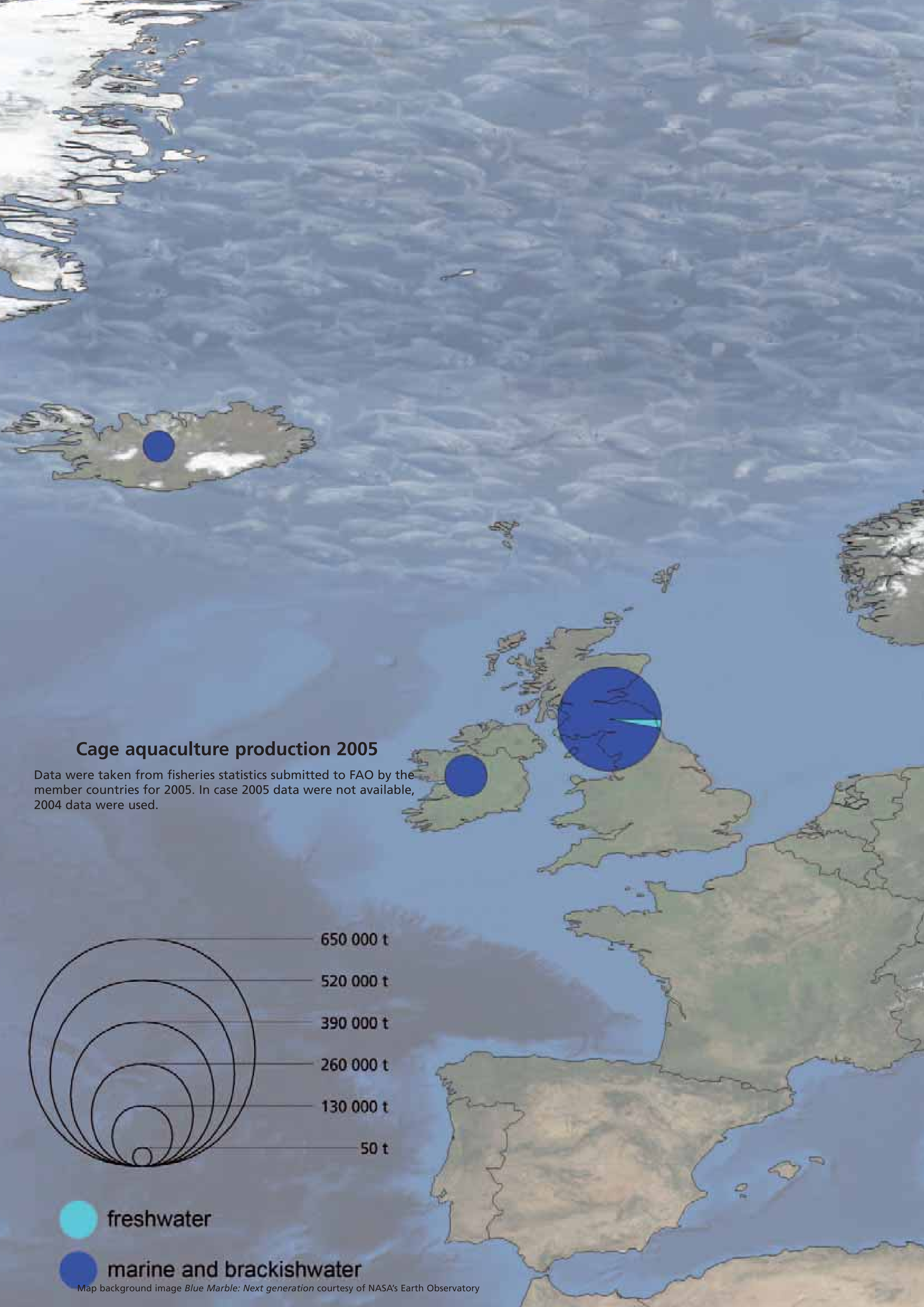
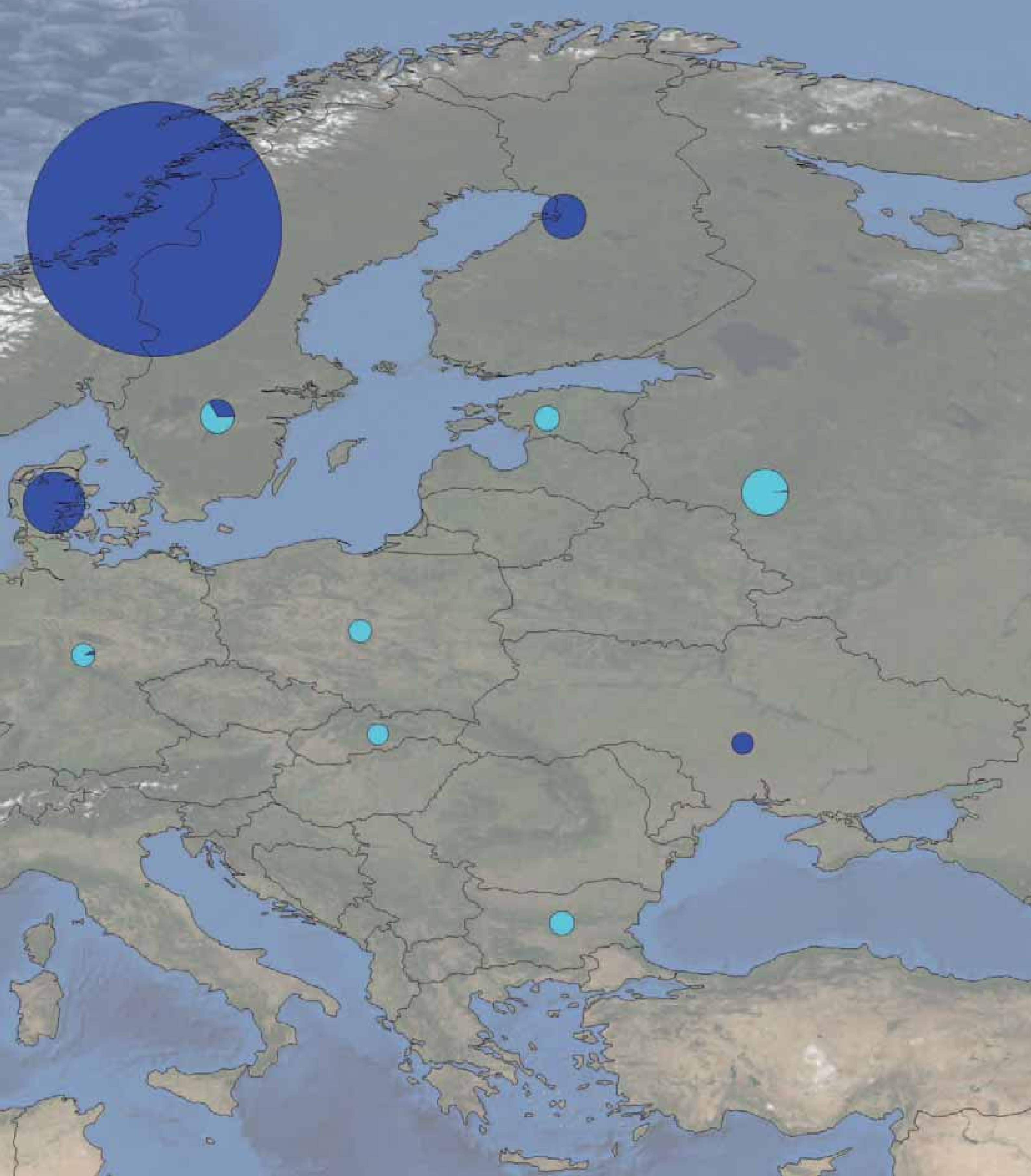
Cage aquaculture production 2005

Data were taken from fisheries statistics submitted to FAO by the member countries for 2005. In case 2005 data were not available, 2004 data were used.



Map background image *Blue Marble: Next generation* courtesy of NASA's Earth Observatory

A review of cage aquaculture: northern Europe



A review of cage aquaculture: northern Europe

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ABSTRACT

Thirty years after the cage aquaculture industry in Europe began, the industry has matured. The main species in northern Europe are the Atlantic salmon (*Salmo salar*) and rainbow trout (*Oncorhynchus mykiss*). The majority of production is in Norway, Scotland, Ireland and Faroe Islands. However, also countries as Finland, Iceland, Sweden and Denmark have a cage culture industry. All relevant aquaculture production using cage technology in northern Europe is carried out in marine waters. The production volume in 2004 is about 800 000 tonnes of Atlantic salmon and about 80 000 of rainbow trout. The production volume of Atlantic salmon is expected to grow further, while rainbow trout for the moment shows a negative trend. There is an increasing interest to expand the production of other species, such as cod and halibut.

There are of course huge differences among European countries in, for example, the degree of exposure at sites, ranging from rainbow trout production in rather sheltered locations in the Baltic Sea to the cultivation of Atlantic salmon in heavily exposed locations in the Faroe Islands. Not all of Europe is appropriate for aquaculture development, as many different factors affect the output and the viability of aquaculture operations (e.g. water quality, availability and cost of space, climatic conditions, etc.). When considering the location of aquaculture sites, it is critical to perform a systematic, integrated assessment of both the positive and negative impacts of new aquaculture developments. Despite the variation in locations, cage culture production in the different European countries is somewhat uniform in terms of use of technology. The cage systems used in modern aquaculture have essentially changed little compared to the first used. Cages are moored or floating, square, hexagonal or circular units with a suspended closed net bag. Fabrication materials have changed from wood to steel and plastic.

Genetic improvement by implementing selective breeding programmes has contributed significantly to increasing the performance and productivity of Atlantic salmon and rainbow trout. However, as these breeding programmes are highly specialized and costly, they tend to become centralized in very few countries and companies. Improved genetics at a reduced cost and a year-round egg availability represent an important motivation for international trade of salmonid eggs. Preventive measures that are acceptable from a biological and environmental point of view have been used to keep disease problems in aquaculture at an acceptable level. Vaccination is now the single most important measure for prevention of bacterial diseases in farmed fish, especially in salmonids. The best indicator of the effect of vaccination as prophylactic measure is the reduction in use of antibiotics in fish farming. Most of the population of Atlantic salmon and rainbow trout is vaccinated against at least three major bacterial diseases (vibriosis, cold-water vibriosis and furunculosis) prior to stocking into sea-water. During a 10 year period the usage of antibiotics has been reduced to an absolute minimum, mainly due to the use of vaccines.

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Even if there has been a significant decrease in the environmental impact from the cage culture industry in Europe, there are still some challenges: escapes, marine eutrophication, sea lice and access to sea areas. Despite many problems there has been a more or less continuous growth in production, and the industry has become an important economical contributor to some of the remoter rural regions of Europe. While some concerns remain, the industry has managed to reduce environmental impacts and improve fish health. However, a further increase in production and introduction of new species will provide new challenges in the coming years. There is a great interest to further develop this industry, providing essential profitable activities to sustain communities living at the margins of Europe. Aquaculture may create new economic niches, leading to increased employment, a more effective use of local resources, and opportunities for productive investments. The contribution of aquaculture to trade, both local and international, is also increasing. Most of the countries involved in aquaculture have developed strategies to promote the development of the aquaculture sector. Development must not be at the expense of product quality, however, or of the environment. It must also be sufficiently efficient that it can compete with other food producers, both within and outside Europe.

BACKGROUND

This paper provides an overview of cage culture farming in Europe, with the exception of the production in the Mediterranean, which is covered in a separate chapter of these proceedings.

The aquaculture industry along the coastline from Gibraltar in the south, via Great Britain, Faroe Islands, Iceland and the Baltic Sea, to the Russian border in the north today plays a major role for many small communities located close to the sea. This role will probably become even more important in the near future because of an increasing demand for fish of high quality, and a decrease in wild catches.

The countries with the greatest production are Norway, followed by Scotland and Ireland. The dominant role of these countries is reflected in the content of this article. The international nature of ownership of today's cage farming businesses is reflected in the similarity in use of technology and in farming practices.

The major species for cage culture in northern Europe are Atlantic salmon (*Salmo salar*) and rainbow trout (*Oncorhynchus mykiss*). However, several new species are becoming increasingly important for the cage culture industry in Europe.

Because this article covers more or less all aspects of cage farming, most of the content is based on review articles, which have been chosen as good introductions to more comprehensive information about the different topics.

HISTORY OF CAGE CULTURE IN THE REGION

The activity of cultivating the water goes back many centuries and was already described in the Far East several thousand years ago (Beveridge and Little, 2002). In Europe, too, cultivation has a long tradition. On an old farm in Norway a stone was found from the 11th century with the inscription: "Eiliv Elg carried fish to Raudsjøen" (Osland, 1990). This shows that new species were introduced into lakes where they bred independently of human intervention. These fish were subsequently harvested by fishing.

In Western Europe in the 19th century, the first fish were hatched and reared under artificial conditions. The motivation was to restock lakes and rivers with fish for anglers. The experience gained through hatching and rearing provided the beginnings for understanding the conditions needed to breed and rear these fish (FEAP, 2002).

Cage fish farming was pioneered in Norway in the late 1950s, in an attempt to produce rainbow trout and Atlantic salmon in the sea. In Scotland the White Fish Authority commenced salmon cage rearing trials around 1965. However, commercial production in Norway didn't begin until the beginning of the 1970s. The industry has since expanded to Scotland and Ireland. The farming of Pacific salmon (coho salmon, *Oncorhynchus kisutch*) began after that of Atlantic salmon, and Norwegian and Scottish technology was transferred to Canada and the USA. Later, significant developments occurred in South America, mainly in Chile, which has now become a major producer (FEAP, 2002; Beveridge, 2004, see also related review for Latin America and the Caribbean).

Cage farming was later adapted to other species in Europe, and has become a profitable business. The rearing of seabream and seabass in net cages in particular has proven to be very successful, and there is also an increase in promising species such as tuna, cod and halibut.

