425-436.

Johnson, S.C. & Albright, L.J. 1991b. The developmental stages of Lepeophtheirus salmonis (Krøyer, 1837) (Copepoda: Caligidae). Canadian Journal of Zoology 69, 929-950.

Johnsson, J.I. & Abrahams, M.V. 1991. Inbreeding with domestic strain increases foraging under threat of predation in juvenile steelhead trout (Onchorhynchus mykiss): an experimental study. Canadian Journal of Fisheries and Aquatic Sciences 48: 243-247

Johnsson, J.I., Højesjø, J. & Fleming, I.A. 2001. Behavioural and heart rate responses to predation risk in wild and domesticated Atlantic salmon. Canadian Journal of Aquatic Sciences 58: 788-794

Johnsson, N., Johnsson, B. & Fleming, I.A. 1996. Does early growth cause a phenotypically plastic response in egg production of Atlantic salmon? Funct. Ecol. 10: 89-96

Julshamn, K., Berntssen, M.H.G. and Lundebye, A.K. 2000. Tungmetaller i fiskefôr (Heavy metals in fishfeed). Norsk fiskeoppdrett 14: 76-78

Julshamn, K., Haldorsen, A.-K. L., Berntssen, M.H.G. og Bøe, B. 2002. Fremmedstoffer (metaller, ddt og pcb) i norskprodusert laksefilet og laksefôr - resultater hentet fra overvåkningsprogrammet i perioden 1995 - 2001 (Metals, DDT and PCBs in Norwegian produced salmon fillet and salmonfeed - results from the surveilance programme 1995 -2001). Fiskeridirektoratets ernæringsinstitutt, Bergen. Norway

Kabata, Z. (1979). Parasitic Copepoda of British Fishes. London: Ray Society.

Karlsen, Ø. and Adoff, G.R. (2003). Havbruksrapporten 2003. Intsitute of Marine Research.

Kimura, M. & Weiss, G.H. 1964. The stepping stone model of population structure and the decrease of genetic correlationwith distance. Genetics 49: 782-791

Kirkemo, A.-M., Bergh, Ø. and Samuelsen, O.B. 2003. Sykdom hos leppefisk (Disease in wrasse). Norsk Fiskeoppdrett nr. 5. 2003. s. 32-35.

Klev, S..M. 2000: Miljøeffekter av intensivt fiskeoppdrett i kystsonen med hovedvekt på utslipp av nitrogen, fosfor og organisk materiale (Environmental effects of intensive fishfarming activity in coastal areas with main focus on the discharges of nitrogen, phosphorus and organic matter). Hovedoppgave, Institutt for husdyrfag, NLH

Kvenseth, P.G., Andreassen, J. and Solgaard. J., 2003. Berggylt - en sterk medisin! (Ballan wrasse - strong medicine!) Norsk Fiskeoppdrett 2003/2: 34-37.

Kvenseth, P.G., Andreassen, J. and Bergh, Ø. 2002. Leppefisk - en liten leppefisk kan berge stor laks! (Wrasse - small wrasse can save large salmon!) I: Glette, J., van der Meeren, T., Olsen, R.E. and Skilbrei, O. (red.), 2002 Havbruksrapport 2002. Fisken og Havet, særnr. 3-2002.

Lawrence, E. 1995. Dictionary of Biological Terms 11th ed. Longman Singapore Publishers (Pte) Ltd. Singapore.

Lenormand, T. 2002. Gene flow and the limits to natural selection. Trends in Ecology and Evolution 17 (4): 183-139

Liodden, J.A., Dalen, M., Knudsen, G. (1998). Bruk av blåskjell til opptak av næringssalter (Use of mussels to remove nutrients). Prosjekt ved Høyskolen i Agder, avd. Grimstad.

Lovdata. (2003). Lakselusforskriften (Salmon lice regulations). www.lovdata.no

Lura, H. & Sægrov, H. 1991. Documentation of successful spawning of escaped farmed female Atlantic salmon, Salmo salar, in Norwegian rivers. Aquaculture 98: 151-159

Marino-Balsa, J.C., Poza, E., Vazques, E. & Beiras, R. 2000 Comparative toxicity of dissolved metals to early larval stages of Palaemon serratus, Maja squinado, and Homarus gammarus (Crustacea: Decapoda). Archives of Environmental Contamination and Toxicology 39: 345-351

Marthinsen, B. and Fossum, B. 2003. Presentation for Bellona. Alpharma, 29. april 2003.