The development of the European aquaculture industry shows an exponential growth in production volume during the last fifty years (Figure 1). In 1950 mariculture represented 86 percent of total aquaculture production, mainly as shellfish (oyster and mussels). Freshwater production was based on carp and portion-sized rainbow trout. Total aquaculture production in Europe was then 169 000 tonnes. More than fifty years later (2004), European aquaculture production has reached a level that is twelve times higher, i.e. 2 204 000 tonnes. At present mariculture and brackishwater culture account for 79 percent of the total production (FAO, 2006). Freshwater aquaculture is currently based on a larger number of species, although carp and rainbow trout are still the dominant species. In mariculture, shellfish is still very important. However, the production share of Atlantic salmon, rainbow trout, seabream and seabass has increased considerably and contributes today 42 percent of the total aquaculture production in Europe. Rearing of these species is mainly based on cage culture technology.

THE CURRENT SITUATION REGARDING CAGE CULTURE IN EUROPE

Aquaculture has become an important source of seafood products in Europe. It is a highly diverse industry and consists of a broad spectrum of species, technology and practices. The contribution of aquaculture to trade, both local and international, is increasing.

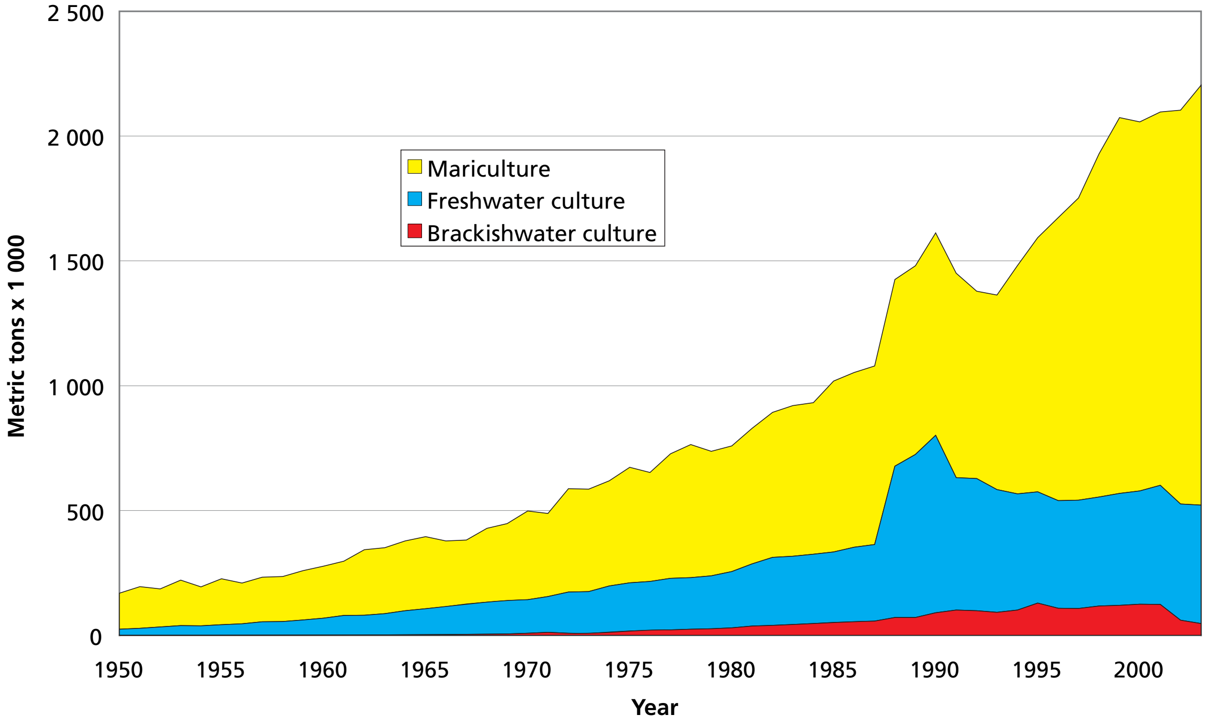
The main species in cage production

At the start of the development of cage culture in Europe, the main species was rainbow trout. Within a few years, however, an increasing share of the production capacity was used for Atlantic salmon. During the last fifteen years, seabass and seabream farming has also grown rapidly in Europe (Figure 2).

Atlantic salmon

Atlantic salmon is an anadromous species with a life cycle of 1–3 years in freshwater (fry-parr stages). After a process of physiological adaptation (smoltification), in which the parr stage transforms

FIGURE 1
Development of total aquaculture production in Europe 1950–2004



Source: FAO, 2006

into smolts, the salmon migrate to the sea where they remain for at least one year, before returning to the river of origin to spawn. Females excavate a shallow depression in the river substrate with their tails in which they lay their eggs that are then fertilized by the males. A few adults survive spawning and return to the sea, and an even smaller proportion return a year or two later to repeat the spawning process.

The natural distribution of Atlantic salmon is throughout the North Atlantic, from North Portugal and Cape Cod (Massachusetts, United States of America) in the south, to the Barents Sea and the Peninsula of Labrador (Canada) in the north (Souto and Villanueva, 2003).

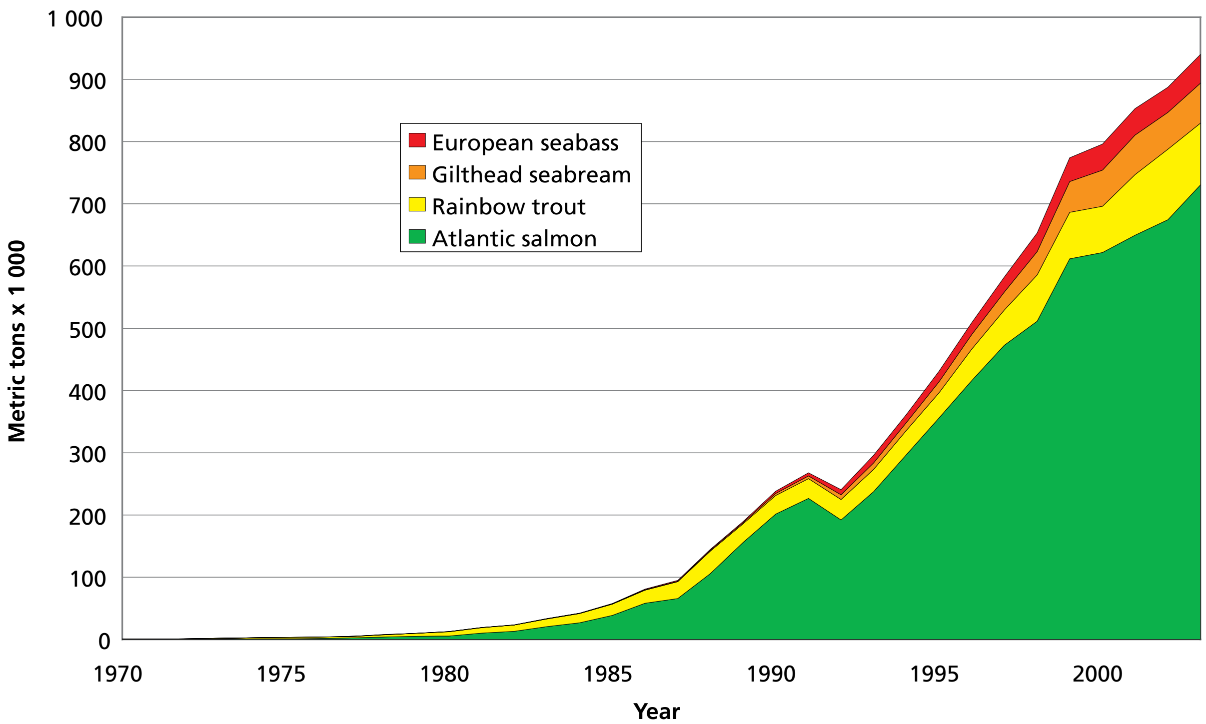
Norway is the main producer of salmon amounting to 72 percent of total European production (Figure 3). In absolute terms, 2004 production figures were highest in Norway (566 000 tonnes) followed by the United Kingdom of Great Britain and Northern Ireland (158 000 tonnes), Faroe Islands (37 000 tonnes) and Ireland (14 000 tonnes). Other countries outside Europe that farm Atlantic salmon include Chile (376 000 tonnes, 2005) and Canada (103 000 tonnes, 2005) (FHL, 2005).

Rainbow trout

The natural habitat of rainbow trout is freshwater with temperatures of about 12–15 °C in summer. It is unclear whether anadromy in the species is a truly genetic adaptation or simply an opportunistic behaviour. It seems that any stock of rainbow trout is capable of migrating, or at least of adapting to sea-water, if the need or opportunity arises. Within their natural range they require well-oxygenated, moderate to fast running water for breeding, although they also are found in cold lakes. Adults feed on aquatic and terrestrial insects, molluscs, crustaceans, fish eggs, minnows, and other small fishes (including other trout); the young feed predominantly on zooplankton. Natural strains of rainbow trout are found in the Eastern Pacific. Rainbow trout is probably one of the most widely introduced fishes and may be regarded as global in its present distribution (Fishbase, 2005). Fish reared in freshwater are usually sold portion-sized (less than 1200 g/fish), and rainbow trout from seawater cages as larger sizes (above 1200 g/fish).

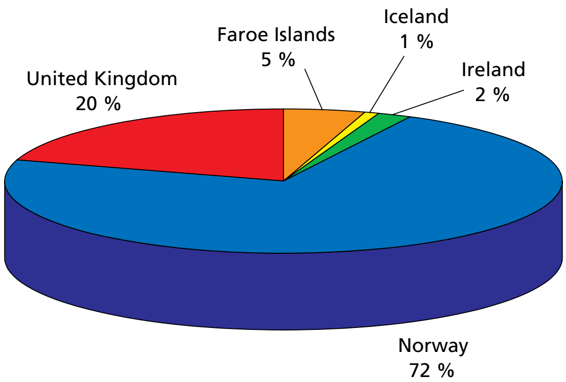
Norway is the main producer of rainbow trout amounting to 79 percent of total European production (Figure 5). In absolute

FIGURE 2
Cage culture production in Europe



Source: FAO, 2006

FIGURE 3
Atlantic salmon production in Europe in 2004



Source: FAO, 2006

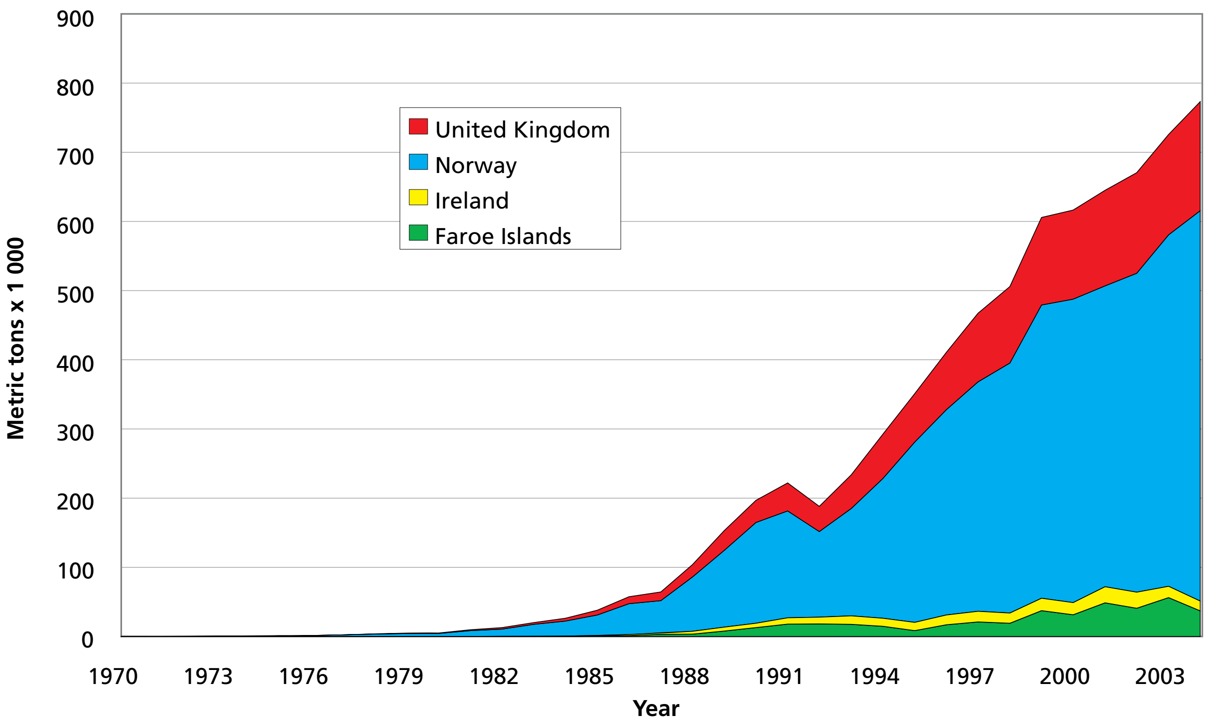
terms, 2004 production figures were highest in Norway (63 401 tonnes) followed by Denmark (8 785 tonnes), Faroe Islands (5 092 tonnes), the United Kingdom of Great Britain and Northern Ireland (1 664 tonnes) and Sweden (1 316 tonnes) (Figure 6). The key country outside Europe that farms rainbow trout is Chile with a production of 118 413 tonnes in 2004 (FAO, 2006).

Other species

There has always been an interest to further develop the aquaculture production of new marine species. Conventional cage designs have been successfully used for flatfish such as halibut (*Hippoglossus hippoglossus*) and for cod (*Gadus morhua*). The main bottleneck in sea cage aquaculture development of new species has been the reliable supply of sufficient numbers of good quality juveniles. It has also proved difficult to establish an economically sustainable industry.

In contrast with the establishment of the salmon and rainbow trout cage culture industries, marine fish producers have had to compete with established fisheries in terms of price. Salmon and rainbow trout were sold at very high prices because of their exclusivity. Production costs could therefore be high from the outset of the development of cage culture production of these species, and the farms would still be profitable. This is not the case for the marine species. As a consequence the establishment of aquaculture production of marine species is dependent on higher starting venture capital. However, because of the fisheries, there is an already established market for marine species.

FIGURE 4
Production (tonnes) of Atlantic salmon in Europe from 1970 to 2004

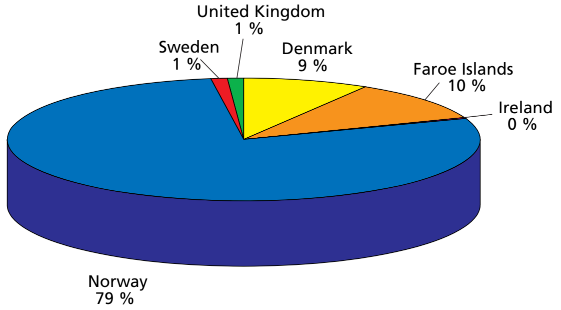


Source: FAO, 2006

Cod: Among the new marine species cod has been the most successful. In Scotland there are currently 14 companies involved in cod farming. Production over the past five years has oscillated between just a few tonnes and 250 tonnes in 2005. In Norway more than 350 licenses have been registered for cod production. However, only about 100 are in use. The production in 2005 was about 5 000 tonnes, and is expected to increase considerably in the next few years (FRS, 2005).

Hallibut: Halibut is a cold water flatfish in which a significant amount of research has already been invested with the aim of establishing economically viable aquaculture production. The market price

FIGURE 5
Rainbow trout production in marine waters in Europe in 2004



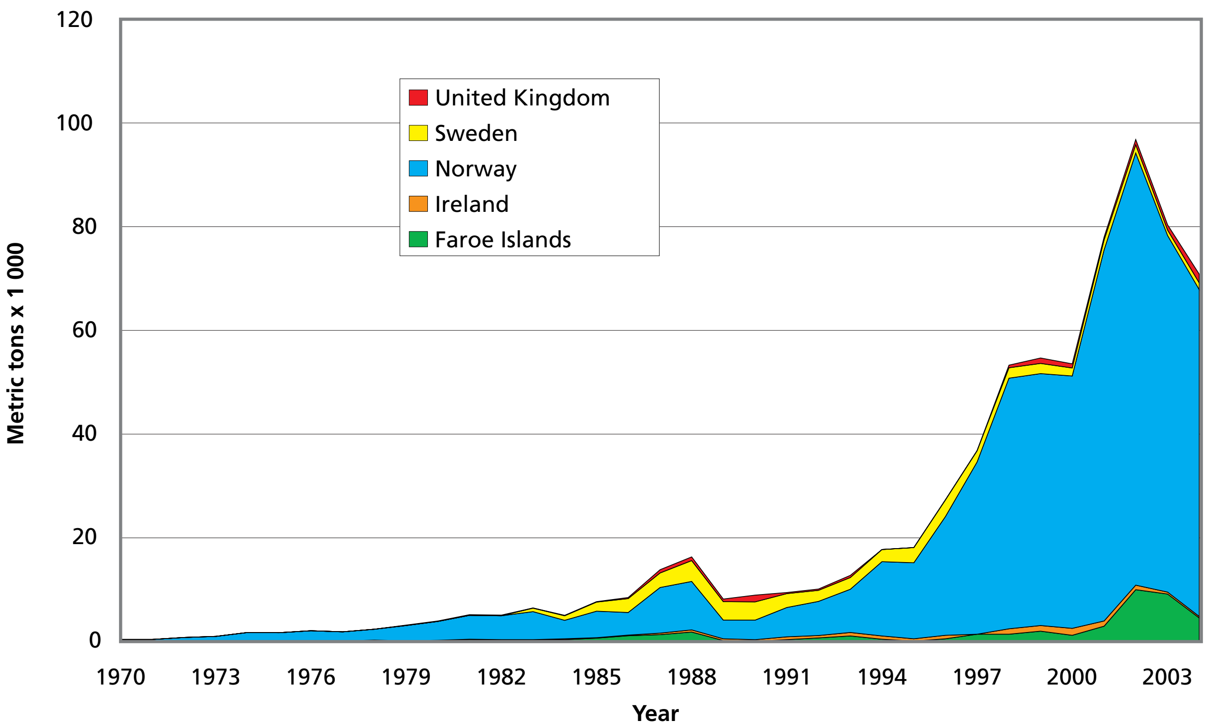
Source: FAO, 2006

TABLE 1
Production of selected cage-raised fish species in Europe in 2004

	Production (tonnes)			
	Iceland	**Norway**	**United Kingdom of Great Britain and Northern Ireland**	**Total**
Haddock	72			**72**
Chars		365		**365**
Atlantic halibut		631	187	**818**
Atlantic cod	636	3 165	8	**3 809**
Total	**708**	**4 161**	**195**	**5 064**

Source: FAO, 2006

FIGURE 6
Rainbow trout production in marine waters in Europe from 1970 to 2004



Source: FAO, 2006

for halibut is high. However, the production time is long and expensive. In Scotland nine companies were in operation in 2005 and production peaked at around 230 tonnes during the period 2003–2005 (FRS, 2005).

Today production is declining, and the volume in Scotland is expected to remain at only a few hundred tonnes per annum destined for niche markets. In Norway there are about 100 aquaculture licenses for halibut, and the annual volume was about 1 000 tonnes in 2005. Production is mainly land based.

Other species raised in cages in Europe are haddock (*Melanogrammus aeglefinus*) and charr (*Salvelinus alpinus alpinus*) (Table 1). Also, mullets (*Mugil* spp.) and tuna (*Thunnus* spp.) are farmed in cages (for details see chapter on cage culture in the Mediterranean region in this volume).

Locations and production

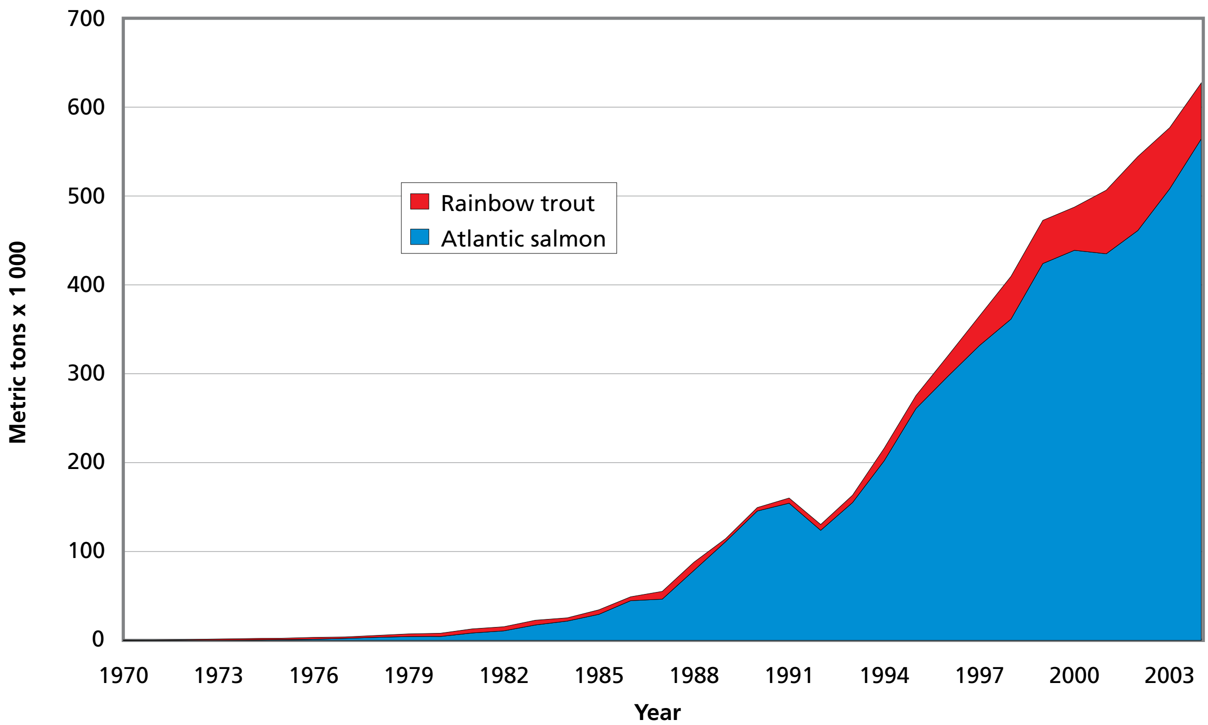
Not all of Europe is appropriate for aquaculture development, as many different factors affect the output and the viability of aquaculture operations (e.g. water quality, availability and cost of space, climatic conditions, etc.). When considering the location of aquaculture sites, it is critical to perform a systematic, integrated assessment of both the positive and negative impacts of new aquaculture developments (Commission of the European Communities, 2002).

There are of course huge differences among European countries in, for example, the degree of exposure at sites, ranging from rainbow trout production in rather sheltered locations in the Baltic Sea to the cultivation of Atlantic salmon in heavily exposed locations in the Faroe Islands. However, cage culture production in the different European countries is somewhat uniform in terms of use of technology (Beveridge, 2004).

During the establishment phase of cage sea farming in Europe, the organization of the industry was based on a large number of small companies, often family based.

With the development of the industry the company structure has become more diverse. The aquaculture sector includes today family operations, medium-scale fish-farm businesses and multinational mariculture enterprises, although it is increasingly dominated by the large multinationals (FAO, 2001). During this period the production volume at each site has become more adapted to the carrying capacity of the site. The level of exposure to organic load is continuously monitored, and the

FIGURE 7
Cage culture production in Norway from 1970 to 2004



Source: FAO, 2006

production volume is regulated according to what is acceptable for each site. There has also been a development towards using sites which provide better conditions for production.

Norway

Thanks to its extraordinary geographical characteristics (coastal waters warmed by the Gulf Stream, a lengthy coastline, rivers fed by melting snow for hatcheries), Norway became the first country to actively promote the development of salmon farming. Norwegian salmon farmers were able to sell their salmon easily to the European, American and Japanese markets because of their port infrastructure, processing facilities and highly developed transport and logistics networks.

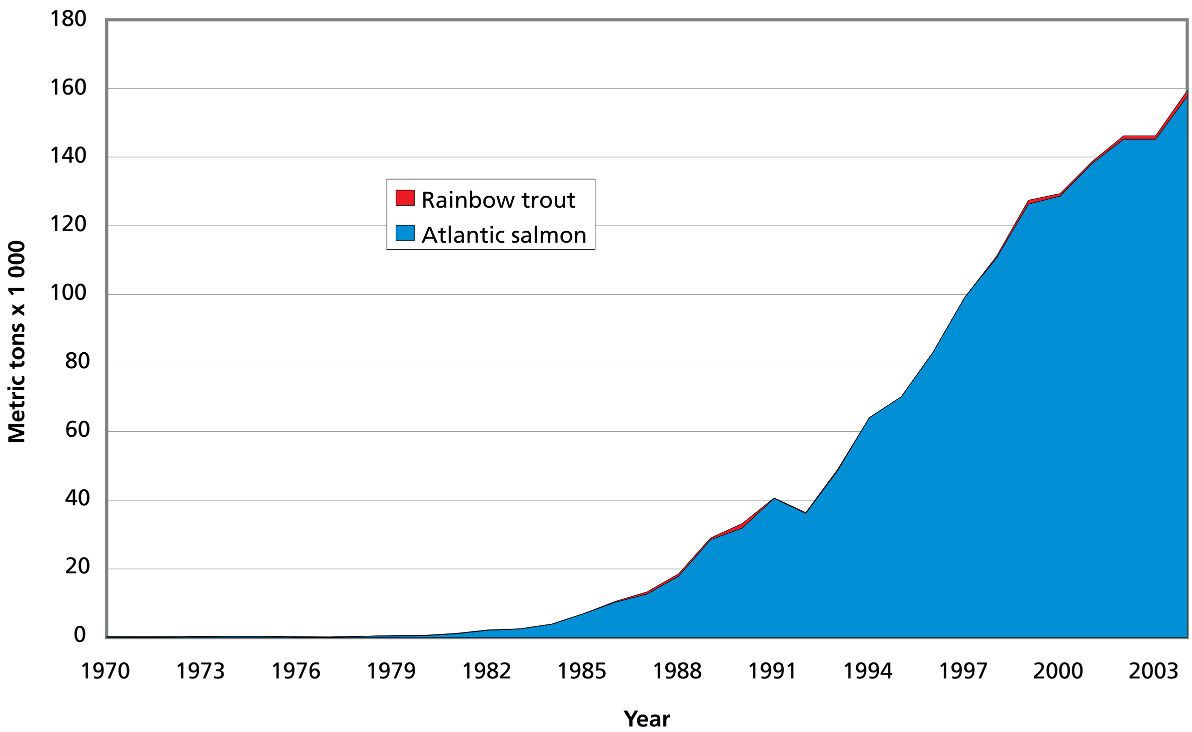
While the first exploratory efforts were made in the late 1950s, the sector really developed in the 1970s once the major technical problems (nutrition, conditioning juvenile fish) were resolved. By the mid-1980s, salmon farming represented Norway's second most valuable seafood production after cod and by the turn of the millennium it had become the country's second most important export item after oil and gas. During the 1980s, the Norwegian industry started to export technology and equipment to Canada, the United States of America and Chile. Extensive research support is provided by the Norwegian Research Council and by specialized institutions, and international expertise has been build up. Today, Norwegian interests play an important role in global salmon farming (FEAP, 2002). Cage culture production of Atlantic salmon and rainbow trout has expanded and intensified considerably over the years and in 2004 amounted to 566 000 tonnes and 63 000 tonnes, respectively (Figure 7).