Martin-Orue, S.M., O'Donnell, A.G., Arino, J., Netherwood, T., Gilbert, H.J. & Mathers, J.C. 2002. Degradation of transgenic DNA from genetically modified soya and maize in human intestinal simulations. British Journal of Nutrition 87(6): 533-542

McHenery, J.G. 1999. Potential Environmental impacts of emamectin benzoate formulated as Slice, for salmonids. A report for Schering-Plough Animal Health Corporation. Cordah Environmental Consultants.

Miller, B. 1998 An assessment of sediment copper and zinc concentrations at marine caged fish farms in SEPA West Region. Scottish Environment Protection Agency, West Region

Ministry of the Environment. 2002. Stortingsmelding nr. 12 (2001-2002) Rent og rikt hav (A clean and rich ocean).

Mjølnerød, I.B., Refseth, U.H., Karlsen, E., Balstad, T., Jakobsen, K.S. & Hindar, K. 1997. Genetic differences between two wild and one farmed population of Atlantic salmon (Salmo salar) revealed by three classes of genetic markers. Hereditas 127: 239-248

Mork, J., Bentsen, H.B., Hindar, K. & Skaala, Ø. 1999. Genetiske interaksjoner mellom oppdrettslaks og vill laks (Genetic interactions between farmed and wild salmon), vedlegg 4 i: Rieber-Mohn G.F. et al: NOU 1999:9 "Til laks åt alle kan ingen gjera?" pp 181-200

NIFES (National Institute of Nutrition and Seafood Research) 2003. Unpublished data.

NIVA. 1996. Kobberbelastning i forbindelse med vasking og impregnering av oppdrettsnøter (Copper load in connection with washing and impregnating netpens). NIVA-rapport 3483-96

Nogva, A. 2000. The effect of the ballan wrasse (Labrus berggylta Ascanius, 1767) on the level of salmon lice of the species Lepeoptheirus Salmonis Krøyer, 1837, and Caligus elongatus Nordmann, 1832, on 2-3 kg Atlantic salmon (Salmo salar L.) in their second year in sea : a pilotstudy. Hovedoppgave, Institutt for husdyrfag, NLH.

Norris, A.T., Bradley, D.G. & Cunningham, E.P. 1999. Microsatellite genetic variation between and within farmed and wild Atlantic salmon (Salmo salar) pop-ulations. Aquaculture 180: 247-264.

Norwegian Animal Health Authority. 2003. Annual report 2002. Oslo.

Norwegian Council on Animal Ethics. 2000. Biologisk kontroll av lakselus i oppdrettsnæringen - bruk av leppefisk (Biological control of salmon lice in the aquaculture industry - the use of wrasse). Statement given august 2000.

Norwegian Medicines Agency. 2000. Terapianbefaling : behandling mot lakselus i oppdrettsanlegg (Teraputic recomendations: treatment against salmon lice in aquaculture). SLK-publikasjon ; 2000:02, Oslo. Norway

NOU 1999:9 see: Rieber-Mohn G.F. et al. 1999

Nutreco, 2002. Social and environmental report 2001.

Nylund, A., Hovland, T., Hodneland, K., Nilsen, F., Lovik, p.: 1994. Mechanisms for transmission of infectious salmon anaemia (ISA). Diseases of Aquatic organisms. 20:95-100.

Olafsen, T., Rosten, T., Winther, U., Hempel, E. og Helland V. 2002. Regulering av oppdrettsnæringen internasjonalt - en sammenligning av reguleringer/rammebetingelser i ulike land (International regulations in the aquaculture instustry - comparing regulations/framework in different countries) . 63 s. KPMG Consulting AS, Senter for havbruk og fiskeri. Utarbeidet for FHL-Havbruk.

Olsen, A. B. 1999. Piscirickettsisose. I: Poppe, T. (red.) 1999. Fiskehelse og fiskesykdommer, s. 348-356. Universitetsforl., Oslo.

Quist, D. & Chapela, I.H. 2001. Transgenic DNA introgressed into traditional maize landraces in Oaxaca, Mexico. Nature 414: 541-543

Rådgivende biologer AS. 2003. Overvaking av lakselusinfeksjonar på tilbakevandra sjøaure i Vest-Agder, Rogaland, Hordaland og Sogn & Fjordane sommaren 2002 (Monitoring of salmon lice infections on returning brown trout i the counties of Vest-Agder, Rogaland, Hordaland and Sogn og Fjordane). Rapport 631

Rasmussen, E. (Product manager, Skretting AS). Personal message. 06.06.2002.

Reed, D.H. & Frankham, R. 2003. Correlation between fitness and genetic diversity Conservation Biology 17(1): 230-237

Renaud,S.M.; Thinh,L-V; and Parry,D.L. (1999). The gross chemical composition and fatty acid composition of 18 species of tropical Australian microalgae for possible use in mariculture. Aquaculture 170:147-159.