Scotland

In 1969, the first commercial salmon farm was established at Loch Ailort on the West Coast. Today, Scottish salmon farms operate in the Highlands, the Western Isles, the Orkney Islands and the Shetland Islands (FRS, 2005).

Many of these areas have a history of high unemployment. This explains why government agencies in the United Kingdom of Great Britain and Northern Ireland and the European Community have provided assistance under a number of support mechanisms for investment loans, training, and technical support to encourage the growth of salmon farming as a viable economic industry.

FIGURE 8
Cage culture production of Atlantic salmon and rainbow trout in Scotland from 1970 to 2004



Source: FAO, 2006

The production of Atlantic salmon in Scotland has grown continuously (Figure 8), largely to supply the markets of the United Kingdom of Great Britain and Northern Ireland but also global markets. In the United Kingdom of Great Britain and Northern Ireland farmed salmon has now become the third most popular seafood after cod and haddock (FEAP, 2002).

Ireland

Irish history is renowned for its mythology and legends and the adventures of the famous seer-warrior Fionn Mac Cumhaill include how he gained his wisdom by tasting the "salmon of knowledge" – an instant measure of the esteem for salmon in this country .

Salmon farming takes place mainly on the west coast – often in very exposed sites – and has developed into an important component of the Irish aquaculture industry (Figure 9), which also includes shellfish and trout production.

Faroe Island

Lying about 300 miles northwest of the Shetland Islands, the Faroe Islands form a self- governing Region of the Kingdom of Denmark. With the decline of fisheries and with little land for agriculture, the Faroese invested in salmon farming early in the 1980s and soon became one of the top salmon producing areas (Figure 10).

Most salmon are raised in very large floating fish farms located in the narrow straits between islands. These are quite vulnerable to storms and have to be well managed with a high degree of mechanization. Salmon farming rapidly became an important export activity for the Faroe Islands, channeling most of its products through Denmark to the European markets (FEAP, 2002).

The salmon production in Faroe Islands has gone through a difficult period in the last years because of the virus disease Infectious Salmon Anaemia (ISA).

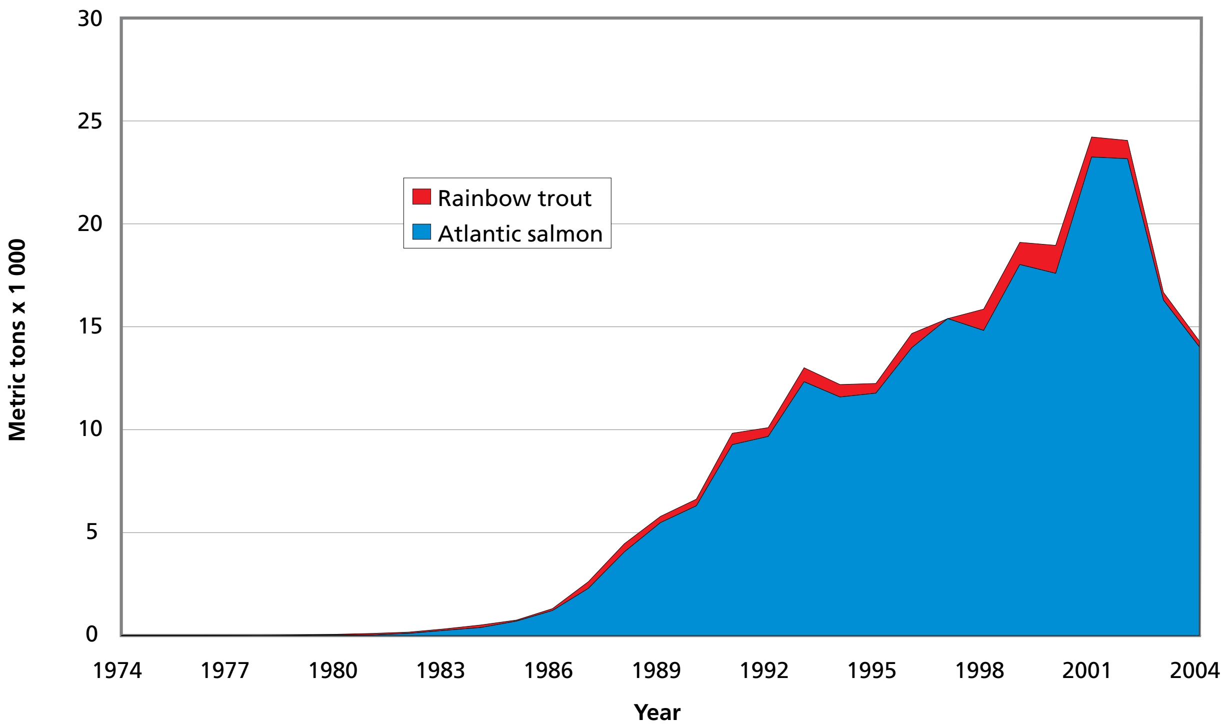
Other countries

Several other countries in northern Europe have cage culture industries. However, compared with the nations mentioned above the production volume is relatively low (Table 2).

Technology

The cage systems used in modern aquaculture have essentially changed little compared to the ones

FIGURE 9
Cage culture production of Atlantic salmon and rainbow trout in Ireland from 1974 to 2004



Source: FAO, 2006

first used. Cages are moored or floating, square, hexagonal or circular units, from which closed net bags are suspended. Fabrication materials have changed from wood to steel and plastic.

The cages consist of a floating collar with net enclosures suspended beneath. They can be described as 'gravity cages' because they depend on weights hanging from the nets to keep them open and have no underwater structural framework. Gravity cages are extremely successful and have supported the development of fish farming for the past 30 years. Steel collar cages are usually square in plan view (Figure 11) while plastic or rubber collar cages are usually circular in plan view (Figure 12) and can be assembled in groups within a grid work of rope and chain moorings (Ryan, 2004).

Cage farming systems specially adapted for flatfish, as shown in Figure 13, have also been developed. These systems consist of several layers of shelves on which the fish can lie.

MAJOR REGIONAL CHALLENGES

Production method

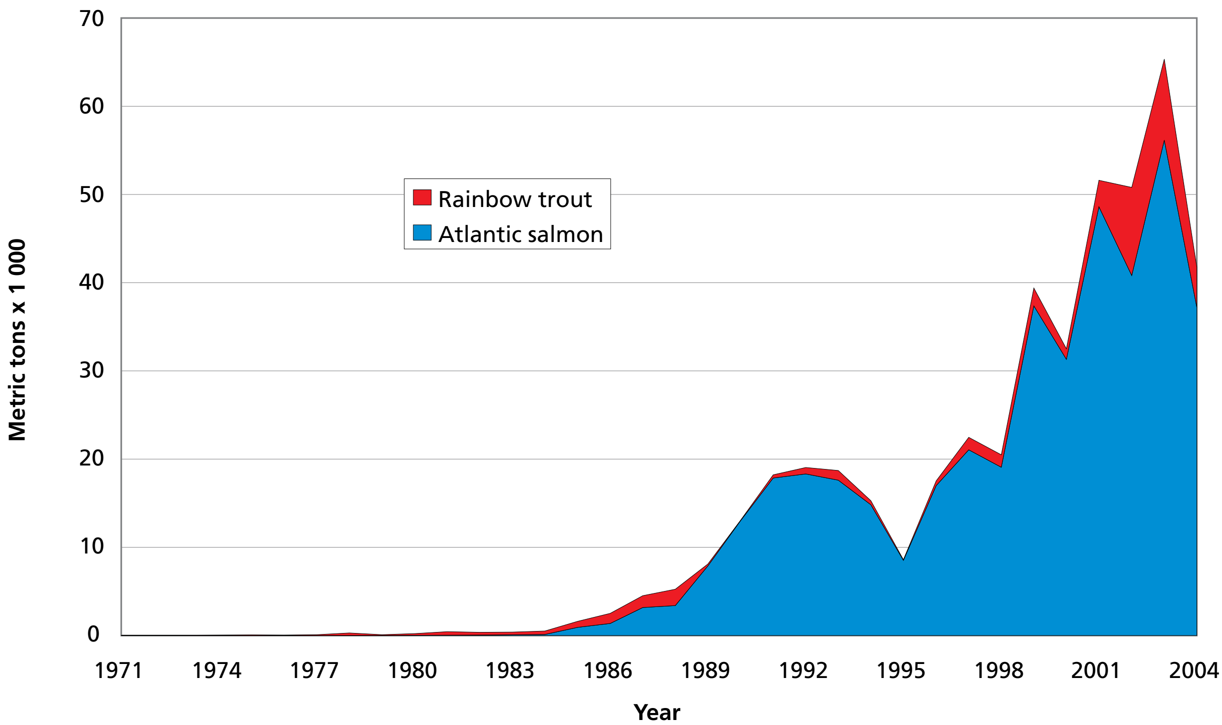
Aquaculture in Europe is still a young industry. The technology for cage culture farming was established some thirty years ago, and soon afterwards the production volume of fish started to increase (Figure 2). At this stage the production of small

TABLE 2
Cage culture production in selected European countries in 2004

	Haddock	Atlantic cod	Arctic char	Atlantic salmon	Rainbow trout	Total
Sweden					4 111	**4 111**
France				735	155	**890**
Iceland	72	636	1 025	6 624	137	**8 494**
Denmark				16	8 770	**8 786**
Finland					10 586	**10 586**
Total	**72**	**636**	**1 025**	**7 375**	**23 759**	**32 867**

Source: FAO, 2006

FIGURE 10
Cage culture production of Atlantic salmon and rainbow trout in the Faroe Islands from 1971 to 2004



Source: FAO, 2006

FIGURE 11
Example of a circular unit

COURTESY OF AQUALINE 2006

FIGURE 12
Example of steel collar cages

COURTESY OF SINTEF FISKERI OG HAVBRUK

quantities, combined with a very high demand for salmonids, led to a very high income per kg production.

Even with a high mortality rate, elevated feed consumption levels and the use of more or less self-made equipment, the aquaculture business was profitable. However, production during these first years disregarded the environment and was not always performed with animal welfare as a priority. Because of the problems during its establishment, the industry still has to contend with a poor reputation and most consumers are more resistant to aquaculture than agriculture, although this may also be because most people do not have the same relation to aquaculture as to agriculture.

Technical issues

Seed supply

For salmonids the development of new knowledge and technology provided controlled spawning and high fertilization rates. Salmonid fish have a relatively large reproductive capacity combined with a high egg survival and sufficient egg production to service the salmon and trout farming industries can be carried out by a small number of producers. The vast majority of salmonid eggs are produced and transferred within countries.

There has been, and are, opposing forces to the international trade of eggs. International trade represents a health risk because of the possibility of transfers of pathological agents. Because of the genetic variation between salmonid stocks, there are also concerns about the possibility of genetic interaction between escapes and wild fish populations (McGinnity *et al.*, 2003; Walker *et al.*, 2006).

Genetic improvement by implementing selective breeding programmes has contributed significantly to increased performance and productivity of Atlantic salmon and rainbow trout.

However, as these breeding programmes are highly specialized and costly, they tend to become centralized in a very few countries and companies. Improved genetics at a reduced cost and a year-round egg availability represent an important motivation for international trade of salmonid eggs.

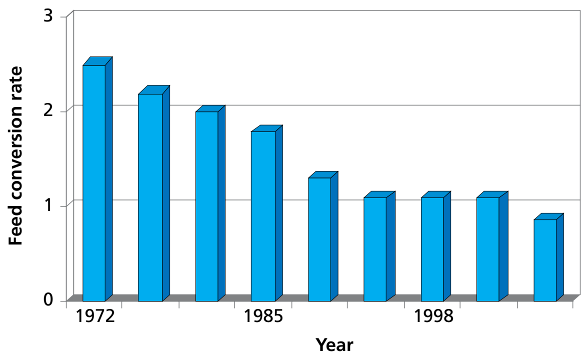
FIGURE 13
Example of cage adapted for flatfish

COURTESY OF AQUALINE 2006

Scotland imported about 14 million Atlantic salmon eggs in 2002, mainly from Iceland but also from Australia and the United States of America. The import of rainbow trout eggs represented more than 20 million and originated from South Africa, Denmark, Isle of Man and Ireland (FRS, 2005).

Trade of eggs between Norway and the European Economic Area (EEA) were prohibited for a time due to protective measures against ISA (Infectious Salmon Anaemia). However, these restrictions were lifted by 1 February 2003 (Aquagen, pers. comm. 2005).

FIGURE 14
Development of the feed conversion rate in production of rainbow trout and atlantic salmon in Norway from 1972 to 1999



Source: Fiskeridirektoratet, 2005

Feeds and feeding

The changes in fishmeal/fish oil ratio in salmon feeds observed over the past two decades would not have been possible if it were not for the tremendous technological developments in feed manufacturing. Until the early 1980s salmon feeds consisted essentially of farm-made semi-moist pelleted feeds composed of minced sardines or other low-value fish mixed with wheat flour and a vitamin/mineral premix.

Although these feeds were usually readily consumed by the salmon, their manufacture was dependent upon a regular supply of fresh `top quality' sardines or other low-value fish. In addition, the diets generally exhibited poor water stability and low feed conversion ratios.

Between the mid-1980s and the early 1990s, farm-made feeds were gradually replaced by dry commercially manufactured steam pelleted feeds, characterized by their high protein and low fat (<18–20 percent) content, and improved feed efficiency.

Since 1993, conventional steam pelleted feeds have been replaced by extruded salmon feeds. The extrusion has resulted in salmon feeds with improved durability (less fines and wastage), increased carbohydrate and nutrient digestibility (due to the increased starch gelatinization and/or destruction of heat-labile plant anti-nutrients), and with improved physical characteristics (including altered density and adjustable pellet buoyancy/sinking characteristics). Lower feed conversion ratios (FCRs) have been obtained through increasing dietary lipid levels, leading to an increase in dietary energy levels and a consequent improved protein and energy nutrient utilization. Extrusion became the main production method because of its many advantages. It is generally accepted that the major reasons for using extruded feeds in the salmon industry is their ability to expand the pellet, thereby facilitating the inclusion of high dietary oil levels. Extruded pellets make an important contribution to the achievement of the present growth rates, a reduced impact on the ocean floor under the cages, stronger pellets that are usable in automatic feeders and the ability to incorporate a wider range of raw materials. The net result of these continuing improvements in feed formulation and feed manufacture, are increased fish growth, decreased feed conversion ratios (Figure 14), and hence lower fish production costs and environmental effects.