Richie, G. 2000. Respons: Mulig hjelp i lusekampen. (Respons: A possible aid in the fight against salmon lice). I dybden, vol. 14, s 224-227.

Richie, G. 2002. Sealice & their control in Marine Harvest. Presentation at Bellona, 6. juni 2002.

Rieber-Mohn, G.F., Eggereide, A., Anfinsen, A.R., Eitun, I., Jørrestol, A., Jonsson, B., Henriksen, M.B., Kristiansen, B., Wahl, E.B.S., L'Abée-Lund, J.H., Pettersen, B., Solberg, M., Mårvik, Ø. & Førde, E. 1999. NOU 1999:9 "Til laks åt alle kan ingen gjera?"

Roche. Roche handbook for quality of farmed salmon and trout. Influence of micronutrients. Roche.

Rosenlund, G. 2001. Vegetabilske oljer i laksefôr (Vegetable oil in salmon feed). I dybden. Volum 16, nummer 1 2001.

Rubin Foundation. www.rubin.no

Røstvik, Inger Oline. 1997. Biologi for akvakultur (Aquaculture biology). 2nd edition. Landbruksforlaget. Oslo

Sanda, R-A., V.L. Torsvik and J. Goksøyr 1992. Transferable drug resistance in bacteria from fish farm sediments. Canadian Journal of Microbiology 38, 1061-1065.

Schram, T.A. 1993. Supplementary descriptions of the developmental stages of Lepeophtheirus salmonis (Krøyer, 1837) (Copepoda: Caligidae). In:Boxhall, G.A. and Tully, O., Nolan, D.T. 2002. A review of the population biology and host-parasite interactions of the sea louse Lepeophtheirus salmonis (Copepoda: Caligidae). Parasitology (2002), 124, S165-S182.

SEPA, 1997. SEPA Policy on the use of Cypermethin in marine cage fish farming. Risk assessments, EQS and recommendations. Scottish Environment Protection Agency, Fish Farming Advisory Group. Policy 30.

SEPA, 1999. Calicide (Teflubenzuron) Authorisation for use as an in-feed sea lice treatment in marine cage salmon farms. Risk assessments, EQS and recommendations. Scottish Environment Protection Agency, Fish Farming Advisory Group. Policy 29.

Simolin, P., Johansen, R., Grimholt, U., Sterud, E., Kvellestad, A., Evensen, Ø. and Horsberg, T.E. (2003). Miljøproblemer i forbindelse med oppdrett av torsk - med fokus på sykdommer og mulighet for spredning av disse til ville bestander (Environmental effects in cod farming - focus on diseases and the possible spreading of disease to wild stocks). Norges veterinærhøgskole. Veterinærinstituttet.

Singer, T.D., Clements, K.M., Semple, J.W., Schulte, P.M., Bystriansky, J.S., Finstad, B., Fleming, I.A. & McKinley, R.S. 2002. Seawater tolerance and gene expression in two strains of Atlantic salmon smolts. Canadian Journal of Aquatic Sciences 59: 125-135

Skiftesvik, A.B. og Bjelland, R.M. 2003. Oppdrett av berggylt (Labrus berggylta). (Farmed ballan wrasse). Norsk Fiskeoppdrett nr. 8, 2003, s. 36-39.

Skretting 2003. En kilo laks av en kilo villfisk (One kg of salmon from one kg of feed). Notat.

Skretting. 2002. Environmental report 2001.

Smith, P., 1996. Is sediment deposition the dominant fate of oxytretracycline used in marine fish farms; a review of available evidence. Aquaculture 146, 157-169.

SNT, 2002. Holder maten mål? 2000-2002.

Soppeland, J. 2002. Gen-jakt på laks (The hunt for salmon genes) Aftenbladet 26.04.02 06:47 (available at: http://www.aftenbladet.no/nyheter/lokalt/article.jhtml?articleID=124188)

Sørum, H., M.C. Roberts and J.H. Crosa 1992. Identification and cloning of a tetracycline resistance gene from the fish pathogen Vibrio salmonicada. Antimicrobial Agents ans Chemtherapy 36, 611-615

Sørum, Henning. 1999. Antibiotikaresistens hos fiskepatogene bakterier (Resistance to antibioticks in fishpathogene bacteria). I: Poppe, T. (red.) 1999. Fiskehelse og fiskesykdommer, s. 348-356. Universitetsforl., Oslo.

SSB (Statistics Norway). 2002. Natural resources and Environment. 2002. Statistical analysis SA55. Kongsvinger. Norway

Strohmeier, T., Aure, J. and Duinker, A. (2003). Blåskjelldyrking - bæreevne, skjellkvalitet og avgiftning (Mussles - Carrying capacity, quality and detoxification). Havbruksrapporten 2003. Institute of Marine Research.