At present, over two thirds of salmon feeds by weight are composed of two marine ingredients, namely fishmeal and fish oil. Compared to other terrestrial animal and plant protein sources, fishmeal is unique as it is not only an excellent source of high quality animal protein and essential amino acids, but it also contains sufficient levels of digestible energy, of essential minerals and vitamins, and of lipids, including essential polyunsaturated fatty acids (http://www.iffo.net/default.asp?fname=1&sWebIdiomas=1&url=23).

Salmonids are currently dependent upon fishmeal as their main source of dietary protein. A similar dependency also exists for fish oil as the main source of dietary lipids and essential fatty acids.

Between 1994 and 2003 the total amount of fishmeal and fish oil used within compound aquafeeds grew more than three-fold, from 963 000 to 2 936 000 tonnes and from 234 000 to 802 000 tonnes, respectively. The increase in usage is in line with the almost three-fold increase in total finfish and crustacean aquaculture production over this period, which increased from 10.9 to 29.8 million tonnes between 1992 and 2003.

On the basis of the International Standard Statistical Classification of Aquatic Animals and Plants (ISSCAAP) used by FAO, the calculated consumption by global salmon aquaculture was:

- fishmeal: from 201 000 to 573 000 tonnes between 1992 and 2003
- fish oil: from 60 400 to 409 000 tonnes between 1992 and 2003
- total fishmeal and fish oil: from 261 400 to 982 000 tonnes

The percentage of dietary fishmeal and fish oil used in salmon feeds has changed dramatically over the past two decades, with fishmeal inclusion levels decreasing from an average level of 60 percent in 1985, to 50 percent in 1990, 45 percent in 1995, 40 percent in 2000 and to the present inclusion level of 35 percent. The decrease has been accompanied by an equivalent increase in dietary lipid levels, from as low as 10 percent in 1985, 15 percent in 1990, 25 percent in 1995, 30 percent in 2000, to as high as 35–40 percent in 2005.

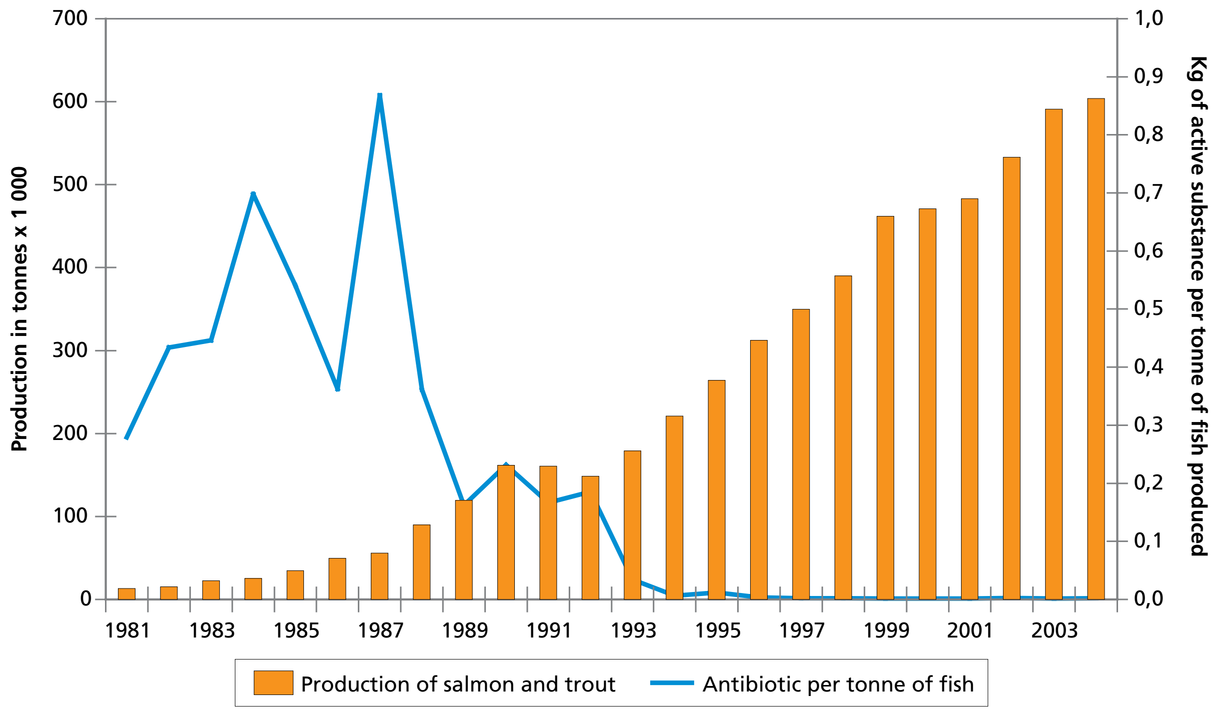
Although on an industry basis the current average level of fishmeal and fish oil used in salmon feeds is approximately 35 percent and 25 percent, respectively, significant differences exist between the major producing countries:

- Canada: mean fishmeal level 20–25 percent, mean fish oil level 15–20 percent;
- Chile: mean fishmeal level 30–35 percent, mean fish oil level 25–30 percent;
- Norway: mean fishmeal level 35–40 percent, mean fish oil level 27–32 percent; and
- United Kingdom of Great Britain and Northern Ireland: mean fishmeal level 35–40 percent, mean fish oil level 25–30 percent.

Since between 50 and 75 percent of commercial salmon feeds are currently composed of fishmeal and fish oil any price increase of these finite commodities will have a significant effect on feed price and farm profitability. In general salmon feed represents about 50 percent of total farm production costs (Figure 17) (Tacon, 2005).

It has been questioned whether farming salmon is a proper use of resources, since the feed used can also be consumed by people directly. In this respect, there has been a special focus on the use of fishmeal and fish oil. Here it is important to note that these resources are largely used for animal feeds in any case. In this context, salmon farming is an efficient use of resources, since fish utilize the feed more efficiently than for example chicken or pigs (Holm and Dalen 2003).

FIGURE 15
Volume of antibiotics per kilogram of harvested salmon and rainbow trout compared to the volume harvested in the years 1981 to 2004



Source: FHL, 2005

Diseases

Intensification of any biological production such as aquaculture will inevitably result in problems, particularly in diseases of infectious origin. Outbreaks of virulent diseases may have serious consequences for aquaculture production, with significant economic impacts at a local, regional and even national level. The losses may be due to reduced production, but restrictions on trade are becoming increasingly important. Diseases in farmed aquatic animals may affect the environment in different ways, for instance by transmission of infectious disease to wild fish populations.

The food safety aspect of diseases in aquatic animals is less than in terrestrial animals as few of the fish diseases have a zoonotic potential. However, as microbial diseases in farmed fish sometimes are treated with antibiotics, both residues and microbial resistance against antibiotics may be undesired effects of fish diseases. Effective risk management is therefore crucial in order to reduce the economical, social and environmental costs due to severe diseases in aquaculture (Woo *et al*., 2002; T. Håstein, pers. comm.).

Production of animal protein has to be sustainable, which means that preventive measures that are acceptable from a biological and environmental point of view should be used to keep disease problems in aquaculture at an acceptable level. Vaccination is now the single most important measure for prevention of bacterial diseases in farmed fish, especially in salmonid fish. The best indicator of the effect of vaccination as prophylactic measure is the reduction in use of antibiotics in fish farming. Currently, the entire population of Atlantic salmon and rainbow trout in Norway is vaccinated against at least three major bacterial diseases (vibriosis, cold-water vibriosis and furunculosis) prior to stocking into seawater. During a 10 year period the usage of antibiotics has been reduced to an absolute minimum, mainly due to the use of vaccines (Figure 15).

Although vaccines in general have proven to be effective in the protection against serious fish diseases, vaccination may be hampered by certain adverse effects. Mortality associated with the vaccination is in general low, but anaesthesia, handling and the intraperitoneal injection itself may cause occasional deaths.

When using injectable vaccines prepared with different types of adjuvants, reactions in the abdominal cavity are usually observed. These reactions may vary from rare to severe, in the form of adhesions in the peritoneal cavity or other local reactions as common findings. Most often, such side effects are related to oil adjuvant injectable vaccines against furunculosis. The reason for this is that sufficient protection against this disease is only achieved with adjuvant vaccines.

In Atlantic salmon, the severity of the lesions is reduced if the size of the fish is at least 70 g and the water temperature is below 10°C. The timing of vaccination will also influence the development of side effects such as adherence, growth and spinal deformities (T. Håstein, pers. comm.).

With the development of vaccines, bacterial diseases are more or less mainly under control. The main challenges today related to fish health are viral diseases, and the one disease with the greatest economical impact is infectious salmon anaemia (ISA). This viral disease of Atlantic salmon was until 1996/1997 reported only to occur in Norway.

However, the disease condition called "haemorrhagic kidney syndrome" reported in Canada was subsequently found to be identical to ISA and ISA was also officially reported from Scotland in 1998 (66th OIE General Session). Atlantic salmon is the only species affected by ISA, but experiments have shown that both rainbow trout and sea trout (*Salmo trutta*) may act as asymptomatic carriers of the disease agent.

During the 1980s and the early 1990s, there was a dramatic increase in ISA outbreaks in Norway where some 90 farms were affected by the clinical disease. The mortality rates varied considerably from insignificant to moderate although a few farms suffered losses as great as 80 percent (Håstein *et al*., 1999).

Other viral diseases which have had a significant influence on the cage culture industry in Europe are inter alia Infectious Pancreatic Necrosis (IPN) and Viral Haemorrhagic Septicaemia (VHS). In recent years viral Pancreas Disease (PD) has become an increasing problem, indicating that fish health is a constant concern, not least among new species which are now being introduced for cage farming.

Socio-economic issues – production costs, marketing, prices, employment

An increase in production and a greater availability of fish have converted cage-reared species from being an exclusive dish served in the best restaurants to a commodity product in the super- and hypermarkets. Quality has increased with quantity as a result of increased production knowledge and better technology. Even so, the increases in production volume have reduced prices to consumers of cage-reared fish because of the competition between producers within and between countries. As a result each producer has been forced to reduce production costs dramatically. For example, the average price of Atlantic salmon and rainbow trout in Norway during the period 1986–2004 dropped from about €7 to about €2 per kg (2004 value).

There are differences in production costs among countries. However, other than for Norway, official figures of production costs for different European producer countries are not available.

In 1986 feed represented 31 percent of Atlantic salmon/rainbow trout production costs, while the purchase of smolt accounted for 26 percent and wages 15 percent. Almost twenty years later feed, smolt and wages represent 56 percent, 13 percent and 9 percent, respectively (Figure 17).

This may be explained by an increase in production efficiency by producing larger quantities per farm, which reduces the need for labour both in the smolt and the grow-out sector. The increase in productivity is a result of better logistics, better technology and improved biological characteristics of the fish.

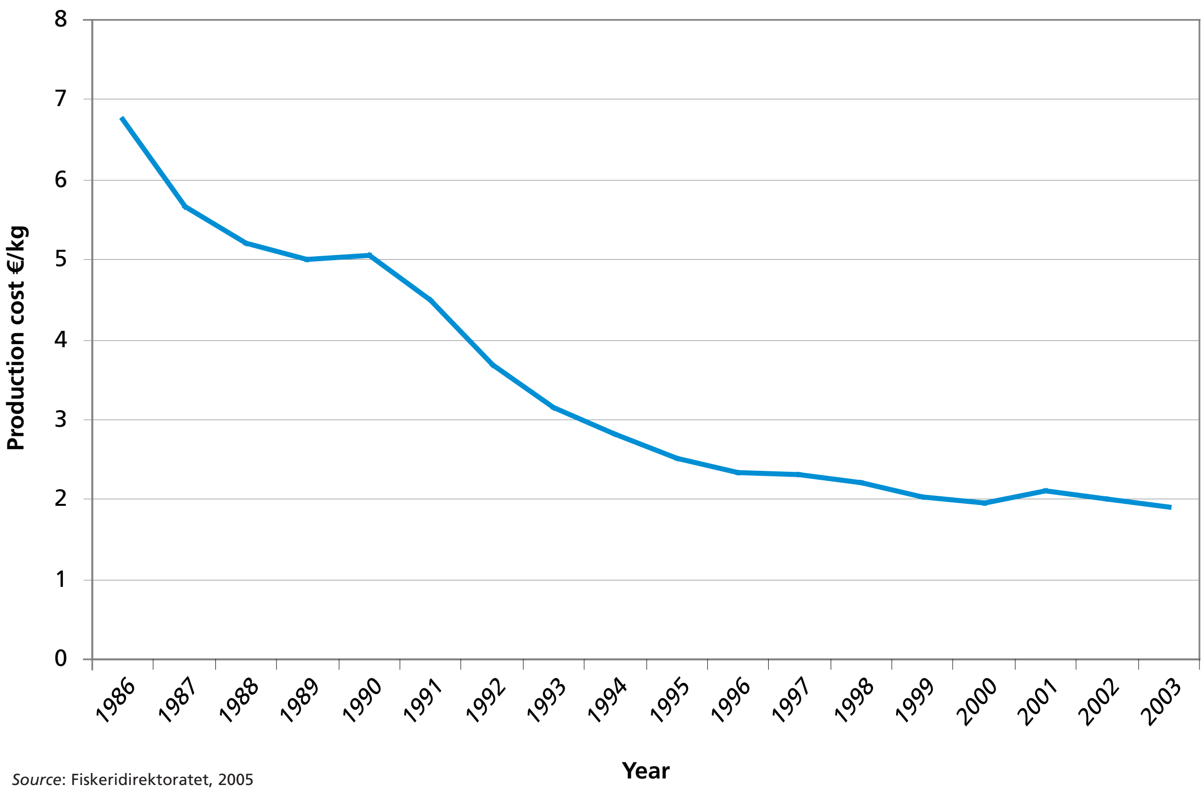
Fish feed has taken an increasing share of the total production cost. This has resulted in a growing focus on the feed conversion rate, which the industry has managed to reduce considerably (Figure 14). This has not only reduced production costs, but also had an important role in minimizing the environmental impact of marine cage aquaculture on the environment.

As seen in Figure 17 wages represent a decreasing share of total production costs, which as mentioned earlier, is the result of increasingly efficient production, where less people produce more fish (Figure 18). In 2004, 2 210 persons produced about 600 000 tonnes of fish in Norway. In other words, the average annual production per person was about 270 tonnes of fish!

In addition to the people employed directly in the on-growing production in Norway, it is estimated that about 20 000 people are indirectly involved in the aquaculture industry as suppliers to the industry. In 2004 these people contributed to an added value of about €1.5 billion (Figure 19). The main contribution is derived from the on-growing units, but the slaughtering and processing industry also play important roles.

FIGURE 16

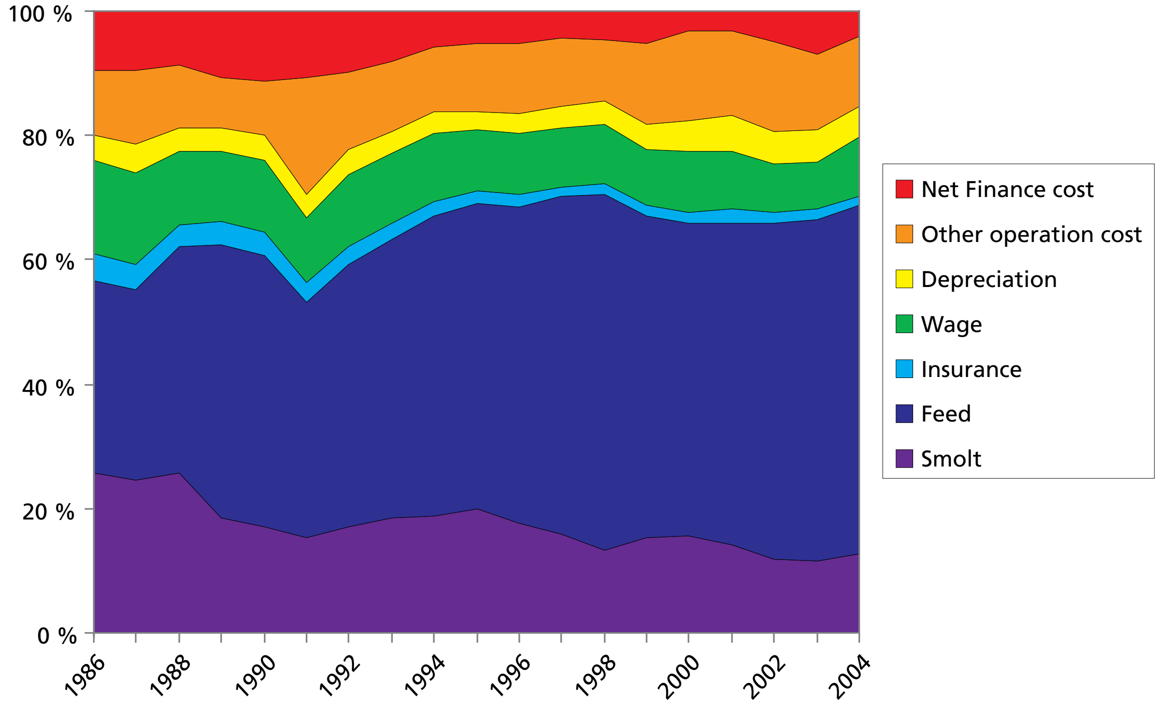
Development in production cost of Atlantic salmon and rainbow trout from 1986 to 2004 (in 2004 € / 1€ = 8 NOK)



Source: Fiskeridirektoratet, 2005

FIGURE 17

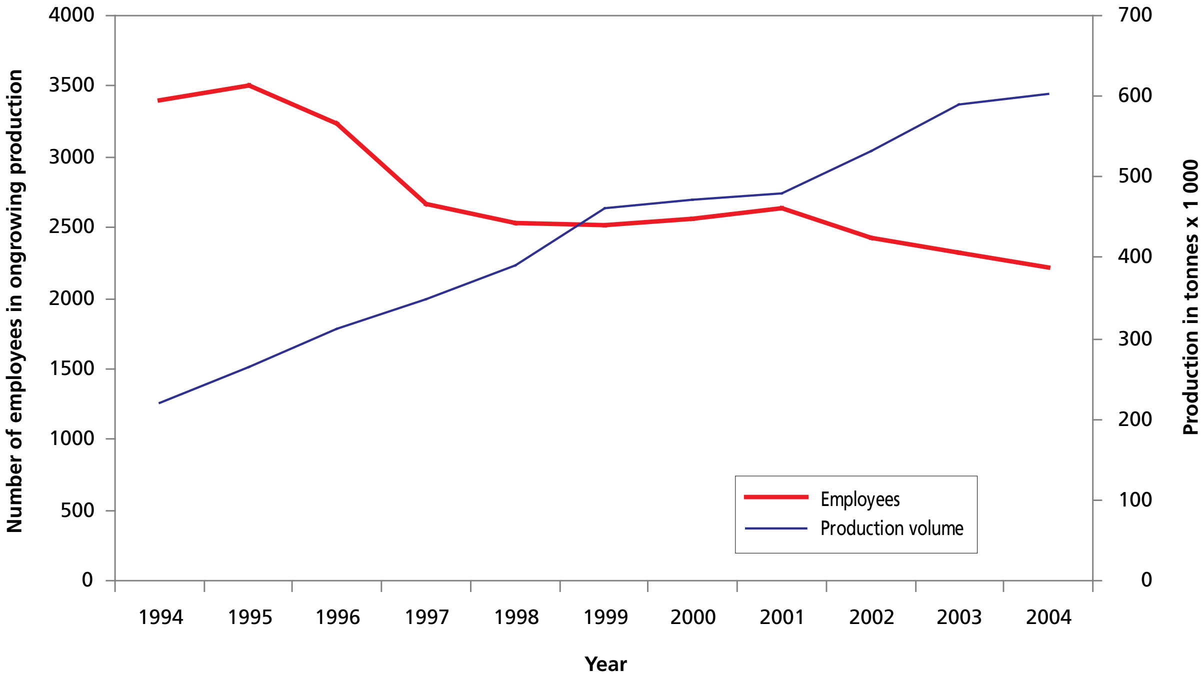
Relative developments in production costs of Atlantic salmon and rainbow trout in Norway



Source: Fiskeridirektoratet 2005

FIGURE 18

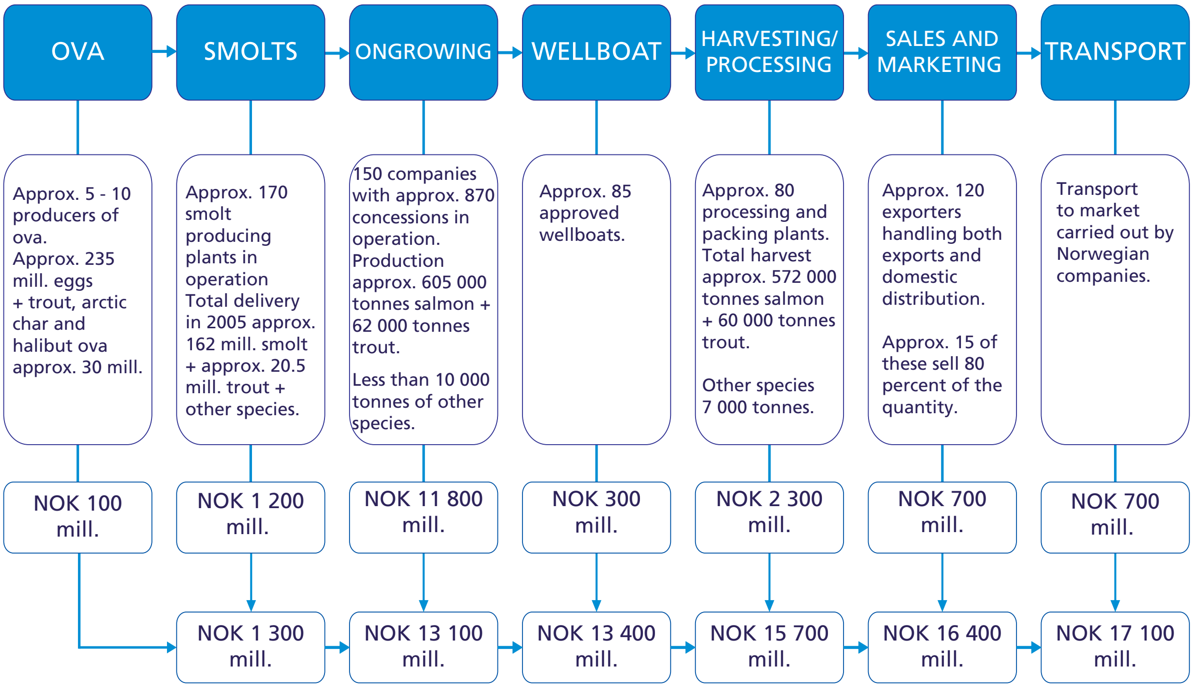
Development of production volume of Atlantic salmon and rainbow trout in Norway and the number of employees



Source: Fiskeridirektoratet 2005

FIGURE 19

Estimated creation of values (in Norwegian Kroner NOK) for cage farming in Norway in 2005



Source: Kontali Analyse AS, pers. comm. 2006

For Ireland and Scotland the great majority of fish is sold within the European Union market, to which they belong. Norway is not a member of the EU, and about 95 percent of fish cross the border to a foreign market.

Being the major producer of Atlantic salmon Norway has, over the last twenty years, experienced accusations of dumping from other salmon producing countries. Both the United States of America and the EU have claimed and continue to claim that Norway has been selling fish below production cost. The dumping cases can be argued to have had a negative impact on the development of a free salmon trade to the detriment of the interests of consumers. For the countries involved it has been difficult to develop long-term market development strategies with the intention of increasing the consumption of cage reared fish.

Environmental impact – escapes, pollution, ecological impacts

Healthy development of the fish farming industry not only requires fulfilling the needs of the farmed fish but also paying attention to the environment. Only a sustainable, environmentally sound aquaculture will gain social acceptance.

Ultimately, sustainability is also in the farmers' interest as healthy and clean waters are an essential prerequisite for first-rate fish products. Optimal results originate from good growth conditions for the fish and proper husbandry.

Even if there has been a significant decrease in the environmental impact from the cage culture industry in Europe, there are still some challenges: escapes, marine eutrophication, sea lice and access to sea areas.

Escapes

Every year fish escape from sea cages. This may be a result of incorrect use of the equipment, technical failure or external factors such as collisions, predators or propeller damages (Beveridge, 2004; Walker *et al.*, 2006). Loss of fish and damage to equipment not only represents an economical loss for the farmers, but also has negative environmental impacts.

How can the addition of more salmon to the rivers actually be harmful? The answer to this question may not be immediately obvious. Research on this problem is time consuming and the answers have not begun to emerge until recently. Escaped farmed salmon can affect wild salmon on several levels, both ecologically and in terms of fitness and the sustainability of wild populations . Escaped fish mix with wild fish at sea as well as in rivers. They thus constitute a competitor to wild salmon for food and space and may spread parasites and disease. Escaped farmed salmon are also capable of breeding with wild stocks, thereby introducing novel genetic material to the wild population that can reduce the lifetime fitness of individuals, driving population numbers down (McGinnity *et al*., 2003). Genetic changes may also result in changes in ecological and behavioural traits (Holm and Dalen, 2003).

Marine eutrophication

In areas with intensive aquaculture production the nitrogen and phosphorus load and accumulation of organic matter may be detrimental to the environment (Naylor *et al*., 2000; Beveridge, 2004). Aquaculture production in Europe is mainly localized in rural areas with low population densities, and thus a low general nutrient load. In these regions there has been an increase in the aquaculture production. Even if the reduction in the feed conversion rate contributed significantly to decreasing impacts per unit fish production effect on the environment, the total nutrient load from the aquaculture industry has increased. As a result the European Commission has issued a number of directives in an effort to reduce impacts from the aquaculture industry. Council Directive 91/676/EEC27 aims to reduce water pollution caused or induced by nitrates from agricultural sources, including the spreading or discharge of livestock effluents. The Commission will study if the directive should be extended to include intensive fish farming (Commission of the European Communities, 2002). The newly issued Water Framework Directive is also likely to result in reductions in nutrient loadings to coastal water if fish farm wastes are identified as causing sites to fail to reach good ecological status.

Adverse impacts due to eutrophication of a location are reversible. Studies show that locations to which large quantities of organic material were added and which 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 depends on local topographical conditions (Holm and Dalen, 2003).

Olsen *et al*. (2005) argue that nutrients should be regarded as resources rather than toxins for marine ecosystems where the aquaculture industry is located. It is also argued that it is acceptable to use the mechanism of dilution to disperse waste products as long as they are free from toxic components. At a current speed of 15 cm/sec, the water at a site is exchanged about 100 times per day. An exchange rate of 2–3 times is typically needed to keep the levels of nutrients in the water column lower than the critical load. Farms located in dynamic sites will usually have volumetric inorganic nutrients loadings that are within the year to year variability of the natural background levels.