Strøm, T. 2002. Lakseoppdrett: Matproduksjon eller matdestruksjon? - en undersøkelse av om fôrforbruket i norsk lakseoppdrett. (Salmon farming - Food production or food destruction?) Report 2/2002 Framtiden i våre henders forskningsinstitutt (FIFI)

Thakur, S. 2001 The ethics of genetic engeneering. Honours degree, University of Otago, Dunedin, New Zealand

Thelin, I og Fagernæs, K.E. 1998. Ektobann vet Medisinpellett "Skretting" Letter from The Norwegian Pollution Control Authority to The Norwegian Medicines Agency. Oslo den 1. april 1998.

Thelin, I og Fagernæs, K.E. 1998. Excis Vet solution 10 mg/l "Grampian" Letter from The Norwegian Pollution Control Authority to The Norwegian Medicines Agency. Oslo den 6. mars 1998.

Thelin, I og Fagernæs, K.E. 1998. New agent for use in aquaculture - Assessing the environmenta effects. Letter from The Norwegian Pollution Control Authority to The Norwegian Medicines Agency. Oslo den 8. sept. 1998.

Torrisen, O.J., Hardy, R.W. and Shearer, K.D. 1989. Pigmentation of Salmonids - Carotenoid Deposition and Metabolism. Critical review in Aquatic Sciences. Vol. 1 s. 209-225. 1989.

Treasurer, J.W. og Grant, A. 1997. The efficacy of hydrogen peroxide for the treatment of farmed Atlantic salmon, Salmo salar L. infested with sealice (Copepoda: Caligidae). Aquaculture 148: s. 265-275.

Tufto, J. & Hindar, K. (in print)

Tufto, J. 2001. Effects of releasing maladapted individuals: A demographic-evolutionary model. American Naturalist 158 (4): 331-340

Tully, O., Nolan, D.T. 2002. A review of the population biology and host-parasite interactions of the sea louse Lepeoptheirus salmonis (Copepoda: Caligidae). Parasitology (2002), 124, S165-S182.

Turujman, S. A., Wamer, W. G., Wei, R. R., and Albert, R. H. (1997) Rapid liquid chromatographic method to distinguish wild salmon from aqua-cultured salmon fed synthetic astaxanthin. J. AOAC Int., 80(3):622-632.

Vannebo, H. et al. 2000. Nasjonal tiltaksplan mot rømming (National action plan against escaping farmed salmon)

Vannebo, H., Aalvik, B., Rabben, S.O. & Olafsen, T. 2000 Handlingsplan for redusert utslipp av kobber fra norsk oppdrettsnæring (Actionplan to reduse the discharge of copper from Norwegian aquaculture). KPMG-Consulting

Verspoor, E. 1988. Widespread hybridization between native Atlantic salmon, Salmo salar, and introduced brown trout (S. trutta). Journal of Fish Biology 32: 327-334.

Waagbø, R. [et al.] (red.).Fiskeernæring. Bergen : Kystnæringen forl. & bokklubb, c2001.

Waagbø, R., Torrissen, O.J., Austreng, E. 2001. Fôr og fôrmidler - den største utfordringen for vekst i norsk havbruk (Feed and feed resources - the greatest challenge for growth in Norwegian aquaculture). En utredning utført på oppdrag for Norges forskningråd.

Watsen, R. and Pauly, D. 2001 Systematic distortion in world catch trends, Nature vol 414, 29 november 2001

Wilken, U. 2001 Undersøkelse af forekomst af antibiotika og kobber i forbindelse med marin akvakultur i tre amter (Investigation of the presens of antibiotics and copper in connection with marine aquaculture in three counties). Arbeidsrapport fra Miljøstyrelsen 8: 1-41

Williamson, J. Gjennombrudd for alternative oljekilder i fiskefôr (A break-trough.for alternative sources to oil in fishfeed). I dybden. Volum 17, nummer 1 2002

WRI World Resources 2000-2001, People and ecosystems: The fraying web of life, Prepared by the United Nations Development Programme (UNDP), the United Nations Environment Programme (UNEP), the World Bank, and the World Resources Institute 2001.

Youngson, A.F., Webb, J.H., Thompson, C.E. & Knox, D. 1993. Spawning of Escaped Farmed Salmon (Salmo Salar) by hybridisation of Female with brown trout (Salmo trutta). Can J. Fish Aquat Sci 50: 1986-1990

Youngston, A.F., Dosdat, A., Sargolia, M. & Jordan, W.C 2001. Genetic interactions between marine finfish species in European aquaculture and wild censpecifics. Journal of Applied Ichthyology 17: 153-162