In Norway, a system has been developed for environmental monitoring of fish farms with regard to the accumulation of organic matter. The system is called MOM – a Norwegian abbreviation translated as Modeling – On-growing Fish Farm - Monitoring. The model includes a simulation and monitoring program. At locations where the utilization ratio is high, more frequent and more comprehensive studies have to be conducted. At lower utilization ratios the requirements of studies are less stringent. The new system for modeling and monitoring fish farms (MOM) has given the government and the industry a better basis for tailoring production and discharges to the carrying capacity of an individual location (Holm and Dalen, 2003).

Sea lice

The salmon lice (*Lepeophtheirus salmonis*) are ectoparasites that use salmonids as a host. Although they have always been present on wild salmonids in marine waters, the louse has gradually become a serious challenge to wild salmon stocks as the aquaculture industry has grown due to a multiplication of potential hosts on farmed fish and an overall increase in infection pressure.

Norwegian authorities require the maintenance of sustainable lice level with regard to salmon and sea trout stocks in individual fjord systems. Existing treatments for controlling the salmon lice can be roughly divided into biological methods, i.e. the use of wrasse (*Crenilabrus melops*, *Ctenolabrus rupestris*, *Centrolabrus exoletus*), and chemical treatment. Wrasse must be used continuously, while chemical treatment is used when the number of sea lice reaches a certain threshold. Regular monitoring of sea lice levels is therefore essential. In Norway fish farmers are obliged to regularly report the number of lice on each site and the information is made available through an internet site establish by the industry itself (www.lusedata.no). In Scotland, integrated lice treatment methods are generally practiced by the salmon farming industry. Much of the salmon farming areas of

Scotland are now covered by Area Management Agreements, in which farms coordinate their intake of fish, fallowing and the use of medicines in order to minimize lice levels. Although there are few hard data, there is anecdotal evidence that wild salmon and sea trout numbers are recovering in such areas as a result.

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 that 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. The area of effect around a fish farm will vary with the type of substance and local environmental conditions, such as currents and aquatic chemistry.

Escaped salmon can contribute to an increase in lice exposure of the wild populations. Measures to reduce the escape of farmed salmon may therefore help to reduce the infection pressure on stocks of wild salmonids (Holm and Dalen, 2003; Walker *et al*., 2006).

Copper impregnation of nets

Installations in the sea will always be subject to fouling by shellfish, algae, barnacles and hydroids (Corner *et al*., 2007). Chemical impregnation is used to reduce fouling on nets but it also has other functions, such as making the net stiff, thereby helping it hold its shape in the water, it helps prevent UV radiation from weakening the net and it fills the gaps between net filaments, thereby reducing the area available to be fouled.

Leaching of copper from fish farm nets remains a cause for concern, Data on copper concentrations in water near fish farms and net cleaning facilities are difficult to find but copper concentrations of over 800 milligrams per kilogram of sediment have been found in sediments under fish farms in areas with low water exchange (Holm and Dalen, 2003; Beveridge, 2004). On-farm washing of copper anti-fouled nets is now prohibited in the UK and is carried out by licensed net manufacturers. There are as yet few viable, more environmentally friendly antifouling alternatives at present.

Access to suitable sea areas

Even if each cage culture production site does not produce a large footprint, there is a potential for conflicts of interest in coastal areas. The aquaculture industry is today well aware of the importance of choosing sites that are optimal for raising fish. Therefore, large areas of the coastline are of no interest to the industry. Regulations require a minimum distance between sites, and a safety area around each production unit. In certain coastal areas there may be conflicts of interest between fisheries, navigation routes, harbours, conservation, recreation activities, the military, etc. In Norway, the Commission's Demonstration Programme on integrated coastal zone management has shown that the best response to such complex situations is an integrated territorial approach addressing the many different problems within an area, involving all stakeholders. Future aquaculture development should be based on Integrated Coastal Zone Strategies and Management Plans,that consider aquaculture in relation to other existing and potential future activities and that take into account their combined impact on the environment. (Commission of the European Communities, 2002)

Policies and legal frameworks

Aquaculture is a highly diverse industry involving a broad spectrum of species, systems and practices. Its may create new economic niches, leading to increased employment, a more effective use of local resources, and opportunities for productive investments. The contribution of aquaculture to trade, both local and international, is also increasing (Commission of the European Communities, 2002). Most of the countries involved in aquaculture have developed strategies to promote the development of the aquaculture sector, as for example "The Code of Good Practice for Scottish Finfish Aquaculture" (Scottish Finfish Aquaculture Working Group, 2006).

In Europe the European Parliament is the most important supranational decision maker. The Commission recognized the importance of aquaculture in the same frame as the reform of the Common Fisheries Policy and the necessity to develop a strategy for the sustainable development of this sector (Commission of the European Communities, 2002).

The aquaculture industry in Europe is organized in a common federation, the Federation of European Aquaculture Producers (FEAP), established in 1968. The FEAP is currently composed of 31 National Aquaculture Producer Associations from 22 European countries. Its main role is to provide a forum for the member associations to promote the establishment of common policies on issues related to production and to the commercialization of aquaculture species in Europe. The decisions or Resolutions are communicated to the appropriate authorities, at a European or national level. The FEAP has also developed a Code of Conduct. The Code is not mandatory but addresses those areas that the Federation considers to be of prime concern. Additionally, the role of the Code is to motivate and assist the development of the principles of best practices (FEAP, 2000).

There are several non-governmental organizations (NGOs) addressing the impact of aquaculture on the environment, related to pollution, food safety and the influence on wild fish populations. The NGOs vary in size, the level of seriousness and activity in the different countries.

THE WAY FORWARD

In an earlier section, this paper described the exponential growth in European cage culture farming since the introduction of modern cages in the early 1970s. During its short history, the industry has experienced a number of drawbacks related to e.g. health, economy and trade conflicts. Despite the many problems, the volume of production has increased. The development of biological skills and technology has resulted in the ability to deliver products throughout the year of a uniform quality and at a low price. Even if the cage culture industry has matured, however, there remain major challenges to be addressed.

The growth in the sector will lead to more competition for resources such as feed and space. Also, consumers have recently experienced several food scandals in Europe. Combined with a higher standard of living, this has resulted in a growing awareness of food safety issues. Consumers have also become more interested in ethical issues related to food production. Hence, the quality of food, production methods and the documentation of these are increasingly important.

The struggle for resources

A Norwegian study concluded that the four most important contributions to the development of the marine sector are competent labour, long-term availability of capital, area (space) and infrastructure. Being a decentralized industrial activity cage mariculture competes with other sectors for labour, capital and the development of infrastructure. It is important for the industry to contribute to the development of small rural communities, making them attractive for people to live. An economically sustainable industry attracts venture capital for further development. In periods of economic depression, however, this has been a problem not least for the development of an industry based on new species.

Europe has the best intentions to take care of small remote communities. The main challenge has been to find industries that may have an interest in being located in decentralized areas. The aquaculture industry is such an activity, and it can be argued that there should be a political acceptance to use economic resources to establish the necessary infrastructure.

An increased occupancy of coastal areas has been more difficult to accept politically. The growing importance of well-performing sites excludes large areas. For areas with acceptable conditions there may often be conflicts with other interests of an environmental, economic, recreational or military nature. Further growth of cage aquaculture may be achieved by increasing production per site, by making more sites available or by moving production offshore.

The European Commission concluded that fish cages should be moved further from the coast, and that more research and development of offshore cage technology must be promoted to this end. Experiences from outside the aquaculture sector, e.g. in oil platform construction, may be exploited by the aquaculture equipment sector, allowing for savings in the development costs of new technologies (Commission of the European Communities, 2002). However, it is important to keep in mind that moving production offshore will significantly increase the need for investment. Increased investment must be compensated by an increase in efficiency in order not to incur higher productions costs. Offshore cage culture production may also increase the risk of escapes, the need for a more complex infrastructure and may no longer be such a significant contributor to rural development.

Feed resources

Fishmeal and fish oils are essential constituents of fish feeds. In the last decade, the amount of fishmeal used to produce feed for aquaculture has increased considerably, but the annual world fishmeal production has remained static (Commission of the European Communities, 2002). Over the past 20 years fishmeal and fish oil production have ranged between 6.2 and 7.4 million tonnes and 1.0 and 1.7 million tonnes respectively, except during the more severe El Niño years. This picture of overall stability of pelagic feed fish supply is against a background of changing use due to market forces. Fishmeal is used for both aquatic and land animals, but as aquaculture demand has increased, this has been met by diverting supplies away from land animals, with use now increasingly being confined to starter and breeder diets for poultry and pigs. Fish oil, previously used largely for hardening margarines/bakery products, is now mainly used in aquaculture. Small amounts now also go to human nutraceuticals; use for hardening has almost been phased out (Shepherd *et al*., 2005).

Since fishmeal and fish oils are limited resources, it is extremely important to continue research efforts to find substitute protein sources in fish feed formulation (Commission of the European Communities, 2002).

One possible source of considerable quantities of fish raw materials is to be 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 only certain species are fished. In addition to the desired species, large amounts of fish are caught as by-catch. Some by-catch is landed and recorded, while the rest often is dumped into the sea. The global discarding of fish has been estimated to be 27 million tonnes. Millions of tonnes of protein are thus dumped annually in to the ocean. In Norway, the authorities have adopted a zero discard policy stating that 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 during certain periods and areas where high by-catches can be expected. The prohibition is also a driving force behind the development of equipment that reduces by-catches. EU member states have a law that is almost the exact opposite of Norway's. EU member states have introduced a prohibition against the landing of fish where a "Total Allowable Catch" has been reached. In many cases, this leads to fishing vessels being forced to dump fish (Holm and Dalen, 2003).

Another possible solution to the challenge of reduced availability of marine resources is the production of feed based on raw materials from lower trophic levels. Current research explores the development of technology for harvesting zooplankton, such as *Calanus finmarchicus* and krill (Crustacea: Malacostraca). These animals are an important source of marine fats, are found in huge quantities in the North Atlantic and are an important food source for Antarctic fish, seabird and cetacean populations. Again, however, such fisheries would have to be carefully managed to avoid unacceptable changes to ecosystem structure and function.

Commercially synthesized protein has been available for use in fish feed. For example, Pronin® is a high quality single cell protein source. It is derived from fermentation using natural gas as an energy and carbon source. Its high protein content (about 70 percent) combined with its nutritional and functional properties make Pronin® well suited as a protein ingredient in feedstuffs for fish and animals. Its use as a protein source for sea and freshwater farmed salmon has been extensively tested and documented. According to the producer up to 33 percent of the protein could be incorporated in the feed for salmon in seawater (http://www.norferm.no).

Plant-based raw materials have also been suggested as an alternative feed resource. Their use in aquaculture feed has increased and a 30 percent plant-based content is becoming common. With the right combination of plant and marine oil, a similar content of healthy omega-3 fatty acids is almost as achievable as with the use of 100 percent marine oil. The major fish feed manufacturers are consequently replacing an increasing share of fish oil in the feed with plant oils (Holm and Dalen, 2003).

Trends regarding the current dietary use of fishmeal and fish oil substitutions vary from country to country, depending upon feed ingredient availability and transportation/importation and processing costs, and the intended market where the salmon is to be sold. In Norway up to 55 percent and 50 percent of dietary protein and lipid, respectively, are of non-marine origin. The most important ingredients are soybean protein concentrate, soybean meal, corn gluten meal, wheat gluten, rapeseed oil, and the crystalline amino acids lysine and/or methionine. In the United Kingdom of Great Britain and Northern Ireland up to 45 percent of dietary proteins are replaced, whereas only a limited amount of fish oil is replaced (up to 10 percent) due to market demands. The protein sources used are maize gluten, soybean products (mostly extracted), wheat gluten, rapeseed oil, and crystalline amino acids (Tacon, 2005).

Consumer demand

In January 2004, a paper in the journal Science reported that the PCB levels in farmed salmon were six times higher than those in wild salmon (Hites *et al*., 2004). Although the recorded PCB levels were well within international food standards, the study received widespread coverage in the media (Chatterton, 2004).

The consumers reacted to the news by refusing to buy and eat salmon. The negative media stories failed to mention that the Science study was funded by the Pew Charitable Trusts – an organization which frequently raises critical issues related to aquaculture (Chatterton, 2004).

This story stresses two very important issues related to the market. Firstly, consumers do care about the quality, safety and production methods of the food. Secondly, there are interest groups that follow the aquaculture industry closely, and question the sustainability of farming fish. This means that the industry has to continuously focus on food safety and production methods, and be able to document a sustainable production of healthy food.

Food safety

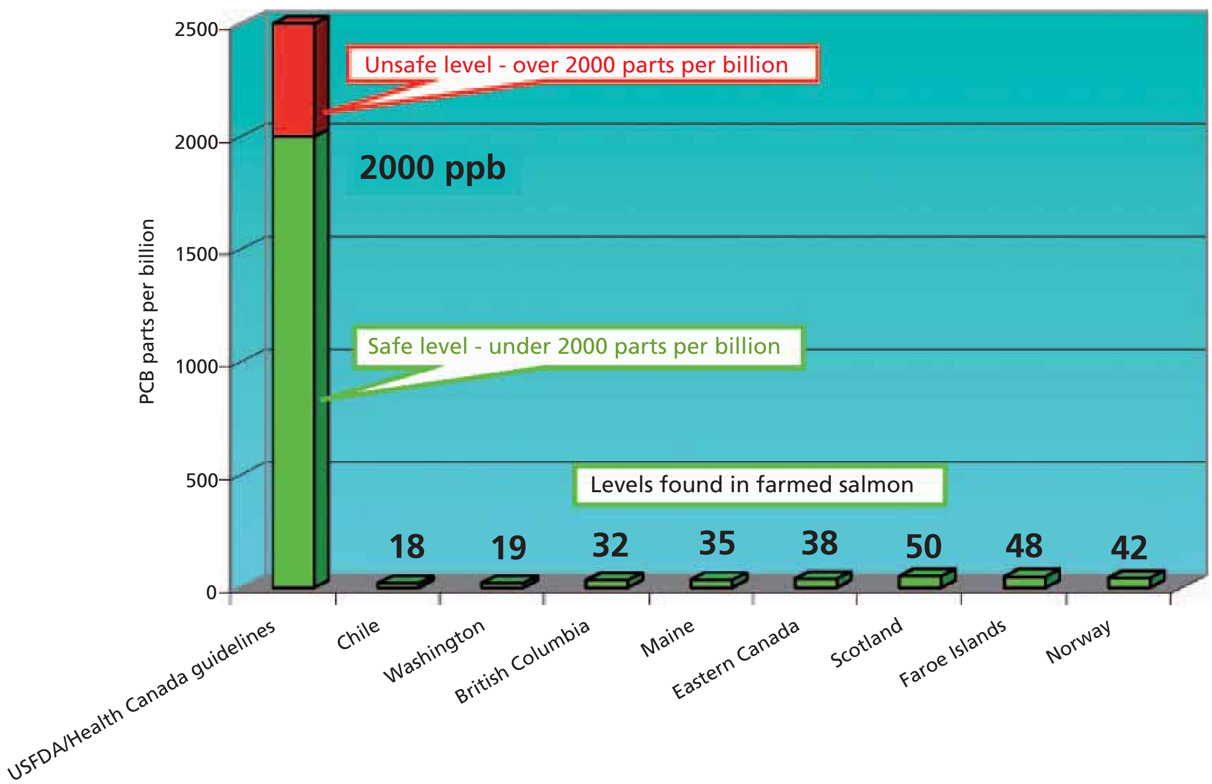
The prime goal of European fish farmers is to produce nutritious products of the highest quality. Aquaculture is a controlled process that allows the farmer to grow and harvest good quality fish, with the following characteristics:

- A healthy fish that has been reared in the best possible conditions
- A protein source of high dietetic quality
- A nutritious source of food
- Available continuously throughout the year
- A product that is consistently fresh
- Good taste and flavour

The FEAP Code of Conduct urges that fish farmers contribute actively towards the balanced and sustainable development of aquaculture and that they make their best efforts to assure the transparent development of the activity to the benefit of the consumer (FEAP, 2000).

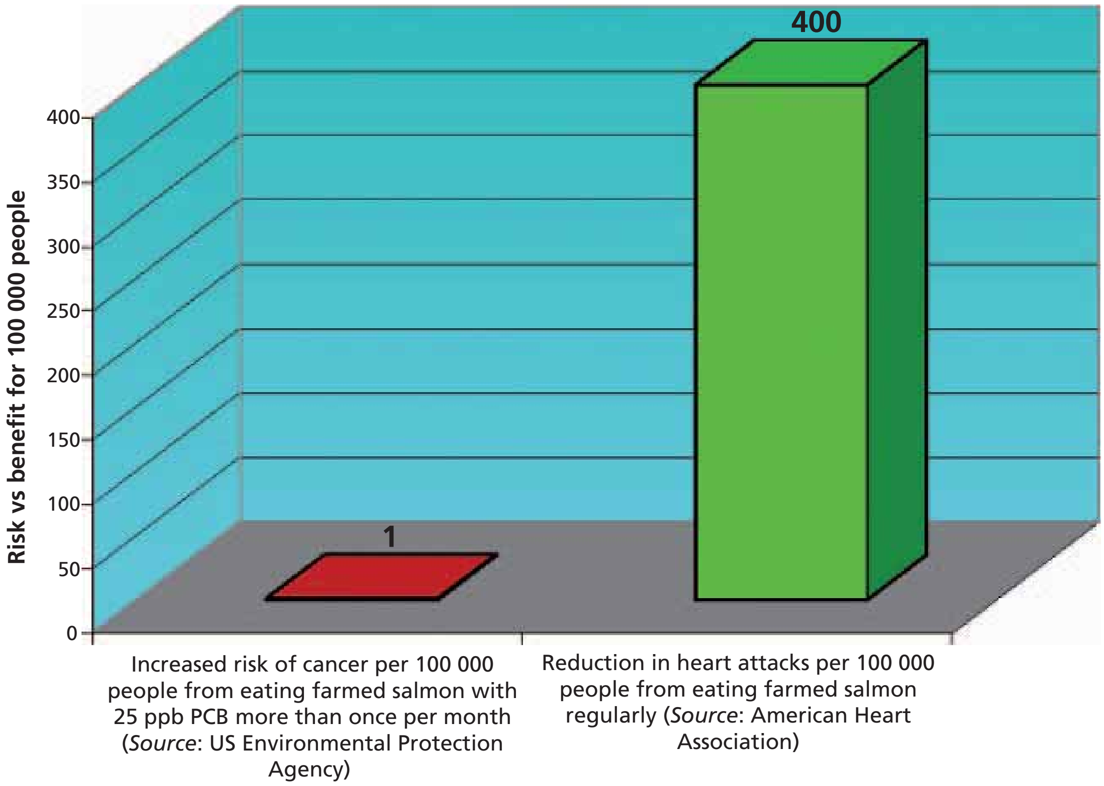
The salmon farming industry is subjected to a host of allegations related to environmental sustainability and human health and nutrition. One of the most serious charges is that farmed salmon contain dangerous levels of PCBs (polychlorinated biphenyls), an industrial compound that is widespread in the environment (see also above).

FIGURE 20
Comparison of US Food and Drug Administration and Health Canada Guidelines for PCBs in food compared to levels found in farmed salmon



Source: *Science*, Vol. 303, Jan. 9. 2004; Positive Aquaculture Awareness, 2003

FIGURE 21
Comparison of health risks and benefits from eating farmed salmon



Source: *Science*, Vol. 303, Jan. 9. 2004; Positive Aquaculture Awareness, 2003

Trace amounts of PCBs may be found in farmed salmon for the same reason they can occur in wild salmon, beef, chicken and many other foods: they accumulate in small amounts in the food chain. Farmed salmon are usually fed fishmeal derived from sustainable anchovy and mackerel fisheries. Anchovies and mackerel may ingest trace amounts of PCBs in their natural environment, which can then find their way into farmed salmon via the feed. However, the level measured is far below what is considered to be a health risk (Figure 20) (Positive Aquaculture Awareness, 2003).

Conscious consumers may be very demanding towards producers of food. If cage culture producers are able to produce first class and healthy products, the focus on food quality can become very positive for the industry. European citizens face an increasing problem related to malnutrition and excess weight. The positive health effects of eating fish are many, among the most important being their contribution to the prevention of heart diseases (Figure 21).

The industry is facing a major challenge in attempting to successfully rebut allegations related to the safety of eating fish. This can only be done by providing sound scientific documentation of the positive health effects of consuming fish and by giving consumers the facts.

Tracebility

Traceability will probably also be of great importance for food safety in the future. The TraceFish organization believes that with increasing information demands from consumers, it is no longer practical to physically transmit all the relevant data along with the product. A more sensible approach is to mark each package with a unique identifier, and then transmit or extract all the relevant information electronically (see http://www.tracefish.org).

Animal welfare

There has been increasing concern about the welfare of fish in general, but especially in aquaculture in recent years as a result of research suggesting that fish, like higher vertebrates, experience pain and suffering (Commission of the European Communities, 2004).

In order to improve welfare of farmed fish protocols and fish husbandry standards, e.g. for fish density and pre-slaughter handling, are to be defined. A set of rapid, inexpensive and non-invasive screening methods may be used as welfare indicators. Welfare is, however, individually based whereas the types of indicators being developed may only provide indicators of average conditions in e.g. sea cages.

Norway and the United Kingdom of Great Britain and Northern Ireland have established research groups dedicated to fish welfare issues and have provided welfare solutions by integrating information from various scientific disciplines such as behaviour, physiology and fish health (Damsgård, 2005).

Socio-economics and marketing

Sea-cage aquaculture is widely spread across Europe and often in rural or peripheral areas, where alternative employment opportunities are chronically lacking. The fundamental issue in the development of the sector is the maintenance of competitiveness, productivity and durability of the aquaculture sector (Commission of the European Communities, 2002).

In general, the total demand for any commodity is expected to grow with population growth, since the latter determines the overall size of the market. It is believed that there will be a decline in demand for high-priced aquatic products, although such demand may shift to lower priced fish products. Future demand for fish will basically be determined by the number of consumers, their eating habits and disposable incomes, as well as by the price of fish products. Many of the changes that will occur in the level and structure of fish consumption will reflect more complex demographic and attitudinal variables. Ageing populations, changing gender roles, smaller household sizes, dietary concerns, food safety issues and ethical concerns are influential factors that exist throughout Europe (FAO, 2001).

Competition between producers of different protein sources is continual. In order to strengthen its position the aquaculture industry has to strengthen the marketing of its products. There has been a generic marketing campaign for salmon in Europe, financed by Norway as a part of the so-called Salmon Agreement. In future, such types of campaign may also be used to stimulate the consumption of aquaculture-reared fish and hence increase the market share of cultivated marine products.

European producers will continue to experience increased competition from fish reared outside Europe. Species such as tilapia (*Oreochromis* spp.) may be produced at a very low price and cannot readily be cultured in cages in Europe. Increased competition should not be met by restrictive international trade practices but by focusing on quality and increased productivity without, of course, bringing it into conflict with obligations related to sustainable production.

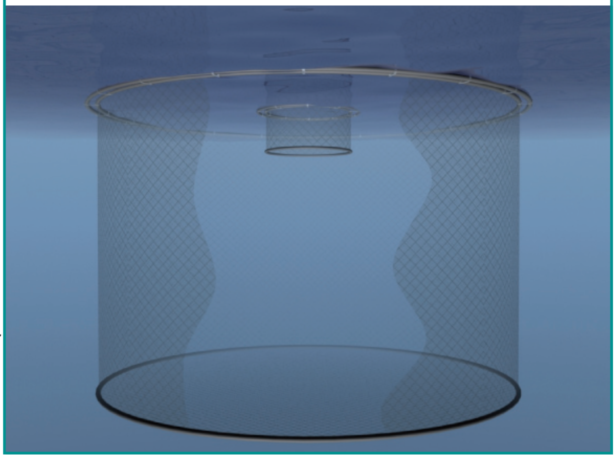
There has been a significant increase in the productivity of the industry (Figure 16), mainly due to improved fish health and growing production volumes. As seen in Figure 17 feed remains a major production cost and there is a major focus on reducing the economical feed conversion rate (ECR) (kilogram feed used per kilogram fish slaughtered). The industry has been successful in reducing the biological feed conversion rate (BFR) (kilogram feed used per kilogram fish produced). A further reduction in the ECR requires lower mortality rates. For the salmon industry, the average mortality in Norwegian sea cages is about 20 percent. Improved fish health management is essential to further reduce mortality rates.

Efficient health management requires measures to reduce the need for therapeutic treatments by avoiding disease outbreaks. This can be achieved by vaccines, where they exist. Strong biosecurity measures are important to avoid entry of pathogens and can be achieved by isolating farms and establishing control systems to all human entries, including veterinaries, clients and service providers. Fallowing is used to help disinfect sites between harvesting and stocking. Good health management should also include daily management targeted to reduce stress (manipulation, density, feeding regimes, etc). Stress is a very important factor, because it can combine with an appropriate pathogen to give rise to a disease outbreak.

There has been a significant increase in productivity per employee (Figure 18), reducing the share of wages in the total production. Nonetheless, because of the high salaries in Europe it is of major importance to further increase productivity per employee in order to compete with producer countries outside Europe. This may be achieved, for example, by increasing total production and production per site and per production unit.

New technology has made it possible to increase the size of each cage (Beveridge, 2004). Figure 22 shows a traditional cage used a few years ago, with a circumference of 40 metres and a depth of

FIGURE 22
Example of the development of using bigger units. Increase from circumference of 40 m and depth of 4 m to circumference of 157 m and depth of 30 m resulting in volumes of 510 m³ and 59 000 m³, respectively



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4 metres giving a total volume of 510 m³. Today some sites are using cages with a circumference of 157 metres and a depth of 30 metres, giving a total volume of 59 000 m³. Such cages can enclose biomasses of 1 100 tonnes. The advantages of using bigger units are among other things fewer units to handle and the possibility to invest more resources in monitoring fish and environmental variables. Positive effects on growth have also been reported. However, there are also considerations with regard to routine fish handling (grading, harvesting, disease treatment) and escapes.

There is an increased focus on the effect of the environment on the growth of fish, in particular in relation to dissolved oxygen levels within cages. Equipment has been developed that can add oxygen to sea cages (Beveridge, 2004).

However, more importantly the quality of the site is of vital importance. A good site has the necessary currents to maintain dissolved oxygen at acceptable levels and to provide the necessary dilution of organic matter preventing accumulation under the production units. The topography of the sea bottom and the depth under the cages are also of great significance in optimizing production.

Many of the best and most suitable sites for aquaculture production in Europe already have aquaculture projects, meaning that there is high competition for the remaining suitable areas. This may result in a move towards more exposed sites offshore. This is likely to prove a great technical and logistical challenge; if solved, however, there is significant potential to increase production. It is reported that Ireland for example could increase its production ten-fold to 150 000 tonnes, generating more than 4500 extra jobs (Ryan, 2004).

CONCLUSIONS

Most food production systems have a negative impact on the environment. Thirty years after the first steps were taken by the pioneers of cage culture production in Europe, the industry has matured. Cage culture production of salmonids is increasingly becoming an environmentally sustainable way of producing high quality food. However, as the consumer becomes even more aware of sustainability and food safety issues, the industry has to continue to improve production methods. Growing demands for fish products also challenge the industry to raise the production without increasing the need for marine raw material. The industry also has to compete with other interests in the use of coastal marine areas.

There is a great interest to further develop this industry, providing essential profitable activities to sustain communities living at the margins of Europe. Development must not be at the expense of product quality, however, or of the environment. It must also be sufficiently efficient that it can compete with other food producers, both within and outside Europe.

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